A Dive into Microcontrollers: A Dark Horse Technology

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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In 1971, a small company doing integrated circuits out west in California named Intel designed the first ever 4-bit microcontroller (MCU). As the years progressed, society began to slow enter the digital age. As a result, MCUs have been taking over as the premiere technology for automation, manufacturing, and critical systems. Initially, the design was ordered by a Japanese company seeking to build a better calculator, however, it would emerge to be one of the greatest yet extremely overlooked pieces of technology known to man. A big reason why the technology is overlooked is because MCUs are not considered consumer tech products. Predominantly, technologies like computers and GPUs are products released into the consumer sphere and marketed as such. MCUs are embedded into devices and not singularly marketed out. They act like the cogs that mesh together to make a clock function reliably. Its ability to embed in the most electronic device makes it an extremely versatile piece of technology. I believe it is an overlooked and inconspicuous technology because it is neither flashy nor flaunting. It is only well known in the industry, and as a result, lacks the publicity that other technologies have. Overall, the microcontroller is one of the greatest unnoticed technological devices and will continue to play an impactful role in both industry and the consumer.

The Roadmap

Initially, I will discuss timeline and milestones that occurred in the development of the MCU. Then, I will explain the application of microcontrollers for both engineers in industry and the consumer. I use history and ethnography to show how the microcontroller has become the substantial technology it is now.

Initially, I provide some overall information regarding microcontrollers. The following sections explain microcontrollers and how they work. In order to understand the inception and timeline, it is necessary to understand the principle of microcontrollers. Following general information on microcontrollers, I discuss a generalized timeline of MCUs. During the development of the microcontroller, there were key events to happen that propelled the technology. Then I discuss of key events and an explanation of how the technology has evolved. It is critical to understand the timeline in order to piece how the MCUs are impactful to society.

Application is another critical section of the paper. In particular, the application of MCUs in industry. It is substantial to pinpoint how MCUs are used and why they are used so often. Overall, this section helps the reader understand the benefits of the microcontroller. In contrast, although most consumers are unfamiliar with MCUs, MCUs can be found in devices used by consumers in their daily lives. The section explores the consumer impact of MCUs and how their versatility plays into society. The section includes examples of products and also specific research papers that point to the development and deployment of these technologies.

The last couple of sections of the paper includes are about impact. I discuss how the MCU has an impact both on engineers and consumers. It will specifically investigate industry and social impact. I use the method of technological determinism to show how the development of the digital age played directly increased the role and usage of microcontrollers. I use the theory to support my claim of social impact and it is imperative to answering my research question. I also discuss how MCUs have impacted both higher education and foundational education. The increase of MCUs and educational MCUs has created a positive foundation for developing engineers. Overall, this section is critical in linking my paper together in support of my research question.

What is a Microcontroller?

In order to understand the impact and timeline of MCUs, we must understand what and MCU does and its application. A microcontroller is a compact integrated circuit designed to perform a specific operation in an embedded system. They are essentially miniaturized computers that control small parts of a large component. Microcontrollers are embedded inside a large system to control a function of a larger component. It receives data from its Input/Output (I/O) peripherals and interprets the data with its central processor. It starts by taking in data from its input ports. The data is then stored as a memory where the processor reads the data and responds based on what an engineer has coded the Central Processing Unit (CPU) to do. Finally, it uses its output ports to communicate the correct response. The diagram below shows a very simple architecture of a microcontroller (Lutkevich, 2019).

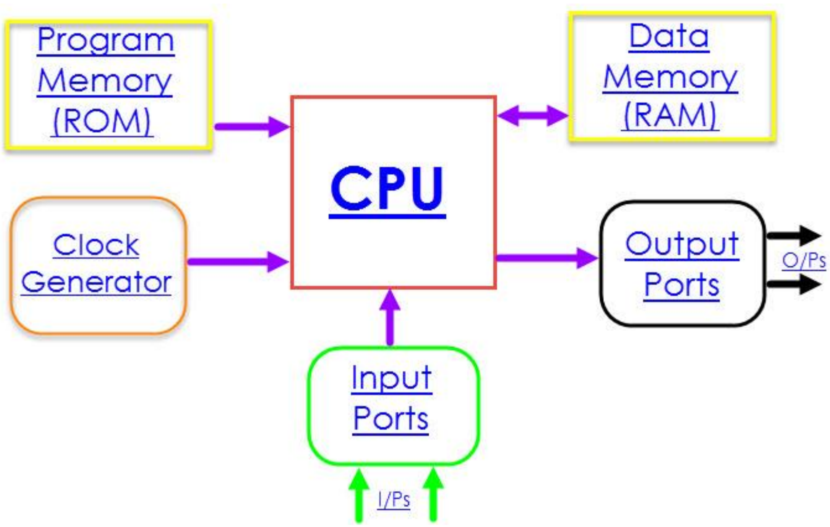

Figure 1. Traditional CPU Diagram

An array of microcontrollers can be embedded into a larger system and be used in conjunction to create a fast and efficient device. One of the big reasons why the microcontroller popularity grew in industry was because it was simple, small, and extremely effective.

Timeline & Important Milestones of MCUs

Inception

During the inception of the microcontroller in the 70s, the MCUs had limited use as a 4-bit calculator. However, as a result of advancements in hardware, MCU units upgraded from 4-bit varieties to 8-bit varieties. Motorola 8-bit MCU in 1977 was the first to introduce a serial communication interface, a reliable form of sending each data bit from I/O peripherals to the CPU. For the next half-century, companies like Intel and Texas Instruments competed over making 8-bit MCU solutions with more memory and a smaller footprint making them extremely cost-competitive.

Pivotal Developments

As the development of MCUs furthered, smaller variants with more cost-efficient applications were being developed. As a result, two pivotal things began to be developed. The first was the development of newer serial communication protocols that were more efficient and reliable. Serial Peripheral Interface (SPI) and I2C (eye-squared-C) were pivotal as they became de facto standards for not only MCUs but most electronic devices. Another pivotal event was the inception and use of RISC-based or (Reduced Instruction Set Computer) computers. Having a reduced instruction set for computers meant that there were less complicated sets of instructions for certain operations which made designing it easier, cheaper, and quicker. These two events skyrocketed the use of MCUs in engineering applications as there became a huge focus on cost-sensitive applications that were perfect for the microcontroller (Raghunathan, 2021).

Software Upgrades

Eventually, as the 21st century began the hardware for integrated circuits improved drastically and so did the MCUs. Aside from the traditional elements like the CPU, ROM, RAM, and I/O, MCUs began coming with Analog Digital Converter (ADC), Digital to Analog Converter (DAC), Serial ports, and many more elements. These added elements improved the capability of the microcontroller and became fully adapted to the current generation of semiconductor chips. Alongside this, by 2010, 32-bit MCUs were the industry norm as semiconductors halved in cost and doubled in performance. Software improvements also helped MCUs become easier to use and program. Originally in the 70s and 80s, MCUs were programmed using assembly code. This is the most low-level programming and is extremely meticulous. For reference, the picture below shows the assembly language that prints the novel "Hello World" in the output display of the computer. Traditionally, a high-level language will only take require one line to print "Hello World" onto the computer console.

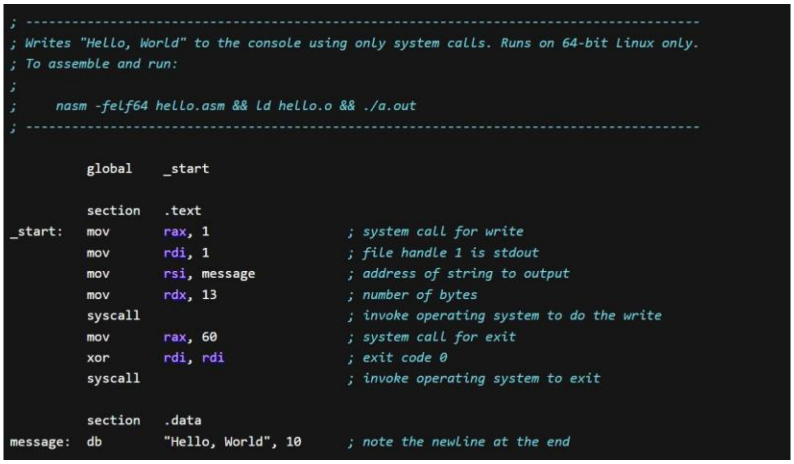

Figure 2. Assembly Code for print("Hello World")

The improvements in the software allowed for MCUs to be coded in C, which is much easier to read and understand. Although C is still considered low-level programming when compared to languages like Python or Java, it is a significant step up from assembly language. Having these software changes made MCUs extremely well-liked in industry by engineers (Lutkevich, 2019).

Improvements and Additional Info

In terms of future work, MCUs are considered standalone devices that are embedded into a system. Their future lies in avenues such as Field Programmable Gate Array (FPGA) which is a technology trying to allow for seamless integration with embedded systems. The future currently is not a huge focus because the hardware behind it must first be upgraded. The image on the next page shows you the change in CPUs as the bit variant increased.

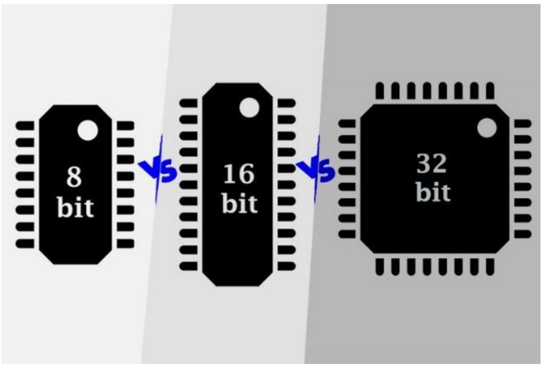

Figure 3. CPU Bit Variant Changes

You can see how the changes in hardware effects its overall size and thus the overall elements attaching to it. The picture on the next page is a full-blown microcontroller, the TI MSP432P401R, used by the UVA ECE department.

Figure 4. Texas Instruments MSP432P401R Microcontroller

The CPU is seen in the middle of the MCU and the various pins on the side are I/O pins and other previously mentioned elements. This particular MCU is an educational one that has the various elements to support learning, a later section will discuss the impact of MCUs on engineering education. In later sections, we will discuss how the MCU has played a impactful role in developing education and supporting new learning and curriculums.

Application: An Engineer's Story

Understanding the microcontroller's timeline and history is essential in revealing how impactful it has been for industry and society. In this section I dive deeper into how the MCU applies both to an engineer and to the average consumer. This will reveal the societal effects of the MCU and the overall impact it has on all different types of people. The microcontroller is an overlooked piece of technology that is highly applicable to all people. It has had a strong impact in the intertwining of technology and society.

Microcontrollers are used by engineers in a wide multitude of industries and applications mainly due to their versatility. MCUs are found to be critical technology in building automation, robotics, internet of things, and communications. One example is using a microcontroller as a digital signal processor. Incoming analog signals from input ports usually have some sort of noise. A microcontroller can use the ADC to DAC to convert noisy analog signals into clean digital signals (Lutkevich, 2019). Using software, an engineer can filter out certain signals and use basic Digital Signal Processing (DSP) methods, and program the MCU as a filter.

Another reason why the microcontroller is so versatile is that it can implore various types of architectures. Architectures are different microcontroller variants. Depending on use, certain microcontrollers will have a varying number of I/O pins, RAM, and on-chip programmable memory (ROM). A huge aspect of the modern-day integrated circuit is timing. For an MCU to work as intended, all hardware must be synced using a clock. Differing MCUs have faster or slower clock generation that impacts their performance speed and use. As mentioned before, MCUs can adopt both RISC and Complex Instruction Set Computers (CISC) which change their performance and ability (Kramer, 2009). This ability to mix and match hardware and the varying architecture of the microcontroller makes it very resourceful. Engineers can find the most cost-effective and efficient microcontroller needed for their specific project. The level of versatility has garnered immense respect for microcontrollers.

In industry, microcontrollers were embedded to perform critical functions in aircraft, robots, and even certain medical devices. Due in part to their size and simple nature, microcontrollers are highly applicable in most electronic/electrical systems. The increase in technology and architecture of the MCU has had a huge role in industries like defense technology, industrial automation, and medical devices.

Application: A Consumer's Unfamiliarity

The popularity of the MCU with engineers, however, is masked by the daily consumers' lack of knowledge of its capability or its existence. Since microcontrollers are not top-of-the-line consumer electronics like iPhones or Mac Books, there is a disparity where consumers don't understand how effective the MCU has been. The microcontroller has and will have an immense impact on your average person. Because the MCU is an embedded product it is often overlooked and works in the background. Almost everything electronic around you uses a microcontroller and people do not even know it.

The simplest microcontrollers control the operation of most everyday electromechanical systems. Items like ovens, refrigerators, televisions, and many more use MCUs to function (Bannatyne 1997). The microcontroller is used as a control device and uses various sensors like temperature, light, and movement to control an electronic response. When the floodlight turns on when you leave the house at night, the microcontroller links both the movement sensor and the light together. These kinds of implementation can be seen in a lot of everyday devices. Like explained earlier, by replacing older analog mechanisms the microcontroller has followed suit in this digital age. Devices consumers use in their homes are now digital and have elements like Wi-Fi and Bluetooth that keep them connected and advancing their digital footprint. Microcontrollers are the primary reason that consumers can now have devices that are "high-tech."

An IEEE paper written in 2021 by J. Guo and Y. Liu talks about using a microcontroller to design a reliable vending machine. The paper discusses using a microcontroller as the center console for the vending machine that processes payment and relays the information via digital signal. The project only uses one microcontroller that can only dispense one product, but to put it into perspective it is extremely powerful what a single microcontroller can do. The overarching technology uses MCUs as Lego pieces that are put together to build a final product (Guo, 2021). Although this paper was written by engineers, I am using it to discuss how microcontrollers are beneficial to daily consumers. The impact is immense because without MCUs certain devices would not be possible. Critical devices with MCUs that we use are comically overlooked.

Connecting it Together – MCU's Impact on Society

It is very important to show how the microcontroller connects both the consumer and the engineer. Often as a consumer, we use electronic devices without being informed about how they work. Many people think of tech as "magic" that just works. Many people do not know what they are doing and this is in part due to how technology is packaged. Its slim and sleek form factor hides its inner shell of what it truly is. If you take apart electronics many consumers will see what is called a circuit board, with tiny components that look like Lego pieces. An engineer sees a circuit board and sees a feat of engineering. They see various parts coming together to make a whole and complete device for the consumer to enjoy. To see the MCU working, you must look under the hood of the device it populates. This is the main reason why the MCU is highly overlooked. The gaming industry has exposed the average consumer to devices like Graphic Processing Units (GPUs) and companies like AMD and Intel release groundbreaking CPUs. The extent of the knowledge of consumers with MCUs, however, is virtually nonexistent. It seems, however, the MCU is evermore present in the consumers' lives.

Industry Impact

When discussing impact, it is important to shine a light on how something affects society as a whole. As mentioned before, the MCU has a large application for engineers. Its increase in application has caused a large effect on engineering. Computer Engineering is becoming more prevalent as digital systems require software to control hardware now. In the mid-20th century, analog hardware design was the norm and there was a huge influx of electrical engineers focusing on designing electronic devices. Since the inception of digital systems, the computer engineering major emerged to study those systems and use the software in place of designing hardware. The MCU's big-picture purpose is to leverage analog inputs, digitize them and induce an output response. The MCU is a prime example of using software to drive hardware. As such, the industry has flourished with new jobs involving embedded engineering and computer engineering. Companies now require engineers well-versed in the use of microcontrollers for their products. Essentially the birth of the MCU has garnered a new type of engineering and thus a large opening of professional work. This impact on the engineering world is quite substantial.

Social Impact

When we look at what kinds of devices require MCUs we can see that there is a large effect on society in general. Imagine a world where the ATM does not exist because the microcontroller was never invented. The idea of technological determinism supports the use of the MCU and how it embeds itself into varying technologies. The inception of the MCU was an effort to shift from analog to digital systems. Technological determinism shows how technology is the key mover in social change. The creation of the digital computer and MCU alike paved the way for a digital age where we began phasing out older analog and mechanical systems for more complex digital systems. An example of this is the refrigerator. Originally called the “ice box”, the refrigerator was simply a metal box with ice that could keep things cool. With the adoption of the MCU and other hardware, it builds upon the original design so that it can control its temperature using electricity (Dafoe, 2015).

We know from technological determinism that the progression of technology is also a result of human's internal logic of efficiency. The advancement of human efficiency created a necessity for things to become easier and to improve quality of life. Transitioning our technology to focus on digital systems directly relates our instinct to improve life. If you think about digital devices like light systems, refrigerators, cars, etc. they all have drastically been improved. As discussed earlier, the microcontroller is at the center of these devices. The digital age has skyrocketed our technology and we can see that the MCU, although overlooked and overshadowed, has played a pivotal role.

Higher Education

One thing that was touched upon earlier was how the MCU impacted higher education and the formation of Computer Engineering. One thing that is overlooked is how the MCU has created a large educational field for younger students that want to go into engineering. First Robotics Competition is a nationwide high school robotics competition where high schoolers design, build and deploy robots against other high school teams. These kinds of extracurricular activities including have played a pivotal role in exposing the younger generation to MCUs. Educational MCUs were created as a result of exposing younger students to computers. Companies like Arduino are creating educational easy-to-use MCUs that use an open-source language so that students all around the world can replicate similar designs. Raspberry Pi is a essentially a Linux-based computer with various built-in hardware interfaces to get students interested in learning about computers and computer science (Toombs, 2018). These devices are becoming prevalent in secondary education and as a result, is impacting the younger generation to do engineering. Students are using these educational MCUs to create robots and in turn, use the open-source library to gain new knowledge in engineering. Kits like the one shown below are just some examples of what younger students are building

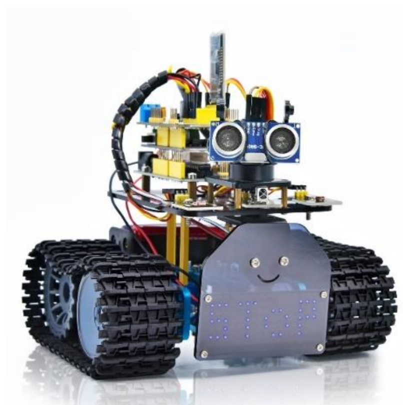

Figure 5. Robot Using Microcontroller

With a limitless ceiling, the MCU has indented itself into education and is positively impacting a generation to become engineers and to understand what consumers believe to be “magic”.

Conclusion

Overall, the timeline of the microcontroller can be described as linear. With its inception in the late 1970s, technology has skyrocketed and has played a substantial role in the industry. The continued increase in its hardware has allowed it to be extremely versatile and able to be put in a lot of situations. Its application stems from both industry-specific but also to everyday items for the daily consumer. The MCU's application and impact have created a positive effect on society. Creating a need for computer engineers, the MCU has single-handedly created new jobs and new fields. Its use is in part due to society’s desire to push the boundaries of technology and continually strive for a digital world. In education, it has piqued the interest of the younger generations and has exposed them to the unknown. As a result, its impact and effect on society can be seen all throughout. Although it is overlooked by many and not widely heard about, the microcontroller is certainly one of the greatest emerging technologies that man has created. It knows no bounds and has no limitations.

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