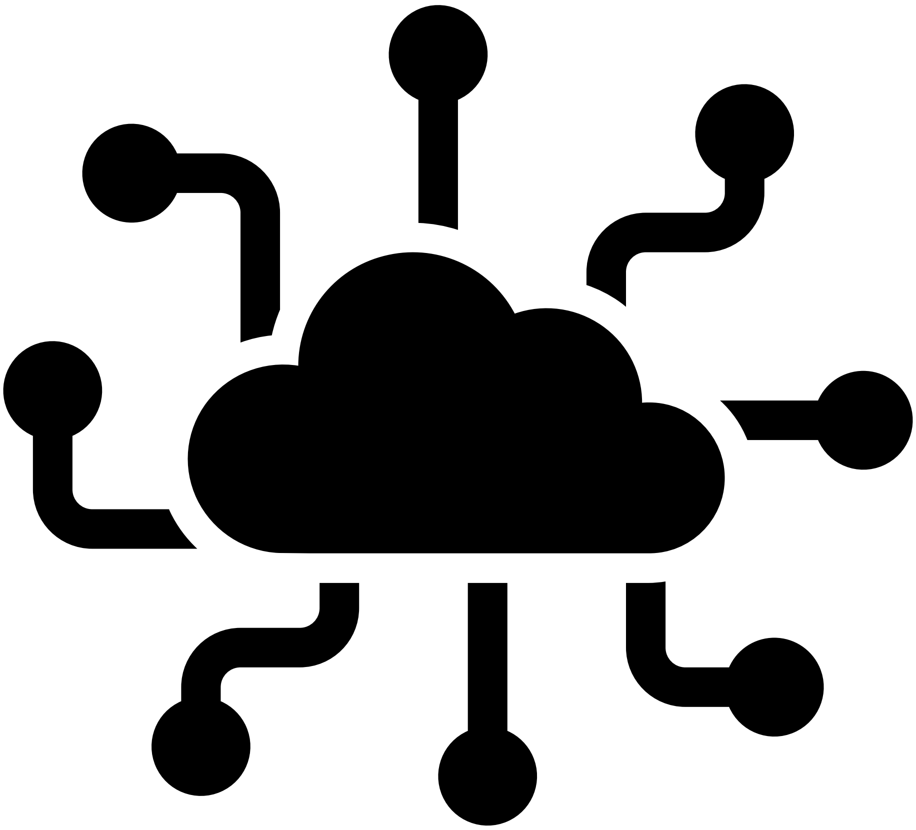
City of Things Prototyping Kit

ROTTERDAM UNIVERSITY OF APPLIED SCIENCES - PROJECT 7/8
LITERATURE RESEARCH – MICROCONTROLLERS & MICROCOMPUTERS



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Changelog

Version	Date	Change	Author
1.0	02-06-2022	Added the abstract, glossary and made minor changes to the research	Tom van Pelt
0.3	29-05-2022	Answered 2nd and 3rd sub-questions and wrote the conclusion	Tom van Pelt
0.2	28-05-2022	Answered first sub-question	Tom van Pelt
0.1	22-05-2022	First draft.	Tom van Pelt

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2. Abstract

In this research for project 78: City of Things Prototyping Kit, a study was carried out to find out which microcontroller or microcomputer would be best suited as an extra microcontroller or microcomputer on the waiter robot. For this project, a prototype of a waiter robot must be made, driven by a hacked hoverboard. An extra microcontroller or microcomputer is needed to control this hacked hoverboard.

This research was carried out by means of literature research. Sources were mainly found on the internet.

The research between three well-known and widely used microcontrollers and microcomputers showed that two were suitable, namely the Raspberry Pi 4 and NVIDIA Jetson Nano Developer Kit. These two microcomputers both have everything needed to control the hacked hoverboard, although the Jetson Nano came out of the comparison a tiny bit better.

Therefore, it can be concluded that the NVIDIA Jetson Nano Developer Kit is the most suitable microcomputer to control the hacked hoverboard. However, the Raspberry Pi 4 will be used, because the Jetson Nano is not in stock anywhere.

3. Introduction

This research is being conducted for the project 'City of Things Prototyping Kit'. The product owners of this project want to know what the impact of smart devices is on society. They want to do this through neighbourhood research. Because it is difficult for them to show residents of a neighbourhood what a smart city implies, they have set up this project where an example of a smart device must be created. The goal of the project is to create an autonomous waiter robot based on a hacked hoverboard. This waiter-robot must eventually be able to map a room, navigate in this room on its own and be sent to waypoints (tables) in the room via commands.

To enable the above capabilities of the waiter robot, an extra microcontroller or microcomputer is necessary. An extra micro-controller/computer is necessary because the controller that is already on the robot can only be directly controlled via custom software running on a separate microcontroller or microcomputer.

There are several micro-controllers/computers which can control the waiter robot. To find out which is the best for this project, research must be conducted.

3.1 Research Question

To make the purpose of this research clear and to make it easier to draw up the conclusion, a research question must be formulated.

Research Question: *'Which microcontroller is the best to control the waiter robot?'*

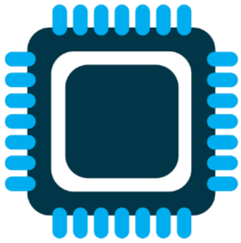
3.2 Sub-Questions

To make it easier to answer the research question, several relevant sub-questions must be formulated and answered.

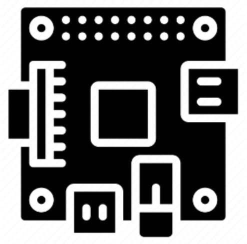
1. Which most frequently used microcontrollers are available?
    a. It is important to know which microcontrollers are available, because, as said, a microcontroller is necessary for this project. If it is not clear which microcontrollers are available, this research cannot be conducted, and the waiter-robot cannot be controlled.
2. What are the advantages and disadvantages of each available microcontroller?
    a. The advantages and disadvantages of the (available) microcontrollers need to be clear to see which microcontroller best fits the requirements of the waiter-robot. For-example, if a microcontroller is too slow in processing data, it is not suitable.
3. Which microcontroller best meets the requirements of the waiter robot?
    a. With the advantages and disadvantages from sub-question 2, it is very easy to see which microcontroller is the best for this project and formulate a good answer (conclusion) to the research question.

4. Theoretical Framework

To be able to carry out this research properly, it must first be clear what exactly microcontrollers and microcomputers are and what the difference is between them.



“A microcontroller is an integrated circuit that contains a microprocessor along with memory and associated circuits and that controls some or all of the functions of an electronic device (such as a home appliance) or system”[1], according to Merriam-Webster. An example of a microcontroller is an Arduino. This device can be used in an embedded system to, for example, turn a LED on and off or send commands via Serial communication.



“A microcomputer is a computer with a central processing unit (CPU) as a microprocessor. Designed for individual use, a microcomputer is smaller than a mainframe or a minicomputer.”[2] “A microcomputer's CPU includes random access memory (RAM), read-only memory (ROM) memory, input/output (I/O) ports, interconnecting wires and a motherboard.”[2] An example of a microcomputer is a Raspberry Pi, which can be used as a computer (albeit not that fast) and as a (micro)controller. It is also able to access the internet via a browser and control a LED.

The main difference between a microcontroller and a microcomputer lies in the fact that a microcomputer, as the name suggests, can be used as a computer with an operating system such as Linux. A microcontroller is not capable of this. Furthermore, a microcomputer is often essentially a small computer with microcontroller functionality built in.

4.1 Real-Life Examples

Figure 1 - Pololu 3pi Robot [4]

To find out which microcontroller or microcomputer is needed, it is useful to first find out which microcontrollers or computers other people or companies use in their waiter robots.

The company Pololu Robotics & Electronics [1] produced a robot called 3pi that is used by restaurants as a waiter-robot. The robot 3pi uses a ATmega328 AVR microcontroller chip. The microcontroller Arduino also uses this chip. Pololu only programmed the chip itself instead of using the standard platform Arduino. The 3pi is a small round (diameter ±10 cm) robot that is very good at line-following and maze-solving. It is not that large so as waiter-robot it would only be capable of moving drinks and small bowls with food.

Another example of a waiter robot is Beta-G [2]. Beta-G was developed by researchers at the universities Newcastle University International Singapore, Nanyang Polytechnic and Newcastle University UK. For their waiter-robot they used a mini-desktop computer, namely the Intel NUC. A NUC is a "Next Unit of Computing. A line of small-form-factor barebone computer kits designed by Intel."[3]

[1] https://www.merriam-webster.com/dictionary/microcontroller
[2] https://www.techopedia.com/definition/4614/microcomputer
[3] https://en.wikipedia.org/wiki/Next_Unit_of_Computing

Figure 2 - Beta-G Robot [2]

The Beta-G robot is a lot larger than the Pololu robot and is therefore suitable for transporting several plates with food at the same time.

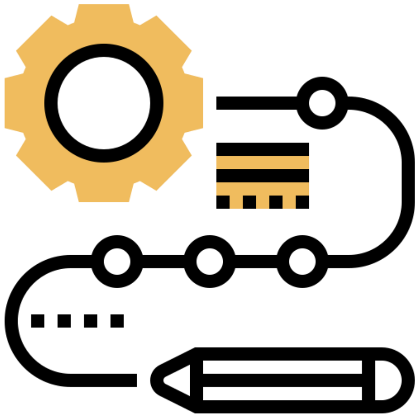
A third example of waiter-robot is Robowaiter III. This robot was made by Jamar Neal and is controlled by a Raspberry Pi 2. In the video [3] you can see that this robot drives by itself and avoids obstacles (children). Just like the Beta-G, this robot is large enough to carry a tray with drinks or food, as shown in the video.

Two of the three aforementioned microcontrollers and microcomputers will be further investigated in the continuation of the research as to whether they are also suitable for the waiter robot of this project. The Intel NUC won't be investigated further because it is not a microcomputer and it must be powered by a 230 Volt power supply, which is not available on the waiter-robot from this project.

5. Methodology

This study is literature research. This research was carried out by using sources from the Internet.

Some of these sources include websites of microcontroller and microcomputer manufacturers, videos of demonstrations of the controllers and reviews and tests of the examined microcontrollers and computers.



The manufacturers' websites were mainly used to look up specifications of the controllers. Videos were used to see how they work and whether they work well or poorly in practice. Reviews and tests of the controllers were used to see if they were reliable and, for example, how fast their processing power is.

The used sources can be found in the references and in the research itself.

Additionally, a comparison is made of how well each of the sensors studied meets certain criteria. Each sensor is given 0 to 5 points per criteria and these points are added up to a total. With this total, it can be quickly determined which microcontroller or microcomputer stands out.

6. Results

6.1 Which most frequently used microcontrollers are available?

According to the website Felgo [5], the 6 Best Microcontrollers for Embedded Computing are the Arduino, Beagleboard, Raspberry Pi, Toradex i.MX, Nvidia Jetson and Intel NUC. The microcontrollers / microcomputers that will not be investigated are the Beagleboard, Toradex i.MX and Intel NUC.

The Beagleboard will not be investigated because it is not used often, and it is comparable to the Raspberry Pi which already offers more connection possibilities out-of-the-box.

The Toradex will not be investigated as it is made for industrial use. It is therefore not really accessible to students and also quite expensive and difficult to use.

Finally, the Intel NUC is also not used because, as mentioned earlier in the theoretical framework, a NUC requires quite a heavy power supply and is therefore not suitable for this project since there is only a battery available and no fixed 230-volt connection.

6.1.1 Arduino

The first widely used microcontroller that will be investigated is the Arduino, specifically the Arduino Uno. The Arduino Uno is a microcontroller board based on the microchip ATmega328P [6]. The Uno has 14 digital input/output pins of which 6 can be used as PWM (Pulse Width Modulation) outputs, 6 analog pins, a 16 MHz ceramic resonator, USB-B connection, DC barrel power connection, an ICSP (In Circuit Serial Programming) connection and a reset button.

Figure 3 - Arduino Uno [12]

More detailed specifications are listed below in Table 1. The pinout of the Arduino can be found in Appendix 1.

Specifications

Specification	
Microcontroller Chip	ATmega328P 16 MHz 8-bit RISC
Digital I/O Pins	14
Operating Voltage	5 V
Input Voltage (Recommended)	7-12 V
Input Voltage (Limit)	6-20 V
Power Consumption	0.24 W
Flash memory	32 kB
SRAM	2 kB
EEPROM	1 kB
Price	Original: € 22, - Remake: € 10, -

Table 1 - Specifications Arduino Uno

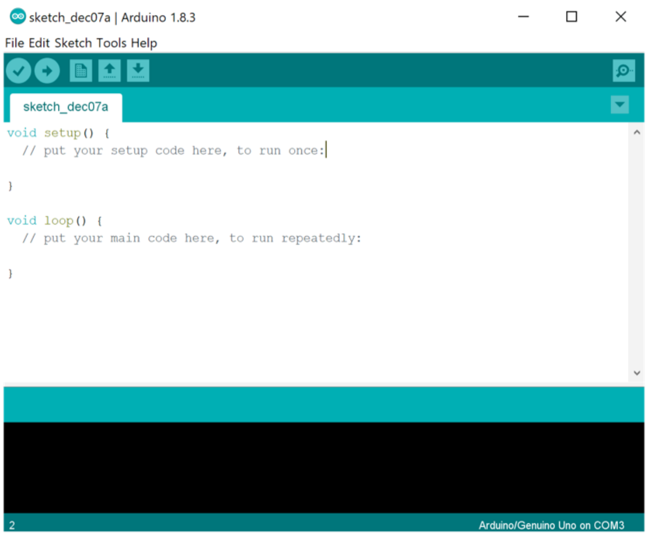


Figure 4 - Arduino IDE [13]

The way to use an Arduino is to use the program "Arduino IDE". With this program the microcontroller can be coded in the programming language C / C++. When a program has been coded without error, it can be uploaded to the flash memory of the Arduino and the Arduino runs this code when it is turned on.

Because the code is uploaded to the flash memory, it remains stored even when the power is not connected. When the power is plugged back in, the Arduino starts executing the code within a few seconds. For this reason, the user only needs to connect the power to run the code and does not need to start the program himself, so it is quite easy to use.

There are also limits to the ease of use. It is not possible to run an operating system such as Ubuntu (Linux) on the Arduino and multiple processes cannot run simultaneously (no multi-threading).

6.1.2 Raspberry Pi

The second device that will be investigated is the microcomputer Raspberry Pi, in particular the Raspberry Pi 4. The Raspberry Pi 4 [8] is a micro desktop computer on which two screens can be connected, an operating system like Ubuntu can be run and LEDs or buttons can be attached to the I/O pins. Due to the aforementioned features of the Pi 4, the Pi can be used as the brain of a robot, media centre, smart home hub and much more.

Detailed specifications of the Raspberry Pi 4 can be seen below in Table 2. The pinout of the Pi 4 can be found in Appendix 2.

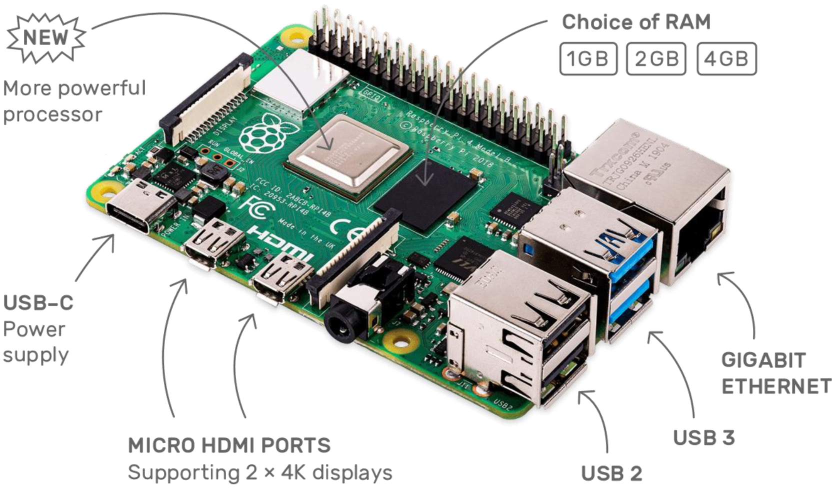


Figure 5 - Raspberry Pi 4 – Overview [8]

Specifications

Specification	
Microcontroller Chip (CPU)	Broadcom BCM2711 1.5Ghz 4-core Cortex A72 (ARM v8) 64-bit
GPU	Broadcom VideoCore VI 0.5 GHz 2GB (FP-16: 64 GPFLOPS)
GPIO Pins	26
(Wireless) Connections	2.4 & 5 GHz Wi-Fi, Bluetooth 5.0, Gigabit Ethernet, 2 USB 3.0 ports, 2 USB 2.0 ports, 2 4K micro-HDMI ports and a USB-C power input port.
Operating Voltage	5 V
Input Voltage (Recommended)	4.7-5.25 V
Input Voltage (Limit)	4.0-6.0 V
Power Supply Current (Recommended)	3.0 A
Power Supply Current (Minimum)	2.5 A (if USB-connected peripherals consume < 500 mA)
Power Consumption	15 W
Storage	Dependent on microSD-card size
SDRAM	1, 2, 4 or 8 GB LPDDR4-3200
Price	From € 40, - until around € 90, - depending on SDRAM size

Table 2 - Specifications Raspberry Pi 4

As shown in Table 2, the Raspberry Pi 4 can do a lot more than the Arduino Uno. It has much more RAM, much more storage capabilities, much more connectivity, much more everything. However, because it can do more, the Pi is also used in a different way, namely more like a computer, instead of a (simple) microcontroller.

To use a Pi, an operating system must first be installed on a microSD card using the Raspberry Pi Imager software on another computer. The recommended operating system to install is Raspberry Pi OS, but a Linux distribution such as the well-known Ubuntu can also be installed. After the chosen operating system is installed, the microSD card must be inserted into the Pi and the Pi can be booted. The Pi, unlike the Arduino, is almost always used as a desktop computer.

Figure 6 - Raspberry Pi Imager (Software)

Although it has so many possibilities, it is not as easy and safe to use as an Arduino. For example, if the power supply is removed from the Pi while it is on, the microSD card in the Pi can become corrupted and no longer be used. This cannot happen with the Arduino. Also, more steps must be taken before the Pi can be used. With the Arduino, it's just writing, uploading, and running the code.
Still, compared to the Arduino, the Pi is the better choice when it comes to connection options and speed of data processing.

However, there is still another good candidate as an additional microcontroller / microcomputer that has not yet been investigated.

6.1.3 Nvidia Jetson

The final device that will be investigated is another microcomputer called the NVIDIA Jetson, in particular the NVIDIA Jetson Nano Developer Kit. According to NVIDIA's website [9] the "NVIDIA Jetson Nano Developer Kit is a small, powerful computer that lets you run multiple neural networks in parallel for applications like image classification, object detection, segmentation, and speech processing. All in an easy-to-use platform that runs in as little as 5 watts." Just like the Raspberry Pi 4, this computer has USB-connections, Ethernet connection, HDMI display output, and more.

Figure 7 - NVIDIA Jetson Nano Developer Kit [14]

Again, the full spec sheet can be found below in Table 3. The pinout of the Jetson Nano is not in the Appendix, because it has already been printed on the board.

Specifications

Specification	
Microcontroller Chip (CPU)	Quad-core ARM A57 1.43 GHz 64-Bit
GPU	128-core Maxwell (FP-16: 472 GFLOPS)
GPIO Pins	22
(Wireless) Connections	(Wi-Fi & Bluetooth via M.2 chip) Gigabit Ethernet, 4 USB 3.0 ports, 1 USB 2.0 Micro-B, 1 4K HDMI port, 1 4k DisplayPort and a USB-C power input port.
Operating Voltage	5 V
Input Voltage (Recommended)	4.7-5.25 V
Power Supply Current (Recommended)	2.5 A
Power Supply Current (Minimum)	2.0 A
Power consumption	10 W
Storage	Dependent on microSD-card size
SDRAM	2 or 4 GB LPDDR4 25.6 GB/s
Price	From around € 60, - until around € 160, - depending on SDRAM size

Table 3 - NVIDIA Jetson Nano Developer Kit Specifications

Looking at the specifications of the Raspberry Pi 4 and the Jetson Nano Developer Kit, the two are very similar. They are both used as a 'normal' desktop computer that can also control LEDs and motors via their GPIO pins. Furthermore, they use a microSD card for storage, they can run on the same power supply, and they have the possibility to connect to the internet.

However, there are some major differences that should not be overlooked. For example, the Jetson does not have Wi-Fi and Bluetooth built in while the Pi does. That said, the Jetson does have a much more powerful GPU (Graphical Processing Unit) than the Pi and is therefore more suitable for processing video image data.

Since the waiter robot will be using an Intel Realsense Stereo Depth camera as an obstacle detection sensor (see other research), the microcontroller / microcomputer must be able to quickly process video images with depth data in them. Given that the Jetson has a graphics processor almost 8 times faster than the Pi, the NVIDIA microcomputer appears to be the better candidate. To be sure of this, it is helpful to summarise all the properties of the three examined microcontrollers / microcomputers in advantages and disadvantages in three tables.

6.2 What are the advantages and disadvantages of each available microcontroller?

6.2.1 Arduino Uno

Advantages	**Disadvantages**
Cheap compared to Pi and Jetson	No multi-threading (multiple processes at the same time)
Very easy to use	Way slower than Pi or Jetson
Very low power consumption [10]	Only two programming languages
In stock in a lot of stores	No USB 2.0 or 3.0 ports
	No internet connection possible
	No Operating System possible

Table 4 - Advantages and Disadvantages Arduino Uno

6.2.2 Raspberry Pi 4

Advantages	**Disadvantages**
Can be used as a desktop computer	More expensive than Arduino
Internet with Wi-Fi and Bluetooth built-in	Very hard to find anywhere in stock
Fastest processor of the three	Harder to use than Arduino
Very all-round, used as a microcontroller or small desktop computer	Consumes a lot more power than Arduino

Table 5 - Advantages and Disadvantages Raspberry Pi 4

6.2.3 NVIDIA Jetson Nano Developer Kit

Advantages	**Disadvantages**
An almost 8 times faster GPU than Pi 4	More expensive than Arduino and Raspberry Pi
More USB 3.0 ports	No Wi-Fi and Bluetooth built-in
Heatsink built-in	Almost impossible to buy somewhere (out of stock)
All-round but more tailored to Artificial Intelligence applications	Harder to use than Arduino
Can also be used as a Desktop computer	Consumes a lot more power than Arduino, but less than Raspberry Pi
Fastest GPU of the three	

Table 6 - Advantages and Disadvantages NVIDIA Jetson Nano Developer Kit

6.3 Which microcontroller best meets the requirements of the waiter robot?

To determine which microcontroller best meets the requirements of the waiter-robot, the most important requirements of the additional microcontroller / microcomputer for the waiter-robot must first be identified.

The most important requirements are:
1. Being able to communicate via UART (Serial Communication).
2. Be able to run several processes simultaneously.
3. Not drawing too much power.
4. Being able to quickly process video image data from the Intel Realsense Stereo Depth camera.
5. Being able to communicate wirelessly.

To make it easier to draw a conclusion from this research later, the five requirements listed above have been listed in Table 7 and a rating system has been used to indicate how well or poorly each microcontroller satisfies each requirement.

	Microcontroller / Microcomputer		
Requirement	Arduino Uno	Raspberry Pi 4	NVIDIA Jetson Nano D.K.
1	5	5	5
2	1	5	4
3	5	2	3
4	0	3	5
5	0	5	4
Total:	12	20	21

Table 7 - Microcontrollers / Microcomputers & Requirements

0 to 5 -> 0 = not applicable / not able to, 1 = very bad, 2 = bad, 3 = neutral, 4 = good, 5 = very good

As can be seen in Table 7, the Jetson Nano has the most points and thus would be the best fit. It received the most points because it is best at processing video data, does not consume too much power and has a fast processor, albeit not as fast as that of the Pi.

The Pi would also be a good candidate. After all, it has almost as many points as the Jetson. However, the Jetson is the better choice because it simply has a much better graphics processor compared to the Pi.

The Arduino Uno is not a good candidate because it cannot communicate wirelessly, it cannot process video data because the Intel Realsense must be connected via USB and the Uno does not have suitable USB connections and it is very bad at running multiple processes at the same time. If the waiter-robot would have used more simple sensors like an ultrasonic sensor and did not need wireless communication, the Arduino would have been the perfect candidate. After all, it consumes almost no power compared to the other two and is very easy to use.

In conclusion, the microcontroller / microcomputer that best meets the requirements of the additional microcontroller for the waiter-robot is the NVIDIA Jetson Nano Developer Kit.

7. Conclusion

To summarize, the NVIDIA Jetson Nano Development Kit is the best choice as an extra microcontroller for the waiter-robot. It is the best choice because it meets almost all the requirements of the extra microcontroller / microcomputer very well. First, it is the best at processing the video data coming from the Realsense camera. After all, it has an almost 8 times more powerful graphics processor than the Raspberry Pi 4 and the Arduino is not even capable of handling the Intel Realsense camera. Secondly, it is good at running multiple processes simultaneously. This is necessary because ROS (Robot Operating System) (see other research) must run, video data processing must take place, commands must be sent via UART to control the hacked hoverboard and network communication must take place to receive input to which table the waiter-robot must drive. Finally, the Jetson is also more energy efficient than the Pi, allowing it to last longer on battery.

However, there's a big drawback the Jetson Nano itself cannot do anything about; it's not in stock anywhere. And if it is in stock somewhere, it's usually in very small numbers and sells out quickly. The Raspberry Pi 4 is also almost unavailable but is more often in stock than the Jetson and therefore one of the project members was able to order one.

So even though the Jetson comes out best in the test, the Raspberry Pi 4 will still be used as a microcontroller despite the much slower GPU.

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8.4 Figures / Appendices

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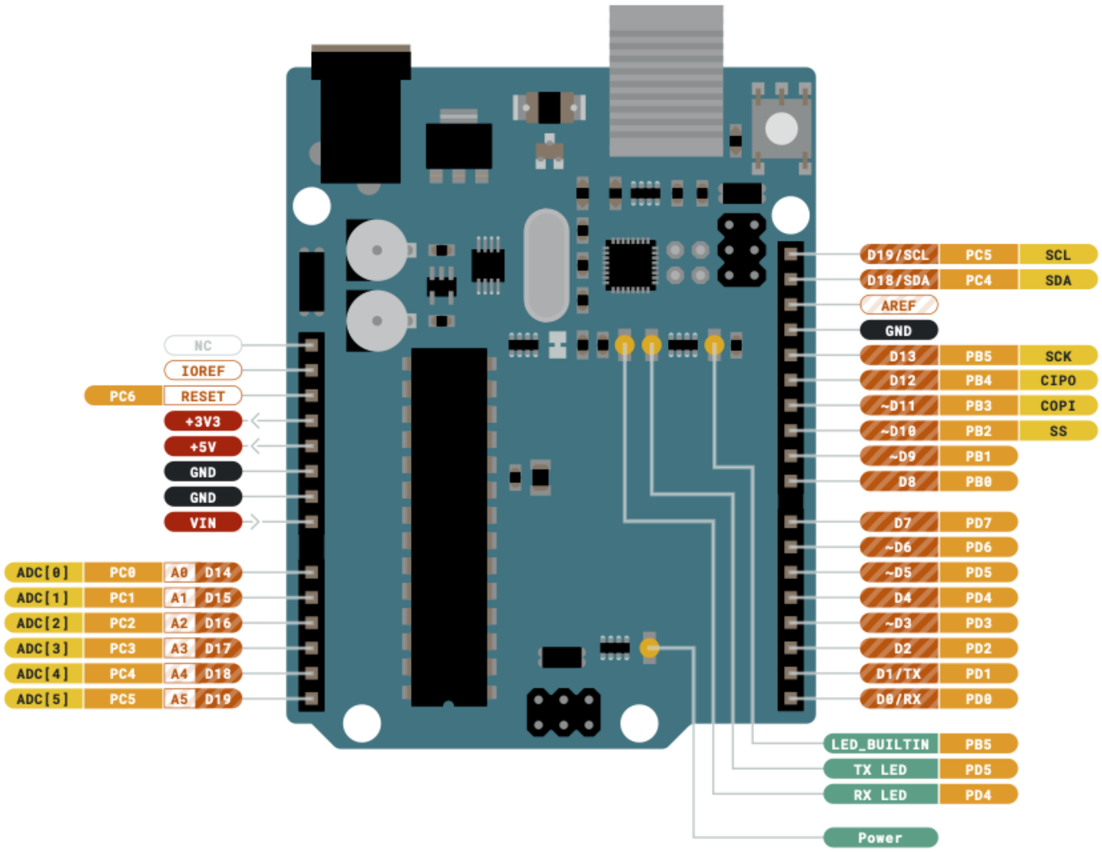
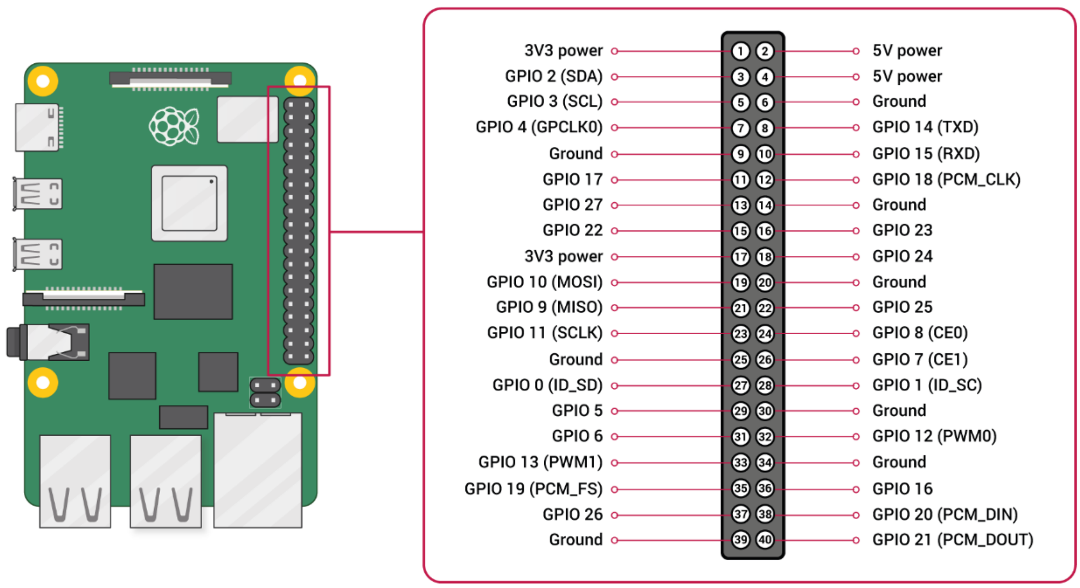
9. Appendix



Appendix 1 - Pinout Arduino Uno [6]



Appendix 2 - Raspberry Pi 4 – Pinout [11]

10. Glossary

Term	Meaning
Artificial Intelligence	AI. “Systems or machines that mimic the problem-solving and decision-making capabilities of the human mind.”[4]
Autonomous	In context of this research: a robot that can move on its own (without direct outside control).
Barebone computer	A computer that consists of a case, motherboard, power supply and ventilation. The rest of the components such as the processor, storage drive, GPU, etc are for the buyer to choose.
Ceramic resonator	Small electronic component used to generate a clock signal to control timing of operations.
Embedded Computing System	Systems made up of hardware and software and designed to perform one specific task such as controlling a LED array or controlling motors by converting input signals to ‘motor control signals’.
Flash memory	Non-volatile memory. A storage medium that can store and erase data. The data stays stored even when it is not powered.
GPIO pins	General Purpose Input/Output pins.
GPU / Graphics Processor	Graphical Processing Unit. A chip that is specifically designed to perform graphical calculations, such as image rendering.
I/O pins	Input / Output pins. Pins that allow you to receive and send on/off signals to LEDs, buttons, etc.
ICSP	In Circuit Serial Programming. Method of programming Arduino boards.
Linux (distribution)	A Unix-like open-source operating system based on the Linux kernel developed by Linus Torvalds.
Multi-Threading	Ability of a CPU (processor) to execute multiple processes at the same time.
NUC	Next Unit of Computing. A line of small-form-factor barebone computer kits designed by Intel.
PWM	[7] Pulse Width Modulation. Technique to control the speed of motors, heat output of heaters and more. It works by pulsating DC current and varying the time each pulse stays ‘on’.
Serial communication	Form of data transmission where data is sent over a data line one bit at a time.
Smart City	A city that wants to provide answers to the challenges of our time, such as the sustainable use of raw materials and energy.
Smart Device	A device that is connected (wirelessly) to a network and can operate autonomously (to a certain extent).
Stereo-Depth camera	A camera that can determine the distance between itself and an object it is 'looking at' by means of two cameras and stereoscopy.
UART	Form of Serial communication.
Ubuntu	Most well-known Linux distribution.
Ultrasonic Sensor	A sensor that calculates the distance from itself to an object in front if the sensor by emission of ultrasonic sound waves and calculating the difference between sending and receiving the soundwave.

[4] https://www.ibm.com/cloud/learn/what-is-artificial-intelligence