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# APPLICATION OF GENERATIVE AI MODELS IN ELECTRONICS DESIGN

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BUDAPEST, 2023

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# Absztrakt

A nyelvi mesterséges intelligenciák a szoftverfejlesztés egy régóta fejlődő ágát képviselik, azonban az eddig létrehozott modellek hiányosságaik miatt nem voltak széleskörűen alkalmazhatók. A ChatGPT (GPT-3.5) modell 2022-es kiadása az OpenAI által egy mérföldkő lehet a nyelvi mesterséges intelligenciák fejlesztését és alkalmazhatóságát illetően. Az új modell képes emberinek látszó szöveget generálni, és azt a benyomást kelti, mintha természetes módon értené a nyelveket és kommunikációt. Az új modell gyorsan terjedt el a világban, és rengeteg kutatásban próbálják feltérképezni lehetséges alkalmazási területeit: tudományos publikálás, oktatás, pénzügy, orvosi terület stb. [1]. Bár rengeteg publikáció jelent meg a ChatGPT-vel kapcsolatban, a mérnöki tudományokban való alkalmazással csak meglepően kevés kiadvány foglalkozik, azok is főleg programozási [2]–[4] vagy vegyészmérnöki oldalról közelítve a problémát [5].

Jelen kutatásban feltérképeztem a ChatGPT modell alkalmazási lehetőségeit egy villamosmérnöki szempontból, egy elektronikai fejlesztés szemszögéből, alkalmazott szenzorikai esettanulmányon keresztül. A chatbot egy okos otthon tervezési projekt kezdeti feladatait kapta bemenetként, hogy felmérhetők legyenek a képességei és határai. A kérdéseknek több célterülete is volt: adatok tág értelmezése és érvelési készség, pontos adatok lekérdezése, munkamenet és programkód generálása, és végezetül irodalomkutatási kérdések. Míg a ChatGPT jó eredményeket mutatott a tágabb kérdéseket illetően, problémái voltak a specifikusabb kérdésekkel, mint például pontos szenzorspecifikációk megadása, munkamenet és kód generálása. A terület, ahol a modell legrosszabban teljesített, az irodalomkutatás volt, ahol a modell kimenete elfogadhatatlan minőségű volt (nem létező kiadványok, hamis szerzőlisták, nem létező DOI–Digitális Objektumazonosító számok stb.).

Amellett, hogy egy részletes kvalitatív analízist szolgáltat a ChatGPT villamosmérnöki alkalmazásairól, ez a kutatás tartalmaz egy rövid összehasonlítást más LLM (Large Language Model) rendszerekkel is, mint például a Bard, vagy a Bing AI. A vizsgált rendszerek megfelelő korlátok között alkalmazhatók a tervezés támogatására, amennyiben a tervező rendelkezik a megfelelő szaktudással.

# Abstract

Conversational AI have been in development for many years; however, they have not been widely applicable due to the deficiencies of the models. The 2022 release of ChatGPT (GPT-3.5) by OpenAI could be a landmark in the development of conversational AI models, as it can produce human-like text and gives an impression of having a natural understanding of the language. ChatGPT took the world like storm, and its possible applications are being researched, such as: publishing, education, financial research, medical assistance, etc [1]. Surprisingly, there are only a handful of papers dealing with the application in terms of engineering sciences and most of those deal with programming [2]–[4] or chemical engineering [5].

In this research, the applications of ChatGPT as an electrical engineering tool were investigated through a case study of applied sensors in embedded electronic systems. The initial electronics-development tasks of a smart home project were prompted to the ChatGPT system to investigate its abilities and limitations. The queries included questions targeting broad understanding of a subject and reasoning, specific data acquisition, workflow, and code generation, and finally literature review. While ChatGPT showed good results in broader subjects, such as choosing a controller unit for the sensors in the study, it had issues with the more specific questions such as providing sensor specifications, code generation and workflow. The most disappointing results came for the prompts regarding literature references and review, where the bot provided information that was completely unacceptable (non-existing papers, fake author lists, non-existent DOI–Digital Object Identifier, etc.).

In addition to providing a detailed qualitative analysis of the potential of ChatGPT in electronics engineering, this paper also includes a brief comparison with other LLM–Large Language Model systems in use today, such as Bard and Bing AI. The evaluated AI tools could be used to support electronics development to a limited extent, assuming the engineer has the proper proficiency to evaluate its answers.

# Introduction

AI had been a field of great interest in previous years. There have been many attempts to create conversational AIs [6], but mostly with little success, as these AI could not provide the user with a natural feeling conversation. ChatGPT is a landmark in the development of conversational AI models, with its ability to understand human input and generate human-like responses, including reasoning tasks. ChatGPT is based on the model GPT-3.0 by OpenAI, a large AI company. ChatGPT (also called GPT-3.5) is the same model, utilizing a different training dataset, that was carefully created to produce better results [1]. At the time of conducting this research, ChatGPT's cutoff that was September of 2021. While ChatGPT's abilities are truly impressive, the current hype about it may give us a distorted view of the real capabilities and limitations of the model, therefore it is necessary to conduct proper research to identify current limitations of the model.

As will be seen in the literature review, while ChatGPT could be a great tool for helping a variety of professions (researchers, financial professionals, medical applications, robotics, engineers, policymakers, etc.) it also present serious questions and issues. First and foremost, of these issues are plagiarism (unwitting or intentional), fabrication of data, spreading misinformation, unethical use, issues with accuracy, lack of in-depth analysis [7]–[11]. Because of these issues, new guidelines are urgently needed for the applications of large language models like ChatGPT in all aspects of our lives, from research and academic publishing to general work-related tasks. In fact, some publishers have already moved to ban papers written entirely by AI and its use must be properly explained [9], [11], [12].

This study seeks to provide a qualitative analysis of the potential application of ChatGPT in electronic engineering through a case study of applied sensors. Multiple facets of the application of ChatGPT were investigated such as broad reasoning, providing specific information, generating code and workflow, and giving literature review. Afterwards, ChatGPT was also compared with other AI that were freely available at the time (Bard, Bing and Copilot).

At the time of writing this paper, some parts of the research have already been published (2023.05.18.) in the journal Sensors (Q2 according to Scimago Journal Rankings and Q1 according to Scopus/Citescore) with the title: "Can ChatGPT Help in Electronics Research and Development? A Case Study with Applied Sensors" (DOI: 10.3390/s23104879) [13]. Parts of the existing publication were used in this paper after rewording. However, the rewording could not be applied to the actual answers, which had to be published and presented in the same way to present consistency. Also, some of the answer contain direct copy of web sources. The research was expanded on considerably, mainly in the following segments: 1.) Previous works and literature review 2.) References 3.) More detailed reviews and explanations of ChatGPT answers 4.) Comparison of ChatGPT with other AI such as Google Bard and Bing AI 5) Brief outlook on circuit design.

The publication is available in the appendix, at the end of this paper (Section 8.2, "Publication in Sensors," page 85).

# 1 Literature review

ChatGPT is a relatively new language model capable of producing human-like text and engaging in conversation with its users. It was released by OpanAI, a large AI company, on 2022.11.30., and has more than 175 billion parameters to optimize during the learning process. It is based on OpenAI's previous LLM model, GPT-3. ChatGPT uses a HITL (Human In The Loop). Uses of ChatGPT have spread widely among the scientific community and should be addressed properly. In the following chapters, I would like to provide a brief review of available literature on ChatGPT in the scientific community.

## 1.1 Generative Pre-Trained Transformer

ChatGPT is a generative pretrained transformer model developed by OpenAI. The term generative pretrained transformer refers to a natural language model that is based on a neural network with a transformer architecture. A transformer neural network can be any neural network, that takes a sequence as its input, and produces a sequence as its output [14]. Before transformer models were invented by Google in 2017, RNNs (recurring neural networks) were used to implement sequence to sequence transduction. RNNs have a loop built into them, allowing data to persist. The issue is that whenever we are working with a sequence, it is necessary for the model to have some sort of memory retention. While in theory RNNs could be implemented such that they could have memory effects and could learn long-term dependencies in the data, in practice they are not effective at doing so. LSTMs (Long-Short Term Memory) are a subset of RNNs with a special structure and were used for sequence-to-sequence transduction, however, they also struggle. Transformer models have the capability to learn the long-term dependencies that are necessary for sequence-to-sequence transduction (i.e.: translation tasks). They are now used by OpenAI and other companies to produce their models.

By definition, a generative model refers to a model that is capable of generating new data instances (hence the word generative) from the data it was trained on [15]. Pre-trained simply refers to the fact, that before the model is trained on a labelled, supervised dataset (supervised learning) it is trained on a large amount of unlabelled data [1], [16]. This training is called unsupervised training and is useful, because it allows the use of very large amounts of data to reach a starting point, from where the model can be fine-tuned to achieve the required performance [16].

As it is a pre-trained transformer system, ChatGPT was first trained on a large corpus of data from the Internet in an unsupervised fashion, then was fine-tuned in a supervised manner, by 40 human labelers (HITL–Human In The Loop training) [6].

Since this paper is not about the inner workings of the models it is unnecessary to go into any more detail, the paragraphs above simply seek to provide relatively understandable definitions for the word GPT.

## 1.2 Currently available AIs

At the moment, ChatGPT has few competitors in the AI space. The most relevant are GPT-4 (which is the paid and more advanced version of ChatGPT, also known as GPT-3.5), Google's Bard AI, and Microsoft's BingAI, which has some parts of GPT-4 incorporated into it for better performance. A smaller LLM available is Copilot by developed by flux.ai for assisting PCB development. The abilities of the available AIs will be compared in later chapters, with ChatGPT being investigated in depth. The main difference between the AIs, which I would like to focus on ahead of time is that ChatGPT and GPT-4 do not have access to the internet and real time data (their training cut-off date of GPT-3.5 is currently 2021.09.), while Bard and BingAI both have real-time access to the Internet. Theoretically this should make them more efficient and accurate when providing data such as specifications or recent events (which might be missing from OpenAI's models).

## 1.3 Applications of ChatGPT and other LLMs

### 1.3.1 Medical field

Interestingly, most of the available articles that have been published on ChatGPT's use concern either the medical field or educational purposes. This phenomenon could point to the trivial conclusion, that ChatGPT has the most applications in fields where language processing and output are more appreciated than for example complex mathematical modelling (i.e.: engineering, physics). This points to the fact, that it is necessary to conduct qualitative and if possible, quantitative analysis of the applications from an engineering point of view, the first of which this study tries to provide. Nevertheless, it is important to briefly review the findings in the existing literature.

ChatGPT's applications in the medical sciences are manifold. First of all, it could help doctors as a "search engine," providing data, literature reviews without the doctor having to do the extensive work involved in going to prior research [10], [17]–[20]. This being said, multiple sources highlight the tendency of ChatGPT to generate plausible sounding, but ultimately false information [10], [19]–[22]. This points out that medical professionals need to be very careful when providing care using the output of ChatGPT, and human supervision should always be exercised. Some studies [23], [24] have also investigated the idea off applying ChatGPT instead of a medical professional: patients would give their information and case details, and the model would supply a diagnosis and recommended course of action. However, both studies suggested, that while AI platforms can provide good diagnosis in many cases, sometimes the experience and intuition of a human actor cannot be disregarded. The authors of [20] and [23] draw our attention to the fact, that large amounts of incorrect information exist on the Internet regarding healthcare, and this could propagate through ChatGPT [10], [25], [26], leading to patients being misinformed.

Some studies have suggested both in the medical and other fields, that ChatGPT could improve communications by providing an intuitive, natural language, easy-to-use interface [10], [27]–[29]. Specifically in the medical field ChatGPT could assist medical professionals by monitoring vital signs, providing documentation, translation, supporting decision making [10], [27]. It is important to note however that whenever human-machine communication is involved in a process, an understanding of the implicit information in the text may be lost [26], [27], [30], which in a medical context could even lead to bad diagnosis being made. Reference [28] points out that question answering systems (QAS) like ChatGPT could be used to improve mental health among populations with elevated risk.

### 1.3.2 Finance

One of the fields that has found many applications for ChatGPT is the financial field, with ChatGPT being investigated in works such as [17], [29], [31]–[33]. Ref [17] investigates the application of the bot in generating finance research and will be discussed in a later chapter, under scientific publishing (Chapter 1.3.5). [29], [33] investigate the applications of ChatGPT in corporate environments, such as consulting services, customer interaction, transaction automation, etc. They emphasize that ChatGPT could facilitate and improve efficiency of communication both inside a company structure and with customers outside a company. They also point out that ChatGPT could substitute for other tools or jobs, therefore improving cost-effectiveness for the company. [33] notes that ChatGPT does not currently have access to the Internet, which could hinder its application in financial, high-pressure business areas. The lack of real-time data accessibility is an issue often brought up when dealing with actual applications [34], [35]. The authors of [33] also give hints about possible ways to identify AI generated text (they find through statistical tools that ChatGPT uses fewer idioms, metaphors and words associated with empathy). [29] states that the bot would need to be trained on a more specialized and precise dataset before being deployed in real-life environments. This sentiment can be found in works from other fields as well [25], [36], [37].

An interesting study in the field of finance investigated the model's accuracy in financial accounting [31]. The authors Found that ChatGPT's answers efficiently imitate those of auditors with longer tenures. The authors also draw attention to the fact that the bot might make incorrect assessments due to its "cognitive inertia." It might not work from reliable data until it has a sufficiently large mass in the literature, leading to false assessments and outputs.

### 1.3.3 Education

Education is one of the fields most concerned with the emergence of AI like ChatGPT. It is obvious that essay writing and problem-solving skills are crucial for professionals in any field, and students should devote time and energy to acquiring these skills. Setting aside the ethical issues regarding the use of ChatGPT in education, it is concerning to think, that some students will now outsource a task to such a bot instead of applying themselves. While the research we found was not conclusive in whether the use of ChatGPT negatively impacts the skills of students, some studies do suggest this might be the case [38]. Most studies highlight possible uses such as generating documentation, exercises, scenarios, personalized learning, summarizing, explaining concepts and functioning as a search engine [25], [27], [38], [39]. A case study in mathematics [38] found that it could sometimes provide correct answers to mathematical questions, but it would interestingly get some questions wrong repeatedly. The reason for this is that ChatGPT is not actually solving the mathematical problems but rather is calculating the most likely answer, which is often wrong [40]. The application of the bot in chemical engineering education was also investigated in [41]. The authors used ChatGPT to generate problem-solving tasks and models, which were then distributed amongst students. The authors found that while the solution is not perfect, LLMs like ChatGPT could be integrated into chemical engineering education to improve students' problem-solving skills and to accommodate them to Industry 4.0.

### 1.3.4 Engineering, robotics, and programming

At the time of writing this paper, research on the applications of ChatGPT in an engineering, or other connected field (such as robotics and programming) is rare – even though many engineers and programmers would admit to using LLMs to enhance their work. In two articles the authors have investigated the applications of ChatGPT in a robotics application [4] and a more general programming application [2], [3]. Their findings were the following.

The possible applications in the field of programming are summarized in ref [2] the writers conclude that ChatGPT could have a multitude of uses, for example: writing documentation for code, code completion, error correction, text-to-code generation and QAS applications. The writers also point out that ChatGPT could provide a natural language interface to facilitate programming. In [3] ChatGPT is investigated as a debugging tool. The authors concluded that its ability to recognize patterns, quickly parse text and generate code could be useful for debugging code. They do however emphasize that it should only be used in conjunction with other debugging tools to verify the correctness of its answers.

Two interesting engineering related applications can be found in [5], [25]. In [25] the authors tried to integrate ChatGPT with systems currently available in manufacturing. While the bot showed early promise, coherence, and good accuracy in general, it sometimes provided false or incoherent answers – which could be a result of bias and misinformation in the dataset. The authors also highlighted that the responses from the bot depended greatly on prior communication. They emphasized that in its current form, it would not surpass an experienced engineer and would need to be trained on much more specified data. Ref [5] tried to integrate ChatGPT into a software used to design chemical reaction arrays. They found that the model had very good accuracy when designing these reactions and is very promising, as it could easily be integrated with the existing solutions. However, the software showed no physical or chemical intuition in its designs.

In an interesting study [42] the authors investigated ChatGPT's application in the programming of numerical methods. They concluded that ChatGPT could efficiently be used to generate code in multiple languages (C++, C, Python, etc.). It could also be used for debugging and rewriting existing code. They also found some limitations, mainly relating to the model's lack of understanding of mathematics (issues with generating matrices, arrays, etc.).

Lastly [4] presented an integration of ChatGPT into a robotics design framework. With proper prompting strategies, the authors showed that ChatGPT could be very useful for designing code for a robot, even providing code for maneuvering the robot (or a small drone) in 3D space. The authors believe the software behaves like it might be keeping track of a 3D model, however this is not supported by other works. They also emphasize that human supervision is necessary when ChatGPT is used to develop robotics and that engineering proper prompts is necessary to guarantee a high quality of AI responses. The paper also gives general principles on prompt engineering.

### 1.3.5 Scientific publishing

One key aspect of ChatGPT is whether it can help in scientific publishing, accelerating the dissemination of data to humanity as a larger entity. Multiple sources have found, that ChatGPT can indeed write articles, papers and parts of papers which not only pass a plagiarism tracker, but could also pass a human reviewer as genuine and well-structured text [7]–[10], [43]. Researchers should also keep in mind that ChatGPT cannot keep track of connections and sources of information [21] and is prone to fabricating data [7].

An interesting study [17] generated a financial research article using ChatGPT and then had a board of experts rate whether it would pass a peer-review committee and be accepted for publication. They found that ChatGPT could reliably write a financial paper when provided with sufficient data. They found that ChatGPT produced the best output on tasks that required it to link large amounts of existing data (idea generation, paper summary) but had issues with more specific questions. This is corroborated by other studies [11], [20]. In [11] the authors tested the applicability of ChatGPT in a medical context, by prompting it to draft a paper about a simulation of a virus spreading in a population consisting of vaccinated and unvaccinated individuals. The bot succeeded, even managing to provide code for proper visualisation of the data and results but had minor issues which it self-corrected upon further prompting. The tendency of ChatGPT to improve its answers upon being prompted repeatedly is well documented [4], [11], [23]. The authors of [11] draw attention to the need for human oversight and ethical issues, which will be addressed later. In [44] the bot successfully wrote a very short article on the use of Rapamycin, but successive questioning caused it to alter its conclusions. This could mean that its initial answers were not properly grounded in facts.

Apart from writing whole articles ChatGPT and LLM AIs could be used to: brainstorm, first draft generation, search engine functions [8], grammar checking, coding, writing a result analysis [7]. The draft generation and result analysis could be contentious points from a scientific integrity point of view.

One important thing to mention regarding the use of ChatGPT in scientific research is that while it can help non-native scientists with language barriers, a paywall could create a large gap between scientists from different financial backgrounds [18], [19], [26], [43], leading to some countries falling behind.

### 1.3.6 Ethical issues

While ChatGPT is widely used as a conversational agent, source of information, personal assistant, etc., it also raises questions of ethical issues. Several articles have highlighted, that while there are legitimate, ethical uses, there are also issues concerning the ethics of using LLMs. First and foremost, plagiarism and data fabrication are made a lot more accessible to researchers with ChatGPT [7], [9]–[11], [25]. Additionally, even if a user tries to use the software responsibly and avoids consciously plagiarising the work of others, the LLM models are trained on a specific dataset and are not transparent on where their data comes from, therefore even legal use could lead to unwitting plagiarism [19]. Similarly, with fabrication of data, even a genuine query might lead to a fabricated answer, as indicated in ref [7], where the model referenced a private database as its source of data (which it could not have accessed, due to it being private). Some authors have even begun citing ChatGPT as a co-author of their papers [44]. While OpenAI seems no to have an issue with this [44], the legality of citing an AI as an author could be questioned, due to the software not being accountable for any possible legal issue, raising the question: Who is? In response to this, multiple publishers have banned ChatGPT as an author, and its use must be properly explained and highlighted [11]. The issue is still not clear, as these guidelines can be broken quite easily. A simple rewording of a manuscript of ChatGPT content could pass AI and plagiarism detection tools [7], in fact it has been shown that ChatGPT can write scientific articles, that would pass a peer-review committee [17].

In this study, ChatGPT was not used other than for the queries regarding the topic of the research: smart home development. The responses have sometimes been slightly modified to preserve space, for example removing empty lines between list items. However, **the content of the answers has not been edited in any way, at any point**.

# 2 Case study in applied sensors

## 2.1 Premise

This study aims to investigate the application of ChatGPT from an electrical engineering point of view. This is a qualitative study, performed as a case study. ChatGPT was presented with the broad flied of applied sensors, specifically the construction of a smart home project. This is a well-established field, with more than x. available publications on WoS (Web of Science), therefore ChatGPT should have no issues providing accurate and valuable information to the queries. The chatbot was first asked general questions about sensor controllers, and as the context of the conversation has been established, was prompted for more practical and precise information such as workflow, sensor models and specifications, literature review, etc. ChatGPT's performance in these field is presented and evaluated in the following sections. First the query and answer will be provided, then a short review of each answer. The complete list of questions and answers is provided in the appendix (Chapter 8.1). It is important to note that ChatGPT's answers are highly dependent on the context and phrasing of the queries, as was established in existing literature [25]. To summarize the contents of the questioning:

1. General choice of platform
2. General suggestions for sensor types
3. Sensor specifications
4. Workflow & code generation
5. Literature review

The workflow of this study is summarised in Figure 2-1.

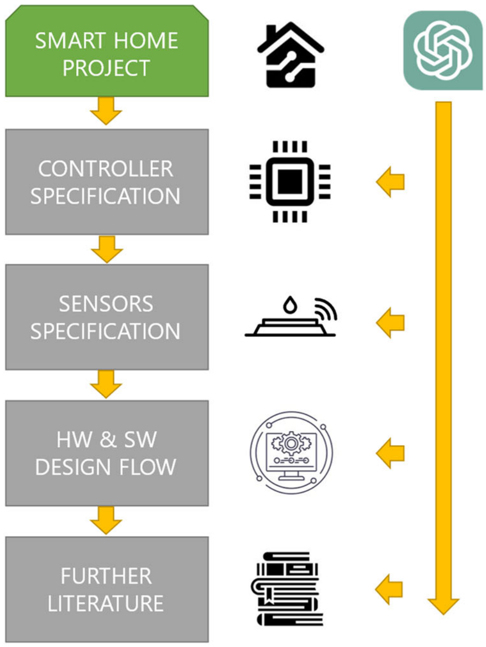


**Figure 2-1 – Workflow of current study [13]**

Not all the queries will be listed in the body of the paper, as that would lead to excessive length. Instead, the queries that were deemed not important enough to include in the body are available in the appendix (Section 8.1).

## 2.2 Queries and responses from ChatGPT

### 2.2.1 Platform choice

It is well established in the existing literature, that ChatGPT's answers are greatly dependent on the context on the conversation and questions asked previously [4], [25]. Therefore, to get the most accurate result when asking for specific sensor models and specifications, it is beneficial to first ask broad questions and test the model's ability to reason, while also providing a model with context and data. For this reason, ChatGPT was first tasked with listing possible controller models.

***Query:*** *I am doing a smart home project. I need to choose a micro-controller for controlling the sensors I need for the smart home. Could you give me options for the controllers? Give 4 to 6 examples, from different manufacturers.*
***ChatGPT:*** *Sure! There are several options for micro-controllers that you can choose from for your smart home project. Here are 6 examples from different manufacturers:*

- *Arduino Uno: This is a popular micro-controller board that is easy to use and has a large community. It has 14 digital input/output pins, 6 analog inputs, and a 16 MHz quartz crystal.*

*• Raspberry Pi: This is a small, affordable computer that can run a full operating system. It has a variety of input/output options, including GPIO pins, USB ports, and Ethernet.*
*• ESP32: This is a powerful micro-controller with built-in Wi-Fi and Bluetooth connectivity. It has 34 GPIO pins, 18 analog inputs, and a dual-core processor.*
*• STM32F4 Discovery: This is a development board based on the STM32F407VGT6 micro-controller. It has 168 MHz Cortex-M4 CPU, 1 MB Flash memory, and 192 KB RAM.*
*• PIC18F4520: This is a popular micro-controller from Microchip Technology. It has 32 KB Flash memory, 1.5 KB RAM, and 36 I/O pins.*
*• NXP LPC1768: This is a micro-controller based on the ARM Cortex-M3 architecture. It has 512 KB Flash memory, 64 KB RAM, and a variety of input/output options.*

*These are just a few examples, and there are many other micro-controllers available on the market. You will need to choose the one that best fits your project's requirements in terms of processing power, memory, and input/output options.*

In the above answer, ChatGPT clearly understands the task and provides six controller models, each of which would be suitable for our needs. To further investigate the abilities of the bot, we asked it to give arguments for each of the listed controllers.

***ChatGPT:*** *Sure! Here are some arguments for choosing each of the micro-controllers I listed:*

*• Arduino Uno: The Arduino Uno is a popular choice for beginners and hobbyists because it is easy to use and has a large community. There are many tutorials and examples available online, making it easy to get started. It has a simple programming environment and is compatible with a wide variety of sensors and shields.*

*• Raspberry Pi: The Raspberry Pi is a powerful micro-controller that can run a full operating system, making it suitable for more complex projects. It has a variety of input/output options, including GPIO pins, USB ports, and Ethernet, making it versatile and flexible. It can also run software like Python, making it easy to integrate with other tools and services.*

*• ESP32: The ESP32 is a powerful micro-controller with built-in Wi-Fi and Bluetooth connectivity. This makes it ideal for projects that require wireless communication, such as remote control or monitoring. It has a large number of input/output pins and a dual-core processor, making it suitable for projects that require a lot of processing power.*

*• STM32F4 Discovery: The STM32F4 Discovery is a development board that is based on the STM32F407VGT6 micro-controller. It has a high processing speed and a large amount of memory, making it suitable for complex projects. It also has a wide range of input/output options, including USB, Ethernet, and audio.*

*• PIC18F4520: The PIC18F4520 is a popular micro-controller from Microchip Technology. It has a relatively low cost and a large number of input/output pins, making it ideal for projects that require a lot of sensors or actuators. It also has a large community and many examples available online, making it easy to get started.*

- *NXP LPC1768: The NXP LPC1768 is a micro-controller based on the ARM Cortex-M3 architecture. It has a large amount of memory and a variety of input/output options, making it suitable for a wide range of projects. It also has a powerful processor and can run at high speeds, making it ideal for projects that require fast processing.*

*In summary, each of these micro-controllers has its own strengths and weaknesses, and the best one for your project will depend on your specific requirements. Factors to consider when choosing a micro-controller include processing power, memory, input/output options, and community support.*

The information supplied by ChatGPT can be considered accurate, though it is fairly general (as is the case in for example ref [45]) and sometimes lacks specific information about the controllers (i.e.: PIC18F4520). The arguments made by the bot are both sufficiently logical and coherent.

Now that it is established that the bot can in fact produce logical and coherent answers if prompted by very broad, general questions (which is also corroborated by literature [17], [25], [32], [44]), we should proceed with more specific questioning, while still maintaining the general nature of the prompts. Next the bot was prompted to narrow its focus to a decision between an Arduino and a Raspberry Pi controller. This method of refining questions is reasonable, since literature indicates that the bot has improved consistency in its answers once a proper context has been established.

***Query:*** *I am trying to make a smart home using an Arduino or a Raspberry Pi controller for my sensors. Which controller should I use?*

***ChatGPT:*** *Both the Arduino and Raspberry Pi controllers have their advantages and disadvantages when it comes to building a smart home.*

*Arduino is a microcontroller board that is designed for simple projects that require low power and have limited processing requirements. It is a good choice if you want to control simple sensors such as temperature, humidity, and light sensors. Arduino is easy to use and is ideal for beginners who are starting to learn about microcontrollers.*

*On the other hand, Raspberry Pi is a small computer that is capable of running a full operating system. It is more powerful than Arduino and has a wider range of capabilities. Raspberry Pi is a better choice if you want to integrate complex sensors such as cameras, voice recognition, and machine learning. It also has the capability of connecting to the internet, which allows for remote control and monitoring of your smart home devices.*

*Therefore, the choice of controller depends on the complexity of your project and the sensors you want to integrate. If you are building a simple smart home system, then an Arduino controller would suffice. However, if you want to build a more advanced system that requires complex sensors and internet connectivity, then Raspberry Pi would be a* *better choice.*

The above answer contains some information that is correct, for example that Raspberry Pi is capable of running an operating system, however, other information in the answer can be argued with, like Arduino being designed for simple projects. Here we run into the issue of training data, as Arduino in fact has a new family of devices that is capable of running higher-level processes similar to a Raspberry Pi. The Portenta family was launched in 2020 [46] (which is before the cutoff date), so information on it should be available on the Internet, and therefore should be included in the training set. Since it is a fairly recent release, information on it included in the training data might be more scarce than other versions of Arduino. Considering the bias of the training data toward the more established models and the probabilistic nature of ChatGPT, it is not surprising that it would omit the newer model. This kind of "inertia" was also highlighted by literature, for example [20], [23], [25], [31], [47].

To conclude this chapter, we can say that ChatGPT's answers were for the most part satisfactory in these broad instances. It should be noted that there was some arguable information provided and that ChatGPT might tend to show "cognitive inertia" leading to sometimes incorrect answers. It should also be kept in mind that the bot might sometimes give answers that are too general to be of usable quality, as can be seen in its answers in [45].

### 2.2.2 Sensors

To begin conversation about specific answers, ChatGPT was first asked to provide sensor types it would use for a smart home project. The recommendations were somewhat arbitrary, but the bot provided reasonable explanations for their use: temperature, light, motion, humidity, gas, water sensors and smoke detectors. Once the recommendations were provided, the bot was asked to give specific models for each sensor. Some examples of the recommended temperature sensors: DHT11, DHT22, LM35, DS18B20, BME280. All of these examples are valid and are used by hobbyists and professionals alike when designing for tasks as mentioned above. The bot also provided meaningful and proper explanations on why these specific temperature sensors should be used. It is both unnecessary and time consuming to go through every sensor model recommended in detail, as the answers were mostly acceptable, however, in the case of light sensors, it is worth examining the answer.

***Query:*** *Can you give me specific examples for light sensors?*
***ChatGPT:*** *Certainly! Here are some popular light sensors you can use with Arduino:*

1. *Photoresistor (LDR): This is a simple light sensor that changes its resistance based*

*on the amount of light it receives. The resistance can be measured with an analog input on the Arduino board. The LDR is a low-cost and easy-to-use option.*

*2. Photodiode: This is a semiconductor device that generates a small electrical current when exposed to light. Photodiodes are highly sensitive to light and can be used in applications that require precise measurements.*

*3. Phototransistor: This is a type of transistor that responds to light by changing its current. Phototransistors are more sensitive than photodiodes and can be used in low-light applications.*

*4. TSL2561: This is a digital light sensor that can measure both visible and infrared light. It has a wide dynamic range and can measure light levels from 0.1 - 40,000+ Lux.*

*5. BH1750: This is a digital light sensor that measures the intensity of light in Lux. It has a range of 1 - 65,535 Lux and communicates with the Arduino via I2C.*

*All of these sensors are readily available and can be easily interfaced with Arduino boards.*

***Query:*** *Can you give me some specific models for light sensors?*
***ChatGPT:*** *Sure! Here are a few specific models of light sensors that you can use with an Arduino board:*

*1. TSL2561: This is a digital light sensor that can measure both visible and infrared light. It is capable of detecting light levels as low as 0.1 lux and has a wide dynamic range.*

*2. BH1750FVI: This is a digital light sensor that uses I2C communication to communicate with the Arduino board. It is capable of detecting light levels ranging from 1 lux to 65,535 lux.*

*3. Photoresistor: A photoresistor (also known as a light-dependent resistor or LDR) is a simple and inexpensive analog sensor that changes its resistance based on the amount of light it detects. The resistance can be measured using an analog input pin on the Arduino board.*

*4. TSL237: This is an analog light sensor that can detect light levels over a wide range of frequencies, from 320 nm to 1050 nm. It can be used to measure the intensity of light or the frequency of light pulses.*

*5. ALS-PT19: This is an analog light sensor that can detect light levels ranging from 0.15 lux to 18,000 lux. It has a small form factor and can be easily integrated into small projects.*

*These are just a few examples of the many light sensors that are available for use with an Arduino board. The specific sensor you choose will depend on your project requirements and preferences.*

The reader should note that the two questions above were phrased differently. The first question used the word "example", while the second questions used the word "model". While to a human it would be obvious that both words refer to the same thing, the bot produced different answers. Strong dependence on wording and non-determinism (same question, different answer) has been noted in previous works [8], [48], [49], and should be kept in mind by an engineer aspiring to use the model to assist their work. We should also note that both answers mix type descriptions (i.e.: photoresistor) with specific types (i.e.: TSL237). This shows that the bot might sometimes misunderstand the context and/or provide incorrect, incoherent or irrelevant information [27], [32].

A similar situation of inconsistency and lack of meaningful information can be seen in the query regarding motion sensors.

> ***Query:*** *Can you give me specific models for motion sensors?*
> ***ChatGPT:*** *Sure! Here are a few specific models of motion sensors that you can use with an Arduino board:*
>
> *1. PIR Motion Sensor (HC-SR501): This is a Passive Infrared (PIR) motion sensor that can detect motion up to 7 meters away. It has a built-in amplifier and can be powered using a 5V power supply. It can be connected to an Arduino board using digital input pins.*
>
> *2. Ultrasonic Sensor (HC-SR04): This is an ultrasonic motion sensor that uses sound waves to detect the presence of objects. It has a range of up to 4 meters and can be connected to an Arduino board using digital input and output pins.*
>
> *3. Accelerometer and Gyroscope (MPU-6050): This is a combination accelerometer and gyroscope sensor that can detect motion and orientation. It is commonly used in drones and other robotics projects, but can also be used in smart home applications. It communicates with the Arduino board using I2C communication.*
>
> *4. Infrared Motion Sensor (IR Motion Sensor): This is a motion sensor that uses infrared radiation to detect movement. It has a range of up to 5 meters and can be connected to an Arduino board using digital input pins.*
>
> *5. Laser Motion Sensor: This is a high-precision motion sensor that uses a laser to detect movement. It has a range of up to 10 meters and can be connected to an Arduino board using digital input pins.*
>
> *These are just a few examples of the many motion sensors that are available for use with an Arduino board. The specific sensor you choose will depend on your project requirements and preferences.*

Even though the query was phrased the same way as for the other sensor types, ChatGPT chose to provide an output formatted in a different way. Whereas previously it gave output in the format <sensor mode>: <explanation>, here it gives the output in format <sensor type> (<sensor model>): <explanation>. This change is unreasonable and incoherent, especially since all sensor-related queries were asked in one session. While this change seems minimal, it could complicate for example parsing the answer with code, where you could reasonable expect the same answer format. The bot also did not give actual models for the last to sets. These are issues that emerge from the probabilistic nature of the bot. Engineers and professionals who use the bot should therefore be aware (at least on a superficial level), on how LLMs operate [12] and the risks they carry. They should also try to reduce the black-box nature of the model [22], [25] as much as possible by proper prompt engineering [4], [19], [25].

ChatGPT was also asked to list the sensor models by price and succeeded in doing so. However, the prices provided by the bot did not match those available at larger retailers used by engineers (Farnell, Mouser, DigiKey, etc.), instead they could be found by browsing other sites more popular among the public (i.e.: Amazon). The prices fluctuated somewhat, which could be because of market movements. In some cases, the prices listed by ChatGPT were inconsistently cheaper or more expensive compared to the ones found manually. The sensor models given were coherent with Arduino being recommended previously.

To conclude the part on sensors, the bot was asked to provide the specifications for the sensors. This is a reasonable query to assess the usability of the bot as a natural language search engine that can provide only relevant information (as suggested in [8], [18], [27]) saving time for the engineer. Only one example query (DHT11) will be included in the body of the text, as all the answers had the same issues.

***Query:*** *Can you give me the specifications of the DHT11 temperature sensor?*
***ChatGPT:*** *Sure! Here are the specifications of the DHT11 temperature and humidity sensor:*

1. *Temperature measurement range: 0 to 50 degrees Celsius with an accuracy of +/- 2 degrees Celsius*
2. *Humidity measurement range: 20% to 90% RH (Relative Humidity) with an accuracy of +/- 5%*
3. *Operating voltage: 3.3V to 5V DC*
4. *Current consumption: 2.5mA max during conversion, 0.5mA standby*
5. *Signal transmission distance: Up to 20 meters*
6. *Sampling rate: 1 Hz (1 reading per second)*
7. *Response time: less than 5 seconds*
8. *Dimensions: 23mm x 12mm x 5mm (L x W x H)*
9. *Digital output: Data is transmitted using a single-wire serial interface with a timing protocol that includes a start signal, data bits, and a checksum for error checking.*

*The DHT11 sensor is a low-cost, basic temperature and humidity sensor that is suitable* *for many simple projects. However, if you require higher accuracy, faster response time, or other features, you may need to consider a more advanced sensor.*

The bot correctly identified and explained the uses and advantages of the DHT11 temperature sensor, but a mistake was also included in the answer. The bot's answers states that the response time is "less than 5 seconds", while the datasheet of the product specifies a response time of minimum 6 s, typical 10 s and maximum 15 s [50]. It can be argued that it is possible that there are multiple datasheets in circulation on the Internet, but other datasheets we could find also gave precise values for the response time [51]. The same question was prompted for the DS18B20, TSL2561, MQ-135 sensors. Each specification had minor issues. DS18B20 had the maximum current drawn listed imprecisely compared to the datasheet, TSL2561 had operating voltage given incorrectly ("2.7V to 3.6 V DC") instead of the correct 0 to 3.8 V [52]. The incorrect information probably came from an application note that included the 2.7 V to 3.6 V information in a confusing manner [53]. For the MQ-35 the operating temperature was falsely listed as "-10 to 50 °C", where the correct information is a maximum of 45 °C [54].

In conclusion, this kind of information is crucial for a design, and identifying it correctly is necessary. While ChatGPT could answer questions for specifics and could even give largely correct answers, it also included errors which could lead to a product not working properly. The imprecise information sounded plausible and was hidden amongst precise data, which makes filtering it out more difficult. It is necessary to conclude that while ChatGPT can give general examples and answer broad questions, when specificity is key, it should not be trusted, and its answers must be verified be a human expert.

### 2.2.3 Workflow & code

Since an engineer's role in designing a system does not end when all the components have been ordered, it is important to assess the abilities of ChatGPT from a workflow and code generation point of view. It was asked to provide the code and workflow for 3 sensors (DS18B20, MQ-4, DHT11). Its answers were in order the following:

***ChatGPT:*** *To connect a DS18B20 temperature sensor to an Arduino, you will need the following components:*

- *DS18B20 temperature sensor*
- *4.7k ohm resistor*
- *Breadboard*
- *Jumper wires*

*Here are the steps to connect the DS18B20 temperature sensor to the Arduino:*

*1. Connect the Vcc pin of the DS18B20 sensor to the 5V pin on the Arduino.*

*2. Connect the GND pin of the DS18B20 sensor to the GND pin on the Arduino.*

*3. Connect the data pin (middle pin) of the DS18B20 sensor to a digital input/output (I/O) pin on the Arduino. In this example, we will use digital pin 2.*

*4. Connect a 4.7k ohm resistor between the data pin and the 5V pin on the Arduino.*

*5. Connect the Arduino to your computer via USB cable.*

*6. Open the Arduino IDE and create a new sketch.*

*7. In the sketch, include the OneWire and DallasTemperature libraries. These libraries can be installed from the Arduino IDE Library Manager.*

*8. Initialize the OneWire and DallasTemperature libraries in the setup() function of the sketch.*

*9. In the loop() function of the sketch, read the temperature data from the DS18B20 sensor using the DallasTemperature library functions. The code would look something like this:*

```
 #include <OneWire.h>
#include <DallasTemperature.h>

#define ONE_WIRE_BUS 2

OneWire oneWire(ONE_WIRE_BUS);
DallasTemperature sensors(&oneWire);

void setup() {
  Serial.begin(9600);
  sensors.begin();
}

void loop() {
  sensors.requestTemperatures();
  float temperature = sensors.getTempCByIndex(0);
  Serial.print("Temperature: ");
  Serial.print(temperature);
  Serial.println("°C");
  delay(1000);
}
```

*In this code, we first define the data pin (digital pin 2) as ONE_WIRE_BUS. Then, we initialize the OneWire and DallasTemperature libraries in the setup() function. In the loop() function, we first use the requestTemperatures() function to request the temperature data from the DS18B20 sensor. Then, we use the getTempCByIndex(0) function to get the temperature in degrees Celsius. Finally, we print the temperature to the serial monitor and add a delay of 1 second before the next reading.*
*10. Upload the sketch to the Arduino board and open the serial monitor to see the temperature readings.*
*That's it! You should now be able to read temperature data from the DS18B20 sensor using the Arduino.*

***ChatGPT:*** *To connect the MQ-4 gas sensor to an Arduino, you will need the following*

*components:*
- *MQ-4 gas sensor*
- *10k ohm resistor*
- *Breadboard*
- *Jumper wires*

*Here are the steps to connect the MQ-4 gas sensor to the Arduino:*

1. *Connect the Vcc pin of the MQ-4 sensor to the 5V pin on the Arduino.*

2. *Connect the GND pin of the MQ-4 sensor to the GND pin on the Arduino.*

3. *Connect the analog output (AO) pin of the MQ-4 sensor to an analog input (A0) pin on the Arduino.*

4. *Connect a 10k ohm resistor between the AO pin and the GND pin on the Arduino.*

5. *Connect the Arduino to your computer via USB cable.*

6. *Open the Arduino IDE and create a new sketch.*

7. *In the sketch, define the analog input pin that you connected the AO pin of the MQ-4 sensor to. In this example, we will use analog input pin A0.*

8. *In the setup() function of the sketch, initialize the serial communication and set the analog input pin as an input.*

9. *In the loop() function of the sketch, read the analog voltage value from the MQ-4 sensor using the analogRead() function, and convert it to a gas concentration value using a conversion formula provided in the MQ-4 datasheet. The code would look something like this:*

```
int mq4Pin = A0; // Define the analog input pin
float rs, ratio, ppm;

void setup() {
  Serial.begin(9600); // Initialize serial communication
  pinMode(mq4Pin, INPUT); // Set the analog input pin as an input
}

void loop() {
  int sensorValue = analogRead(mq4Pin); // Read the analog voltage value
  rs = (1023.0 - sensorValue) / sensorValue; // Calculate the sensor resistance
  ratio = rs / 9.83; // Calculate the ratio of sensor resistance to clean air resistance
  ppm = pow(10, ((log10(ratio) - 1.218) / (-0.224))); // Convert the ratio to gas concentration (ppm)
  Serial.print("Gas concentration: ");
  Serial.print(ppm);
  Serial.println(" ppm");
  delay(1000); // Wait for 1 second before the next reading
}
```

*In this code, we first define the analog input pin as mq4Pin. Then, in the setup() function, we initialize the serial communication and set the mq4Pin as an input. In the loop() function, we use the analogRead() function to read the analog voltage value from the MQ-4 sensor, and then calculate the gas concentration value in parts per million (ppm) using a conversion formula provided in the MQ-4 datasheet. Finally, we print the gas concentration value to the serial monitor and add a delay of 1 second before the next* *reading.*

*10. Upload the sketch to the Arduino board and open the serial monitor to see the gas concentration readings.*
*That's it! You should now be able to read gas concentration data from the MQ-4 sensor using the Arduino. Note that the conversion formula may vary depending on the gas you are detecting and the sensitivity of the sensor, so it's important to consult the datasheet for the specific MQ sensor you are using.*

***ChatGPT:***
*1. Here are the steps to connect a DHT11 temperature sensor to an Arduino:*

*2. Identify the pins on the DHT11 temperature sensor: The DHT11 has four pins, with the leftmost pin being VCC (power), the second pin being the data pin, the third pin being not connected (NC), and the rightmost pin being ground (GND).*

*3. Connect the DHT11 sensor to the Arduino: Connect the VCC pin of the sensor to the 5V pin on the Arduino, the data pin to any digital input pin on the Arduino (for example, pin 2), and the GND pin to the GND pin on the Arduino.*

*4. Download and install the DHT library: The DHT11 sensor requires a library to be used with the Arduino. You can download the DHT library from the Arduino IDE library manager or from the Adafruit Github repository.*
*Import the DHT library into your Arduino sketch: To use the DHT library in your sketch, you need to include the following line at the beginning of your code:*

```
#include <DHT.h>
```

*5. Initialize the DHT11 sensor in your Arduino sketch: In your setup() function, initialize the DHT11 sensor by calling the DHT constructor and passing in the data pin that you connected the sensor to:*

```
DHT dht(2, DHT11); // Initialize DHT sensor on digital pin 2
```

*6. Read the temperature and humidity from the DHT11 sensor: In your loop() function, call the readTemperature() and readHumidity() functions on the DHT object to get the current temperature and humidity readings from the sensor:*

```
float temperature = dht.readTemperature(); // Read temperature in Celsius
float humidity = dht.readHumidity(); // Read humidity as a percentage
```

*That's it! You should now be able to read the temperature and humidity values from the DHT11 sensor in your Arduino sketch.*

What we can notice first in the workflows is that even though the questions were phrased the same way, the answer is visually different. While DS18B20 and MQ-4 answers have the code in one segment, the DHT11 workflow has the code in separate paragraphs. This is inconsistent and impedes the application of the bot into the design workflow, as it obviously cannot be relied on to produce the output in the same format (which would make it easier to parse automatically). Also, for DHT11 and MQ-4 the code generated has some comments to explain the behaviour, the DS18B20 does not, leaving the user to figure out what the bot meant (while the bot being aware of the utility of commenting is definitely a pleasant feature). The generated code was put into Arduino's IDE (Integrated Development Environment) to check the syntax. This step requires minimal knowledge of the IDE to validate the code generated by ChatGPT (aside from knowing what the code actually means). In the example of the MQ-4 the generated code contains some formulae:

```
rs = (1023.0 - sensorValue) / sensorValue; // Calculate the sensor resistance
ratio = rs / 9.83; // Calculate the ratio of sensor resistance to clean air resistance
ppm = pow(10, ((log10(ratio) - 1.218) / (-0.224))); // Convert the ratio to gas concentration
```

When prompted where it got this piece of code, the bot responded that it is from the datasheet, however, the datasheet does not contain such information [55]. This is an issue from a viewpoint of explainability and transparency, which are important aspects when working with an AI tool, as highlighted in [22], [25], [30].

When prompted about the source of the code in general (DS18B20) it responded with:

> ***ChatGPT:*** *I wrote the code example based on my knowledge and experience with using the OneWire and DallasTemperature libraries to read temperature data from a DS18B20 sensor. However, the code structure and some of the function calls may be similar to code examples found in the official Arduino documentation, online forums, or tutorials.*

Otherwise, the workflow provided with the codes was checked and found to be correct. The pin alignment, resistor sizes, even the 1-wire communication were correctly identified according to the available datasheets [50], [55], [56]. Regarding the code of DHT11, there is a reference to a DHT.h library which is not straightforward. Altogether while the workflow is mostly correct and plausible, some expertise is necessary to verify the answer, which could have different depth and applicability in different cases. At this point, assuming the user is an experienced engineer, verifying the output of the model could take more time than it would have taken the user to connect the sensors without the use of AI.

### 2.2.4 Literature review

To conclude the chapter on ChatGPT, it was asked to do a brief literature review. In our first attempt the query did not specify the need for DOI, and exact references and the bot simply provided a summary page of information without any references for the data, which is useless in terms of scientific publication (where references are necessary). For the second query, we specified the task more precisely, asking for exact references and DOI numbers, forcing the bot to include those in its answer.

***Query:*** *Could you please provide me with references to scientific literature regarding using Arduino as a sensor controller? Could you also include the DOI numbers of the references?*
***ChatGPT****: Sure, here are a few references to scientific literature regarding using Arduino as a sensor controller, along with their DOI numbers:*

*1. J. H. Shin and J. M. Kim, "Smart home energy management system using Arduino and Raspberry Pi," Journal of Renewable and Sustainable Energy, vol. 10, no. 5, p. 053703, Sep. 2018. DOI: 10.1063/1.5045643*

*2. F. T. Y. Harahap, S. Sutikno, M. C. Sanjaya, A. F. A. Fauzi, and B. Purba, "Development of IoT-based weather station system using Arduino," International Journal of Electrical and Computer Engineering, vol. 11, no. 4, p. 3001, Aug. 2021. DOI: 10.11591/ijece.v11i4.pp3001-3011*

*3. S. A. Sulaiman, S. A. Abu-Bakar, M. A. Al-Qdah, M. R. Baharom, and M. F. Azmi, "Design and development of smart home energy management system using Arduino," IOP Conference Series: Materials Science and Engineering, vol. 1092, no. 1, p. 012001, Mar. 2021. DOI: 10.1088/1757-899X/1092/1/012001*

*4. J. R. de Sousa and M. F. de Sousa, "Data acquisition and control system based on Arduino platform for low-cost greenhouse monitoring," Measurement, vol. 168, p. 108273, Jan. 2021. DOI: 10.1016/j.measurement.2020.108273*

*5. F. L. Villegas, J. F. Castillo, J. M. Lopez, and A. Tellez, "Data acquisition system using Arduino and Android for monitoring water quality," Revista Facultad de Ingeniería, vol. 30, no. 55, p. 67, Dec. 2021. DOI: 10.19053/01211129.v30.n55.2021.13007*

*I hope these references are helpful for your research!*

At first the above response seems extremely plausible. Every reference has a title, list of authors, some reference to a journal and a DOI number. Upon closer inspection we can find the following. Searching on platforms like Google Scholar, Web of Science, etc. shows that these works do not exist. Some studies do exist with similar names. The lists of authors have similar issues. While some authors from ChatGPT's answers (there were multiple queries targeting literature review) do exists in similar fields, they did not write these specific (non-existent) papers. DOI numbers are also misleading, as they either lead nowhere, or to random publications. This points to an issue: the bot does not understand the context of the questions but can calculate what a scientific reference would look like, and therefore is capable of producing these false, but very convincing references. In its current state the bot is not capable of producing a trustworthy literature review.

Another interesting answer came when the bot was prompted to produce references for connecting sensors to the Arduino. In this case the bot actually provided four accessible references (links) out of five to resources, however one of them was not a live link. This link "https://www.arduino.cc/en/Tutorial/HomePage" was at the time of access (2023.03.29.) being forwarded to Arduino's current document repository [57]. After feeding the link to Archive.org [58] "Wayback Machine" it turns out that the old link was last accessible on 4 January 2022 [58]. This is after the cutoff date of ChatGPT pointing out the issue of the ChatGPT database being outdated in some cases.

## 2.3 Comparison with other AI

To finish this paper, BingAI, Copilot and Bard (the latter of which only recently became available in Hungary) were prompted some questions. Not every question was asked, only one example in each. The questions were:

1. Provide 6 controller examples
2. Make an argument for each example
3. Give sensor types
4. Give examples of temperature sensors
5. DS18B20 specification
6. DS18B20 workflow
7. References

### 2.3.1 Bard

The Bard AI is Google's attempt to create a conversational AI. It became available in Hungary during the summer of 2023 [59] and is connected to the Internet, so it should be able to provide real-time data and references.

For the first question, Bard gave five examples of controllers (1 less than ChatGPT) with a short description of each. The answer was coherent and contained reasonable information, while also being well-structured. The second answer was also reasonable and informative, and the bot also provided a pro-con list for each controller, which could be useful (the other bots did not provide such lists). When asked about sensor types the bot promptly gave examples like temperature sensors, door and window sensors, air quality sensors, etc.; all of which could be useful for a smart home project. It also provided application examples in its answers, these were redundant however and reduced the comprehensibility of the answer.

When prompted about sensor models, it gave multiple examples with short descriptions. It also provided some recommendations on what specifications a user should pay attention to depending on their project, which is a nice addition to the answer. In the specification of the DS18B20 it made an error regarding the power consumption of the device, listing a smaller current than is included in the datasheet [56]. The workflow for connecting the sensor was clear, easy to understand and included a well commented code that compiled without error in the Arduino IDE.

The literature review, like the case of ChatGPT was completely unreliable. It provided the following answer:

> ***Bard:*** *Sure. Here are a few references to scientific literature regarding using Arduino as a sensor controller, with DOI numbers:*
>
> *Low-Cost Microcontrollers for Smart Home Applications: A Case Study of Arduino (DOI: 10.1109/ACCESS.2021.3053154)*
> *Arduino-Based Sensor Controller for Agricultural Monitoring (DOI: 10.1007/978-3-030-35767-2_35)*
> *Arduino as a Sensor Controller for Environmental Monitoring (DOI: 10.1016/j.envsoft.2018.05.007)*
> *Arduino-Based Sensor Controller for Industrial Automation (DOI: 10.1007/978-3-319-76947-5_2)*
> *Arduino-Based Sensor Controller for Robotics Applications (DOI: 10.1007/978-3-319-76947-5_3)*
> *These papers provide a good overview of the different ways that the Arduino can be used as a sensor controller. They also discuss the challenges and opportunities of using the Arduino in different applications.*
>
> *I hope this information is helpful. Please let me know if you have any other questions.*

None of the above publications exist and the DOI numbers either point to the wrong publications or do not exist. The only saving grace for Bard's answer is that because the publications lack the author list it is obvious at first glance that these references are not trustworthy.

### 2.3.2 BingAI

The BingAI is integrated into Microsoft Edge and is accessible to anyone with a Microsoft account. It is actually based on some parts of GPT-4 [60], which is OpenAI's model following GPT-3.5 and is supposedly producing higher quality output [61]. It could possibly outperform ChatGPT, and therefore should be investigated.

Like Bard and ChatGPT, when prompted with general questions BingAI performed well. It gave 5 examples of controllers (again, 1 less than ChatGPT) and their short descriptions. The answer was coherent and useful. When prompted further it made reasonable arguments for choosing each controller, however some of the information it gave was also given in its previous answer and did not actually serve to increase the depth of the conversation. When asked about specific sensor types, BingAI made suggestions like muscle sensor, pulse sensor, heart rate monitor, etc. While the context of the conversation had been established previously it did not carry over to the answer. This resulted in giving an incoherent answer that is uninformative for a smart home development project. The prompt could have been reformatted to include "smart home" in its wording, however this shows that compared to the other AI, it has issues with following the context of the conversation.

When prompted for temperature sensor models BingAI provided multiple examples and lots of links (see appendix) to tutorials. The answer itself contained very little information regarding the sensors:

> ***BingAI:*** *There are many temperature sensors that can work with Arduino such as LM35, TH02, HDC1000 or HTS221. One of the most popular temperature sensors is the DS18B20 temperature sensor which is inexpensive, easy to use and waterproof. It is a one-wire digital temperature sensor that requires only one data line (and GND) to communicate with the Arduino. Each DS18B20 temperature sensor has a unique 64-bit serial code which allows you to wire multiple sensors to the same data wire. I hope this helps! [...]*

The above response lacks descriptions of the sensors, which the other bots provided. The workflow for the DS18B20 was provided and was correct and easy to read, however it lacked any code, which – again – the other bots generated without having to be specifically prompted.

Regarding the literature references this bot managed to provide 5 references. 4 articles existed, 3 of the four had bad author lists, fake or no DOI (despite being specifically asked for DOI numbers). 1 out of 4 had a DOI pointing to an actual reference in a connected field but had the title and authors wrong. Clearly the bot cannot be trusted to provide a literature review and it produced a plausible but incorrect answer.

### 2.3.3 Copilot by Flux

Copilot is a large language model tool developed by flux.ai to aid PCB designers. It should be capable of understanding the full scope of a PCB development project and provide answers to natural language queries [62]. As it is an LLM developed specifically for electrical engineering assistance, we thought it was prudent to examine its performance in relation to ChatGPT and the other bots. To achieve this, it was prompted the same set of queries as BingAI and Bard.

Copilot provided interesting answers to the queries. First, like the other bots, it was prompted to provide options for a microcontroller for a smart home project. It gave multiple examples, like ATmeg328P, ESP32, CC3200, etc. While its answer was generally coherent and clear with plenty of information on each controller, most of the options, like for example the ATmeg328P were individual chips, which would not be easily usable in a smart home project, where you probably do not want to design a whole PCB. The other bots also provided some chip recommendations, but most of their answers were microcontroller boards. The preference of Copilot of standalone chips could be due to the fact that it was designed for assistance with PCB design. Upon further prompting for arguments for each case, it provided greater depth in its answer. Overall, it performed well for general questions.

Regarding sensor specifications, it provided multiple types (temperature, humidity, light, has door/window sensors, etc.) which could be used in a smart home project. When prompted for specific models, it provided six temperature sensors. The model was also asked to provide the specification for the DS18B20 sensor, which it did. In its answer it includes: “Stainless Steel Probe Version Available: Ideal for applications that require moisture resistance.” There is no mention of such a version in the datasheet [56], however it is commercially available [63]. The workflow for connecting the sensor was correct, with only one minor inaccuracy: the answer referred to the data pin of the DS18B20 as “DATA”, while it is called “DQ” in the datasheet [56]. The bot also generated correct code with the workflow, which compiled without issues in the Arduino IDE.

Lastly, for the query regarding literature references, the bot gave the following answer:

> ***Copilot:*** *I'm sorry, but as an AI developed by Flux.ai, I don't currently have the capability to search and provide links to scientific literature or DOI numbers. I recommend using academic databases such as Google Scholar, IEEE Xplore, or others that have been designed specifically for that purpose.*

The bot clearly admitted that it is not capable of providing a good literature review. While this is a failure from the standpoint of applicability (it cannot be used for this task), it is an excellent response to deny answering instead of providing a false set of plausible looking references.

# 3 A short outlook on circuit development

One of the difficult parts of an electrical engineer's work is to design electrical circuits. Often one must solve an issue that is at least in small parts different from existing and universally applied solutions. In these cases, it might take a long time to do a proper survey of existing literature, condense down the acquired data and take intuitive steps to create a solution that fits the specific needs of the project at hand. An AI tool that could help produce the solution faster could be useful in these cases. To assess the ability of the AI tools in this paper, two questions were asked from each, regarding the design of a Howland current source, which is a well-established circuit, often applied in measurement circuits when we need to provide a highly accurate current with low noise. There is abundant literature on the circuit in various fields, such as bioelectricity [64], [65], eddy current probes [66], impedance measurement [67], etc. A quick search for "Howland current source" on ScienceDirect returns more than 3000 hits. The expected circuit:

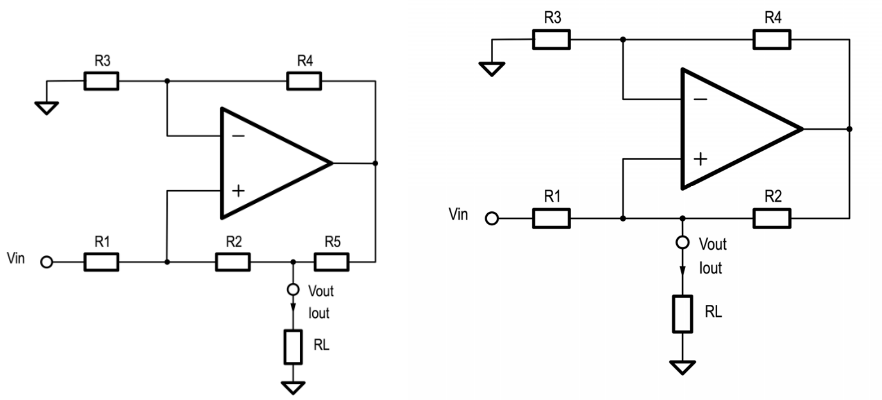


**Figure 3-1 – Howland current source [68] with a) feedback resistor b) feedback amplifier**

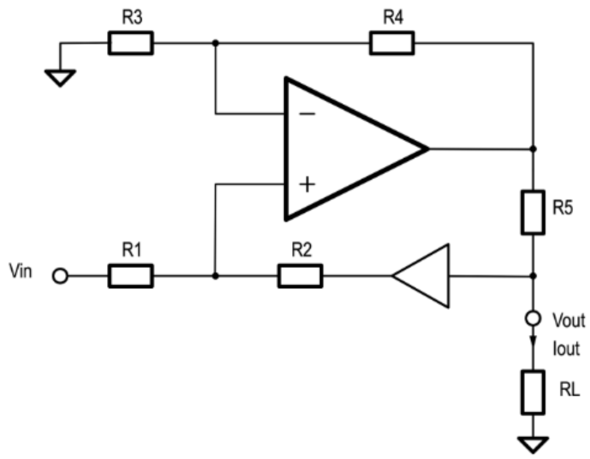


**Figure 3-2 – Howland current source with feedback resistor and buffer [68]**

Each bot was asked two questions:

- Can you tell me what the schematic of a Howland current source would look like?
- Can you tell me what the schematic of a Howland current source with a feedback buffer would look like?

None of the answers supplied by the bots was satisfactory for use as an electrical engineer. Most of the answers were confusing, difficult to comprehend and took a long time to extract out information, often directing the user to another website, where the information was available. While in general Bing, ChatGPT and Bard provided factually correct answers, meaning the contents, while not detailed enough to be comprehensible if someone was not familiar with the given circuit were correct, however, instead of providing the user with the equations for the most often used configuration (Figure 3-1/a) they provided equations for a less often used configuration (Figure 3-1/b). The reason the latter is used less is that the output potential is the same as the input potential, and most of the time feedback resistor is added to the circuit. This means their answers were not of sufficient quality for use as an engineer, or a hobbyist for that matter, as a manual search for details cannot be avoided.

None of the bots tried to provide an image for the circuit except for ChatGPT, which provided the following "image":

```
      +Vcc
       |
       R1
       |
       |    R2
       +----/\/\----+
       |            |
       |            |
       |            |
       |            |
       |            |
       |            |
       |            |
       +---/\/\----+
       |    R3
       |
       R4
       |
       |
       Iout
```

**Figure 3-3 - Howland schematic provided by ChatGPT**

The above schematic is unacceptable as a circuit schematic, as it is not possible to tell what electronic parts the various symbols represent.

Lastly, Copilot's answer should be discussed separately. The bot – unlike the others – tried to provide a description of the schematic but failed to do so utterly. First, it was more difficult to interpret the textual description than it would have been to look at a real schematic, second, the text could be interpreted in multiple ways, and third, each interpretation was wrong. For example:

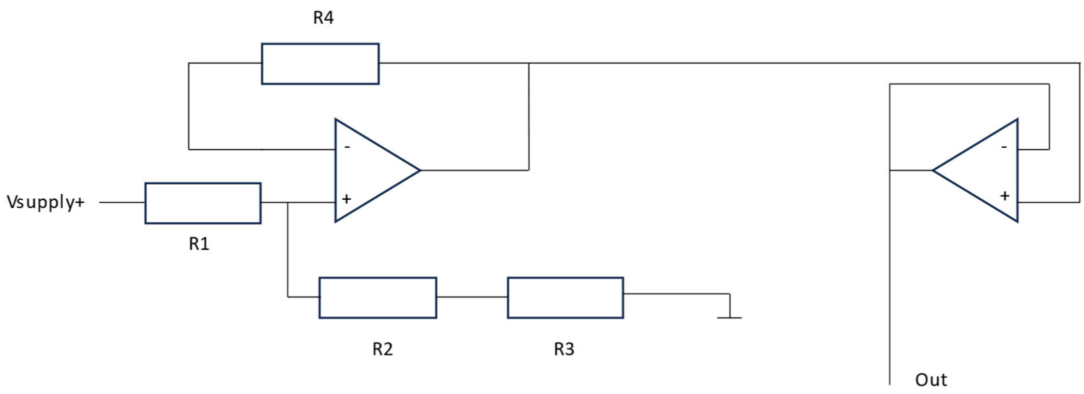


**Figure 3-4 – Copilot's answer for the Howland source with feedback buffer (one possible interpretation)**

The above schematic is not equivalent with the feedback buffer schematic in Figure 3-2.

Altogether none of the bots are acceptable as tools for circuit development and should be avoided at this point.

# 4 Discussion

Figure 4-1 summarizes the performance of ChatGPT across different domains. Table 4-1 gives a performance table for ChatGPT, based on the work in [39]. ChatGPT could interact with the user in a meaningful way. It could provide answers to general questions in a coherent and insightful, though sometimes shallow, and superficial manner. The limitations of its training were apparent in its answers (i.e.: Arduino Portenta family being omitted). The bot provided plausible examples for the controller of a smart home project.

Regarding sensor types and specifications, the bot performed somewhat inconsistently. It provided multiple sensor types when prompted. When prompted for specific sensor models, it sometimes mixed the models with measurement principles. Otherwise, the models provided were acceptable for an Arduino board and still available on the market, showing that the bot could follow the overall context of the conversation. The bot also gave some pricing information, which was close to the present pricing. In the specifications the bot provided mostly usable information, however it did make some minor errors (around 10 % of the information provided). The erroneous data was close to the actual values. If the training data was more recent it is possible that the answer would have been more accurate, as fewer resources would be available for the bot to work from, and most of those resources would be the manufacturers' documents.

ChatGPT could provide workflow and code for connecting the sensors to the Arduino board. It was asked to provide the workflow for 3 different sensors, and each time it provided the correct physical interfacing solution, recommended by the manufacturers' datasheets. The bot also generated code without needing to be prompted specifically. The code was generally correct but had minor issues and included confusing formulae in some cases. Also, the formatting of the answers for the workflow related questions was not consistent. Altogether, a beginner engineer could benefit from being quickly provided a workflow, even if it has some minor issues and need modifications. One caveat is that the bot should be examined with questions regarding larger projects, where it could make more errors (the examples in this paper were very simple). It could turn out that using the bot and correcting the errors made could create more working hours for an experienced engineer than would otherwise be necessary.

In the case of generating a literature review – which is an area of application often advocated for in literature [10], [20], [30] – the bot performed unacceptably. It created a list of references that upon first impression looks convincing and plausible, with all the required data available (author list, DOI, journal title, etc.). However, upon further inspection it turned out that the data provided was fake. The keywords, authors and journals were often real, but not incorrect for the given citations. The tendency of the bot to fabricate data has been noted in existing literature on its applications [7], [11], [17], [25]. There could be multiple explanations of why it fabricated the data. First, it could simply be, that the bot cannot handle a large amount of coherent information to produce a correct citation, but this is refuted by the fact that it performed well in other areas, where it was required to handle large amounts of coherent information. Second, it could be an issue of data availability, where it cannot access a lot of journals due to a paywall or an exclusion from the training set, but this also unlikely, since the topic of discussion was very well established and there should be at least a few references available to the bot. The last possible cause is that the bot is not capable of tracking the sources of the information it uses. Coupled with the fact that it does not actually understand the query like a human, rather just calculates the most probable response word-by-word, and that during training, "I do not know the answer" would most often be wrong, it could be that the bot prefers generating false data rather than admit a limitation. Whether this is an inherent artifact of the GPT design in unclear, but Copilot's response to the literature review prompt is promising, as it denied providing information outside its capability. While some studies suggest ChatGPT could help with documentation, others suggest that it is more like a creative tool [69], helping to find relevant keywords, new directions for research, etc. Most studies seem optimistic regarding the model's abilities to assist with organizational tasks (i.e.: hypothesis validation, identification of gaps and inconsistencies in knowledge) [1]. It should also be noted, that when it was prompted for more commercially available data (like datasheets), it could provide working links (4 out of 5).

Finally, it should be noted that the bot is very sensitive to phrasing and previously established context. It also tends to provide different answers to the same question [8], [22], [48], leading to branching discussions upon re-prompting. Because of this, the present experiment shows a use case that is not necessarily reproducible in the classical manner, since even with the same prompts, the bot could give different answers. This increases the difficulty of assessing the tool's applicability from both a technical and societal aspect.

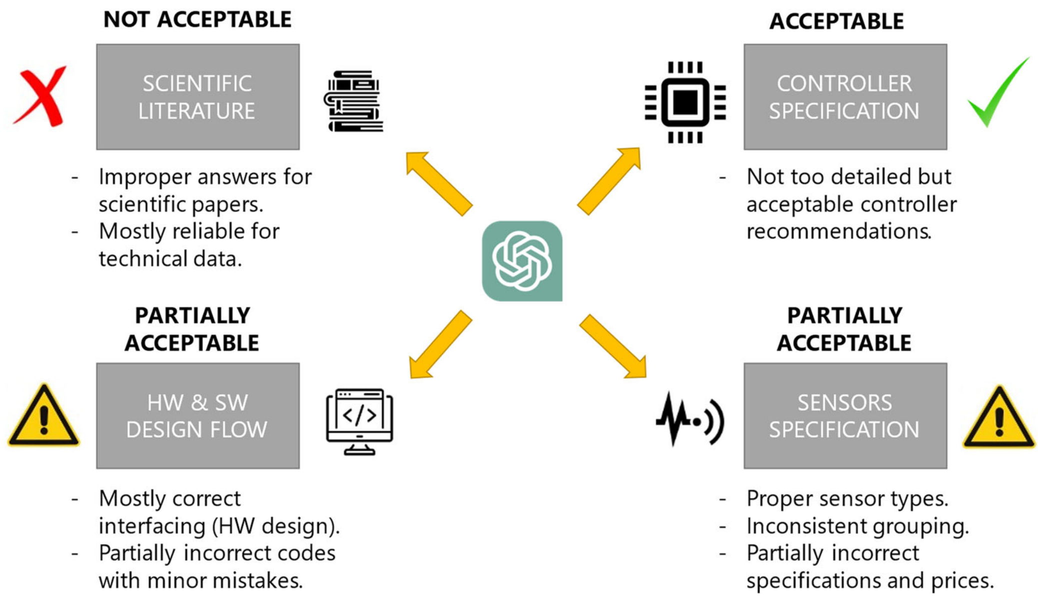


**Figure 4-1 – Summary of ChatGPT's performance across different domains**

| Subjects | Overall Performance | Comments |
|---|---|---|
| Choice of controller for smart home application | Acceptable | Outstanding choice with proper details on different types, Arduino was the leading choice, understandable discussion, usable but shallowly detailed information |
| Sensor types | Partially acceptable | Type choice was proper, with inconsistencies in listing and presentation. No commercialization was apparent |
| Sensor specification | Partially acceptable with minor technical errors | Specifications were mostly ok, minor problems were found in specification parameters (only on per type) and pricing. Probably due to limited availability on the Internet |
| Hardware interfacing | Partially acceptable | Interfacing details were almost acceptable with minor inconsistencies in presentation. The descriptions were written with varied required basic knowledge for understanding. |
| Code | Partially acceptable with occasional technical errors | Correct syntax, uneven commenting, minor addressing issues. |
| Literature | Unacceptable | Totally unacceptable for academic demands. Fabricated titles with real authors and fake, sometimes working, but not connected DOIs. Technical data is addressed in a more reliable form. |

**Table 4-1 – Performance of ChatGPT across different domains [13]**

Table 4-2 summarizes the ability of BingAI, Copilot and Google Bard. Besides ChatGPT, the recent study also investigated the use of other LLMs. The three other bots were only prompted with a subset of the questions presented to ChatGPT; therefore, this comparison provides more of a hint at the possibilities, rather than an in-depth investigation of the abilities of the three other machines. Even when the bots did not perform adequately, they were not prompted further, as that would have skewed the comparison. For example, BingAI did not provide code with the workflow, so it was not specifically prompted for code, as that was not in the subset of selected prompts, rather it was noted that it failed to provide a crucial piece of information.

To summarize, all the other bots performed well for general questioning and reasoning, as would be expected. Copilot mostly provided microcontroller chips instead of boards to the first prompt (what controller it would recommend). While these would not be as useful for a smart home project, the context had not been established at that point, so while a little out-of-context, it is still an acceptable answer. Regarding sensor types, Bard and Copilot provided acceptable answers, while BingAI failed to follow the concept of the smart home and produced an answer that lacked any useful information. The bots performed well for specifications, with Copilot providing the best results. All bots could provide a good physical workflow, but BingAI failed to generate the code – which would be a crucial part of the integration process, and probably the one that a beginner engineer would struggle with most. The code generated by the other AI was acceptable. The literature review of BingAI and Bard was completely unacceptable, with Copilot providing an exemplary answer: it highlighted its inability to provide a literature review. Altogether all three of the bots show promise, but Copilot show the best results compared to ChatGPT.

| | **BingAI** | **Google Bard** | **Copilot** |
|---|---|---|---|
| **Choice of controller** | Acceptable, coherent, shallow | Acceptable, coherent | Acceptable, coherent, little out-of-context |
| **Sensor types** | Incoherent, out of context, unacceptable | Coherent, in context, with application examples, acceptable | Coherent, in context, acceptable |
| **Sensor specification** | Little information, multiple links to resources | Minor errors | Acceptable |
| **Hardware interfacing** | Correct workflow, but didn't generate code | Correct workflow, easy to read, code generated | Correct workflow, minor semantic error, code generated |
| **Code** | - | Acceptable, no errors | Acceptable, no errors |
| **Literature** | Unacceptable | Unacceptable | Acceptable, admitted limitation |

**Table 4-2 – Comparison of BingAI, Bard and Copilot**

# 5 Conclusion

In this paper the applicability of ChatGPT – a novel model by OpenAI – was investigated in the field of electrical engineering, through an example of a case study in applied sensors. ChatGPT was prompted with increasingly specific questions regarding a smart home development project. It answered the queries with a consistent manner and narrowed its focus as necessary to the more specific details like sensor specification and literature review.

It was found that while ChatGPT provided valuable information in broader questions like choosing a controller, or recommending sensor types (light sensor, temperature sensor, etc.) it produced slightly incoherent or imprecise results in more specific questions like specifications, hardware-software integration workflow and programming code. It needed human verification for the results to be usable. It was also found, that when prompted for literature references the bot produced non-existent and faulty references while sounding plausible. Technical documentation was referenced correctly although with limited applicability.

Copilot, BingAI and Bard were also superficially investigated. They performed similarly to ChatGPT. The other AI also tackled broader problems well, but provided more accurate responses in some cases, though it should be noted that they faced fewer queries and could possibly make more errors if prompted further. Regardless, BingAI for example produced better accuracy in case of providing a sensor specification. None of the AI could produce a reliable reference list. Notably Copilot admitted that it was not capable of providing references, which is an excellent answer compared to the other AI, which fabricated their output. Interestingly, BingAI had issues following the context of the conversation, and produced some incoherent answers, even though it is based on ChatGPT's next generation, GPT-4.

At the time of writing this paper, these AI tools should not be used without human verification and should only be used to augment human work rather than replace it. It should also be noted that these AI are completely unsuitable for some tasks (i.e.: providing references) in their current states.

# 6 Funding

Supported by the **ÚNKP-23-2-I-BME-44** New National Excellence Program of the Ministry of Culture and Innovation from the source of the National Research, Development and Innovation Fund.

Új Nemzeti Kiválóság Program

Kulturális és Innovációs Minisztérium

National Research, Development and Innovation Office Hungary

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# 8 Appendix

## 8.1 Queries and answers

### 8.1.1 ChatGPT

#### 8.1.1.1 General questions

***Query:*** *I am doing a smart home project. I need to choose a micro-controller for controlling the sensors I need for the smart home. Could you give me options for the controllers? Give 4 to 6 examples, from different manufacturers.*
***ChatGPT:*** *Sure! There are several options for micro-controllers that you can choose from for your smart home project. Here are 6 examples from different manufacturers:*

- *Arduino Uno: This is a popular micro-controller board that is easy to use and has a large community. It has 14 digital input/output pins, 6 analog inputs, and a 16 MHz quartz crystal.*

- *Raspberry Pi: This is a small, affordable computer that can run a full operating system. It has a variety of input/output options, including GPIO pins, USB ports, and Ethernet.*

- *ESP32: This is a powerful micro-controller with built-in Wi-Fi and Bluetooth connectivity. It has 34 GPIO pins, 18 analog inputs, and a dual-core processor.*

- *STM32F4 Discovery: This is a development board based on the STM32F407VGT6 micro-controller. It has 168 MHz Cortex-M4 CPU, 1 MB Flash memory, and 192 KB RAM.*

- *PIC18F4520: This is a popular micro-controller from Microchip Technology. It has 32 KB Flash memory, 1.5 KB RAM, and 36 I/O pins.*

- *NXP LPC1768: This is a micro-controller based on the ARM Cortex-M3 architecture. It has 512 KB Flash memory, 64 KB RAM, and a variety of input/output options.*

*These are just a few examples, and there are many other micro-controllers available on the market. You will need to choose the one that best fits your project's requirements in terms of processing power, memory, and input/output options.*

***Query:*** *Make an argument for choosing each of the controllers!*
***ChatGPT****: Sure! Here are some arguments for choosing each of the micro-controllers I listed:*

- *Arduino Uno: The Arduino Uno is a popular choice for beginners and hobbyists because it is easy to use and has a large community. There are many tutorials and examples available online, making it easy to get started. It has a simple programming environment and is compatible with a wide variety of sensors and shields.*

*• Raspberry Pi: The Raspberry Pi is a powerful micro-controller that can run a full operating system, making it suitable for more complex projects. It has a variety of input/output options, including GPIO pins, USB ports, and Ethernet, making it versatile and flexible. It can also run software like Python, making it easy to integrate with other tools and services.*

*• ESP32: The ESP32 is a powerful micro-controller with built-in Wi-Fi and Bluetooth connectivity. This makes it ideal for projects that require wireless communication, such as remote control or monitoring. It has a large number of input/output pins and a dual-core processor, making it suitable for projects that require a lot of processing power.*

*• STM32F4 Discovery: The STM32F4 Discovery is a development board that is based on the STM32F407VGT6 micro-controller. It has a high processing speed and a large amount of memory, making it suitable for complex projects. It also has a wide range of input/output options, including USB, Ethernet, and audio.*

*• PIC18F4520: The PIC18F4520 is a popular micro-controller from Microchip Technology. It has a relatively low cost and a large number of input/output pins, making it ideal for projects that require a lot of sensors or actuators. It also has a large community and many examples available online, making it easy to get started.*

*• NXP LPC1768: The NXP LPC1768 is a micro-controller based on the ARM Cortex-M3 architecture. It has a large amount of memory and a variety of input/output options, making it suitable for a wide range of projects. It also has a powerful processor and can run at high speeds, making it ideal for projects that require fast processing.*

*In summary, each of these micro-controllers has its own strengths and weaknesses, and the best one for your project will depend on your specific requirements. Factors to consider when choosing a micro-controller include processing power, memory, input/output options, and community support.*

***Query:** I am trying to make a smart home using an Arduino or a Raspberry Pi controller for my sensors. Which controller should I use?*
***ChatGPT:** Both the Arduino and Raspberry Pi controllers have their advantages and disadvantages when it comes to building a smart home.*

*Arduino is a microcontroller board that is designed for simple projects that require low power and have limited processing requirements. It is a good choice if you want to control simple sensors such as temperature, humidity, and light sensors. Arduino is easy to use and is ideal for beginners who are starting to learn about microcontrollers.*

*On the other hand, Raspberry Pi is a small computer that is capable of running a full operating system. It is more powerful than Arduino and has a wider range of capabilities. Raspberry Pi is a better choice if you want to integrate complex sensors such as cameras, voice recognition, and machine learning. It also has the capability of connecting to the internet, which allows for remote control and monitoring of your smart home devices.*

*Therefore, the choice of controller depends on the complexity of your project and the sensors you want to integrate. If you are building a simple smart home system, then an*

*Arduino controller would suffice. However, if you want to build a more advanced system that requires complex sensors and internet connectivity, then Raspberry Pi would be a better choice.*

#### 8.1.1.2 Sensor types & models

***Query:*** *Can you give me specific models for temperature sensors?*

***ChatGPT:*** *Sure, here are some popular temperature sensor models you can use with Arduino:*

*1. DHT11: This is a digital temperature and humidity sensor that is low cost and easy to use. It has a range of -40°C to 80°C with an accuracy of ±2°C.*

*2. DHT22: This is an upgraded version of the DHT11 and can measure temperature and humidity more accurately. It has a range of -40°C to 125°C with an accuracy of ±0.5°C.*

*3. LM35: This is an analog temperature sensor that has a linear output voltage that is directly proportional to the temperature in Celsius. It has a range of -55°C to 150°C with an accuracy of ±0.5°C.*

*4. DS18B20: This is a digital temperature sensor that uses a single wire interface to communicate with Arduino. It has a range of -55°C to 125°C with an accuracy of ±0.5°C.*

*5. BME280: This is a combined digital temperature, humidity, and pressure sensor. It has a temperature range of -40°C to 85°C with an accuracy of ±1°C.*

*All of these sensors are widely available and can be easily interfaced with Arduino board*

***Query:*** *Can you give me specific examples for light sensors?*

***ChatGPT:*** *Certainly! Here are some popular light sensors you can use with Arduino:*

*1. Photoresistor (LDR): This is a simple light sensor that changes its resistance based on the amount of light it receives. The resistance can be measured with an analog input on the Arduino board. The LDR is a low-cost and easy-to-use option.*

*2. Photodiode: This is a semiconductor device that generates a small electrical current when exposed to light. Photodiodes are highly sensitive to light and can be used in applications that require precise measurements.*

*3. Phototransistor: This is a type of transistor that responds to light by changing its current. Phototransistors are more sensitive than photodiodes and can be used in low-light applications.*

*4. TSL2561: This is a digital light sensor that can measure both visible and infrared light. It has a wide dynamic range and can measure light levels from 0.1 - 40,000+ Lux.*

*5. BH1750: This is a digital light sensor that measures the intensity of light in Lux. It* *has a range of 1 - 65,535 Lux and communicates with the Arduino via I2C.*

*All of these sensors are readily available and can be easily interfaced with Arduino boards.*

***Query:** Can you give me some specific models for light sensors?*

***ChatGPT:** Sure! Here are a few specific models of light sensors that you can use with an Arduino board:*

1. *TSL2561: This is a digital light sensor that can measure both visible and infrared light. It is capable of detecting light levels as low as 0.1 lux and has a wide dynamic range.*

2. *BH1750FVI: This is a digital light sensor that uses I2C communication to communicate with the Arduino board. It is capable of detecting light levels ranging from 1 lux to 65,535 lux.*

3. *Photoresistor: A photoresistor (also known as a light-dependent resistor or LDR) is a simple and inexpensive analog sensor that changes its resistance based on the amount of light it detects. The resistance can be measured using an analog input pin on the Arduino board.*

4. *TSL237: This is an analog light sensor that can detect light levels over a wide range of frequencies, from 320 nm to 1050 nm. It can be used to measure the intensity of light or the frequency of light pulses.*

5. *ALS-PT19: This is an analog light sensor that can detect light levels ranging from 0.15 lux to 18,000 lux. It has a small form factor and can be easily integrated into small projects.*

*These are just a few examples of the many light sensors that are available for use with an Arduino board. The specific sensor you choose will depend on your project requirements and preferences.*
***Query:** Can you give me specific models for humidity sensors?*

***ChatGPT:** Sure! Here are a few specific models of humidity sensors that you can use with an Arduino board:*

1. *DHT11: This is a low-cost digital humidity sensor that can also measure temperature. It has a range of 20% to 90% relative humidity and can measure temperatures from 0°C to 50°C. It communicates with the Arduino board using a single-wire interface.*

2. *DHT22: This is a more accurate digital humidity sensor that can measure humidity in the range of 0% to 100% with an accuracy of +/- 2%. It can also measure temperature in the range of -40°C to 125°C with an accuracy of +/- 0.5°C. It communicates with the Arduino board using a single-wire interface.*

3. *SHT31-DIS-B: This is a high-precision digital humidity and temperature sensor that can measure relative humidity in the range of 0% to 100% with an accuracy of +/- 2%.*

*It can also measure temperature in the range of -40°C to 125°C with an accuracy of +/- 0.3°C. It communicates with the Arduino board using I2C communication.*

*4. BME280: This is a digital sensor that can measure humidity, temperature, and barometric pressure. It can measure humidity in the range of 0% to 100% with an accuracy of +/- 3%. It can also measure temperature in the range of -40°C to 85°C with an accuracy of +/- 1°C. It communicates with the Arduino board using I2C or SPI communication.*

*5. Capacitive Humidity Sensor (SY-HS-220): This is an analog humidity sensor that can measure humidity in the range of 0% to 100% with an accuracy of +/- 5%. It can be connected to the Arduino board using an analog input pin.*

*These are just a few examples of the many humidity sensors that are available for use with an Arduino board. The specific sensor you choose will depend on your project requirements and preferences.*

***Query:** Can you give me specific models for gas sensors?*

***ChatGPT:** Sure! Here are a few specific models of gas sensors that you can use with an Arduino board:*

*1. MQ-2: This is a gas sensor that can detect smoke, propane, methane, and other gases. It has a high sensitivity and a fast response time. It can be connected to the Arduino board using an analog input pin.*

*2. MQ-3: This is a gas sensor that can detect alcohol vapor, ethanol, and other gases. It has a high sensitivity and a fast response time. It can be connected to the Arduino board using an analog input pin.*

*3. MQ-4: This is a gas sensor that can detect methane, natural gas, and other gases. It has a high sensitivity and a fast response time. It can be connected to the Arduino board using an analog input pin.*

*4. MQ-5: This is a gas sensor that can detect LPG, propane, hydrogen, and other gases. It has a high sensitivity and a fast response time. It can be connected to the Arduino board using an analog input pin.*

*5. MQ-7: This is a gas sensor that can detect carbon monoxide. It has a high sensitivity and a fast response time. It can be connected to the Arduino board using an analog input pin.*

*These are just a few examples of the many gas sensors that are available for use with an Arduino board. The specific sensor you choose will depend on the type of gas you want to detect, the sensitivity required, and other project requirements. It's important to read the data sheet and instructions carefully before using any gas sensor to ensure safe and accurate measurements.*

***Query:** Can you give me specific models for water sensors?*

***ChatGPT:*** *Sure! Here are a few specific models of water sensors that you can use with an Arduino board:*

*1. YF-S201 Water Flow Sensor: This is a water flow sensor that can be used to measure the flow rate of water. It has a minimum flow rate of 1.5L/min and a maximum flow rate of 30L/min. It can be connected to the Arduino board using digital input pins.*

*2. Soil Moisture Sensor (YL-69): This is a sensor that can be used to measure the moisture level of soil or water. It has a built-in potentiometer that can be used to adjust the sensitivity of the sensor. It can be connected to the Arduino board using an analog input pin.*

*3. Water Level Sensor (FS-IR02): This is a sensor that can be used to detect the water level in a tank or reservoir. It uses infrared technology to detect the water level and can be connected to the Arduino board using a digital input pin.*

*4. Conductivity Sensor (SEN-11342): This is a sensor that can be used to measure the conductivity of water. It has a measurement range of 0-2000µS/cm and can be connected to the Arduino board using an analog input pin.*

*5. Water Quality Sensor (SEN-13944): This is a sensor that can be used to measure the pH, temperature, and conductivity of water. It can be connected to the Arduino board using I2C communication.*

*These are just a few examples of the many water sensors that are available for use with an Arduino board. The specific sensor you choose will depend on the type of water parameter you want to measure, the sensitivity required, and other project requirements.*

***Query:*** *Could you order the temperature sensors you told me about by price?*

***ChatGPT:*** *Sure! Here are the temperature sensors I mentioned earlier ordered by price (from lowest to highest):*

*1. LM35 Precision Centigrade Temperature Sensor - This is the most affordable temperature sensor on the list and costs around $1 to $2 per unit.*

*2. DHT11 Temperature and Humidity Sensor - This is a low-cost temperature and humidity sensor that costs around $2 to $3 per unit.*

*3. DS18B20 Programmable Digital Temperature Sensor - This is a high-precision digital temperature sensor that costs around $3 to $4 per unit.*

*4. TMP36 Temperature Sensor - This is an analog temperature sensor that costs around $4 to $5 per unit.*

*5. LM335 Precision Temperature Sensor - This is another analog temperature sensor that costs around $5 to $6 per unit.*

*It's important to note that prices may vary depending on the supplier and the quantity ordered.*

***Query:*** *Could you order the list of gas sensors by price?*

***ChatGPT:*** *Sure! Here are the gas sensors I mentioned earlier ordered by price (from lowest to highest):*

*1. MQ-2 Gas Sensor - This is a low-cost gas sensor that can detect various gases such as smoke, propane, and methane, and costs around $2 to $3 per unit.*

*2. MQ-4 Gas Sensor - This is another low-cost gas sensor that is sensitive to methane, propane, and butane, and costs around $2 to $4 per unit.*

*3. MQ-5 Gas Sensor - This is a low-cost gas sensor that can detect various gases such as natural gas, propane, and hydrogen, and costs around $3 to $5 per unit.*

*4. MQ-6 Gas Sensor - This is a low-cost gas sensor that is sensitive to LPG, butane, and propane, and costs around $2 to $5 per unit.*

*5. MQ-7 Gas Sensor - This is a low-cost gas sensor that is sensitive to carbon monoxide and costs around $3 to $6 per unit.*

*6. MQ-135 Air Quality Sensor Module - This is a low-cost gas sensor that can detect various gases such as benzene, alcohol, smoke, and CO2, and costs around $5 to $10 per unit.*

*It's important to note that prices may vary depending on the supplier and the quantity ordered.*

#### 8.1.1.3 Sensor specifications

***Query:*** *Can you give me the specifications of the DHT11 temperature sensor?*

***ChatGPT:*** *Sure! Here are the specifications of the DHT11 temperature and humidity sensor:*

*1. Temperature measurement range: 0 to 50 degrees Celsius with an accuracy of +/- 2 degrees Celsius*
*2. Humidity measurement range: 20% to 90% RH (Relative Humidity) with an accuracy of +/- 5%*
*3. Operating voltage: 3.3V to 5V DC*
*4. Current consumption: 2.5mA max during conversion, 0.5mA standby*
*5. Signal transmission distance: Up to 20 meters*
*6. Sampling rate: 1 Hz (1 reading per second)*
*7. Response time: less than 5 seconds*
*8. Dimensions: 23mm x 12mm x 5mm (L x W x H)*
*9. Digital output: Data is transmitted using a single-wire serial interface with a timing protocol that includes a start signal, data bits, and a checksum for error checking.*
*The DHT11 sensor is a low-cost, basic temperature and humidity sensor that is suitable for many simple projects. However, if you require higher accuracy, faster response time, or other features, you may need to consider a more advanced sensor.*

***Query:*** *Can you give me the specifications for the TSL2561 light sensor?*

***ChatGPT:*** *Sure! Here are the specifications for the TSL2561 light sensor:*

1. *Operating voltage range: 2.7V to 3.6V DC*
2. *Interface: I2C (up to 400 kHz) or SMBus (up to 100 kHz)*
3. *Measurement range: 0.1 to 40,000+ Lux (light levels)*
4. *Dynamic range: 16-bit resolution*
5. *Sensitivity: 0.1 Lux per count*
6. *Accuracy: +/- 0.5% at 1,000 Lux*
7. *Power consumption: 0.6 mA typical (operating), 15 uA typical (idle)*
8. *Operating temperature range: -40°C to +85°C*
9. *Dimensions: 3.0mm x 3.0mm x 0.8mm (L x W x H)*
10. *Photodiode type: 2 channels - one for infrared (IR) and one for visible light (VIS)*

*The TSL2561 light sensor is a high-precision digital sensor that can be used for a wide range of applications, including ambient light sensing, backlight dimming, and camera auto-brightness control. Its high sensitivity, accuracy, and dynamic range make it suitable for use in environments with varying light levels, such as indoor or outdoor lighting. It can be controlled using an Arduino board or other microcontroller via the I2C or SMBus interface.*

***Query:*** *Can you compare the MQ-2 and MQ-6 sensors based on their specifications and price?*

***ChatGPT:*** *Sure! Here's a comparison between the MQ-2 and MQ-6 gas sensors based on their specifications and price:*

*MQ-2 Gas Sensor:*

1. *Detects: LPG, propane, hydrogen, methane, and other gases*
2. *Sensitivity: Adjustable using a potentiometer*
3. *Operating voltage: 5V DC*
4. *Power consumption: ~150mA*
5. *Warm-up time: 2 minutes*
6. *Interface: Analog output*
7. *Detection range: 300-10000ppm*
8. *Price: $2 to $3 per unit (approximate)*

*MQ-6 Gas Sensor:*

1. *Detects: LPG, butane, and propane*
2. *Sensitivity: Adjustable using a potentiometer*
3. *Operating voltage: 5V DC*
4. *Power consumption: ~150mA*
5. *Warm-up time: 2 minutes*
6. *Interface: Analog output*
7. *Detection range: 200-10000ppm*
8. *Price: $2 to $5 per unit (approximate)*

*From the specifications, we can see that both sensors are quite similar in terms of their operating voltage, power consumption, warm-up time, and interface. However, the MQ-2 has a wider detection range and can detect more types of gases compared to the MQ-*

*6. On the other hand, the MQ-6 is slightly more expensive than the MQ-2 but is still relatively affordable.*

*In terms of sensitivity, both sensors have an adjustable sensitivity using a potentiometer, which allows users to fine-tune the sensor to detect specific concentrations of gases. The MQ-2 has a higher sensitivity range compared to the MQ-6, which means it can detect smaller concentrations of gases.*

*Overall, the choice between the MQ-2 and MQ-6 gas sensor would depend on the specific application and the types of gases that need to be detected. If a wider range of gases need to be detected, then the MQ-2 would be the better choice, but if only LPG, butane, and propane need to be detected, then the MQ-6 would be suitable.*

***Query:** Can you give me the specifications of the DS18B20 temperature sensor?*

***ChatGPT:** Sure! Here are the specifications for the DS18B20 temperature sensor:*

- *Temperature range: -55°C to +125°C*
- *Accuracy: ±0.5°C between -10°C and +85°C*
- *Resolution: Programmable from 9 to 12 bits*
- *Supply voltage: 3.0V to 5.5V*
- *Current draw: 1mA max*
- *Communication: 1-Wire interface*
- *Size: 6mm x 6mm x 1mm (TO-92 package)*

*The DS18B20 is a digital temperature sensor that uses the 1-Wire interface, which means that multiple sensors can be connected to a single pin on the Arduino. The resolution of the sensor can be adjusted to trade off between measurement speed and accuracy, with higher resolutions providing better accuracy but taking longer to measure.*

***Query:** Can you give me the specifications of an MQ-135 Air Quality Sensor Module?*

***ChatGPT:** Sure! Here are the specifications of an MQ-135 Air Quality Sensor Module:*

1. *Operating voltage: 5V DC*
2. *Power consumption: ~ 150mA*
3. *Interface: Analog output*
4. *Detection range: 10ppm to 10,000ppm of various gases such as benzene, alcohol, smoke, CO2, etc.*
5. *Sensitivity: 1.5 to 3.6*
6. *Warm-up time: Over 48 hours*
7. *Dimensions: 32mm x 22mm x 27mm (L x W x H)*
8. *Operating temperature: -10 to 50°C*
9. *Operating humidity: 95%RH or lower (no condensation)*
10. *Sensing element: SnO2 (Tin dioxide) semiconductor*

*The MQ-135 air quality sensor module is a low-cost gas sensor module that can detect a wide range of gases that are harmful to human health or the environment. It is commonly used in air quality monitoring systems, smoke detectors, and gas leak detectors. The sensor uses a Tin dioxide (SnO2) semiconductor sensing element to detect various gases, and the output is an analog voltage that can be read by an Arduino or other microcontroller board. The sensitivity of the sensor can be adjusted by adjusting the* *potentiometer on the module. However, the sensor needs to be preheated for 48 hours before use to achieve accurate readings.*

#### 8.1.1.4 Workflow & Code

***Query:*** *How would you connect a DS18B20 temperature sensor to the Arduino?*

***ChatGPT:*** *To connect a DS18B20 temperature sensor to an Arduino, you will need the following components:*

- *DS18B20 temperature sensor*
- *4.7k ohm resistor*
- *Breadboard*
- *Jumper wires*

*Here are the steps to connect the DS18B20 temperature sensor to the Arduino:*

1. *Connect the Vcc pin of the DS18B20 sensor to the 5V pin on the Arduino.*

2. *Connect the GND pin of the DS18B20 sensor to the GND pin on the Arduino.*

3. *Connect the data pin (middle pin) of the DS18B20 sensor to a digital input/output (I/O) pin on the Arduino. In this example, we will use digital pin 2.*

4. *Connect a 4.7k ohm resistor between the data pin and the 5V pin on the Arduino.*

5. *Connect the Arduino to your computer via USB cable.*

6. *Open the Arduino IDE and create a new sketch.*

7. *In the sketch, include the OneWire and DallasTemperature libraries. These libraries can be installed from the Arduino IDE Library Manager.*

8. *Initialize the OneWire and DallasTemperature libraries in the setup() function of the sketch.*

9. *In the loop() function of the sketch, read the temperature data from the DS18B20 sensor using the DallasTemperature library functions. The code would look something like this:*

```
#include <OneWire.h>
#include <DallasTemperature.h>

#define ONE_WIRE_BUS 2

OneWire oneWire(ONE_WIRE_BUS);
DallasTemperature sensors(&oneWire);

void setup() {
  Serial.begin(9600);
  sensors.begin();
}

void loop() {
  sensors.requestTemperatures();
  float temperature = sensors.getTempCByIndex(0);
  Serial.print("Temperature: ");
  Serial.print(temperature);
  Serial.println("°C");
```

```
    delay(1000);
  }
```

*In this code, we first define the data pin (digital pin 2) as ONE_WIRE_BUS. Then, we initialize the OneWire and DallasTemperature libraries in the setup() function. In the loop() function, we first use the requestTemperatures() function to request the temperature data from the DS18B20 sensor. Then, we use the getTempCByIndex(0) function to get the temperature in degrees Celsius. Finally, we print the temperature to the serial monitor and add a delay of 1 second before the next reading.*
*10. Upload the sketch to the Arduino board and open the serial monitor to see the temperature readings.*
*That's it! You should now be able to read temperature data from the DS18B20 sensor using the Arduino.*
*Query: Did you write this code, or did you copy it from somewhere?*
*ChatGPT: I wrote the code example based on my knowledge and experience with using the OneWire and DallasTemperature libraries to read temperature data from a DS18B20 sensor. However, the code structure and some of the function calls may be similar to code examples found in the official Arduino documentation, online forums, or tutorials.*

***Query:** How would you connect the MQ-4 gas sensor to the Arduino?*

***ChatGPT:** To connect the MQ-4 gas sensor to an Arduino, you will need the following components:*

- *MQ-4 gas sensor*
- *10k ohm resistor*
- *Breadboard*
- *Jumper wires*

*Here are the steps to connect the MQ-4 gas sensor to the Arduino:*

1. *Connect the Vcc pin of the MQ-4 sensor to the 5V pin on the Arduino.*

2. *Connect the GND pin of the MQ-4 sensor to the GND pin on the Arduino.*

3. *Connect the analog output (AO) pin of the MQ-4 sensor to an analog input (A0) pin on the Arduino.*

4. *Connect a 10k ohm resistor between the AO pin and the GND pin on the Arduino.*

5. *Connect the Arduino to your computer via USB cable.*

6. *Open the Arduino IDE and create a new sketch.*

7. *In the sketch, define the analog input pin that you connected the AO pin of the MQ-4 sensor to. In this example, we will use analog input pin A0.*

8. *In the setup() function of the sketch, initialize the serial communication and set the analog input pin as an input.*

*9. In the loop() function of the sketch, read the analog voltage value from the MQ-4 sensor using the analogRead() function, and convert it to a gas concentration value using a conversion formula provided in the MQ-4 datasheet. The code would look something like this:*

*int mq4Pin = A0; // Define the analog input pin*
*float rs, ratio, ppm;*

```
void setup() {
  Serial.begin(9600); // Initialize serial communication
  pinMode(mq4Pin, INPUT); // Set the analog input pin as an input
}

void loop() {
  int sensorValue = analogRead(mq4Pin); // Read the analog voltage value
  rs = (1023.0 - sensorValue) / sensorValue; // Calculate the sensor resistance
  ratio = rs / 9.83; // Calculate the ratio of sensor resistance to clean air resistance
  ppm = pow(10, ((log10(ratio) - 1.218) / (-0.224))); // Convert the ratio to gas concentration (ppm)
  Serial.print("Gas concentration: ");
  Serial.print(ppm);
  Serial.println(" ppm");
  delay(1000); // Wait for 1 second before the next reading
}
```

*In this code, we first define the analog input pin as mq4Pin. Then, in the setup() function, we initialize the serial communication and set the mq4Pin as an input. In the loop() function, we use the analogRead() function to read the analog voltage value from the MQ-4 sensor, and then calculate the gas concentration value in parts per million (ppm) using a conversion formula provided in the MQ-4 datasheet. Finally, we print the gas concentration value to the serial monitor and add a delay of 1 second before the next reading.*

*10. Upload the sketch to the Arduino board and open the serial monitor to see the gas concentration readings.*
*That's it! You should now be able to read gas concentration data from the MQ-4 sensor using the Arduino. Note that the conversion formula may vary depending on the gas you are detecting and the sensitivity of the sensor, so it's important to consult the datasheet for the specific MQ sensor you are using.*

***Query:*** *Where did you get the code?*

***ChatGPT:*** *I wrote the code myself based on the specifications of the MQ-4 gas sensor and the requirements of the project. The code uses the Arduino's built-in functions and syntax to read the analog voltage from the MQ-4 sensor and convert it to gas concentration values. The conversion formula used in the code is based on the MQ-4 datasheet, which provides a general formula for calculating gas concentration based on the sensor resistance ratio.*

***Query:*** *How would you connect a DHT11 temperature sensor to the Arduino?*

***ChatGPT:***
*1. Here are the steps to connect a DHT11 temperature sensor to an Arduino:*

*2. Identify the pins on the DHT11 temperature sensor: The DHT11 has four pins, with the leftmost pin being VCC (power), the second pin being the data pin, the third pin* *being not connected (NC), and the rightmost pin being ground (GND).*

*3. Connect the DHT11 sensor to the Arduino: Connect the VCC pin of the sensor to the 5V pin on the Arduino, the data pin to any digital input pin on the Arduino (for example, pin 2), and the GND pin to the GND pin on the Arduino.*

*4. Download and install the DHT library: The DHT11 sensor requires a library to be used with the Arduino. You can download the DHT library from the Arduino IDE library manager or from the Adafruit Github repository.*
*Import the DHT library into your Arduino sketch: To use the DHT library in your sketch, you need to include the following line at the beginning of your code:*

```
#include <DHT.h>
```

*5. Initialize the DHT11 sensor in your Arduino sketch: In your setup() function, initialize the DHT11 sensor by calling the DHT constructor and passing in the data pin that you connected the sensor to:*

```
DHT dht(2, DHT11); // Initialize DHT sensor on digital pin 2
```

*6. Read the temperature and humidity from the DHT11 sensor: In your loop() function, call the readTemperature() and readHumidity() functions on the DHT object to get the current temperature and humidity readings from the sensor:*

```
float temperature = dht.readTemperature(); // Read temperature in Celsius
float humidity = dht.readHumidity(); // Read humidity as a percentage
```

*That's it! You should now be able to read the temperature and humidity values from the DHT11 sensor in your Arduino sketch.*

#### 8.1.1.5 Literature review

***Query:*** *Could you do a literature review on smart home control with Arduino for a research paper?*

***ChatGPT:*** *Sure, I can provide a brief literature review on smart home control with Arduino for a research paper.*

*Arduino is a popular microcontroller platform for developing smart home systems due to its versatility, low cost, and ease of use. There are many existing studies and projects that have used Arduino to control various aspects of a smart home, such as monitoring environmental conditions, automating appliances, and improving home security.*

*One study by Varghese et al. (2017) presented an Arduino-based smart home system that used a variety of sensors to monitor the temperature, humidity, gas levels, and motion in a house. The system also included automatic control of lights and fans based on occupancy and environmental conditions. The authors reported that the system was able to improve energy efficiency and reduce utility costs.*

*Another project by Cai et al. (2018) described an Arduino-based smart home system that used a Raspberry Pi as a central control unit. The system included sensors for* *monitoring temperature, humidity, and light levels, as well as a camera for home security. The system was also able to automate the control of lights, fans, and other appliances based on user preferences and environmental conditions.*

*In a study by Pandey et al. (2019), an Arduino-based smart home system was designed for elderly care, using sensors to monitor the health and safety of the occupants. The system included sensors for measuring heart rate, body temperature, and blood pressure, as well as motion sensors and an emergency button for alerting caregivers in case of a fall or other emergency.*

*These examples demonstrate the versatility and potential applications of Arduino-based smart home systems. However, there are also some limitations and challenges to consider, such as the need for appropriate sensor selection and calibration, as well as security and privacy concerns. Overall, Arduino provides an accessible and cost-effective platform for developing smart home systems, and further research in this area could lead to more advanced and sophisticated applications in the future.*

***Query:*** *Could you provide the citations for these references?*

***ChatGPT:*** *Sure! Here are the citations for the studies I mentioned in my previous response:*

*Varghese, J., Jayachandran, S., & Jayachandran, S. (2017). An Arduino based smart home system. International Journal of Pure and Applied Mathematics, 114(10), 505-514.*

*Cai, H., Liu, Z., & Liu, J. (2018). Design of Arduino-based smart home control system. In Proceedings of the 2nd International Conference on Computer Science and Application Engineering (pp. 637-641). ACM.*

*Pandey, S., Gupta, R., & Singh, A. (2019). An Arduino based elderly care system for smart home. In Proceedings of the 2nd International Conference on Intelligent Computing and Communication (pp. 97-106). Springer, Singapore*
*Query: Could you give me references on how to connect and control sensors from with an Arduino?*
*ChatGPT: Certainly! Here are some references that provide guidance on how to connect and control sensors with an Arduino:*

*1. Arduino official documentation: https://www.arduino.cc/en/Tutorial/HomePage*
*The Arduino official documentation provides numerous tutorials and guides for working with different sensors and modules. This is a good starting point for beginners who are looking to get started with Arduino-based projects.*

*2. Adafruit Learning System: https://learn.adafruit.com/*
*Adafruit is a popular supplier of Arduino components and also provides a comprehensive learning system that covers many different topics related to Arduino programming and interfacing with various sensors and modules.*

*3. SparkFun Electronics: https://learn.sparkfun.com/tutorials/tags/arduino*
*SparkFun Electronics is another popular supplier of Arduino components and provides*

*a wide range of tutorials and guides on working with different sensors and modules.*

*4. Instructables: https://www.instructables.com/howto/arduino+sensor/*
*Instructables is a community-driven website that provides step-by-step instructions for a wide range of DIY projects, including those that involve working with Arduino-based sensors and modules.*

*5. Arduino Stack Exchange: https://arduino.stackexchange.com/*
*The Arduino Stack Exchange is a Q&A site for Arduino enthusiasts and developers. It's a great resource for finding answers to specific questions related to interfacing with sensors and modules*

.

***Query:*** *Could you give me citations for using an Arduino for sensorics?*

***ChatGPT:***
*1. Cai, H., Liu, Z., & Liu, J. (2018). Design of Arduino-based smart home control system. In Proceedings of the 2nd International Conference on Computer Science and Application Engineering (pp. 637-641). ACM.*
*This paper describes the design of a smart home control system based on Arduino that uses sensors to collect data and control various home appliances.*

*2. Mohsin, M., Alvi, A. H., & Hasan, M. H. (2016). Smart home automation using Arduino. International Journal of Emerging Trends & Technology in Computer Science, 5(4), 246-251.*
*This paper presents a smart home automation system using Arduino and various sensors to monitor and control home appliances.*

*3. Azeem, A., & Bashir, F. (2016). Smart homes using Arduino. International Journal of Advanced Computer Science and Applications, 7(8), 203-208.*
*This paper describes the implementation of a smart home system using Arduino and various sensors to control lighting, temperature, and security.*

*4. Gu, J., & Han, H. (2017). Study on the application of arduino in the development of intelligent home system. In 2017 2nd International Conference on Intelligent Transportation Engineering and Smart City (pp. 166-171). IEEE.*
*This paper describes the use of Arduino and various sensors in the development of an intelligent home system that includes temperature control, lighting control, and air quality monitoring.*

*5. Varghese, J., Jayachandran, S., & Jayachandran, S. (2017). An Arduino based smart home system. International Journal of Pure and Applied Mathematics, 114(10), 505-514.*
*This paper describes the implementation of a smart home system using Arduino and various sensors to control lighting, temperature, and security.*

***Query:*** *Could you please provide me with references to scientific literature regarding using Arduino as a sensor controller? Could you also include the DOI numbers of the references?*

***ChatGPT:*** *Sure, here are a few references to scientific literature regarding using*

*Arduino as a sensor controller, along with their DOI numbers:*

*1. J. H. Shin and J. M. Kim, "Smart home energy management system using Arduino and Raspberry Pi," Journal of Renewable and Sustainable Energy, vol. 10, no. 5, p. 053703, Sep. 2018. DOI: 10.1063/1.5045643*

*2. F. T. Y. Harahap, S. Sutikno, M. C. Sanjaya, A. F. A. Fauzi, and B. Purba, "Development of IoT-based weather station system using Arduino," International Journal of Electrical and Computer Engineering, vol. 11, no. 4, p. 3001, Aug. 2021. DOI: 10.11591/ijece.v11i4.pp3001-3011*

*3. S. A. Sulaiman, S. A. Abu-Bakar, M. A. Al-Qdah, M. R. Baharom, and M. F. Azmi, "Design and development of smart home energy management system using Arduino," IOP Conference Series: Materials Science and Engineering, vol. 1092, no. 1, p. 012001, Mar. 2021. DOI: 10.1088/1757-899X/1092/1/012001*

*4. J. R. de Sousa and M. F. de Sousa, "Data acquisition and control system based on Arduino platform for low-cost greenhouse monitoring," Measurement, vol. 168, p. 108273, Jan. 2021. DOI: 10.1016/j.measurement.2020.108273*

*5. F. L. Villegas, J. F. Castillo, J. M. Lopez, and A. Tellez, "Data acquisition system using Arduino and Android for monitoring water quality," Revista Facultad de Ingeniería, vol. 30, no. 55, p. 67, Dec. 2021. DOI: 10.19053/01211129.v30.n55.2021.13007*

*I hope these references are helpful for your research!*

***Query:*** *Could you narrow the last query to application in smart homes?*

***ChatGPT:*** *Sure, here are some references on the use of Arduino as a sensor controller in smart homes:*

*1. S. K. Saha and S. R. Bhadra, "A Low-Cost Smart Home Monitoring System Using Arduino and Cloud-Based IoT Services," in IEEE Internet of Things Journal, vol. 5, no. 3, pp. 1487-1496, June 2018. DOI: 10.1109/JIOT.2018.2834859*

*2. H. Wang and X. Song, "Smart Home Based on Arduino and Android," in 2016 IEEE International Conference on Mechatronics and Automation (ICMA), Harbin, China, 2016, pp. 2342-2347. DOI: 10.1109/ICMA.2016.7558836*

*3. S. K. Saha and S. R. Bhadra, "Smart home energy management system using Arduino and IoT," in 2017 4th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI), Yogyakarta, Indonesia, 2017, pp. 1-6. DOI: 10.1109/EECSI.2017.8239159*

*4. J. Liu, X. Wang and C. Huang, "Smart home control system design based on Arduino," in 2017 2nd IEEE International Conference on Information Science and Control Engineering (ICISCE), Changsha, China, 2017, pp. 1971-1974. DOI: 10.1109/ICISCE.2017.296*

*5. K. Sami and S. M. A. Bhuiyan, "Smart Home Automation System using Arduino and*

*GSM Module," in 2018 4th International Conference on Electrical Engineering and Information Communication Technology (ICEEICT), Dhaka, Bangladesh, 2018, pp. 1-5. DOI: 10.1109/ICEEICT.2018.8460067*

*I hope these references are helpful to you!*

### 8.1.2 BingAI

***Query:*** *I am doing a smart home project. I need to choose a micro-controller for controlling the sensors I need for the smart home. Could you give me options for the controllers? Give 4 to 6 examples, from different manufacturers.*

***BingAI:*** *Here are some micro-controller options for controlling the sensors you need for your smart home project:*

- *Arduino Uno - This is a popular micro-controller board that is easy to use and has a large community of users. It is also affordable and has a wide range of sensors that can be used with it.*

- *Raspberry Pi - This is a single-board computer that can be used as a micro-controller for your smart home project. It is more powerful than the Arduino Uno and can run a full operating system.*

- *ESP32 - This is a low-cost micro-controller that has built-in Wi-Fi and Bluetooth capabilities. It is also compatible with the Arduino IDE.*

- *Particle Photon - This is another micro-controller board that has built-in Wi-Fi capabilities. It is easy to use and has a large community of users.*

- *STM32F4 Discovery - This is a high-performance micro-controller board that has a lot of features and capabilities. It is more expensive than some of the other options on this list, but it is also more powerful.*

*I hope these options help you choose the right micro-controller for your smart home project!*

***Query:*** *Make an argument for choosing each of the controllers!*

***BingAI:*** *Sure! Here are some arguments for choosing each of the micro-controllers:*

- *Arduino Uno - This is a great choice if you are new to micro-controllers and programming. It is easy to use and has a large community of users that can help you if you get stuck. It is also affordable and has a wide range of sensors that can be used with it.*

- *Raspberry Pi - This is a good choice if you need more processing power than the Arduino Uno can provide. It can run a full operating system and has built-in Wi-Fi and Bluetooth capabilities. It is also more versatile than the Arduino Uno and can be used for other projects besides smart home automation.*

- *ESP32 - This is a good choice if you need a micro-controller with built-in Wi-Fi and*

*Bluetooth capabilities. It is also compatible with the Arduino IDE, which makes it easy to use if you are already familiar with the Arduino platform.*

• *Particle Photon - This is a good choice if you need a micro-controller with built-in Wi-Fi capabilities. It is easy to use and has a large community of users that can help you if you get stuck.*

• *STM32F4 Discovery - This is a good choice if you need a high-performance micro-controller with a lot of features and capabilities. It is more expensive than some of the other options on this list, but it is also more powerful.*

*I hope these arguments help you choose the right micro-controller for your smart home project!*

***Query:*** *I am using an Arduino board to make my house into a smart home. What types of sensors would you recommend?*

***BingAI:*** *Here are some sensors that you can use with your Arduino board for your smart home project:*

• *Optical Fingerprint Reader - This sensor can be used to integrate fingerprint identification into your smart home project.*

• *Pulse Sensor - This sensor can be used to measure heart rate and blood oxygen levels.*

• *MAX30102 Pulse Oximeter and Heartrate Sensor - This sensor can be used to measure heart rate and blood oxygen levels.*

• *AD8232 Heart Rate Monitor - This sensor can be used to measure heart rate.*

• *Galvanic Skin Response Module - This sensor can be used to measure changes in skin conductance.*

• *MQ-3 Alcohol Sensor - This sensor can be used to detect alcohol vapor.*

• *Muscle Sensor - This sensor can be used to detect muscle activity.*

• *TTP223B Touch Sensor - This sensor can be used to detect touch.*

*I hope these sensors help you get started on your smart home project!*

***Query:*** *Can you give me specific models for temperature sensor for an Arduino board?*

***BingAI:*** *There are many temperature sensors that can work with Arduino such as LM35, TH02, HDC1000 or HTS221. One of the most popular temperature sensors is the DS18B20 temperature sensor which is inexpensive, easy to use and waterproof . It is a one-wire digital temperature sensor that requires only one data line (and GND) to communicate with the Arduino. Each DS18B20 temperature sensor has a unique 64-bit serial code which allows you to wire multiple sensors to the same data wire . I hope this*

*helps!*
*További információ:*
1. *https://arduinogetstarted.com/tutorials/arduino-temperature-sensor*
2. *https://randomnerdtutorials.com/9-arduino-compatible-temperature-sensors-for-your-electronics-projects/*
3. *https://randomnerdtutorials.com/guide-for-ds18b20-temperature-sensor-with-arduino/*
4. *https://www.makerguides.com/ds18b20-arduino-tutorial/*

*There are many temperature sensors that can work with Arduino such as LM35, TH02, HDC1000 or HTS221. One of the most popular temperature sensors is the DS18B20 temperature sensor. It is inexpensive, easy to use and waterproof. You can wire multiple sensors to the same data wire and get temperature from multiple sensors using just one Arduino digital pin.*
*További információ:*
1. *https://arduinogetstarted.com/tutorials/arduino-temperature-sensor*
2. *https://randomnerdtutorials.com/9-arduino-compatible-temperature-sensors-for-your-electronics-projects/*
3. *https://randomnerdtutorials.com/guide-for-ds18b20-temperature-sensor-with-arduino/*
4. *https://www.makerguides.com/ds18b20-arduino-tutorial/*
5. *https://arduinogetstarted.com/tutorials/arduino-temperature-sensor*
6. *https://randomnerdtutorials.com/9-arduino-compatible-temperature-sensors-for-your-electronics-projects/*
7. *https://randomnerdtutorials.com/guide-for-ds18b20-temperature-sensor-with-arduino/*
8. *https://www.makerguides.com/ds18b20-arduino-tutorial/*
9. *https://arduinogetstarted.com/tutorials/arduino-temperature-sensor-lcd*
10. *https://arduinogetstarted.com/tutorials/arduino-temperature-humidity-sensor*
11. *https://arduinogetstarted.com/tutorials/arduino-temperature-sensor-relay*
12. *https://arduinogetstarted.com/tutorials/arduino-cooling-system-using-ds18b20-temperature-sensor*
13. *https://www.youtube.com/watch?v=-_XkGju35MI*

***Query:** I am doing a smart home project using an Arduino as sensor controller. Can you give me literature references for the topic, including the DOI numbers for the references? Please give at least 5 references.*

***BingAI:** I found some literature references that might be helpful for your smart home project using an Arduino as sensor controller. Here are some of them:*

- *Naing, M. T., & Hlaing, S. S. (2019). Arduino Based Smart Home Automation System. ResearchGate. DOI: 10.13140/RG.2.2.29460.13447*

- *Zhenyu, L., & Xuefeng, L. (2013). Smart Home System Based on IPV6 and ZIGBEE Technology : Arduino UNO: Home Automation: Smart home system: Designed and built a smart home system that interconnected all the embedded devices in the home using IoT and thus facilitated communication between them. ScienceDirect.*

- *Al-Sheikh, A., Al-Qahtani, A., & Al-Mutairi, M. (2018). SMART HOME SYSTEM*

*USING ARDUINO. ResearchGate. DOI: 10.13140/RG.2.2.14287.38562*

- *Al-Sheikh, A., Al-Qahtani, A., & Al-Mutairi, M. (2017). ARDUINO BASED SMART HOME AUTOMATION SYSTEM - ResearchGate DOI: 10.13140/RG.2.2.19108.39043*

- *Kaur, R., & Singh, G.(2020). Smart Home Automation System using Arduino and Android Application - ResearchGate DOI: 10.13140/RG.2.2.23889.48480*

*I hope these references help you with your project!*

### 8.1.3 Bard

***Query****: I am doing a smart home project. I need to choose a micro-controller for controlling the sensors I need for the smart home. Could you give me options for the controllers? Give 4 to 6 examples, from different manufacturers.*

***Bard:***
*Here are 4 to 6 examples of microcontrollers from different manufacturers that you can use for your smart home project:*

*Arduino Uno (Microchip)*
*ESP32 (Espressif Systems)*
*Raspberry Pi Pico (Raspberry Pi)*
*Teensy 4.1 (PJRC)*
*STM32F407VET6 (STMicroelectronics)*
*These microcontrollers are all popular choices for smart home projects because they are relatively inexpensive, easy to use, and have a wide range of features.*

*Here is a brief overview of each microcontroller:*

*Arduino Uno: The Arduino Uno is a great choice for beginners because it is easy to set up and use. It has a variety of input and output pins, which makes it easy to connect to sensors and actuators.*
*ESP32: The ESP32 is a powerful microcontroller that is well-suited for smart home projects that require Wi-Fi or Bluetooth connectivity. It has a dual-core processor and a large amount of memory, which makes it capable of running complex applications.*
*Raspberry Pi Pico: The Raspberry Pi Pico is a low-cost microcontroller that is based on the Raspberry Pi RP2040 chip. It has a variety of input and output pins, as well as a built-in USB interface.*
*Teensy 4.1: The Teensy 4.1 is a powerful microcontroller that is well-suited for smart home projects that require high performance. It has a quad-core processor and a large amount of memory.*
*STM32F407VET6: The STM32F407VET6 is a powerful microcontroller that is well-suited for smart home projects that require demanding applications, such as video processing or machine learning. It has an ARM Cortex-M4 processor and a large amount of memory.*
*Which microcontroller is best for your smart home project will depend on your specific needs and requirements. For example, if you are building a simple smart home project that only requires a few sensors and actuators, then the Arduino Uno is a good choice. If you are building a more complex smart home project that requires Wi-Fi or Bluetooth*

*connectivity, then the ESP32 or Teensy 4.1 are good choices.*

*Once you have chosen a microcontroller, you can start connecting your sensors and actuators to it. You can also start developing software to control your smart home devices. There are many resources available online to help you get started.*

***Query:*** *Make an argument for choosing each of the controllers!*

***Bard:*** *Arduino Uno:*

*Pros:*
*Easy to use*
*Inexpensive*
*Large community of users and developers*
*Cons:*
*Limited processing power*
*Not ideal for complex projects*
*ESP32:*

*Pros:*
*Powerful microcontroller with dual-core processor and large amount of memory*
*Wi-Fi and Bluetooth connectivity*
*Inexpensive*
*Cons:*
*Can be more difficult to use than the Arduino Uno for beginners*
*Raspberry Pi Pico:*

*Pros:*
*Low cost*
*Based on the Raspberry Pi RP2040 chip, which is a powerful and versatile microcontroller*
*Variety of input and output pins, as well as a built-in USB interface*
*Cons:*
*Can be more difficult to use than the Arduino Uno for beginners*
*Teensy 4.1:*

*Pros:*
*Powerful microcontroller with quad-core processor and large amount of memory*
*High performance*
*Cons:*
*More expensive than other microcontrollers on this list*
*Can be more difficult to use than the Arduino Uno for beginners*
*STM32F407VET6:*

*Pros:*
*Powerful microcontroller with ARM Cortex-M4 processor and large amount of memory*
*Well-suited for demanding applications such as video processing or machine learning*
*Cons:*
*Most expensive microcontroller on this list*
*Can be more difficult to use than the Arduino Uno for beginners*

*Which microcontroller you should choose for your smart home project depends on your specific needs and requirements. If you are building a simple project that only requires a few sensors and actuators, then the Arduino Uno is a good choice. If you are building a more complex project that requires Wi-Fi or Bluetooth connectivity, then the ESP32 or Teensy 4.1 are good choices. If you are building a project that requires high performance or demanding applications, then the STM32F407VET6 is a good choice.*

*Here is a more detailed argument for choosing each microcontroller:*

*Arduino Uno: The Arduino Uno is a great choice for beginners because it is easy to set up and use. It has a variety of input and output pins, which makes it easy to connect to sensors and actuators. There is also a large community of users and developers who create tutorials, libraries, and other resources for the Arduino Uno.*

*ESP32: The ESP32 is a good choice for projects that require Wi-Fi or Bluetooth connectivity. It is also a good choice for projects that require a lot of processing power or memory. The ESP32 is more difficult to use than the Arduino Uno for beginners, but there are many resources available online to help you get started.*

*Raspberry Pi Pico: The Raspberry Pi Pico is a good choice for projects that require a low-cost microcontroller. It is also a good choice for projects that require a variety of input and output pins. The Raspberry Pi Pico is more difficult to use than the Arduino Uno for beginners, but there are many resources available online to help you get started.*

*Teensy 4.1: The Teensy 4.1 is a good choice for projects that require high performance. It is also a good choice for projects that require a lot of processing power or memory. The Teensy 4.1 is more expensive than other microcontrollers on this list, and it can be more difficult to use than the Arduino Uno for beginners.*

*STM32F407VET6: The STM32F407VET6 is a good choice for projects that require a lot of processing power or memory. It is also a good choice for projects that require demanding applications such as video processing or machine learning. The STM32F407VET6 is the most expensive microcontroller on this list, and it can be more difficult to use than the Arduino Uno for beginners.*

*Ultimately, the best way to choose a microcontroller for your smart home project is to consider your specific needs and requirements. If you are unsure which microcontroller to choose, you can ask for help from a friend, family member, or online community.*

***Query:*** *I am using an Arduino board to make my house into a smart home. What types of sensors would you recommend?*

***Bard:*** *There are many different types of sensors that you can use to make your house into a smart home. Here are a few recommendations:*

*Temperature sensors: Temperature sensors can be used to monitor the temperature in your home and control your heating and cooling system.*
*Motion sensors: Motion sensors can be used to detect movement in your home and trigger security lights or turn on lights when you enter a room.*
*Door and window sensors: Door and window sensors can be used to detect if a door or*

*window has been opened or closed, which can be useful for security or energy conservation.*
*Light sensors: Light sensors can be used to measure the amount of light in a room and automatically turn on lights when it gets dark or turn off lights when you leave a room.*
*Humidity sensors: Humidity sensors can be used to measure the humidity in your home and control your humidifier or dehumidifier.*
*Air quality sensors: Air quality sensors can be used to measure the quality of the air in your home and trigger a ventilation system or air purifier if the air quality is poor.*
*Water leak sensors: Water leak sensors can be used to detect water leaks in your home and trigger an alarm or shut off the water supply.*
*In addition to these basic sensors, there are also many specialized sensors that you can use for your smart home project. For example, you could use a soil moisture sensor to water your plants automatically, or you could use a smart lock to lock and unlock your doors remotely.*

*The best way to choose which sensors to use for your smart home project is to consider your specific needs and requirements. Think about what areas of your home you want to automate and what types of information you want to collect. Once you have a good idea of what you need, you can start shopping for sensors.*

*Here are a few examples of how you can use sensors to make your house into a smart home:*

*Use a temperature sensor to control your heating and cooling system, so that you are always comfortable in your home.*
*Use a motion sensor to turn on the lights when you enter a room, so that you never have to fumble for a light switch in the dark.*
*Use a door sensor to trigger a security alarm when someone enters your home without your permission.*
*Use a humidity sensor to control your humidifier or dehumidifier, so that your home is always at a comfortable humidity level.*
*Use an air quality sensor to trigger a ventilation system or air purifier if the air quality in your home is poor.*
*Use a water leak sensor to detect water leaks in your home and shut off the water supply, so that you don't have to worry about flooding.*
*These are just a few examples of how you can use sensors to make your house into a smart home. With the right sensors and a little bit of creativity, you can automate your home to make it more comfortable, efficient, and secure.*
*Query: Can you give me specific models for temperature sensor for an Arduino board?*
*Bard: Sure. Here are a few specific models of temperature sensors that you can use with an Arduino board:*

*LM35: The LM35 is a linear temperature sensor that produces an output voltage that is proportional to temperature. It is a very popular temperature sensor for Arduino projects because it is easy to use and inexpensive.*
*TMP36: The TMP36 is another linear temperature sensor that is similar to the LM35. It is also a good choice for Arduino projects because it is easy to use and inexpensive.*
*DS18B20: The DS18B20 is a digital temperature sensor that uses the 1-Wire protocol to communicate with the Arduino. It is more accurate than the LM35 and TMP36, but it is also more expensive.*

*DHT11: The DHT11 is a digital temperature and humidity sensor that uses the 1-Wire protocol to communicate with the Arduino. It is a very popular temperature and humidity sensor for Arduino projects because it is inexpensive and easy to use.*
*DHT22: The DHT22 is a digital temperature and humidity sensor that is similar to the DHT11, but it is more accurate. It is also more expensive than the DHT11.*
*Which temperature sensor you choose for your Arduino project depends on your specific needs and requirements. If you are looking for an inexpensive and easy-to-use temperature sensor, then the LM35 or TMP36 are good choices. If you need a more accurate temperature sensor, then the DS18B20 or DHT22 are good choices.*

*Here are some additional factors to consider when choosing a temperature sensor for your Arduino project:*

*Temperature range: Make sure that the temperature sensor you choose has a temperature range that covers the temperatures you expect to measure.*
*Accuracy: Consider how accurate you need the temperature sensor to be. If you need a very accurate temperature sensor, then you will need to choose a sensor with a higher accuracy rating.*
*Response time: Consider how quickly you need the temperature sensor to respond to changes in temperature. If you need a temperature sensor with a fast response time, then you will need to choose a sensor with a lower response time rating.*
*Cost: Temperature sensors can range in price from a few dollars to several hundred dollars. Choose a temperature sensor that fits your budget.*
*Once you have chosen a temperature sensor, you will need to connect it to your Arduino board. The specific steps involved in connecting the temperature sensor to your Arduino board will vary depending on the type of temperature sensor you choose. However, there are many tutorials available online that can help you get started.*

***Query:** Can you give me the specifications of the DS18B20 temperature sensor?*

***Bard:** Sure. Here are the specifications of the DS18B20 temperature sensor:*

*Temperature range: -55°C to +125°C (-67°F to +257°F)*
*Accuracy: ±0.5°C (from -10°C to +85°C)*
*Resolution: 9, 10, 11, or 12 bits (programmable)*
*Conversion time: 750ms at 12-bit resolution*
*Supply voltage: 3.0V to 5.5V*
*Power consumption: 100µA (active mode), 0.5µA (sleep mode)*
*Interface: 1-Wire*
*The DS18B20 is a digital temperature sensor, which means that it outputs a digital signal that represents the temperature. This makes it easy to connect the DS18B20 to a microcontroller, such as an Arduino board.*

*The DS18B20 uses the 1-Wire protocol to communicate with the microcontroller. The 1-Wire protocol is a simple communication protocol that allows multiple devices to communicate with the microcontroller using a single data pin.*

*The DS18B20 is a popular temperature sensor for Arduino projects because it is inexpensive, easy to use, and accurate. It is also a good choice for projects that require multiple temperature sensors, as the 1-Wire protocol allows you to connect multiple*

*DS18B20 sensors to the same data pin.*

*Here are some of the advantages of using the DS18B20 temperature sensor in your Arduino project:*

*It is inexpensive and easy to use.*
*It is accurate and reliable.*
*It supports multiple temperature sensors on a single data pin.*
*It has a wide temperature range (-55°C to +125°C).*
*It has a low power consumption.*
*If you are looking for a temperature sensor for your Arduino project, the DS18B20 is a good choice to consider.*

***Query:*** *How would you connect a DS18B20 temperature sensor to the Arduino?*

***Bard:*** *To connect a DS18B20 temperature sensor to an Arduino, you will need the following:*

*DS18B20 temperature sensor*
*Arduino board*
*Jumper wires*
*Breadboard (optional)*
*Once you have gathered your materials, follow these steps:*

*Connect the VDD pin of the DS18B20 to the 5V pin of the Arduino.*
*Connect the GND pin of the DS18B20 to the GND pin of the Arduino.*
*Connect the DQ pin of the DS18B20 to a digital pin on the Arduino. I recommend using digital pin 2, as this is the pin that is typically used for the DS18B20 sensor.*
*If you are using a breadboard, you can connect the DS18B20 sensor to the Arduino using jumper wires. If you are not using a breadboard, you can solder the DS18B20 sensor directly to the Arduino board.*

*Once the DS18B20 sensor is connected to the Arduino, you can start reading the temperature data from the sensor. To do this, you will need to install the OneWire and DallasTemperature libraries for Arduino. You can install these libraries using the Arduino IDE Library Manager.*

*Once the libraries are installed, you can write a sketch to read the temperature data from the DS18B20 sensor. Here is a simple example:*

```
#include <OneWire.h>
#include <DallasTemperature.h>

OneWire oneWire(2); // Digital pin 2 is used for the DS18B20 sensor
DallasTemperature sensors(&oneWire);

void setup() {
  Serial.begin(9600); // Initialize serial communication
  sensors.begin(); // Initialize the DallasTemperature library
}

void loop() {
  // Request temperature readings from all sensors
  sensors.requestTemperatures();

  // Wait for the temperature readings to be ready
  while (!sensors.isConversionComplete()) {
```

```
    delay(100);
  }

  // Get the temperature reading from the first sensor
  float temperature = sensors.getTempCByIndex(0);

  // Print the temperature reading to the serial monitor
  Serial.print("Temperature: ");
  Serial.println(temperature);

  // Wait for 1 second before reading the temperature again
  delay(1000);
}
```

*This sketch will read the temperature data from the first DS18B20 sensor that is connected to the Arduino. You can modify the sketch to read the temperature data from multiple DS18B20 sensors by changing the sensors.getTempCByIndex(0) line to sensors.getTempCByIndex(i), where i is the index of the sensor you want to read the temperature data from.*

*You can also modify the sketch to log the temperature data to a file or send the temperature data to a cloud service. The possibilities are endless!*

***Query:** Could you please provide me with references to scientific literature regarding using Arduino as a sensor controller? Could you also include the DOI numbers of the references?*

***Bard:** Sure. Here are a few references to scientific literature regarding using Arduino as a sensor controller, with DOI numbers:*

*Low-Cost Microcontrollers for Smart Home Applications: A Case Study of Arduino (DOI: 10.1109/ACCESS.2021.3053154)*
*Arduino-Based Sensor Controller for Agricultural Monitoring (DOI: 10.1007/978-3-030-35767-2_35)*
*Arduino as a Sensor Controller for Environmental Monitoring (DOI: 10.1016/j.envsoft.2018.05.007)*
*Arduino-Based Sensor Controller for Industrial Automation (DOI: 10.1007/978-3-319-76947-5_2)*
*Arduino-Based Sensor Controller for Robotics Applications (DOI: 10.1007/978-3-319-76947-5_3)*
*These papers provide a good overview of the different ways that the Arduino can be used as a sensor controller. They also discuss the challenges and opportunities of using the Arduino in different applications.*

*I hope this information is helpful. Please let me know if you have any other questions.*

### 8.1.4 Copilot

***Query:** I am doing a smart home project. I need to choose a micro-controller for controlling the sensors I need for the smart home. Could you give me options for the controllers? Give 4 to 6 examples, from different manufacturers.*

***Copilot:** Sure, here are some good options for microcontrollers for a smart home project:*

*1. ATmega328P by Atmel (now owned by Microchip): This is the microcontroller used* *in Arduino UNO. It is a versatile and popular choice for various projects because of its ease of use and large support community.*

*2. ESP32 by Espressif: This is a highly integrated solution for Wi-Fi-and-Bluetooth IoT applications, with around 20 independent I/O pins. It also supports a variety of peripherals and is able to run multiple tasks concurrently.*

*3. CC3200 by Texas Instruments: This is a single-chip microcontroller unit with integrated Wi-Fi connectivity, designed for IoT applications. It has robust security protocols, which could be key for a smart home system.*

*4. PIC32MZ by Microchip: This series has high processing power and offer a wide range of peripherals.*

*5. STMicroelectronics' STM32F series: STMicroelectronics offers a wide range of options in the STM32F series which can be a good fit for your application. They offer a variety of I/O options, integrated peripherals (like high-resolution ADCs, PWM generators, etc.), and power-saving features.*

*6. nRF52840 by Nordic Semiconductor: This one is specifically designed with complex IoT projects like smart home systems in mind. It includes a 32-bit MCU, plus it has an on-chip NFC tag and support for Bluetooth 5.0, ANT, Zigbee, and Thread.*

*Before selecting a microcontroller, you should consider the requirements of your specific project, such as the required processing power, memory, I/O, and power consumption*

***Query:*** *Make an argument for choosing each of the controllers!*

***Copilot:*** *Sure, let's elaborate on the strong points for each microcontroller:*

*1. ATmega328P by Atmel: It's a great choice for small, simple projects due to its low price and the extensive community of hobbyists and professionals alike built around the Arduino ecosystem. It's really straightforward to prototype with, and moving from an Arduino board to a standalone ATmega328P MCU is quite seamless if you intend to make a final, embedded project.*

*2. ESP32 by Espressif: The highlight here is its built-in Wi-Fi and Bluetooth functions. If your smart home project requires wireless communication, this could significantly simplify your design. It also has capabilities for low power consumption, making it suitable for battery-powered IoT devices.*

*3. CC3200 by Texas Instruments: This single-chip MCU also provides built-in Wi-Fi, just like ESP32. But it's even more powerful, and emphasizes security features, which are essential for smart home devices connected to the Internet, where protection of user's private data is a concern.*

*4. PIC32MZ by Microchip: If your smart home project requires high processing power and multiple interface options like USB, UART, SPI, etc., this could be the right choice. The PIC32MZ comes with a rich set of peripherals and advanced hardware features, as well as a 32-bit MIPS core that can reach up to 200 MHz.*

*5. STMicroelectronics' STM32F series: This series offers a wide variety of options with different levels of memory and processing power. For high-performance smart home systems, you might pick one of the upper-end options like the STM32F7, which includes a FPU (Floating Point Unit) and a Chrom-ART accelerator for multimedia applications.*

*6. nRF52840 by Nordic Semiconductor: If your smart home project requires short-range wireless communication, this chip would be a solid choice because it supports not just Bluetooth 5.0, but also other protocols like ANT, Zigbee, and Thread. It also includes a USB 2.0 controller, enabling direct connection to a computer or other USB devices.*

*In essence, there's no one-size-fits-all answer as it heavily depends on the requirements and constraints of your specific project. Consider the processing capabilities, energy efficiency, development community support, number and types of interfaces (GPIO, ADC, DAC, etc.), wireless communications requirements, etc. when choosing your microcontroller.*

***Query:*** *I am using an Arduino board to make my house into a smart home. What types of sensors would you recommend?*

***Copilot:*** *Designing a smart home with an Arduino can be an exciting project. Here are some sensors which would be beneficial for a smart home project:*

*1. Temperature Sensor (Like the DHT22 or DS18B20): This type of sensor can help automate heating and cooling systems.*

*2. Humidity Sensor (Like the DHT22): Humidity sensors work well for automatic venting, dehumidifying, or indicating when it's a good time to water plants.*

*3. Motion Sensors (Like the PIR sensor): These sensors can be used for various security applications, for turning lights on or off, or even for home automation tasks such as opening and closing doors.*

*4. Light Sensors (Like the LDR - Light Dependent Resistor): Use these to automate* *lighting, making lights brighter or dimmer depending on the ambient light level.*

*5. Gas Sensors (Like the MQ-2 or MQ-5): They can detect gas leaks which can be a vital safety feature for any home.*

*6. Door/Window Sensors (Like the Reed switch): They are used in security systems to alert when a door or window is opened.*

*7. Sound Sensor: Can be used to implement functions that are controlled or triggered by claps or voice.*

*8. Pressure Sensor (Like the BMP180): These are good for weather stations, as they can help predict changes in weather based on atmospheric pressure.*

*9. Soil Moisture Sensor: Use these for automated plant watering systems.*

*10. Water Leak Sensor: Great for detecting leaks in your pipework before they become a bigger problem.*

*An Arduino is perfectly capable of handling any of these sensors. They all serve different purposes, so you'll want to choose ones that meet the specific needs of your project. Remember that each sensor requires a certain number of input/output pins on the Arduino, so make sure to plan accordingly.*

***Query:** Can you give me specific models for temperature sensor for an Arduino board?*

***Copilot:** Sure, here are a few popular temperature sensor models that are compatible with Arduino:*

*1. DS18B20: This is a digital temperature sensor that uses the One-Wire protocol. It's accurate, easy to use, and multiple DS18B20 sensors can be connected to the same data pin.*

*2. DHT11: This is a digital temperature and humidity sensor. Its temperature range is 0 - 50°C with ±2°C accuracy. However, it's somewhat slower and less accurate than other models.*

*3. DHT22 (also known as the AM2302): This is similar to the DHT11 but has a wider range (-40 - 80°C) and better accuracy (±0.5°C).*

*4. BME280: This is a sensor that measures temperature, humidity, and air pressure all in one.*

*5. MCP9808: A high-accuracy digital temperature sensor with ±0.5°C accuracy across its -20°C to +100°C range.*

*6. TMP36: This is an analog temperature sensor that's easy to use and doesn't require any complex calculations to get the temperature.*

*Each of these models works with Arduino differently. Some are digital (like the DS18B20, DHT11, DHT22, and MCP9808), and others are analog (like the TMP36). Make sure to consider this, as well as the power requirements and precision of the sensor when choosing one for your project.*

***Query:*** *Can you give me the specifications of the DS18B20 temperature sensor?*

***Copilot:*** *Sure. The DS18B20 temperature sensor is a popular device used in many Arduino and other microcontroller projects. Here is a summary of its key specifications:*

- *Temperature Range: -55 °C to +125 °C*
- *Accuracy: ±0.5°C Accuracy from -10°C to +85°C*
- *Power Supply Range: 3.0V to 5.5V*
- *Output: Digital, using One-Wire protocol*
- *Unique 64-Bit Serial Code: Each DS18B20 has a unique serial code, which allows you to use multiple sensors on the same data line.*
- *Stainless Steel Probe Version Available: Ideal for applications that require moisture resistance.*
- *Programmable Resolution: From 9 bits to 12 bits.*

*Please note: to use this sensor with the Arduino, you'll need to include the OneWire library. This allows the Arduino to communicate with the sensor over the One-Wire protocol.*

***Query:*** *How would you connect a DS18B20 temperature sensor to the Arduino?*

***Copilot:*** *Here's a simple guide showing how to connect a DS18B20 temperature sensor to an Arduino board:*

*1. Hardware Connection:*

*Connect the VCC (sometimes referred to as VDD) pin of the DS18B20 to the 5V pin on* *the Arduino.*

*Connect the GND pin of the DS18B20 to the GND pin on the Arduino.*

*Connect the DATA pin of the DS18B20 to a digital I/O pin on the Arduino. For example, we can use digital pin 2.*

*Note: You also need to connect a resistor (usually 4.7k ohms) between the VCC and DATA lines. This is a pull-up resistor required for the correct operation of the sensor's one-wire communication protocol.*

*2. Software Programming: In your Arduino IDE, use the OneWire and DallasTemperature libraries for interacting with the DS18B20 sensor. Here is a simple program to read temperature from your sensor and print it to the serial monitor:*

```
#include <OneWire.h>
#include <DallasTemperature.h>

// Data wire is plugged into digital pin 2 on the Arduino
#define ONE_WIRE_BUS 2

OneWire oneWire(ONE_WIRE_BUS);

// Pass our oneWire reference to Dallas Temperature sensor
DallasTemperature sensors(&oneWire);

void setup(void)
{
  // Start serial communication for debugging purposes
  Serial.begin(9600);
  // Start up the library
  sensors.begin();
}

void loop(void)
{
  // Call sensors.requestTemperatures() to issue a global temperature and Requests to all devices on the bus
  sensors.requestTemperatures();

  Serial.print("Celsius temperature: ");
  // Why "byIndex"? You can have more than one DS18B20 on the same bus.
  // 0 refers to the first IC on the wire
  Serial.println(sensors.getTempCByIndex(0));
}
```

*Before you can use this code, make sure to install the OneWire and DallasTemperature libraries in your Arduino IDE. You can do this by going to Sketch -> Include Library -> Manage Libraries and then search for these two libraries and install them.*

*What this program does is to request the temperature from your DS18B20 sensor, and then output this temperature to the serial monitor in your Arduino IDE.*

*Source(s):*

*p/blog/arduino-uno-schematic-diagram p/projects*

***Query:** Could you please provide me with references to scientific literature regarding using Arduino as a sensor controller? Could you also include the DOI numbers of the references?*

*__Copilot:__ I'm sorry, but as an AI developed by Flux.ai, I don't currently have the capability to search and provide links to scientific literature or DOI numbers. I recommend using academic databases such as Google Scholar, IEEE Xplore, or others that have been designed specifically for that purpose.*

## 8.1.5 Queries on circuit development

***Query 1**: Can you tell me what the schematic of a Howland current source would look like?*
***Query 2**: Can you tell me what the schematic of a Howland current source with a feedback buffer would look like?*

### 8.1.5.1 ChatGPT

***Answer 1:** A Howland current source is a type of circuit used to generate a precise and stable current output based on an input voltage. It is named after its inventor, Malcolm Howland. The circuit typically consists of two operational amplifiers (op-amps) and a few passive components. The Howland current source is commonly used in various applications, including instrumentation and measurement systems.*

*Here is the schematic diagram of a basic Howland current source:*

```
+Vcc
 |
 R1
 |
 |   R2
 +----/\/\----+
 |            |
 |            |
 |            |
 |            |
 |            |
 |            |
 |            |
 +---/\/\----+
 |   R3
 |
 R4
 |
 |
 Iout
```

*In this schematic:*

*+Vcc is the positive supply voltage.*
*R1 and R4 are resistors, and they set the input voltage range of the current source.*
*R2 and R3 are precision resistors that determine the output current.*
*The operation of the Howland current source is based on the principle of the virtual short circuit between the inverting and non-inverting inputs of operational amplifiers (op-amps). When configured correctly, it generates an output current that is*

*proportional to the voltage difference between the non-inverting and inverting inputs, which can be controlled by changing the values of R1 and R4. The output current, Iout, is given by the formula:*

*Iout = (V1 - V2) / (R2 || R3)*

*Where:*

*V1 is the voltage at the non-inverting input of the first op-amp.*
*V2 is the voltage at the inverting input of the second op-amp.*
*R2 and R3 are the values of the resistors.*
*"||" represents parallel resistance.*
*By adjusting the values of R1, R2, R3, and R4, you can control the current source's output current over a wide range. This makes it a versatile circuit for various applications where a precise and stable current source is required.*

***Answer 2:*** *A Howland current source with a feedback buffer is a modification of the basic Howland current source that includes an additional operational amplifier (op-amp) to provide buffering and impedance matching for the output current. This buffer helps isolate the output from the load, making it more stable and maintaining a consistent current. Here's a schematic diagram of a Howland current source with a feedback buffer:*

```
+Vcc
|
R1
|
|   R2
+----/\/\----+
|           |
|           |
|           |
|           |
|           |
|           |
|           |
+---/\/\----+
|   R3
|
R4
|
|
Iout
|
|
+---------+
|         |
|         |
|  Op-Amp|
|   (A3)  |
|         |
+----|----+
     |
     Rf
     |
     |
     Vout
```

*In this schematic:*

*+Vcc is the positive supply voltage.*
*R1 and R4 are resistors, setting the input voltage range.*
*R2 and R3 are precision resistors that determine the output current as in a typical Howland current source.*
*The additional operational amplifier (Op-Amp A3) with feedback resistors Rf and Vout provides buffering and impedance matching for the output current.*
*The feedback buffer (A3) helps to isolate the output current (Iout) from the load and provides a high input impedance, making the current source more stable. The output voltage (Vout) is taken from the buffer, which can be connected to external circuitry without significantly affecting the current source's performance.*

*The operation of the Howland current source with a feedback buffer is similar to the basic Howland current source. The output current is still determined by the voltage* *difference between the non-inverting and inverting inputs of the operational amplifiers (Op-Amps A1 and A2), and R2 and R3, as mentioned in the previous response.*

*The buffer, Op-Amp A3, ensures that the output current is well-defined and isolated from the external load. The feedback resistor Rf is chosen to set the gain of the buffer, which can be adjusted for specific applications.*

*This modified Howland current source with a feedback buffer is often used in situations where precise, stable current sources are needed, and the load impedance or requirements of the connected circuitry make it necessary to include a buffer.*

#### 8.1.5.2 Bard

***Answer 1:*** *The schematic of a Howland current source is shown below: https://circuitcellar.com/resources/quickbits/howland-current-source/*

*The circuit consists of an operational amplifier (op-amp), two resistors (R1 and R2), and a load resistor (RL). The input voltage (Vin) is applied to the non-inverting input of the op-amp, and the output current (Iout) flows through the load resistor.*

*The Howland current source works by forcing the voltage across the load resistor to be equal to the input voltage. This is achieved by the op-amp, which acts as a negative feedback amplifier. The op-amp adjusts the current flowing through the load resistor until the voltage across it is equal to the input voltage.*

*The output current of the Howland current source is given by the following equation:*

*Iout = Vin / R2*
*This means that the output current is proportional to the input voltage and inversely proportional to the resistor R2. The resistor R1 is used to set the gain of the circuit.*

*The Howland current source is a versatile circuit that can be used in a variety of applications. It is often used in precision circuits, such as test and measurement equipment, and in power electronics applications, such as LED drivers and motor controllers.*

*Here is an example of a Howland current source circuit that can be used to drive a 100 mA LED:*

*Vin = 10 V*
*R1 = 10 kΩ*
*R2 = 100 Ω*
*RL = 100 Ω*
*The output current of this circuit will be 100 mA, regardless of the voltage drop across the LED.*

*The Howland current source is a powerful tool that can be used to generate precise and controlled currents. It is a versatile circuit that can be used in a variety of applications.*

***Answer 2:*** *The schematic of a Howland current source with a feedback buffer is shown below:*
*https://www.ti.com/lit/an/sboa441/sboa441.pdf?ts=1697272101354*

*The circuit is similar to the standard Howland current source, but with an additional op-amp (U2) used as a feedback buffer. The feedback buffer isolates the load resistor (RL) from the input voltage (Vin), which improves the accuracy and stability of the circuit.*

*The feedback buffer works by forcing the voltage at the non-inverting input of U1 to be equal to the voltage at the output of U1. This is achieved by the feedback loop, which consists of resistors R3 and R4.*

*The output current of the Howland current source with feedback buffer is given by the following equation:*

*Iout = Vin / R2*
*This is the same equation as for the standard Howland current source, which means that the output current is proportional to the input voltage and inversely proportional to the resistor R2.*

*The Howland current source with feedback buffer is a more accurate and stable circuit than the standard Howland current source. It is often used in precision applications, such as test and measurement equipment, and in power electronics applications, such as LED drivers and motor controllers.*

*Here is an example of a Howland current source with feedback buffer circuit that can be used to drive a 100 mA LED:*

*Vin = 10 V*
*R1 = 10 kΩ*
*R2 = 100 Ω*
*R3 = 10 kΩ*
*R4 = 10 kΩ*
*RL = 100 Ω*
*The output current of this circuit will be 100 mA, regardless of the voltage drop across the LED.*

*The Howland current source with feedback buffer is a powerful tool that can be used to generate precise and controlled currents. It is a versatile circuit that can be used in a variety of applications.*

#### 8.1.5.3 BingAI

***Answer 1:*** *Certainly! A Howland current source is a voltage-controlled current source that can both source and sink current proportional to an input voltage. It was devised by Professor Bradford Howland at MIT in the early 1960s 1. The basic Howland current source circuit looks a lot like a differential amplifier, except the output node is at the non-inverting input of the op amp. The current flowing out of this node through the load is the sum of the currents entering the node via R1 and R2 1. Figure 1 in 1 shows the basic configuration. The current flowing through the load resistor is the sum of the currents through the resistors R1 and R2. We can also see that the op amp forms a non-inverting amplifier. This gives us two equations:*

*v_i = v_+ - v_-*
*i_o = (v_+ - v_-) / R_3 + (v_+ - v_o) / R_4*

*Substituting the second into the first gives the expression:*

*i_o = (v_i - v_o) / R_2 + (v_o / R_4)*

*Note that the expression in brackets is in inverse units of resistance and is effectively the output impedance of the circuit as seen from the output node. Let's call this R_0. Now we have:*

*i_o = (v_i - v_o) / R_2 + (v_o / R_0)*

*If we set the ratio of R_1/R_2 equal to the ratio of R_3/R_4 (for example by making all these resistances the same), the impedance of the output node will tend towards infinity and the output will therefore be a voltage-controlled current source with value of v_i / R_1 1. In reality, you do have to have well-matched resistor ratios and an op amp with good CMRR in order to get the best out of the circuit. The references below suggest some techniques for trimming out any mismatch 1 2.*

*I hope this helps!*

***Answer 2:** Certainly! A Howland current source with a feedback buffer is a voltage-controlled current source that can both source and sink current proportional to an input voltage. It is an extension of the basic Howland current source circuit that includes a buffer amplifier in the feedback loop. The buffer amplifier isolates the load from the output impedance of the op-amp, which improves the stability of the circuit 1.*

*The basic Howland current source circuit looks a lot like a differential amplifier, except the output node is at the non-inverting input of the op amp. The current flowing out of this node through the load is the sum of the currents entering the node via R1 and R2 1. Figure 1 in 1 shows the basic configuration.*

*The addition of a buffer amplifier in the feedback loop of a Howland current source results in a circuit that can deliver high precision and low noise performance 2. Figure 2 in 2 shows an example schematic of a Howland current source with a feedback buffer. The buffer amplifier is implemented using an operational amplifier (op-amp) with high input impedance and low output impedance. The op-amp is configured as a voltage follower, which provides unity gain and high input impedance to the feedback loop. The output of the op-amp is connected to a shunt resistor, which sets the output current level. The input voltage is applied to the non-inverting input of the op-amp, while the inverting input is connected to the output node via a feedback resistor 2.*

I hope this helps!

#### 8.1.5.4 Copilot

***Answer 1:** A Howland current source is a type of op-amp circuit that outputs a virtually constant current despite changes in the load resistance. Here's a simple schematic:*

*1. You'll start by placing a general-purpose operational amplifier (U1), for example the LM741. Its inverting input (pin 2) and the non-inverting input (pin 3) will be connected to different parts of your circuit. The op-amp's positive power supply (pin 7) and negative power supply (pin 4) will be connected to your power source.*

*2. Connect a resistor (R1) from the non-inverting input (pin 3) of the op-amp to ground.*

*3. The inverting input (pin 2) of the op-amp connects to the junction of two resistors: R2, which goes to your positive voltage supply (V+) and RLoad, your load resistor, which goes to ground.*

*4. Now, connect another resistor R3 between the op-amp's output at pin 6 and its non-inverting input at pin 3.*

*5. Lastly, R4 is placed in parallel with RLoad, and one of its terminals is also connected to the op-amp output (pin 6).*

*Note: In the Howland Current Pump, stability and hence the output impedance is affected by the tolerance of the resistors R1, R2, R3, and R4. In order to create a stable current source, R1, R2, R3, and R4 should be precisely matched as follows: R3/R1 = R4/R2.*

*Since the proposed project has no components yet, I couldn't give a schematic design specifically utilizing components from the project. If you tell me which components are present, I can help you figure out how to wire them to form a Howland current source.*

*Source(s):*

*https://docs.flux.ai/tutorials/tutorial-creating-a-part-from-scratch*
*https://docs.flux.ai/Introduction/walkthrough-3-parts*

***Answer 2:*** *Certainly.*

*The Howland current source is a type of operational amplifier circuit that can generate a current that is mostly independent of the load resistance. Additionally, a feedback buffer may be included in the Howland current source to provide superior impedance transformation and reliability.*

*Here is the schematic description:*

*1. An operational amplifier (OPA) is the heart of the circuit. Its non-inverting (+) input and inverting (-) input are important connection points.*

*2. Four resistors, let's denote them R1, R2, R3, and R4, are used for setting up the output current. R1 is connected between the positive rail (V+) and the non-inverting input.*

*3. R2 and R3 are connected in series between the non-inverting input and the ground.*

*4. R4 is the critical component - it's connected between the inverting input and the output terminal (where the load would be connected).*

*5. The feedback buffer is usually another OPA that is connected in voltage follower configuration: its non-inverting input is connected to the output of the Howland circuit (after R4), and its output serves as the improved output of the circuit.*

*This pretty much covers the basic layout of a Howland current source with a feedback buffer. Please note that actual component selection and values, as well as power supply considerations and more, will depend on your specific requirements and constraints. This includes the desired output current range, load impedance range, power supply voltages, and any accuracy or precision constraints.*

*Source(s):*

*https://docs.flux.ai/reference/currentsource https://docs.flux.ai/reference/tristate*

## 8.2 Publication in Sensors

*sensors*

MDPI

*Article*

# Can ChatGPT Help in Electronics Research and Development? A Case Study with Applied Sensors

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**Abstract:** In this paper, we investigated the applicability of ChatGPT AI in electronics research and development via a case study of applied sensors in embedded electronic systems, a topic that is rarely mentioned in the recent literature, thus providing new insight for professionals and academics. The initial electronics-development tasks of a smart home project were prompted to the ChatGPT system to find out its capabilities and limitations. We wanted to obtain detailed information on the central processing controller units and the actual sensors usable for the specific project, their specifications and recommendations on the hardware and software design flow additionally. Furthermore, an extensive literature survey was requested to see if the bot could offer scientific papers covering the given topic. It was found that the ChatGPT responded with proper recommendations on controllers. However, the suggested sensor units, the hardware and software design were only partially acceptable, with occasional errors in specifications and generated code. The results of the literature survey showed that non-acceptable, fabricated citations (fake authors list, title, journal details and DOI—Digital Object identifier) were presented by the bot. The paper provides a detailed qualitative analysis, a performance analysis and critical discussion of the aforementioned aspects while providing the query set, the generated answers and codes as supplied data with the goal to give added value to electronics researchers and developers if trying to reach out for the tools in their profession.

**Keywords:** generative large language model; ChatGPT; sensors; electronics; engineering; development; IoT



**Citation:** Tafferner, Z.; Illés, B.; Krammer, O.; Géczy, A. Can ChatGPT Help in Electronics Research and Development? A Case Study with Applied Sensors. *Sensors* **2023**, *23*, 4879. https://doi.org/10.3390/s23104879

Academic Editor: Longfei Zhou

Received: 6 April 2023
Revised: 5 May 2023
Accepted: 12 May 2023
Published: 18 May 2023



## 1. Introduction

ChatGPT is a variation of the large language model (LLM) named GPT-3 from OpenAI, trained on a given dataset [1]. ChatGPT, which is based on GPT-3 using a specific algorithm for learning, could be used for brainstorming in a conversational way [2], and as it turns out from recent literature, its possibilities can bring a revolution to working environments in various professions. However, considering the recent hype around it can also mean false recognition of its current capabilities. While the application of ChatGPT seems to spread in a wide spectrum, there are also concerns that were already raised in the scientific society.

Most of the recent papers (as seen below) present a serious concern: While generative chatbots are transformative tools of the future, urgent guidelines are needed in the case of most professions to mitigate the problems arising with the uncertainties around them [1]. It is also a serious problem that sometimes it gives convincing but false information (reported by many of the papers) and that the tool could not provide in-depth analysis. Further concern centers on the possible future monetization strategies around the tool, which could widen the gap between researchers of different wealth. It could also raise issues of cheating and unoriginal content in education and scholarly assignments. However, the tool could accelerate research, improve workflow, lower language barriers or show new ideas.

### 1.1. Aspects of LLM in Scientific Works

One significant issue is that ChatGPT might pose a danger from a scientific publishing point of view as it can rewrite content to make plagiarism detection nearly impossible. There are tools to mitigate this problem, to detect AI generated text. Despite the fact that these applications are being developed to help detect the unethical use of generative AI, they are not functioning yet perfectly, and a simple rewording by the user could fool the detection systems [3]. It was highlighted by Bhattacharya et al. that ChatGPT works from existing text, and it can produce output that comes out negatively from a plagiarism tracker [4]. Aljanabi et al. reported that the output from ChatGPT is not always accurate, but the team emphasized that it can be helpful in academic writing (getting references, rewriting or generating text, proposing style, etc.). ChatGPT can function as a search engine [5]. It was noted that it cannot handle mathematical calculations and other types of specific queries. The widely cited help that ChatGPT can provide needs further assessment in our opinion.

According to the authors, the tool could be useful for detecting security vulnerabilities as well. While the AI is supposed to be able to generate a literature review (or even complete papers and arguments [6]), it actually lacks an understanding of the implicit ideas in a text [7], which are incredibly important in human–human communication. This phenomenon could introduce errors to the answer. Also, intensive "Socratic" questioning can make ChatGPT change its answers, suggesting that they were not logically coherent or lacked sufficient proof and founding [8]. The tool often provides convincing text that can contain false parts in its details [4], and due to the black-box setup of the AI tools [9], transparent mitigation is difficult. Another issue of using an LLM, like ChatGPT, is that it is trained on a very large dataset. While this data is supposed to be diverse, there is no guarantee of a diversity of opinions. Therefore, the dataset should include biases, those could propagate through the AI and appear in the text generated [10], without the knowledge of the users. Bias, commercialization and technical precision should be investigated for a wide array of scientific and technical fields and professions.

### 1.2. Application in Medical Sciences

From a medical application point of view, ChatGPT could be useful for treating patients in surgery (analyzing vital signs, pain tolerance, medical history, facilitating communication, etc.). It could help doctors make a diagnosis without having to do an extensive manual literature review [11,12]. Macdonald et al. used the tool for a socio-medical experiment [13]. They simulated virus spreading among a population, and ChatGPT was asked to help with determining the effectiveness of the fictive vaccine and drafting a research paper. ChatGPT generated abstracts passed plagiarism. After the dataset being described, ChatGPT could explain and offer potential study steps, and ChatGPT could generate code for studying the dataset. It contained some faults, but after feedback, it could self-correct itself. As for manuscript writing, ChatGPT generated a coherent abstract for the paper. It was possible to use ChatGPT to do a literature review, but in this example, it provided faulty information. This important aspect needs to be assessed in other fields as well.

Macdonald found that ChatGPT could become a resource for researchers to develop papers and studies faster but with careful assessment of the given answer. Khan et al. found that ChatGPT is useful for checking grammar in written text, and it could be useful as a teaching tool for generating tasks in a medical environment [11]. In the reference [3], the authors also came to a similar conclusion. The tool can provide research assistance by providing text summaries, answering questions and generating bibliographies. It can translate, which could be useful for researchers who need to write in a second language and do not have a subscription tool for translation. In clinical management, it could improve documentation, support decision-making and facilitate communication with patients. There are noted deficiencies though: A lack of real understanding was reported, originating from the fixed and closed database. Besides, no data was found after 2021, and it could also generate unoriginal content with incorrect answers at times. This was also emphasized by Gordjin and Have [14]. Liebrenz showed that ChatGPT can also write an article for The Lancet Digital Health about AI and medical publishing ethics [15]. They highlighted that monetization of AI could produce a gap between researchers of different wealth. However, the availability of further monetized tools (such as ChatGPT4) was not available at the moment, so critical comparison could not have been performed by the authors.

### *1.3. Application in Finance and Education*

Moving on to a different profession, Dowling and Lucey used the tool to assess their research process in finance research [16]. A literature review was done on both public (already included) and private (fed to ChatGPT) data. Idea generation, data identification, prep and testing framework proposition were done. The generated studies were stated by a board of referees to be of acceptable quality for a peer-reviewed finance journal. However, data analysis was missing from ChatGPT's actual capabilities.

As for educational use, Rillig et al. [17] discussed the application in environmental research and education. Due to the working principle of the algorithm, biases in the training data could produce bias in the output of ChatGPT. The LLM output could easily be confused with an expert's answer, even though it has no real understanding, so Rillig et al. also highlighted these risks during applications. ChatGPT could be used to accelerate research by outsourcing tasks to ChatGPT, improving workflow. Furthermore, it can also help non-native English speakers to write papers, develop ideas, etc. Nevertheless, ChatGPT could raise issues of cheating in education as well. The papers usually do not propose in-depth solutions for the problems; they only imply the need.

### *1.4. Application in IT and in Engineering Sciences*

From the aspect of IT sciences and electrical engineering, Wang et al. noted [7] that "Stack Overflow" introduced a temporary ban on code generated by ChatGPT because of a low percentage of being totally correct. The bot gave plausible but incorrect answers during the presented discussions. Surameery and Shakor highlighted bug-fixing capabilities of the tool and suggested ChatGPT as a part of a more comprehensive debugging toolkit, not only as a sole solution used by developers [18]. Biswas showed mostly the positive aspects of the tool in programming, such as a technical query answering machine for explanations, guides and diagnosing problems [19]. Vemprala et al. showed a possible application mindset for robotics, where ChatGPT partially substitutes the engineer in the loop and where eventually a user can use the LLM as a tool to connect to further robots solving tasks [20]. The literature is very limited for electronics, software- and electrical engineering applications, which needs further investigations via various use cases and their documentations.

To see how efficiently ChatGPT can help in electronics research and development, we adapted the methodologies and approaches presented in the previous papers and investigated the applicability of ChatGPT for electrical engineering, design and development, where our focus was positioned to a widely studied topic: smart home applications with sensors. The question was: Can ChatGPT be a tool or a useful companion for an electrical engineer developer? The paper presents the experimental methodology, the query running with the bot with the supplemented data and the discussion of the results. The main novelty of our work is to show the applicability of the tool in an area that was not discussed before, and our findings might help discussions and arguments regarding the application from the professional industrial level to education and academic sciences.

## 2. Experimental Information

We wanted to investigate if ChatGPT could help us with the development steps in a smart home project. Our case study is a relevant example since smart home and IoT related developments are very popular lately (IEEE Xplore lists 13.000 articles for the term "smart home" since 2013). So, the bot could work on a well-established topic, which is also interesting from the aspect of actual hardware and software development. Furthermore, the complexity of the topic is deep enough to test the ability of ChatGPT to give answers to various layers of the problem, such as:

- controllers as a central unit, sensor component types, parameters, comparison of different types;
- logic connection between components;
- how can the sensors be programmed with an embedded mindset;
- actual code generation;
- and expanding the view with literature references.

We focused mainly on the electrical engineering aspects of the project, excluding data acquisition, repository, database and further IoT related questions. The workflow was the following:

1. ChatGPT was introduced to the problem by the first query: whether to use a Raspberry Pi or an Arduino board as a sensor controller for a smart home. This question is general for a start and requires the chatbot to look up information and reason for either solution.
2. Afterwards, more specific questions have been asked. When it was already decided which controller should be used, the bot was asked to provide a list of sensors that would be recommended for the board.
3. Then the bot was asked to provide specific sensor models for each type of sensor, to list the sensors, to compare two alternatives or to provide the specifications and prices for the sensors.
4. The bot was also asked about the workflow of connecting specific sensors to the controller and supporting software development.
5. Finally, it was prompted to provide a literature review and references with DOI (Digital Object Identifier) numbers included. This step was done at the end of our queries due to the nature of the bot; the bot can dwell deeper into the topic once a human user establishes it and carries forward the discussion.

Our methodology is also presented in the following Figure 1.

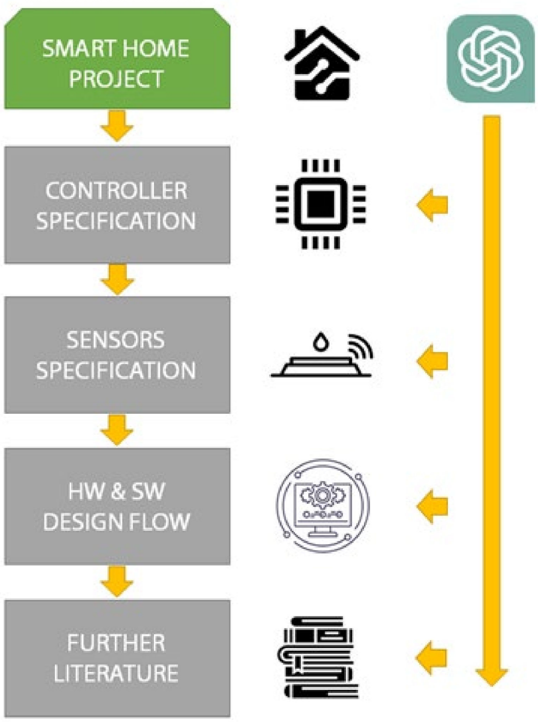


**Figure 1.** Workflow with ChatGPT in the use case of building a smart home device with sensors.

ChatGPT (based on GPT-3.5, OpenAI, San Francisco, USA) was used for our experiments. The official cutoff date of the training data was in 2021 [21], which limits the current possibility of the tool. However, established information was well available before this date regarding our topic and queries. The queries were appointed to the tool between 13 and 19 March 2023, so the current work represents the state of the bot in that time. While the next version of ChatGPT Plus (GTP-4) is supposed to have better performance, it just became available during our investigations and was locked behind a paywall. Furthermore, controversies were noted, and concerns were raised regarding the new version of the tool (with an eventual ban of it in Italy) [22]. So, we aimed to stick to the more well-known version of the tool. Also, during the manuscript composition, Bard (Google) was not available in the country, meaning that general accessibility is still an issue. Bing (Microsoft) bots became available with interfacing to the internet [23], and it was freely available, so we decided to add a short (but not comprehensive) comparison between 3.5 and Bing.

## 3. Results

While it is difficult to present quantitative analysis on the problem, we try to discuss the results qualitatively, aiming for technological precision and quantitative assessment only where possible (e.g., in the case of written codes, data and specific information). The full data set (including codes, queries and responses) is available in Supplementary Materials, which might be necessary for full assessment by the reader, as the full query text inclusion would boast the paper significantly. Supplementary Materials availability is highlighted in the papers "Supplementary Materials" and "Data Availability Statement" section.

### *3.1. General Questions Regarding Building a Smart Home Application, Specification of a Controller*

In the first step, we asked ChatGPT which controller we should use for developing a smart home application.

***ChatGPT***: "Sure! There are several options for micro-controllers that you can choose from for your smart home project. Here are 6 examples from different manufacturers:

Arduino Uno: This is a popular micro-controller board that is easy to use and has a large community. It has 14 digital input/output pins, 6 analog inputs and a 16 MHz quartz crystal.

Raspberry Pi: This is a small, affordable computer that can run a full operating system. It has a variety of input/output options, including GPIO pins, USB ports and Ethernet.

ESP32: This is a powerful micro-controller with built-in Wi-Fi and Bluetooth connectivity. It has 34 GPIO pins, 18 analog inputs and a dual-core processor.

STM32F4 Discovery: This is a development board based on the STM32F407VGT6 micro-controller. It has 168 MHz Cortex-M4 CPU, 1 MB Flash memory, and 192 KB RAM.

PIC18F4520: This is a popular micro-controller from Microchip Technology. It has 32 KB Flash memory, 1.5 KB RAM and 36 I/O pins.

NXP LPC1768: This is a micro-controller based on the ARM Cortex-M3 architecture. It has 512 KB Flash memory, 64 KB RAM and a variety of input/output options.

These are just a few examples, and there are many other micro-controllers available on the market. You will need to choose the one that best fits your project's requirements in terms of processing power, memory and input/output options."

At this point, we asked ChatGPT to give arguments on choosing a device.

***ChatGPT***: "Sure! Here are some arguments for choosing each of the micro-controllers I listed:

Arduino Uno: The Arduino Uno is a popular choice for beginners and hobbyists because it is easy to use and has a large community. There are many tutorials and examples available online, making it easy to get started. It has a simple programming environment and is compatible with a wide variety of sensors and shields.

Raspberry Pi: The Raspberry Pi is a powerful micro-controller that can run a full operating system, making it suitable for more complex projects. It has a variety of input/output options, including GPIO pins, USB ports and Ethernet, making it versatile and flexible. It can also run software like Python, making it easy to integrate with other tools and services.

ESP32: The ESP32 is a powerful micro-controller with built-in Wi-Fi and Bluetooth connectivity. This makes it ideal for projects that require wireless communication, such as remote control or monitoring. It has a large number of input/output pins and a dual-core processor, making it suitable for projects that require a lot of processing power.

STM32F4 Discovery: The STM32F4 Discovery is a development board that is based on the STM32F407VGT6 micro-controller. It has a high processing speed and a large amount of memory, making it suitable for complex projects. It also has a wide range of input/output options, including USB, Ethernet and audio.

PIC18F4520: The PIC18F4520 is a popular micro-controller from Microchip Technology. It has a relatively low cost and a large number of input/output pins, making it ideal for projects that require a lot of sensors or actuators. It also has a large community and many examples available online, making it easy to get started.

NXP LPC1768: The NXP LPC1768 is a micro-controller based on the ARM Cortex-M3 architecture. It has a large amount of memory and a variety of input/output options, making it suitable for a wide range of projects. It also has a powerful processor and can run at high speeds, making it ideal for projects that require fast processing.

In summary, each of these micro-controllers has its own strengths and weaknesses, and the best one for your project will depend on your specific requirements. Factors to consider when choosing a micro-controller include processing power, memory, input/output options and community support."

We can say, that the information is accurate, and the bot was giving logical arguments with precise information on this very general initial case.

To narrow down the focus, we gave Arduino or Raspberry Pi as a choice. Early investigations showed that the answers give a broader point of view at the beginning of a query-set, so a narrowed approach is beneficial for a start. The bot was able to distinguish the two different systems, with reasonable responses on the general overview regarding the two systems capabilities. It gave advantages and disadvantages about the use.

***ChatGPT***: "Both the Arduino and Raspberry Pi controllers have their advantages and disadvantages when it comes to building a smart home.

Arduino is a microcontroller board that is designed for simple projects that require low power and have limited processing requirements. It is a good choice if you want to control simple sensors such as temperature, humidity and light sensors. Arduino is easy to use and is ideal for beginners who are starting to learn about microcontrollers.

On the other hand, Raspberry Pi is a small computer that is capable of running a full operating system. It is more powerful than Arduino and has a wider range of capabilities. Raspberry Pi is a better choice if you want to integrate complex sensors such as cameras, voice recognition and machine learning. It also has the capability of connecting to the internet, which allows for remote control and monitoring of your smart home devices.

Therefore, the choice of controller depends on the complexity of your project and the sensors you want to integrate. If you are building a simple smart home system, then an Arduino controller would suffice. However, if you want to build a more advanced system that requires complex sensors and internet connectivity, then Raspberry Pi would be a better choice."

We found that the answer contained some correct information; however, some other information can be argued with. The discussion did not go to the level of more recent advances of the systems. Arduino also offers newer devices (Portenta family [24], established in 2020) for higher-level tasks with similar capabilities to the Raspberry lineup. This information was either omitted by the timely limit of the background training data for ChatGPT 3.5 or by the fact that ChatGPT is orienting its answers towards the more common knowledge established over a longer period. According to Hernando, the origins of Arduino can be traced back to 2003–2005 [25], so the answer given by the bot was a more superficial assumption based on a longer-term general knowledge. The final conclusion of

ChatGPT was found to be acceptable; most of the information was valid; and it could argue along a wide range of commercially available products without obvious bias towards one or the other.

*3.2. Sensors and Specifications*

We also asked for specific types of sensors, where the bot suggested temperature, light, motion, humidity, gas, water and smoke sensors and their combinations with short descriptions, which helps accessibility to the topic even at a beginner level. We emphasize again that, for full analysis, the reading of Supplementary Materials is recommended.

While the scope would be too wide for analyzing all types, we focused first on temperature sensors. ChatGPT suggested five "popular" alternatives: DHT11, DHT22, LM35, DS18B20 and BME280. It provided short descriptions for each type in its answer. Each component is valid and widely used by hobbyists and professionals in the field. The query followed with light sensors. ChatGPT gave a mix of the types (e.g., photoresistors, photodiodes, phototransistors) and specific sensor modules (e.g., TSL2561, BH1740) in its five-step answer. To sum up, the bot was mixing types and specific commercial components in the answer, which is inconsistent in its manner.

Altogether, from two questions on "specific light sensors" and "specific light sensor models", the bot listed six components and three type descriptions (with a repeated description on photoresistors). It was clear that slightly different queries affected the answer inconsistency, but the effect seemed rather minor and seemed to be originated from the randomness of each individual answer by the bot. Again, the bot was mixing types and components.

As for motion sensors, five examples were listed. The listing was presented in a third format, where the declared type was followed with a specific component name as well. (e.g., PIR Motion Sensor (HC-SR501)). However, inconsistencies were found, as for five different types, only three actual sensor components were listed, the rest was again general listing. The bot did not provide a real module for infrared motion sensors and laser motion sensors. The same mixed listing was found in the case of humidity sensors. Albeit the bot could give five actual sensor types this time, only one type was specified on its working principle (capacitive humidity sensor (SY-HS-220). Gas, water level and smoke detectors were also sorted by incoherent listing; however, all types were found to be commercially available.

ChatGPT was also asked to list the sensors by price, the bot was able to find ranges of the price, and it arranged a list based on the prices. The ranges seemed valid according to a manual search in popular web shops on the internet. All information seemed to be coherent with current availability for 10 components, but actual prices varied a bit (at the same or one range lower as the current prices). This might not only be due to the recent increase in prices—some components were inconsistently cheaper or more expensive in the list.

The bot suggested Arduino for the project previously, so the follow-up was coherently provided according to this controller type. In short, ChatGPT could carry forward the information precisely from question to question.

After the more general queries on sensors, we asked to suggest specific data for three different sensors. One query focused on the DHT11. The following specifications were given.

***ChatGPT:*** "Here are the specifications of the DHT11 temperature and humidity sensor:

1. Temperature measurement range: 0 to 50 degrees Celsius with an accuracy of +/−2 degrees Celsius
2. Humidity measurement range: 20% to 90% RH (Relative Humidity) with an accuracy of +/−5%
3. Operating voltage: 3.3 V to 5 V DC
4. Current consumption: 2.5 mA max during conversion, 0.5 mA standby
5. Signal transmission distance: Up to 20 m
6. Sampling rate: 1 Hz (1 reading per second)

7. Response time: less than 5 s
8. Dimensions: 23 mm × 12 mm × 5 mm (L × W × H)
9. Digital output: Data is transmitted using a single-wire serial interface with a timing protocol that includes a start signal, data bits, and a checksum for error checking.

The DHT11 sensor is a low-cost, basic temperature and humidity sensor that is suitable for many simple projects. However, if you require higher accuracy, faster response time, or other features, you may need to consider a more advanced sensor."

The bot was able to summarize the applicability of the sensor in an efficient manner, but a mistake was found. The response time was not accurate. The datasheet gives 6 s minimum, 10 s typical and 15 s max for this parameter [26], compared to the bot's version of "less than 5 s". It was suggested that DHT11 has different datasheets available on the web, but an alternative, widely available datasheet version was also backing up our finding with precise response time values [27]. We asked the same question for DS18B20 sensor too Supplementary Materials, where we found that the maximum of the current draw was imprecise for the suggestions (1 mA suggested value vs. 1.5 mA in real life). For two other sensors (TLS2561, MQ-135), the operating voltages, active power consumption and operating temperatures were imprecise (for full details, see Supplementary Materials), in the meanwhile, staying in similar range as the datasheet values. For TLS2561, ChatGPT gave an "Operating voltage range of: 2.7 V to 3.6V DC", which is actually 0 V to 3.8 V according to datasheet [28]. It was found that the "2.7 V to 3.6 V DC" was received from an application note [29], where the "voltage range" noting is similarly confusing as it is missing the lower boundary of the range. For MQ.135: ChatGPT gave "Operating temperature: −10 to 50 °C", which is actually max. 45 °C [30].

Overall, this information can be crucial during design, so while ChatGPT can focus its interest on specific components, many details need validation by human hand. It is suggested that the bot was trained on older data or misleading information was found in the training dataset. Altogether it can be concluded that most of the given data were usable though some responses contained imprecise information in similar, easily confusing or deceiving range as original values found in technical specifications.

### *3.3. Workflow and Code*

To aid embedded coding, ChatGPT was asked how to connect a DS18B20 temperature sensor to the Arduino [31]. The component was chosen randomly from the previous set of results discussed in Section 3.2. The answer was the following.

***ChatGPT**:* "To connect a DS18B20 temperature sensor to an Arduino, you will need the following components:

- DS18B20 temperature sensor
- 4.7 k ohm resistor
- Breadboard
- Jumper wires

Here are the steps to connect the DS18B20 temperature sensor to the Arduino:

1. Connect the Vcc pin of the DS18B20 sensor to the 5 V pin on the Arduino.
2. Connect the GND pin of the DS18B20 sensor to the GND pin on the Arduino.
3. Connect the data pin (middle pin) of the DS18B20 sensor to a digital input/output (I/O) pin on the Arduino. In this example, we will use digital pin 2.
4. Connect a 4.7 k ohm resistor between the data pin and the 5 V pin on the Arduino.
5. Connect the Arduino to your computer via USB cable.
6. Open the Arduino IDE and create a new sketch.
7. In the sketch, include the OneWire and DallasTemperature libraries. These libraries can be installed from the Arduino IDE Library Manager.
8. Initialize the OneWire and DallasTemperature libraries in the setup() function of the sketch.
9. In the loop() function of the sketch, read the temperature data from the DS18B20 sensor using the DallasTemperature library functions. The code would look something like this:

In this code, we first define the data pin (digital pin 2) as ONE_WIRE_BUS. Then we initialize the OneWire and DallasTemperature libraries in the setup() function. In the loop() function, we first use the requestTemperatures() function to request the temperature data from the DS18B20 sensor. Then we use the getTempCByIndex(0) function to get the temperature in degrees Celsius. Finally, we print the temperature to the serial monitor and add a delay of 1 s before the next reading.

10. Upload the sketch to the Arduino board, and open the serial monitor to see the temperature readings."

According to the given response, we validated the steps by the datasheet. The component list was valid, as well the connections of the pins and components. Even highlighting the 1-Wire communication was correct. The official datasheet backs up our findings about the response [31]. The suggested code is also working, but minimal knowledge of the IDE (Integrated Development Environment) is required to assess the steps given by the bot. We also did the query with the DHT11 Supplementary Materials, and we received again, convincing points. The datasheet was suggesting that the pin alignment was correct [32]. However, there was a DHT library recommendation, which all authors agreed upon, that was not straightforward to understand and include with the work. Overall, it was found that more preliminary knowledge is required to use the second query, and it was found that the depth of the solution might vary from use case to use case.

To the question about the origins of the suggestions, ChatGPT responded with a sound answer:

***ChatGPT**:* "I wrote the code example based on my knowledge and experience with using the OneWire and DallasTemperature libraries to read temperature data from a DS18B20 sensor. However, the code structure and some of the function calls may be similar to code examples found in the official Arduino documentation, online forums or tutorials."

The generated code can be found in ***CodeForDS18B20.cpp*** in the Supplementary Materials dataset of the article.

The question regarding the use of an MQ-4 gas sensor was also asked from the bot. This time the results were considerably less reliable. ChatGPT cited the datasheet of the MQ-4 sensor for a formula [33], where the datasheet did not contain such information. So, human validation was again required at this point to validate the data provided by the bot. From this aspect, the formula was not included in the official support materials, so we can claim this part unreliable.

In the codes, commenting was also found for better understanding; however, the comments were not consequential in their amount and detail. It is a big advantage however that the tool was aware of commenting.

Altogether, ChatGPT can give partially plausible solutions for simple hardware and software tasks, like interfacing a controller and a sensor, but it also gave false findings, which elevates the need of human control over the results.

### *3.4. Literature Survey on the Topic*

About the literature survey, the following question was given to ChatGPT: "Could you do a literature review on smart home control with Arduino for a research paper?" ChatGPT responded with a general introduction on the topic of Arduino in relation with smart home control and gave three literature references as examples. For example:

***ChatGPT**:* "One study by Varghese et al. (2017) presented an Arduino-based smart home system that used a variety of sensors to monitor the temperature, humidity, gas levels and motion in a house. The system also included automatic control of lights and fans based on occupancy and environmental conditions. The authors reported that the system was able to improve energy efficiency and reduce utility costs."

When we asked about the citations, ChatGPT provided a plausible response at first glance. The following citation was presented for the article above.

***ChatGPT**:* "Varghese, J., Jayachandran, S., & Jayachandran, S. (2017). An Arduino based smart home system. International Journal of Pure and Applied Mathematics, 114(10), 505–514."

Looking for the given citation in widely used search-engines (Google Scholar, Academia.edu) and in the article list of the given journal, it was found that this paper did not ever exist. The names of the authors were found in similar research topics, but it was an initial red flag that the second and third authors were the same (Jayachandran, S.). Also, the title is a fabricated one, as well as the rest of the bibliographic information. In the next step, ChatGPT was asked to give references to scientific literature (recommend articles) regarding Arduino as a sensor controller (also including the DOI numbers of the papers). The response was a list of five references, with similarly false information. During the investigations, an interesting aspect was revealed about the following suggested article:

***ChatGPT**:* "J. R. de Sousa and M. F. de Sousa, "Data acquisition and control system based on Arduino platform for low-cost greenhouse monitoring," Measurement, vol. 168, p. 108273, Jan. 2021. DOI: 10.1016/j.measurement.2020.108273"

It turns out, there is no such article available on the web. But the DOI seemed to be in connection with the given journal, which would also fool the unsuspecting eye, believing that the reference is correct. The DOI is an existing one, but it does not refer to the given article. The paper of Ziolowsky et al. has nothing to do with the discussed applied sensors topic [34].

For the question on the actual help for fitting sensors to Arduino, the bot provided five references with short descriptions, and four out of them were actually accessible. One of these examples was not a live link, but the browser forwarded the request to a proper one. The given link "https://www.arduino.cc/en/Tutorial/HomePage (accessed on 29 March 2023)" seemed to forward us to the actual (current) document repository of Arduino [35]. This case needed deeper assessment. The link was fed to the reliable Archive.Org "Wayback Machine", and it turned out that the archived (March 2023) link is redirected to the actual repository as shown above with the following HTTP response [36]:

"https://www.arduino.cc/en/Tutorial/HomePage |
16:41:50 26 March 2023
Got an HTTP 302 response at crawl time | Redirecting to . . .
https://docs.arduino.cc/tutorials/"

According to Archive.org [36], it seemed that 04:07:56, 4 January 2022 was the last timestamp, when the originally suggested link was accessible. This is in line with the communicated capability of ChatGPT 3.5, that is, relying on a 2021 learning database—the bot could not know that the tutorials were removed to an alternative website.

### *3.5. An Outlook and Comparison with Bing*

While the basic assumption to compare Bing to the closed database-trained ChatGPT 3.5 is not a balanced act, we asked the questions on controllers, argument on them, sensor types, specific information on getting started and specific literature. All details are available in Supplementary Materials.

We found that Bing gave us five valid controllers (when asked about 4–6 different types, pointing to a middle solution in quantity). The arguments and information were valid, but the descriptions were a bit shorter. Out of five examples, four were the same with the recommendations of GPT. Also, Arduino was the primary choice here as well.

As for sensor types, Bing gave eight different sensors, where most of them were healthcare based ones. So the focus was much more precise in the case of ChatGPT. For a more specific query on temperature sensors, five different types were listed. DS18B20 was highlighted again as a widely used one. Bing could recommend altogether 17 valid links for tutorials and videos. This aspect is clearly realized by the connection to the web.

While we asked for at least five literature references, we were given five articles. Four articles were available of the five ones, but three articles were written by other authors as it was stated by the bot. Also, all of the DOIs were imprecise. Most links were cited from ResearchGate, which might come from the bias to search in open access materials and libraries. It can be stated that even this tool has problems, so literature survey with the tool is not acceptable from academic precision aspects.

## 4. Discussion

The summary of our findings is presented in Figure 2 and in the performance metrics Table 1, based on the work of Lo [37]. We found that ChatGPT was able to narrow down an initial assumption in developing a smart home project with a proper choice of controllers and sensors. The bot gave superficial but altogether usable recommendations for a controller, choosing from a wide range of items, limited by the its training. It also described a wide range of sensors for the project, with relevant descriptions accessible to even a beginner practitioner in the field.

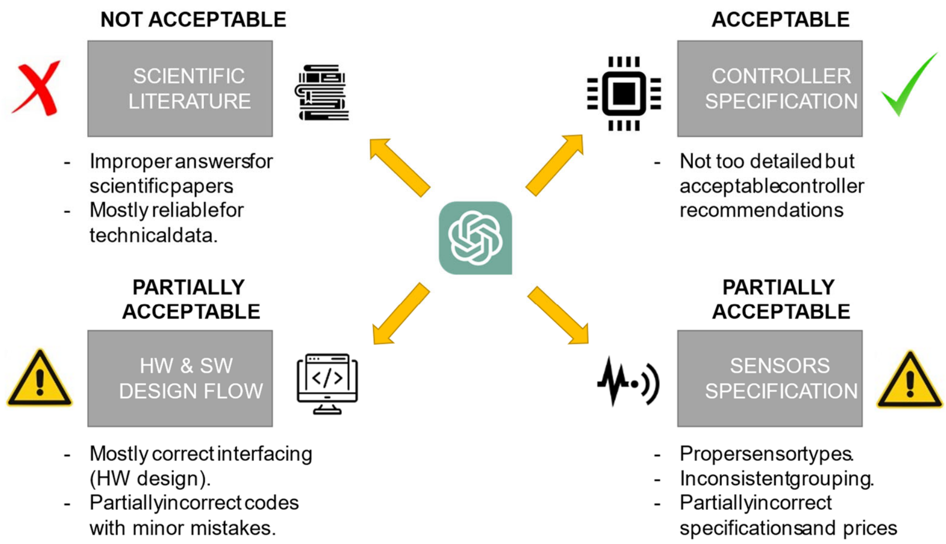


**Figure 2.** Summarizing our findings regarding main aspects and the acceptability of the given answers by ChatGPT.

**Table 1.** Performance evaluation of ChatGPT-3.5 across different subjects.

| Subjects | Overall Performance | Comments |
|---|---|---|
| Choice of controller for smart home application | **Acceptable** | Outstanding choice with proper details on different types, Arduino was the leading choice, understandable discussion, usable but shallowly detailed information. |
| Sensor types | Partially acceptable | Type choice was proper, with inconsistencies in listing and presentation. No commercialization was apparent. |
| Sensor specification | Partially acceptable with minor technical errors | Specifications were mostly ok, minor problems were found in specification parameters (only one per type) and pricing. Probably due to limited availability to the internet. |
| Hardware interfacing | Partially acceptable | Interfacing details were almost acceptable with minor inconsistencies in presentation. The descriptions were written with varied required basic knowledge for understanding. |
| Code | Partially acceptable with occasional technical errors | Correct syntax, uneven commenting, minor addressing issues. |
| Literature | **Unacceptable** | Totally unacceptable for academic demands. Fabricated titles with real authors and fake, sometimes working, but not connected DOIs. Technical data is addressed in a more reliable form. |

As for the sensors and specifications, the bot was able to sort out different sensor types for the task, which were fitting to the request, and which are still on the market. The sorting of the sensors was correct from the aspect of the price, but the listings (or groupings) were inconsistent from the aspect of sensor type (by measurement principle) and actual sensor component type. We also found that most of the sensor specifics were correct, but around 10% of the given parameters were imprecise (albeit in range, close to the actual values). The bot was able to follow the discussion via initial assumptions fixed in the queries (such as following up with the Arduino platform). The bot was also giving popular examples and was not focusing on very specific components but widely available ones. If the training dataset is new enough, mistakes in given data could be less, and exact parameters could be more precise; however, various versions of datasheets floating around (e.g., in the case of cheap Far East sensors) might also leave space for confusion.

The workflow of interfacing a sensor module to a controller was covered by the ChatGPT in a partially proper manner. It was able to give appropriate design solutions for physically interfacing the sensor module and also generated a code that provided correct syntax and references to the application of the given sensor module. The request was repeated with another sensor component, where the answers were similarly convincing, but contained minor errors. It must be noted that the task was relatively simple. However, at this level, the bot can help engineers in the learning phase or give an immediate response for a task, which would eventually require a significant amount of working hours.

The capability of the bot for a literature survey is found to be unreliable. It recommends seemingly correct and relevant citations for given technical themes. But all of them are fake, fabricated by relevant keywords, existing authors, journal names and DOIs, which are real but incorrect for the actual examples. It is suggested that in the nature of this LLM, the bot is assembling keyword-based information and cannot handle large, coherent data, like a literature citation. Or simply, the literature is not available to the bot due to commercial nature. In a very recent study, there is a suggestion, that the ChatGPT is more like a creative tool in case of literature analysis than exact documentation assistant [38]. However, it further raises questions about how the information is handled in other scientific fields; as the aforementioned review material mentions [39], most papers seem optimistic from the data organizing side capabilities (e.g., in hypothesis validation or the identification of gaps and inconsistencies in current knowledge). The fabricated literature responses had an added value though: It contained coherent listings of thematically correct key-words, which could further aid the literature survey of a human learner or a beginner in the field. It is important to note that for more technical or commercial related information (such as datasheets and tutorials), ChatGPT could provide four accessible links out of five. One link was an older one, but it was automatically redirected to a working page by the host.

It has to be also noted that the flow of the discussion cannot be reinstated or repeated in the same manner, so further information and branching discussions are given to the user distinctively from time to time. Our experiment presented a use case that is not classically reproducible in the traditional manner. This also makes it more difficult to assess the application of the tool from both technical and societal aspects.

Overall, our results are clarifying the technical depth and precision of the literature survey shown in [5,6,11], showing that exact literature survey, or "searching" can be unreliable. The partially acceptable results with minor failures were similar to be found in [4]. As we found, the accessibility and applicability of the tool points to a curious recommendation, which is similar to [18–20]. The performance analysis was similar to other ChatGPT use cases [37].

## 5. Conclusions

In this article, we investigated the applicability of the novel LLM-based ChatGPT for electrical engineering development of a smart home project. ChatGPT followed our queries with a consistent manner, focusing on the controller and narrowing down the question to different sensor types, their interfacing, some exemplary software and related literature.

It was found that the sensor recommendations were valid, but part of the given specification, prices, hardware-software integration and the resulting code were slightly imprecise, which needed human validation. Furthermore, the listings were inconsistent from the sensor type and commercial module type aspects.

It was found that, by requesting actual scientific literature (articles, journal papers), the results were fabricated, fake and unreliable. However, with limited usability, technical documentation was referenced correctly by ChatGPT, and the key words were found to be accurate.

Interestingly, it was found that Bing (connected to the web) made similar performance as the older ChatGPT 3.5 version, where controller choice was acceptable, sensor technical details were containing minor problems, and literature survey was unacceptable.

For the future, similar tasks should be investigated with the continuously evolving versions and the competitors, such as the recently launched Bing or the Bard platform. The work could be continued with the inclusion of PCB (printed circuit board) design and related simulations. Our work does not tackle the ethical side and fair, responsible use, which is a societal aspect. Concerns are high regarding the application of such tools; even leading professionals are asking for a "pause time" from AI developers to catch up with regulations. Also, it is suggested to focus on information technology and engineering R&D aspects during the development of further releases. As the tool is coming from the same broadly interpreted profession, as our field, it would be important for the tool to meet requirements in data precision (especially with literature and technical information), so that it does not include errors to the developers working with it.

The takeaway message is that, with proper regulations and future improvements, chatbots can be an effective device in electronics development projects, as a supplementary tool in the available, traditional toolset.

**Supplementary Materials:** The following supporting information can be downloaded at: http://real.mtak.hu/id/eprint/163609 (accessed on 5 April 2023).

**Author Contributions:** Conceptualization, A.G.; methodology, A.G. and Z.T.; software, Z.T.; validation, B.I. and A.G.; investigation, Z.T.; data curation, Z.T. and O.K.; writing—original draft preparation, A.G. and Z.T.; writing—review and editing, A.G. and B.I.; visualization, A.G.; supervision, A.G. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Supplementary Data is available at: http://real.mtak.hu/id/eprint/163609 (accessed on 5 April 2023).

**Conflicts of Interest:** The authors declare no conflict of interest.

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