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Proficient ambient intelligence based on the wisely selection of data sources in heterogeneous environments

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Abstract

Nowadays society tends to be more and more technologically evolved, with that a lot of personal information is shared with computational systems through online records; microphones that perform voice recognition in which it is processed remotely; application of filters on person portraits or recognition of the age at which the image is saved on a server to improve the standard of an Artificial Intelligence (AI).

The devices we currently interact with end up compiling information about our consumption habits, routines, collected photographs, videos or personal content. Sometimes exposing our privacy to third parties, it is not noticeable where that data is been saved, or that is being stored. And if we could have a simpler device to perform some tasks, in which there was no camera, microphone or storage. No personal data will be processed locally or remotely, so the regulation European Union (EU) law on data protection and privacy, General Data Protection Regulation (GDPR), will not affect this kind of device. Furthermore, if a device of this nature was located in a public place, there would be no need for any requirement, consent or authorization to the intervening users or only those who approach the device, because would not differentiate the user or even recognize him, since the collection of gesture commands is performed through non-evasive sensors.

Recently the world was surprised by the cases of a new coronavirus which caused a pandemic on a planetary scale. New rules had to be applied, to the way we interact with objects in order not to spread the disease.

It was created a prototype discriminated in this study, using a grid of ultrasonic sensors, capable of recognize trained gestures. This interaction can be made from a distance of the prototype, and do not require contact, in which it solves a human interaction with the computer avoiding that the user has to use the touch on a component, thus avoiding the contagion of Corona virus disease of 2019 (COVID-19).

The early stage results evidence that the proposed system is suitable to create a new input type of Human Interface Device (HID), and may replace devices as a remote control of television, to a new way to interact with information panels in public places, like a shopping mall, airports, train and bus stations.

Keywords

3D printing, Arduino, ATtiny, gesture recognition, HCI, HID, multimedia keys, non-evasive sensors, gesture recognition, ultrasound sensors

Resumo alargado

Hoje em dia a sociedade tende a estar cada vez mais evoluída tecnologicamente, consequentemente muitas informações pessoais são compartilhadas com sistemas computacionais através de registros online; microfones que realizam reconhecimento de voz, em que é processado remotamente; aplicação de filtros em retratos de pessoas ou reconhecimento da idade, em que a foto é guardada em um servidor para melhorar o padrão de uma Inteligência Artificial (AI).

Atualmente os dispositivos com os quais interagimos acabam compilando informações sobre os nossos hábitos de consumo, rotinas, fotos e vídeos armazenados ou conteúdos pessoais. Por vezes, expondo nossa privacidade a terceiros, não é perceptível onde os dados foram guardados ou onde estão a ser armazenados. E se pudéssemos ter um dispositivo mais simples para realizar algumas tarefas, em que não possuísse câmera, microfone ou armazenamento. Nenhum dado pessoal será processado local ou remotamente, portanto, a legislação da União Europeia (EU) sobre proteção e privacidade de dados, Regulamento Geral de Proteção de Dados (GDPR), não afetará este tipo de dispositivo. Além disso, se um dispositivo desta natureza estivesse localizado em local público, não haveria necessidade de qualquer exigência, consentimento ou autorização aos utilizadores intervenientes ou até mesmo aos que apenas se aproximam do dispositivo, pois não distinguiria o utilizador e também não o reconheceria, já que a recolha de comandos por gestos é realizada por via de sensores não evasivos.

Recentemente, o mundo foi surpreendido por vários casos de um novo coronavírus que causou uma pandemia em escala mundial. Novas regras tiveram que ser aplicadas, à forma como interagimos com os objetos para não espalhar a doença.

Foi criado um protótipo discriminado neste estudo, utilizando uma grelha de sensores ultrassônicos, capaz de reconhecer gestos treinados. Esta interação pode ser feita à distância do protótipo, e não requer contato, no qual se resolve uma interação humana com o computador evitando que o utilizador use o tato no dispositivo, evitando assim o contágio de (COVID-19).

Os resultados da fase inicial evidenciam que o sistema proposto é adequado para criar um novo tipo de Dispositivo de Interface Humana (HID), podendo substituir dispositivos como um controle remoto de televisão, ou uma nova forma de interagir com painéis de informação em locais públicos, como um shopping center, aeroportos, estações de comboios e de autocarros.

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Acronyms

AI Artificial Intelligence

ASL American Sign Language

CAD Computer-aided design

COVID-19 Corona virus disease of 2019

CPU Central Processing Unit

DC Direct Current

DHT Digital Humidity and Temperature

DTW Dynamic Time Warping

EU European Union

FDM Fused Deposition Modeling

FoV Field of View

FPS Frames per second

GDPR General Data Protection Regulation

GPU Graphics processing unit

HCI Human-computer interaction

HID Human Interface Device

IDE Integrated Development Environment

I2C Inter-Integrated Circuit

IR Infrared light

LCD Liquid-crystal Display

LED Light-emitting diode

LMC Leap Motion Controller

OS Operating System

OTG On-The-Go

PLA Polylactic Acid

RAM Random-access memory

RGB Red Green Blue

ROM Read-only memory

RX Receive

SDA Serial Data

SDK Software development kit

SCL Serial Clock

STL Standard Triangle Language

THT Through-hole

ToF Time-of-flight

TX Transmit

UART Universal Asynchronous Receiver/Transmitter

UBI Universidade da Beira Interior

UML Unified Modeling Language

USB Universal Serial Bus

VR Virtual Reality

1. Introduction

1.1 Focus

Technology tends to evolve so that the interaction between the human and the machine is less complex and intuitive. The majority and also the most used of these interactions are carried out in the sense of touch: through physical buttons, touch screen buttons, hand-held pointing devices (e.g: touchpad, trackpoint), motion sensors (e.g: joystick) and others. Current year 2020 the World Heath Organization declared world pandemic state due to the spread of COVID-19, one of the spread methods it is through touch [4]. Interact with objects has changed, now other procedures were adopted to avoid contagion in routines that are performed every day to avoid exposure. Identify that unexplored ways a user can interact with a computer without use the touch, creating market opportunities and open a new and potential areas of research, such as new HID using gesture recognition.

Gesture recognition can be a interface to provide data to a host computer, interpreting movements as a source of input. Usually this input it's acquired by a camera, and the images collected to be post processed calculating the depth of objects, and compared with a predetermined gesture library until get a match. A gesture can be defined with a physical movement or a static variation, it will focus on interpreting static gestures.

1.2 Objectives

The first objective of this dissertation is develop and construct electronic hardware and algorithm software, and performance a proof of concept that would be possible interact with static gestures created by the human upper limbs, without movement, and these actions are interpreted as commands. In order to not collect image or save user data, improve privacy, and restrict the use of touch, only sensors were used.

Once that goal was achieved, the research work and engineering is expected to produce a prototype, and will be used as research methodology. The second objective of this dissertation is design a plastic structure, to assemble the electronic components, and improve the accuracy detection of the gestures.

As a last objective this commands should be executed on a host computer. And the recognition of gestures, and the prototype itself will be evaluated, demonstrated and validated.

1.3 Main Contributions

This section is dedicated to the scientific contributions of this dissertation to the state-of-the-art in gestural recognition via sensors connected to microcontrollers developed on Arduino boards.

The main contribution is a functional prototype capable to recognize a series of limited gestures, the study of necessary hardware, to create a completely new system. Molds to reproduce the plastic structure where the method dovetail joint used in woodworking, was redesigned and adapted for 3D printed models, and this method could be suitable for future projects, where the size of the model is larger than the 3D printer bed.

The survey results obtained to evaluate the design, performance and usability. Also the feedback from test users, which allowed to know better the obstacles of the technology, and where it can be improved.

1.4 Dissertation Structure

This dissertation is organized in six chapters. This chapter, the first, presents the context of the dissertation, focusing on the topic under study, the objectives, the main contributions and the dissertation structure and its main contribution.

Chapter second presents the literature review in the existing commercial model devices, and what are capable to do. And some other academic research related to gestural recognition.

Chapter third is divided in 3 main sections: present the necessary hardware requirements for create a proof of concept, among other optional material for the future construction of a prototype; the study of how the sensors and integrated circuits will be placed, the design and the 3D printing of the plastic structures; and the last it is focused on the algorithm operation, on the communication between boards and execution diagrams in the host system.

In the chapter four will be presented the possible gestures recognized by the prototype, and the visual feedback given to the user when the command is recognized.

Chapter five will explain how the prototype should be used, possible problems/solutions with a troubleshooting, a user experience survey and discussion between the existing commercial devices.

Conclusion and future work are available in the Chapter six.

2. State of the Art

In this chapter, will be identify the products already commercialized that involve gestural recognition will be identified, and a summary of the studies already carried out in this area that may be related.

2.1 Products on the market

After due research, the device most similar to intended to recreate with this study, would be *Microsoft Kinect* introduced in 2010 and was discontinued in 2017, but it used two cameras (one Red Green Blue (RGB) color model and the other Infrared light (IR)) and microphones. [5] The intention as mentioned in the section 1.2, would be not to use any of these inputs. This device should be mounted above or ideally on top of the monitor, the prototype developed in this study must be mounted always on the top.

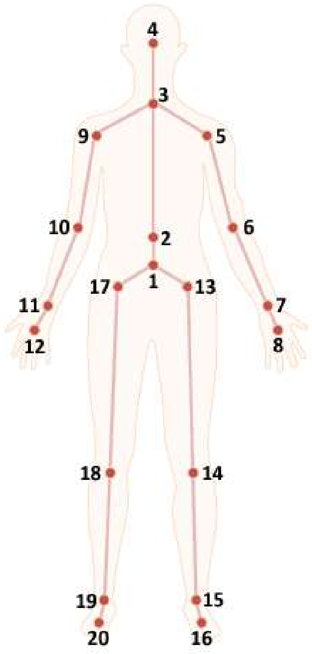

Figure 2.1: Skeleton joints points tracked by Kinect v1

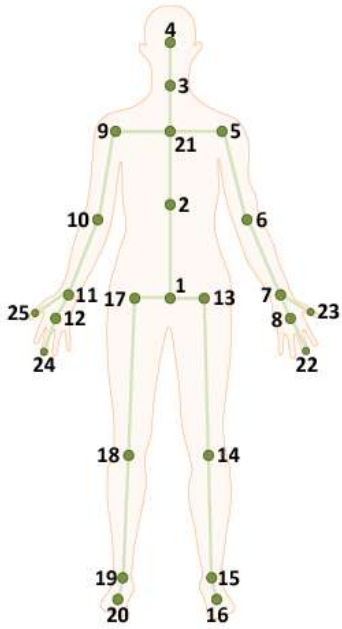

Figure 2.2: Skeleton joints points tracked by Kinect v2

The Kinect v1 launched in 2010, it is based on a three-dimensional grid that was projected on the objects nearby and on the user, capturing a full body image, through the IR camera and a IR Light-emitting diode (LED) is projecting light to obtain the field distance deep, that later a 3D model was reconstructed using the collected images, using computational power of the host computer.

In this 3D model the inanimate objects were differentiated from humans, and were converted into a digital anatomy frame human skeleton, as is represented in the figure 2.1, and provides 20 joint points from the head to toe [6].

Table 2.1: Skeleton joints subtitles of figures 2.1 and 2.2

	Kinect v1	Kinect v2
1	Hip center	Spine base
2	Spine	Spine middle
3	Shoulder center	Neck
4	Head	
5	Left shoulder	
6	Left elbow	
7	Left wrist	
8	Left hand	
9	Right shoulder	
10	Right elbow	
11	Right wrist	
12	Right hand	
13	Left hip	
14	Left knee	
15	Left ankle	
16	Left foot	
17	Right hip	
18	Right knee	
19	Right ankle	
20	Right foot	
21		Spine shoulder
22		Left hand tip
23		Left thumb
24		Right hand tip
25		Right thumb

In this study it is intended for user performs the gestures to be recognized using only with forearm and the hand, that would correspond to join points 10 to 12 (forearm, wrist and right hand) and 6 to 8 (forearm, wrist and left hand) in the Kinect tracker classification, as it show in table 2.1. It will use a similar principle of creating a grid to identify the location of the upper members, however it will be physical instead of be created virtually via software, and composed by a grid of sensors, with two axes X and Y, so with be a 2D instead of 3D grid. Is important for the user in this Human-computer interaction (HCI) get some feedback during the usage of this hardware peripheral, which it's provided through hearing and seeing senses.

Kinect v2 was a new version, launched in 2013, and instead of a IR to calculate distance like the precious model, uses a Time-of-flight (ToF) measurement method using the speed of light to to calculate the distance [5]. And improves the Skeleton in number of joints points 25, instead of 20, like it show the figure 2.2, some joints have been renamed [7], presented in the table 2.1.

Another device it's the *Ultraleap Leap Motion Controller (LMC)* launched in 2013, this not so invasive because it is positioned to only track and capture the user's hands images. Use also 2 cameras as the kinect, but both are IR and also 3 IR LED to illuminate the area,

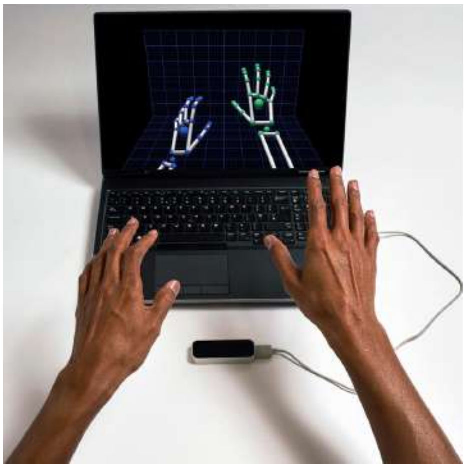

Figure 2.3: Leap Motion installed on a desk

Figure 2.4: Leap Motion installed in a VR helmet

and make possible the cameras track with high precision the movements of the fingers [8]. This device can be installed on the desk near to the monitor, as show the figure 2.3, or in a Virtual Reality (VR) helmet, as show the figure 2.4. Will be the detached device that will have a faster update rate in this study, translating to a high Frames per second (FPS). Both devices (*Leap Motion* and *Kinect*) have Software development kit (SDK) libraries, supported by the vendors company.

2.2 Related Work

In order to be able to compare the capabilities of the hardware, the table 2.2 was compiled with the best known devices on the market, and also an integrated circuit on which was also based this study. Each of the devices presented has one or more associated scientific articles, which demonstrate some of the hardware's capabilities. Some cells are blank because the authors did not present this information in the article.

Focusing only on studies applied to gesture recognition, using the *Kinect v1*, having as data entry a frame skeleton, it would be easier to recognize gestures using all of the upper limbs, with the advantage of SDK allows to extract direct information from the joint points, and after compare vectors with a data base. However, the research [9] used *Kinect v1* cameras to segment a human hand, capturing just the joins 7 and 8 containing cropping the image to 120x120 px, converting and producing a 2D grid projection of the hand in a grey scale image, and obtaining the outline of the hand, without delving into the subject, would be compared with the 5 trained shapes that the study intended to approach.

It is possible to identify some facts from this article, to use in this study, the authors tried in the first place isolate only the body part that they intended to use as input of data. Avoiding collecting information that is not necessary, creating the device in shape and size in which it is only possible to intervene what it intend to get, in this case the forearms.

Regarding simpler technologies and low consumption, in [11] the authors used a single piezoelectric transducer emitting pulses and 8 microphones in the periphery forming a grid, with the purpose of receiving the echo, creating a ultrasonic receiver. With this

Table 2.2: Comparison between hardware and respective algorithms in scientific articles

	Article [9]	Article [10]	Article [11]	Article [12]	Article [13]
Hardware	Kinect v1	Kinect v2	Integrated Circuit	Leap Motion	
Size	27.94 x 6.35 x 3.81 cm	24.9 x 6.6 x 6.7 cm		7.87 x 3.05 x 1.27 cm	
Type of Source	RGB Camera 1280x720 px at 12 fps	RGB Camera 1920x1080 px at 30 fps	Piezoelectric Transducer 40 Hz	2x IR Cameras 640x240 px at 60 fps	
	IR Camera 640x480 px at 30 fps	IR Camera 512x424 px at 30 fps	8 microphones 192 kHz		
	4 microphones 16 kHz	4 microphones 48 kHz			
Depth Resolution	320x240 px at 30 fps	512x424 px at 30 fps	17x17 px at 50 fps	640x240 px at 60 fps	
Field of view	57° horizontal	70° Horizontal	40° Horizontal	150° Horizontal	
	43° vertical	60° Vertical	40° Verifical	120° Vertical	
Mapping	IR	ToF	ToF	Mathematical methods	
Tracking capacity	All body	All body	Fingers	Hands, Wrist and forearm	
Tracking in focus	Hand	Hands and Fingers	Fingers	Hands, Fingers and Wrist	
Recommended Distance	0.85 - 4 m	0.5 - 4.5 m	30 - 100 cm	2.5 - 60 cm	
Range of gestures in Study	5 - Static	5 - Movement	4 - Static	15 - Static 27 - Movement	32 - Static
Acuracy	30 - 40 %		64.5 - 96.9 %	53.33 - 86.67 %	90 - 92.66 %
Data Provided to the Host	Refined depth map Color image 20 joints Skeleton user	Refined depth map Color image 25 joints Skeleton user	RAW audio data	RAW data	
Consuption	12 w	15 w	2.5 w	2.5 w	
Mininum latency	102 ms	20 ms	1.7 ms	8 ms	

signals construct images with depth and intensity pixels, and also capturing the hand gestures, and comparing with 4 trained shapes.

Highlighted in this article the idea of using distances to create a map, using the grid structure, can be useful using more accurate sensors.

As for more complex models, in [12], the LMC was used to convert finger gestures to identify 44 Thai alphabet sign language, this signs have a combination of 3 steps, to form this non-verbal communication. Just the first step of the set of gestures to form the letter is static, and second and third have movement in the wrist or fingers. In the LMC all the raw data are processed in the host computer, so the latency depends in the most from specs of this machine. RAW type data is collected directly from the source, without filtering or lossy compression, in this article scenario, only relevant data to the algorithm was extracted.

In [13] although the authors developed their work with 3 different sign languages, it will focus only on American Sign Language (ASL), due to the alphabet familiarization. Using also the LMC and excluding the alphabet letters with movements (”J” and ”Z”), and similar postures (”2” and ”V”, ”6” and ”W”), the accuracy rate has increased considerably compared to the article [12], because all the signs are static.

Taking advantage of the new skeleton joints points of the *Kinect v2*, particularly from ”thumb” and ”tip” connected to the ”hand” joint, the authors of [10] developed an algorithm of Dynamic Time Warping (DTW) to recognize gestures by fingers, due the absence of finger tracking support in the *Kinect* SDK. The purpose of this gesture is to recognize the hand position and the direction that is taking from a 3D environment, based on the guidance of the fingers, to a 2D grid. At the same time that the direction is calculated, it is able to recognize the number of fingers being displayed.

Concluding this chapter, the points highlighted in this last section will serve as the basis to create the prototype: gestures will be much accurate if will be static; isolate the necessary body parts for the input source; and create a grid map using the data collected.

3. Methods

3.1 Hardware

A HID is a type of computer device is mainly used to allow human control over the computer host, also a method by which a human control an electronic information system either by inputting data or providing output. Examples of an input HID would be a keyboard, a mouse, or a gamepad. This devices works by reports: A Input that send data from the device to the Operating System (OS); A Output that receive data from the OS or show information to the user; And feature reports related with the device configuration [14]. In this section will be presented the hardware requirements to build a device with these characteristics, as well as the technical specifications in focus, for each of the selected components, the led reasons to the component choice, and the design or general scheme.

In order to interconnect the components of this hardware, the type welding Through-hole (THT) was used, due to the ease of connecting different perfboards and fast prototyping in prefabricated boards. This technology involves the insertion of the metal components terminals into drilled holes at the printed circuit boards, and solder on the opposite side.

3.1.1 Microcontrollers

A microcontroller is a small and low-cost microcomputer, which is designed to perform the specific tasks of embedded systems, are used to execute a single task within an application. Are easy to replace and the design and hardware cost is low. Has integrated Central Processing Unit (CPU), Random-access memory (RAM), Read-only memory (ROM) and input/output (I/O) ports. This project will use only 8-bit microcontrollers to execute arithmetic and logical operations, and will be programmed in C/C++ language.

In order to receive the information from the sensors, I chose to use Arduino boards, due to its modular and easy expansion capabilities. This will give total control over the platform unlike a proprietary hardware. In the following table 3.1 a brief description and comparation between the most well-known board: Arduino UNO, and the 2 boards that will be used in the prototype: Mega2560 and ATtiny85. [15] All the boards are the revision 3.

The code for these microcontrollers will be compiled and sent via the Arduino Integrated Development Environment (IDE), is a cross-platform software provided by *Arduino Software* company, and include a debugger, libraries, documentation sample code with links

Table 3.1: Basic comparison of microcontrollers

	Arduino UNO	Arduino Mega 2560	Digispark ATtiny85
Processor	ATmega328P	ATmega2560	ATtiny85
CPU Speed	16 MHz	16 MHz	16.5 MHz
Output Voltage	3.3V / 5V	3.3V / 5V	5V
Input Voltage	6-20V	6-20V	6-16V
Power consumption	47 mA	70 mA	36 mA
Digital/Analog/PWM I/O	20/6/6	70/16/15	6/4/2
Flash (Kb)	32	256	8
USB 2.0 Type	Standard B	Standard B	Standard A

for electronic schemes. Is compatible not just with original Arduino boards, but also with compatible with other vendors development boards. The sketch code starts with two main functions: *setup()* that will be executed just one time, normally used for initialize Serial ports and sensors, and *loop()* function that will be executed infinitely, while the microcontroller is on.

3.1.1.1 Arduino Mega 2560

The model of the board selected for the project was the Arduino Mega 2560 was chosen for two reasons: more input and output capacity, reducing the complexity of using multiplexers and thus having a faster input; More flash memory to be able to store more instructions than a Arduino UNO.

Because the board used in the prototype is not an original Arduino AG brand, but a compatible board created by another brand, the Universal Serial Bus (USB) controller is different. Instead of the controller ATmega16U2 (USB to microcontroller) as in the figure 3.1 has a cheaper and simple CH340 (USB to Serial converter chip), and it can only realize USB to Universal Asynchronous Receiver/Transmitter (UART) interface. Using a ATmega16U2 instead it would be easy to edit the firmware, becoming not only a USB to serial converter to the ATmega2560, but also a HID. The solution was to add a second microcontroller to the circuit, the ATtiny85.

In order to group and weld the components to be used, a prefabricated board was used, designated as Mega2560 R31 Shield, for future references it will be treated as a shield. Without components after soldering the terminals will look like the figure 3.2. In addition to being a perfboard, this shield, fits directly on the Arduino Mega 2560 pins top, expanding the same through female header sockets. There is also a reset button and a clamping terminal for each port, facilitate the connection of the sensor wires, and its easy replacement.

3.1.1.1.1 USB - Serial 0

Regarding the first type of communication in focus, it will be the serial ports, are used for communication between the board and a computer host, or other devices, all the official Arduino boards have at least one serial port, the Mega2560 have 4 hardware serial ports. The Serial port 0 will be used to update the compilation and debugging of the sensors as well commands to execute. By default, pin 0 Receive (RX) and 1 Transmit (TX) on the

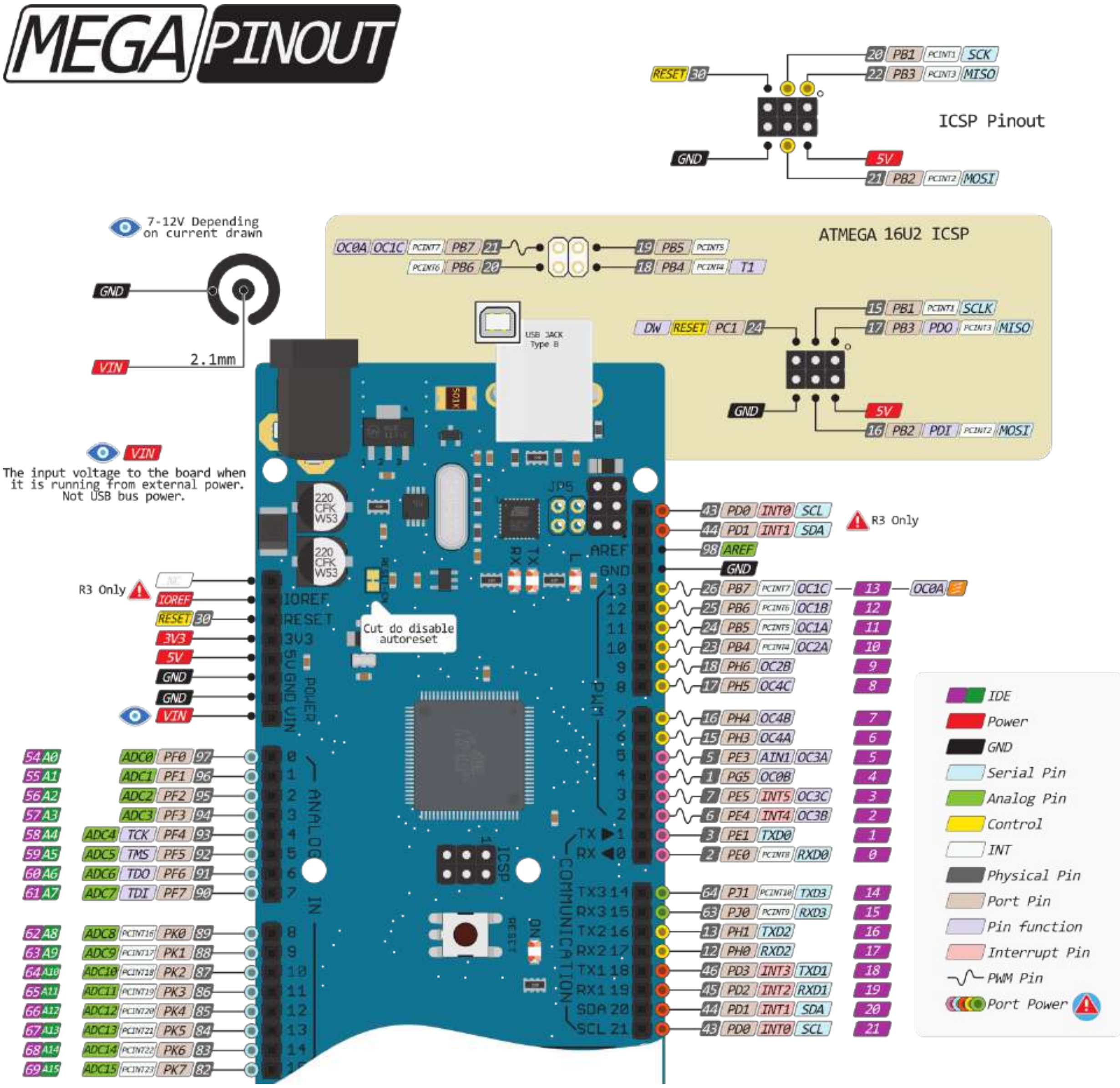

Figure 3.1: Arduino Mega 2560 rev3 - Part 1 [1]

board are used, correspond to the Serial 0 on the Mega2560 board.

For debug in the shell prompt can be used (replace the port number):

```
$ screen /dev/cu.usbserial-141220
```

3.1.1.2 Digispark ATtiny85

The Digispark is a Attiny85 based microcontroller development board based in Arduino, but with fewer connecting pins and considerably less memory. It is smaller than a traditional pen drive, as shown in the figure 3.3 [16].

This microcontroller will only have the function of transmitting Mega2560 commands to the host computer. To compile the code in IDE, it is necessary to add a repository[1] in the preferences of board manager. For the installation press Tools > Board > Boards Manager

[1]Additional URL: `http://digistump.com/package_digistump_index.json`

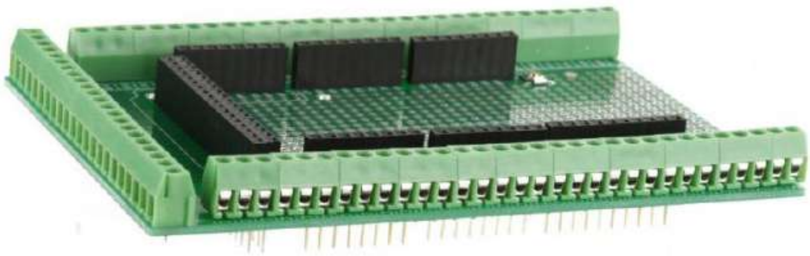

Figure 3.2: Mega 2560 R31 Shield isometric photo

> Digistump AVR Boards > Install, to compile is necessary to select the board and the programmer micronucleus. In macOS is necessary to remove the old dependencies in the shell prompt:

```
$ cd ~/Library/Arduino15/packages/arduino/tools/avr-gcc
$ mv 4.8.1-arduino5 orig.4.8.1
$ ln -s /Applications/Arduino.app/Contents/Java/hardware/tools/avr 4.8.1-arduino5
```

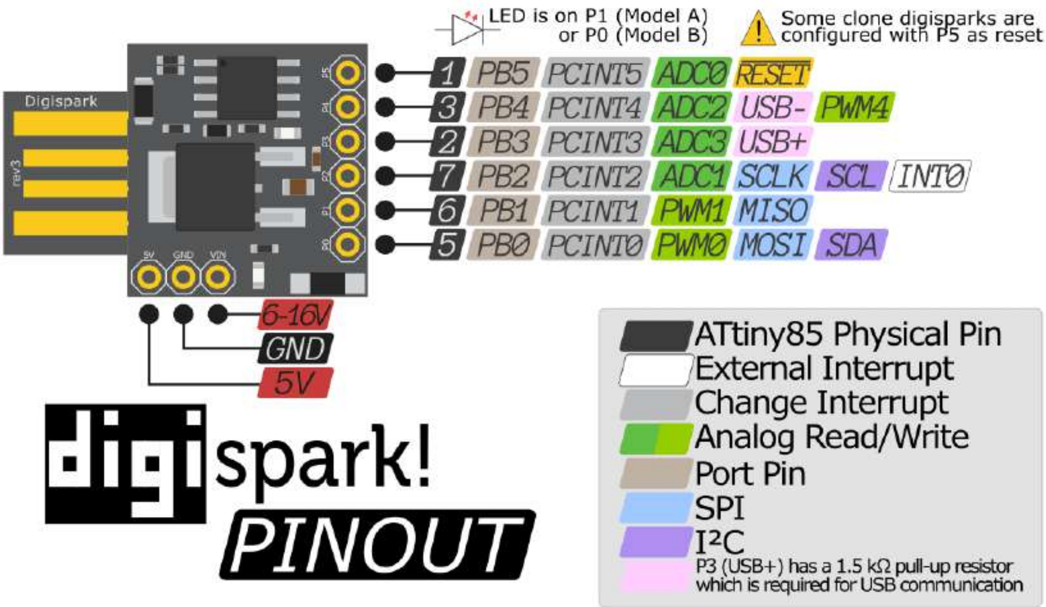

Figure 3.3: Digispark ATtiny85 rev3

3.1.1.2.1 Serial 1 - Software Serial

It will be connected to Serial 1 of Mega2560 via a serial port created over software at the ATtiny85, because there isn't dedicated physical hardware serial ports for this purpose in this microcontroller, like in a Arduino, so will be used 2 wires TX and RX as shown in figure 3.4, and we will have to include a library in the source code to obtain a virtual serial port.

Due to the original *SoftwareSerial.h* library from Arduino IDE was incompatible with the ATtiny85, a library *SoftSerial.h* provided by Digistump referenced in previous subsection 3.1.1.2 had to be used. Still it was too big for the flash memory to be compiled with other libraries, generating conflicts. The solution is use a fork modified library *SoftSerial_INT0.h*, of the previous library, that use the internal interrupt instead the physical I/O changing the interrupt vector by default [17].

The command numbers to be executed will be the only data transmitted, between the Mega2560 and the ATtiny85 board.

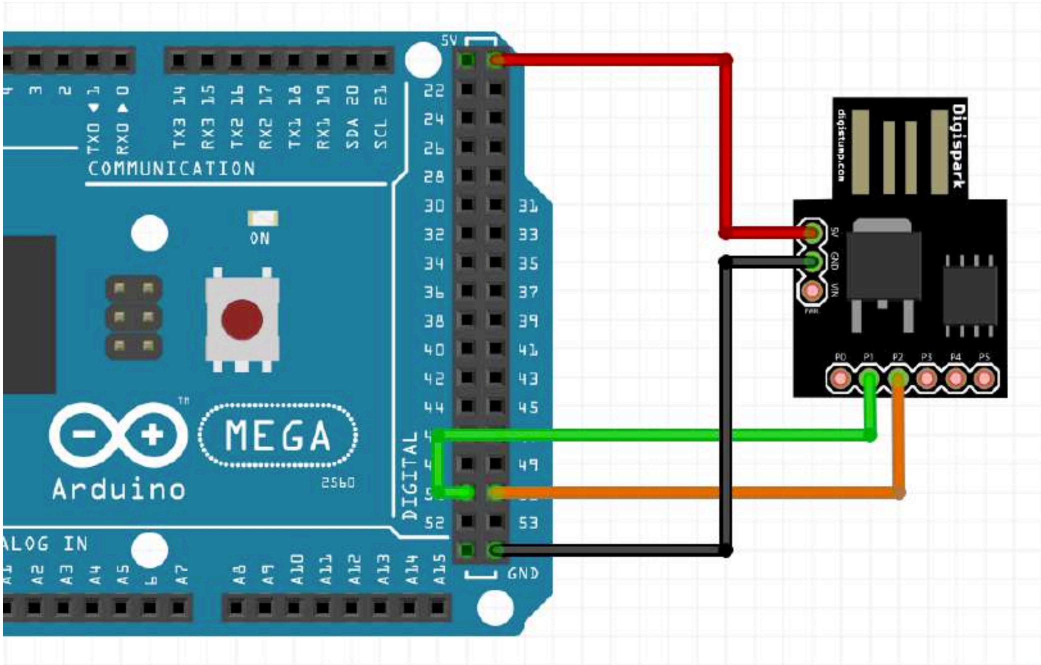

Figure 3.4: Connection between Mega2560 (left) to ATtiny85 (right) [2]

3.1.1.2.2 USB - USB HID

In order to emulate a existing HID device, in this case a keyboard, it try to use the Digistump original *DigiKeyboard.h* library, but like the *SoftSerial.h*, was some conflict issues. The alternative was *TrinketHidComboC.h* library [18] allows to implement a simple a keyboard, mouse, gamepad and other devices inside the Arduino environment. Using these alternative libraries, it was possible to compile the program for this microcontroller, still leaving 11% of free flash memory.

3.1.2 Distance Sensors

Tree distance sensors of different types were tested: ultrasonic (HC-SR04), IR (VL53L1X) and laser (TOF10120), and only one was selected for the prototype. Considering that the measurement was performed during the day with strong sunlight, and either work on principle of signal reflection, and signal delay period, like in the figure 3.5. The distance range in the datasheets are bigger, than the max optimal distance in the table 3.2, but it just consider the best results in the test bed.

Both light sensors, allow to reach a longer distance, but the values fluctuated too much even when the measurement was made against a motionless object. Possibly this oscillation is due to sunlight, however they were discarded due to the 24 mm oscillation, and the Field of View (FoV) higher than 25º, could cause erroneous readings on neighboring sensors.

The ultrasound sensor was selected to the project, due to its smaller FoV and the oscillation of the value against a statistical object was more precise, about 10 mm.

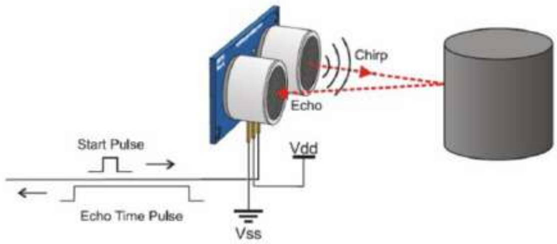

Figure 3.5: Work principle of the HC-SR04 sensor [3]

But late in the project development it was found that the accuracy could have a lower tolerance, and with the laser sensor, it could get better results using the latest algorithm. Considering the time-of-flight technology present in the IR and laser sensors, does not critically depend on angle of obstacle. Since these readings will be performed on the human upper limbs, and knowing that the arms have a cylindrical shape, the obstacle angle will be very important, and readout from an angle greater than 30º in the HC-SR04, is sometimes not determined [19]. As well as the use of certain fabrics on the sleeves, they may cause variations in readout, using ultrasounds.

Table 3.2: Distance sensors technical specifications

	VL53L1X	**HC-SR04**	**TOF10120**
Operating Voltage	2.6-3.5V	5V	3-5V
Max Operating Current	15-40 mA	15 mA	35-59 mA
Max optimal distance	70 cm	60 cm	70 cm
Response time	33 ms	15 ms	30 ms
Field of View	27º	15º	25º
Working Frequency	10 Hz	40 Hz	940 nm

Part of algorithm checks all ultrasonic sensors present and which one has the shortest distance between the user and the prototype. After get the lowest triggered, an LED is activated on the top of the respective sensor. If more than one sensor has a tolerably low distance, than the one has been triggered, the LEDs on the top of this sensors will be turned on also.

The visualization of these LEDs by the user is important, so it can know which of the sensors it is activating and this way obtain an immediate feedback. Always more than 3 sensors are activated, a matrix is created for future comparison.

3.1.3 Ambient Sensors

In order to give more information of the environment, was installed a Digital Humidity and Temperature (DHT) sensor, which can be useful for other sensors calculus.[20] The reading accuracy is present in the table 3.3, in the prototype was welded the DHT11, just because it was the only one in stock available. However the most suitable would be the DHT22, it allows negative temperatures and would be more accurate.

Table 3.3: DHT sensors technical specifications

	DHT11	DHT22
Operating Voltage	3-5V	3-5V
Max Operating Current	2.5mA	2.5mA
Humidity Range	20-80 $\pm 5\,\%$	0-100 $\pm 5\,\%$
Temperature Range	0 to 50°C $\pm 2\,°C$	-40 to 80°C $\pm 0.5\,°C$

3.1.4 Speaker

It was necessary to obtain faster feedback when one of the gestures was triggered, without the need to be checking the output from serial port 0. A buzzer piezo has been welded to the shield prototype, model BeStar P3009EB indicated in the table 3.4, so that when a gesture made by the user is detected, a sound is triggered. During start-up, when the prototype is turned on, this sound is played, it is part of the sound test.

Table 3.4: BeStar P3009EB technical specifications

	BeStar P3009EB
Operating Voltage	3-20V
Max Operating Current	13 mA
Sound Level	75 dB
Resonance frequency	3.2 kHz

Some sounds were extracted from the library Adafruit animal [21], with slight changes to be more notorious.

3.1.5 LCD

For the user get more visual content feedback, a Liquid-crystal Display (LCD) screen is installed on top of the prototype, and will show this information by order:

- Command to execute
- Temperature in ºC
- Icon of last command to executed
- Shortest distance between the user and sensors in cm
- Humidity in %

As a example of this information, the figure 4.2 show the location of the previous items in the LCD.

The Hitachi HD44780 LCD from table 3.5, was used for this prototype, and additional a LCM1602 module to control the display with a Inter-Integrated Circuit (I2C) interface, composed of a set of 2 signal wires, Serial Data (SDA) and Serial Clock (SCL), plus 2 energy

Table 3.5: HD44780 technical specifications

	HD44780
Operating Voltage	2.7-5.5V
Max Operating Current	121.5 mA
Characters per Line	2 rows x 16 characters
Characters pixel size	8 rows x 5 columns

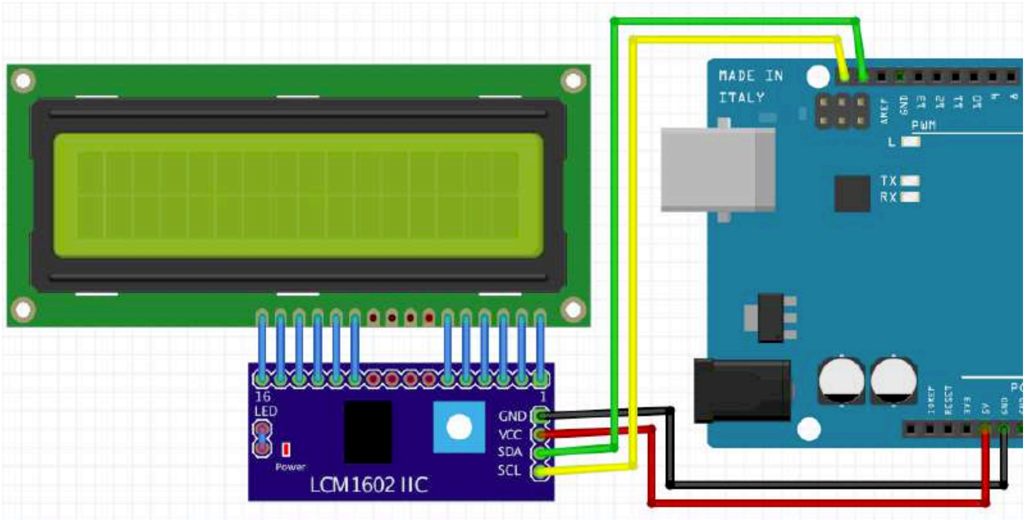

Figure 3.6: Connection between HD44780 LCD (top left) with LCM1602 module (bottom left) to Mega2560 (right)

wires was figure 3.6 demonstrates, avoiding 8 additional wires if was connected directly to the Mega2560.

To facilitate the programming of the LCD, the library *LiquidCrystal_I2C.h* [22] was used. Because it already has several functions to position the cursor, clean the display and control the back light. In order to graphically help the user, to identify which was the gesture recognized by the prototype, the LCD will show the icon of command executed, and will remain till a new gesture be recognized. Icons used were designed an online tool [23], and were stored in *iconPack.h* library.

3.1.6 Power Source

The standard USB connection delivers 5V to Mega2560 and allows you to draw 500mA in total. Considering the electrical power from the USB microcontroller is not sufficient for the entire circuit, an external Direct Current (DC) electrical source was added, the LIO1473, represented in the figure 3.6. The use of this power supply is optional, and the batteries can be connected to the DC port of the Arduino Mega2560, having the same max load of 800 mA through the linear power regulator, however in order to avoid turning on and off, removing the DC socket, this method is more functional with a button for this purpose. This circuit board does not have a datasheet, just a basic information in the table 3.6.

The DC input power for this circuit is provided from a battery, which includes six rechargeable Panasonic eneloop 1900 mAh AA batteries cells in series, each has $1.2V \times 6$

Table 3.6: LIO1473 power source technical specifications

	LIO1473
Input voltage DC	6-12V
Output voltage DC	3.3V / 5V ($\pm 0.05\,\%$ error)
Mac Output voltage DC	12V direct output
Max load current	800mA
Input interface	5.5×2.1mm DC female

Figure 3.7: LIO1473 top Photo

cells equals to 7.2V of output power. To turn on the prototype it is necessary to press the only blue button in this board, a red power indicator LED will turn on, and just after connect the USBs cables to avoid undervoltage.

Table 3.7: Energy consumption by component group

	Consumption (mA)	Qty	Total (mA)
Arduino Mega 2560	70	1	70
Digispark ATtiny85	36	1	36
Electrical resistors		11	0
Blue 5mm 626nm LEDs	20	9	180
Electrical Capacitor		3	0
HC-SR04 Sensor	15	9	135
DHT11 Sensor	2.5	1	2.5
BeStar P3009EB	13	1	13
Hitachi HD44780	121.5	1	121.5
	Total energy consumption		558

Discarding the consumption of linear regulators, capacitors and electrical resistors, the table 3.7 shows the total consumption of the components in idle. The battery life is approximately 204 minutes, according to the equation 3.1.

$$\begin{gathered}\frac{Capacity(Ah)}{Loadcurrent(A)} = Time(h) \\ \frac{1900mAh}{558mA} \approx 3,41h \times 60 \approx 204min\end{gathered} \tag{3.1}$$

3.1.7 Circuit diagram

In order to schematize the electronic connections, Fritzing was the open-source and cross-platform Computer-aided design (CAD) software selected, to design the prof of concept, allowing a quick experimentation of the circuit, and at a later stage the prototype design.

The circuit diagram, with all the electronic components that will be presented in the following sections, is represented in the figure 3.8, and the wire colors correspond with the same match color in the prototype, to facilitate interpretation.

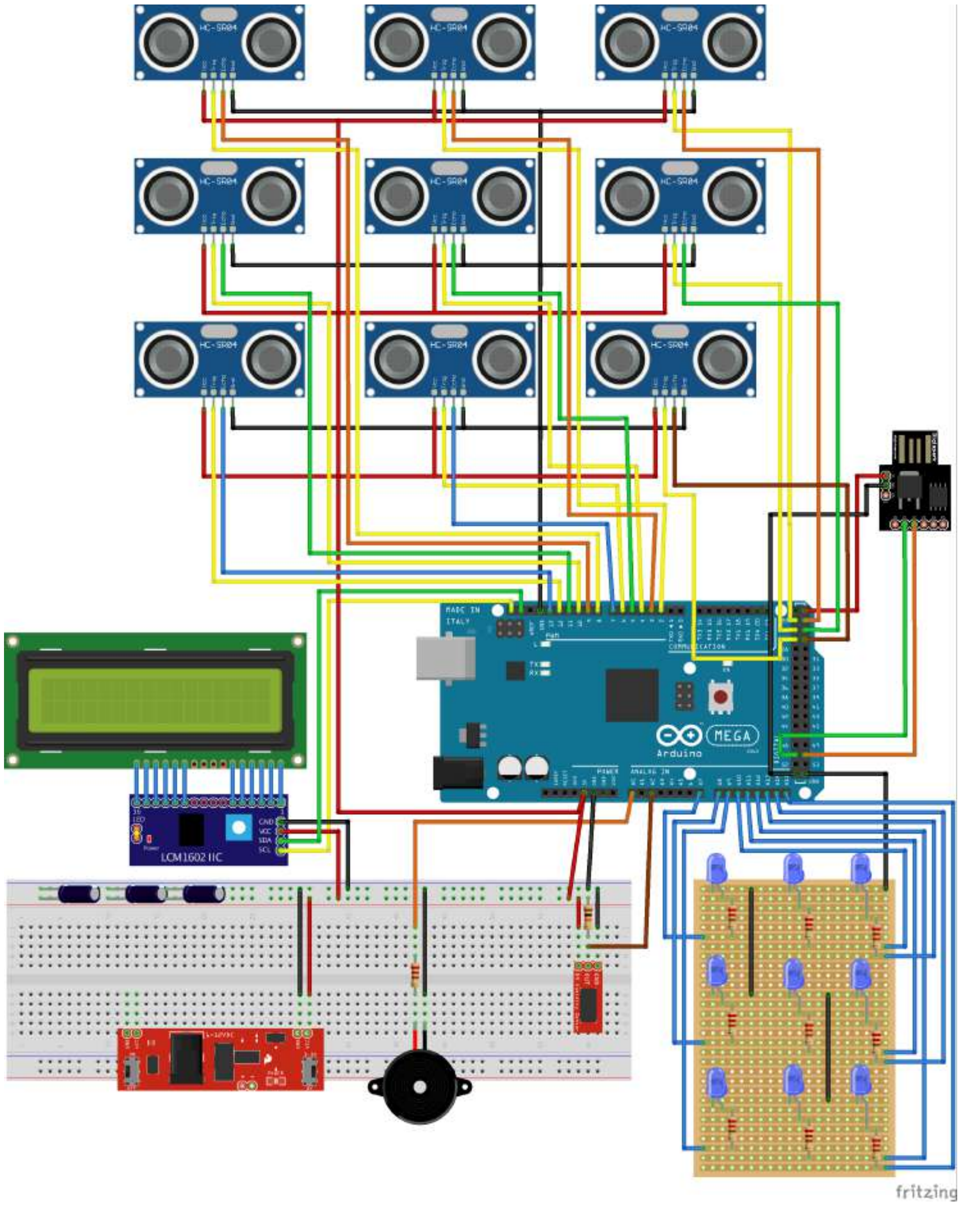

Figure 3.8: Prototype circuit diagram

3.1.8 Budget

The prices of the components to develop the prototype, are described in the following table 3.8 were based on the RS-Components store, due to having a more stable price over time, and marked with the letters ”RS”, and in appendix A.1 contains the respective prices by quantity. Not all products were available in the previous store, so Amazon was selected for the remaining items, and marked with the letter ”A”, Annex A.2 contains the list of products. The shipping costs will not be taken into consideration, items in stock or delays, it serves only as a reference value on August 27th, 2020.

Table 3.8: Electronic components budget

	Qty	Price	Set Price	Store
Arduino Mega 2560	1	34.58	34.58	RS
Digispark ATtiny85	1	2.98	2.98	A
Mega 2560 R31 Shield	1	13.79	13.79	A
Electrical resistors	11	0.03	0.34	RS
Blue 5mm 626nm LEDs	9	0.46	4.10	RS
Electrical Capacitor	3	0.23	0.68	RS
HC-SR04 Sensor	9	1.30	11.70	A
DHT11 Sensor	1	2.82	2.82	A
BeStar P3009EB	1	0.50	0.50	RS
Hitachi HD44780	1	5.20	5.20	A
LIO1473 Power Source	1	2.65	2.65	A
Baterry Holder AAx6	1	1.31	1.31	RS
Eneloop AA 1900mAh	6	4.00	24.00	RS
Snap T-Type to DC	1	0.61	0.61	RS
Connector DC 5.5mm	1	1.72	1.72	RS
Terminal block 5mm	2	1.30	2.60	A
	Total (Euro)		109.57	

Table 3.9: Wiring budget

	Qty (cm)	Price	Store
Red unicore wire 0.5mm2	720	12.91	A
Black unicore wire 0.5mm2	720		A
Green unicore wire 0.5mm2	400		A
Yellow unicore wire 0.5mm2	400		A
USB 2.0 extention cable type A	150	3.85	RS
USB 2.0 cable type B	150	7.85	RS
	Total (Euro)	24.61	

3.2 Plastic Structure

The prototype structure must be rigid, this way the sensors are always kept the same distance between them and also from the user, and can receive valid values from the hardware with minimal error tolerance.

This prototype was designed so it can be expanded in the future, if it is necessary to increase its size, to enhance interaction with the user, thus avoiding vertical or horizontal adjustment so that any user regardless of their height or length of the upper limbs can interact with.

The software used to create the structure components in CAD was the Autodesk Fusion 360, creating editable file format with *.f3d extension. Being capable to use the same software to export this files in Standard Triangle Language (STL), which create the file format *.stl.

For quick prototyping, 3D printing is the quickest way to manufacturing a physical three-dimensional model, there are several 3D printing techniques, the one we will be using will be Fused Deposition Modeling (FDM), which create the object by successive layers of extrude melted plastic material. A heated printer head extruded is fed by a filament coil of the type of material to be used, and after melted are deposited in the printer bed.

Bearing in mind that until the final model of the structure, several different designs would be made, and a large part of the material would not be reused, it was determined that the material for the extrusion would be the Polylactic Acid (PLA) filament, due to its biodegradability and low cost.

For converting STL files to be 3D printed by layers, was used the software Ultimaker Cura (4.6.1), converting stereolithography CAD in G-code. The G-code provides a compilation not only the layers of the design to be printed, but also the print speed, extrusion flow from the print head, printing bed and print head temperature, and structure supports. Structure supports are necessary when the filament extrusion occurs without support of the printing bed, or is approximately 5 mm away from a layer. After printing these structures are easily removed by hand, or with the help of pliers. This G-code with the necessary supports will be provided, in case it is necessary to replicate the pieces.

Printing a single piece there would be a need to have a printer with a bed with large dimensions, in which economically it would not be viable.

Due to the challenge of creating a completely new support, that would be modular and could be assemble, and also low cost production, was chosen a printer with a small bed size. In this way, all printed models must fit together, forming a single piece. The printer used was the Creality Ender 3X, with a 0.4mm nozzle size, and have a usable print area of 220 x 220 mm. However to print the biggest parts is just necessary a 124 x 175 mm print area.

In order to minimize the use of supports in the G-Code, and also reduce the use of filament and the printing time, the parts must be printed with the front side facing the printing table. Along the accomplish imprint made, adjustments were done in order to improve the desired quality, using less filament.

These were the basic parameters for all parts:

- Low Quality 0.28
- Cubic subdivision Infill
- 10 % Infill
- Top/Bottom layers 2
- Top/Bottom thickness 0.56

3.2.1 Sensors Support

All supports have a look of a puzzle piece shape, these differ by having 4 plans with dovetail joints. Each corner has a hole, it was initially designed to tie the supports in a grid, but it was not necessary due to the strict tolerance in the printing process. This way, all the supports allow for fitting by hand, without applying pressure or tools.

Throughout the design development this part has suffered several changes, in the figure 3.9, from the left to right the evolution of design in the begging supporting just a single sensor position till the last with multiple dispositions, and supporting more than one kind of sensor, for future implementation.

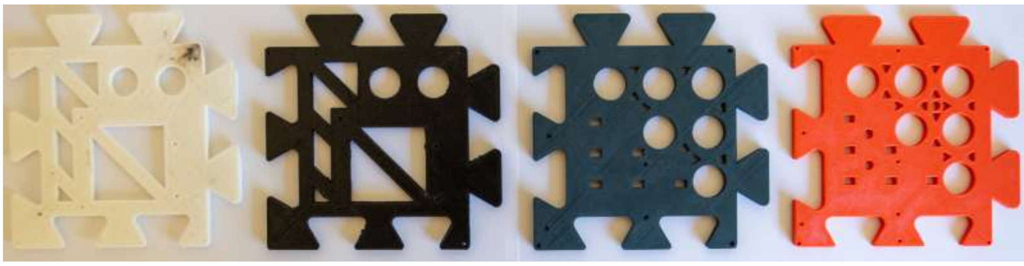

Figure 3.9: Sensors support design evolution

These will be the central supports for the sensors, represented in the figure 3.10, allowing to be spaced horizontally at the same distance, and vertically respectively. Each support should only have an ultrasonic (larger circular cavities) or IR/laser sensor (rectangular cavities) mounted. In the current project, it has already been defined in section 3.1.2, that will be used only ultrasound sensors. In the final prototype, the ultrasonic sensors are horizontally coupled.

This support has small circular cavities for LEDs, and triangular cavities for the ultrasonic sensor support springs. The use of these springs was inspired by the support of car headlights. Vibrations are avoided using this method, due to the elastic material of the rubbers that allows them to absorb it, allowing also quick replacement of the sensor for maintenance.

For the gestures could be performed by any human being, the lowest measure of the length of the forearm was considered [24], for the placement and distance of the sensors in the grid, created by this set of supports. Considering that an adult woman has a minimum forearm length of 20.5 cm and an adult man 23.8 cm, the maximum distance from end

Figure 3.10: Sensors Support - front isometric view

to end diagonally in the sensor grid is 30 cm, allows users to also use their palms and forearms to reach the extremes of the Prototype grid.

3.2.2 Center Base Support

The construction of the prototype must start with this support, figure 3.11, after all the printed parts. All frame supports will have the same wider width so that all electronic components inside of the structure will not be visible to the user. The weight distribution allows this support to be on a tripod to adjust the prototype to the user's height, at the bottom there is a tripod mount, visible in the figure 3.12. The Slik 17G was the tripod used in the test bed.

Figure 3.11: Center Base Support - front isometric view

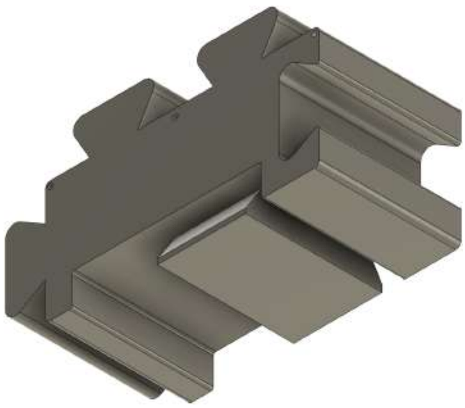

Figure 3.12: Center Base Support - bottom back isometric view

3.2.3 Right Base Support

Represented in figures 3.13 and 3.14, this support allows to dovetail joint the center base support and the right side cornerstones, have also a flat foothold. Just have 2 plans with dovetail joints.

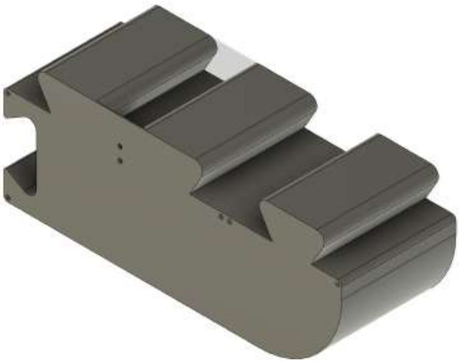

Figure 3.13: Right Base Support - front isometric view

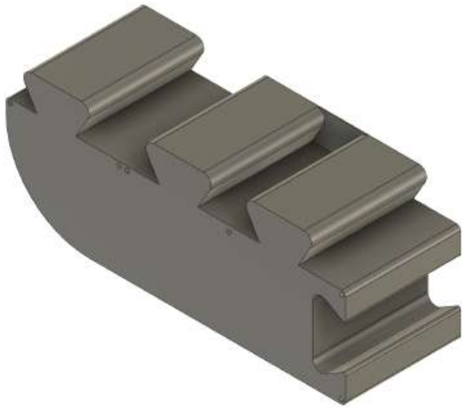

Figure 3.14: Right Base Support - back isometric view

3.2.4 Left Base Support

This support in the figure 3.15 it has the same characteristics as the right base support. Just have 2 plans with dovetail joints and all are male, as the figure 3.16 shows. Additionally have inside a battery compartment, with an angle for easy removal of the battery for recharging, and a duct for USBs and charging cables. This compartment is printed with support structures.

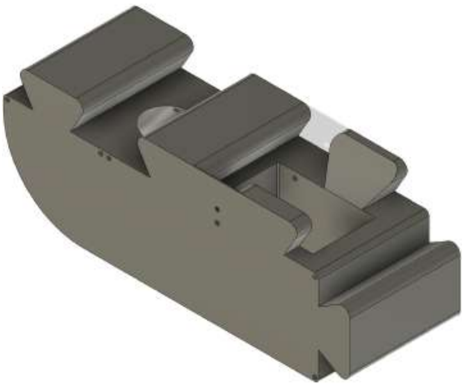

Figure 3.15: Left Base Support - front isometric view

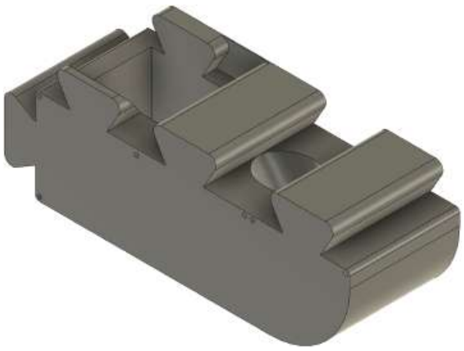

Figure 3.16: Left Base Support - back isometric view

3.2.5 Right and Left Cornerstones

The cornerstones in figure 3.17 and 3.19, allows to dovetail joint the left or right base support or/and cornerstones; the right or left top support and another cornerstone. Have 3 plans with dovetail joints, the left cornerstone have 3 male dovetails and right cornerstone just have 1. It has a grommet hole in the back order to fix on the wall, as it show the figure 3.18 and 3.20. Due to the low importance of this support it can be printed with 5 % infill, except if it is intended to use the grommet hole.

Figure 3.17: Right Cornerstone - front isometric view

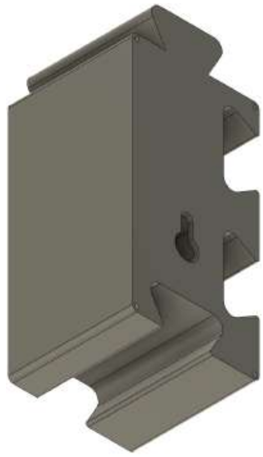

Figure 3.18: Right Cornerstone - bottom back isometric view

Figure 3.19: Left Cornerstone - front isometric view

Figure 3.20: Left Cornerstone - bottom back isometric view

3.2.6 Right and Left Top Support

These supports represented in the figure 3.21 and 3.22 have the terminal function of closing the plastic structure of the prototype, joint the cornerstones and the center top support. The right top support is identified by just having female dovetail joints, as the figure 3.22 shows. Can be printed with 5 % infill.

Figure 3.21: Right Top Support - front isometric view

Figure 3.22: Right Top Support- bottom back isometric view

Figure 3.23: Left Top Support - front isometric view

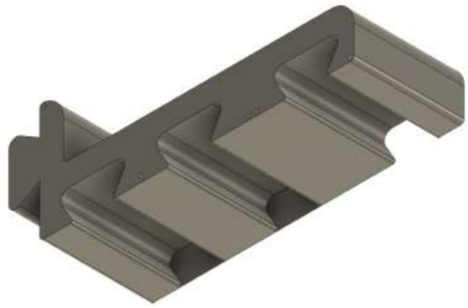

Figure 3.24: Left Top Support - bottom back isometric view

3.2.7 Center Top Support

Holding the right and left top support, this support as the figure 3.25 shoes, it close the structure. The interior of this support is hollow, as the figure 3.26 shows, and is printed with several internal support structures.

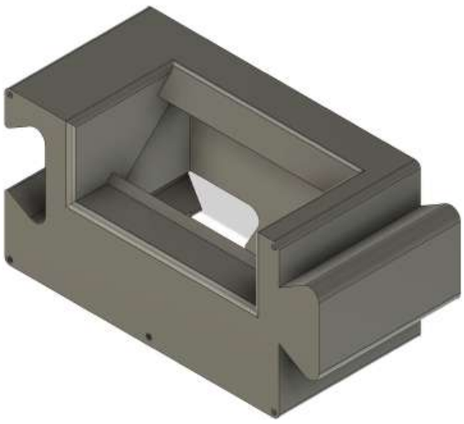

Figure 3.25: Center Top Support - front isometric view

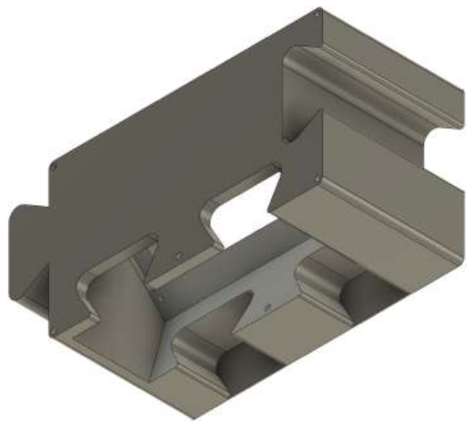

Figure 3.26: Center Top Support - bottom back isometric view

3.2.8 Mainboard Support

This support represented in figure 3.27, fits over the 3 base supports (right, center and left), allowing to strengthen the link between these.

Circuit boards are inserted by sliding (ATtiny85 and LIO1473), the main microcontroller (Mega2560) is screwed to the support and the respective shield is inserted vertically through the Arduino pinout.

Underneath the arduino board assembly, triangular spacing further cable routing from sensors supports. Each triangular space is identified with the position, to subserve the connection of the wires from sensors and LEDs.

When this support is in the rail, it is not possible to remove the internal battery, this way the support lock the battery and can't be removed when the circuit is connected, and also prevent battery moving out of position during transport of the prototype.

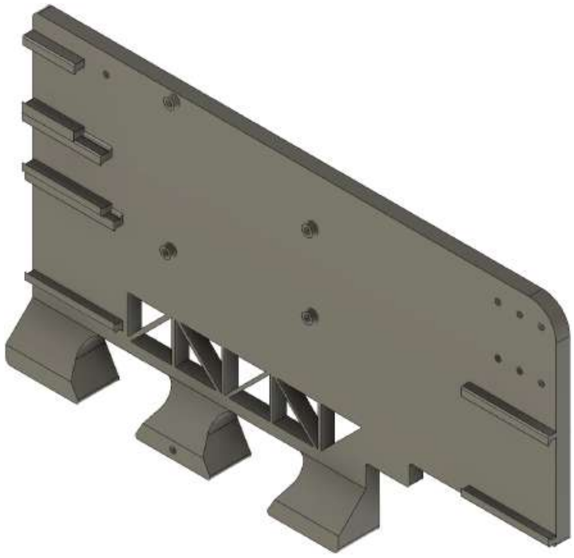

Figure 3.27: Mainboard Support - front isometric view

3.2.9 Budget

In the table 3.10 have time and filament cost, needed to print all components. The different positioning of the part on the printing bed, will vary the printing values: time and the necessary filament, so these values are approximate. For the pieces that need printing structure supports, the time and filament necessary for printing them was not considered in the table. However these structure supports are included in the provided g-code, and can be open and viewed on Ultimaker Cura.

Table 3.10: 3D printing budget

	Print Time (min)	**Weight (g)**	**Filament (m)**	**Qty**	**Total Print Time (min)**	**Total Filment (m)**
Sensors S.	139	23	7.55	9	1251	67.95
Central Base S.	325	65	21.85	1	325	21.85
Right Base S.	428	88	29.56	1	428	29.56
Left Base S.	441	87	29.19	1	441	29.19
Right Cornerstone	281	49	16.53	3	843	49.59
Left Cornerstone	295	53	17.92	3	885	53.76
Right Top S.	311	49	16.37	1	311	16.37
Left Top S.	303	49	16.51	1	303	16.51
Center Top S.	317	51	17.24	1	317	17.24
Mainboard S.	209	38	12.73	1	209	12.73
					5313	314.75

Considering that PLA filament coil have a density of $1.25g/cm^3$, and a volume of $0.8cm^3/g$ or $800cm^3/kg$, a regular reel of 1 Kg will have 332.77 meters, according to the calculation 3.4, being necessary 314.75 meters (plus the structural supports) it will be sufficient for the printing of all the parts. The total printing time will be 88 hours and 33 minutes, not considering the necessary time maintenance between prints.

$$CylinderVolume = \pi . r^2 . height \quad (3.2)$$

$$height = \frac{Volume}{\pi . r^2} \quad (3.3)$$

$$33277 = \frac{800}{\pi . 0.0875^2} \quad (3.4)$$

3.3 Requirement Analysis

This section presents the design and implementation of the prototype architecture. It start presenting the conceptual design of the proposal and then presenting Unified Modeling Language (UML) diagrams of the main actions and procedures. For the realization of the UML diagrams, the VisualDesigner 5.4 freeware software was used.

3.3.1 Behavioral Diagrams

In the diagrams that will be presented in these sections, the actions that generate output for the debugging console will be omitted, due to not being relevant to the figure, since all actions generate status and output information.

In the figure 3.28, the mode of interaction with the prototype is represented, the user is executing the ”next” gesture, exemplified also in the section 4.4, in this case triggering 5 sensor points on the grid, although this gesture can be recognized triggering between 4 to 6 sensor points, due to the recognition training performing the same gesture in different ways, during the learning procedure.

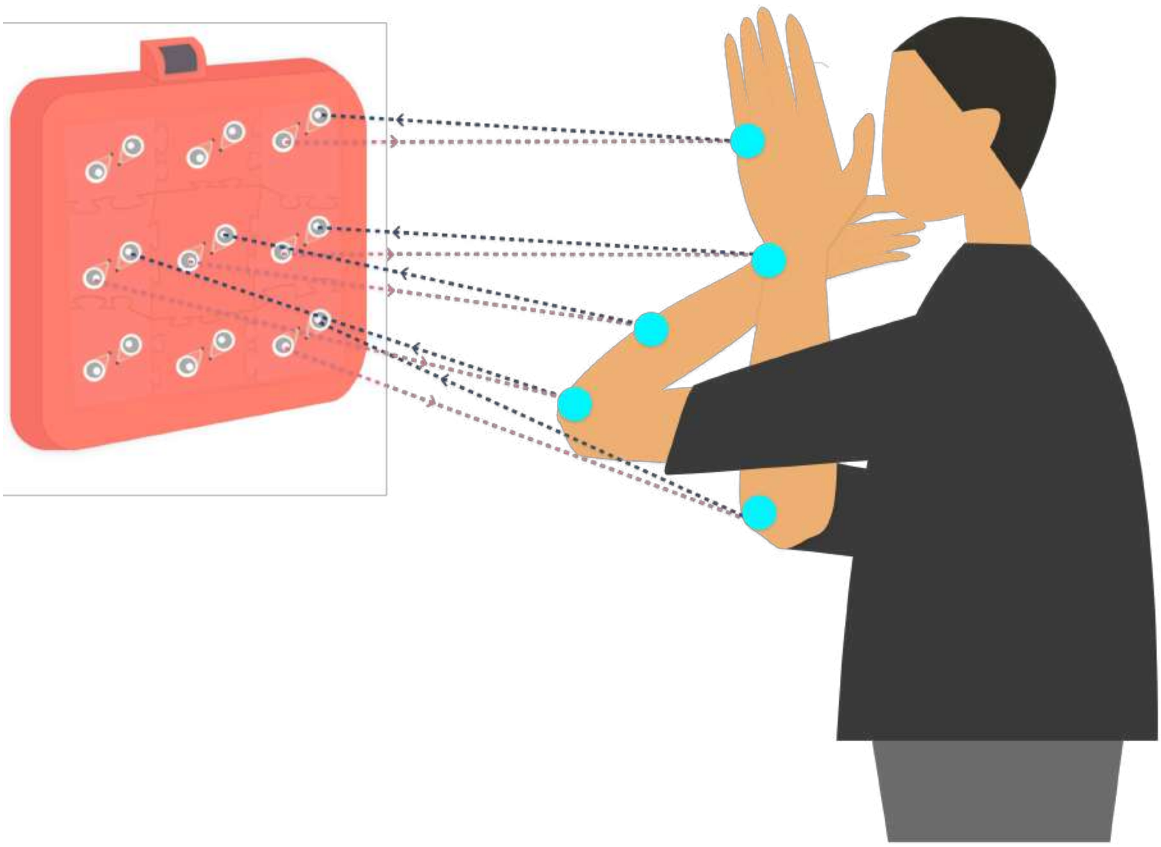

Figure 3.28: Conceptual Diagram usage

3.3.1.1 Use Case Diagram

Use diagrams represent how a user interacts with the features of the prototype in system development and with a graphical overview of the functionality. In the figure 3.29, describe the sequence of actions by the user, and how the system can be used.

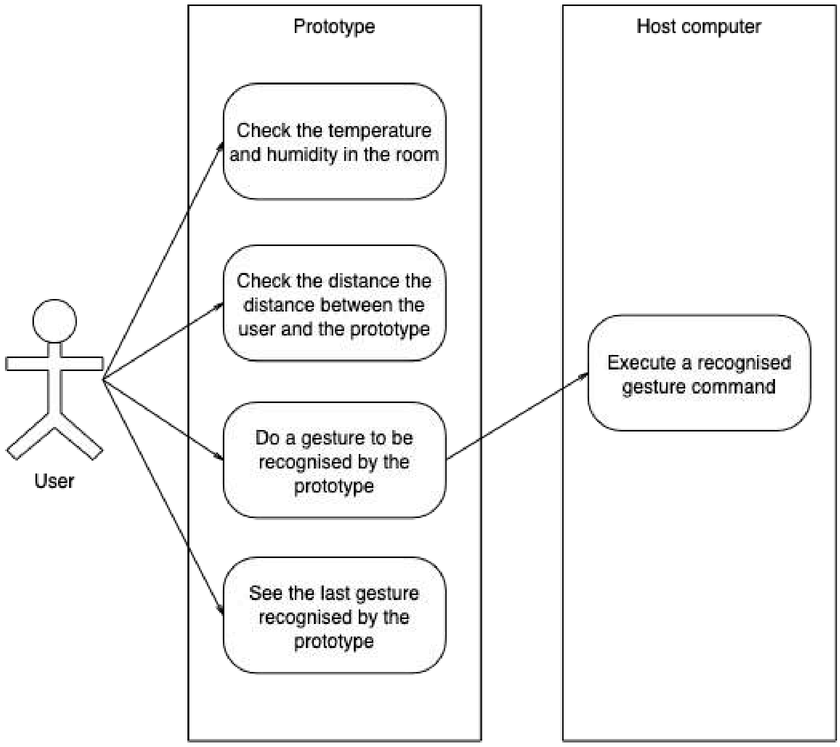

Figure 3.29: Prototype User Case Diagram

3.3.1.2 Activity Diagrams

The activity diagrams are used to describe the dynamic behavior of the system, and the operational components of the system step-by-step, and show the overall control flow between activities. In the first step performed by the prototype algorithm, represented in figure 3.30, is to obtain the sensors values, and to present them.

As an example of the console output when a real gesture is found to decrease the volume:

```
$ Humidity: 18.00%  Temperature: 23.00C Heat index: 21.83C
$ 114cm 19cm 69cm 6cm 8cm 7cm 20cm 19cm 46cm
```

An a example when a a ultrasonic wave from another sensor collide is detected or a big variation of the value:

```
$ Variation found in sensor: 3 Old Value: 86
$ Variation found in sensor: 3 New Value: 5
$ After Retify New Value: 5
```

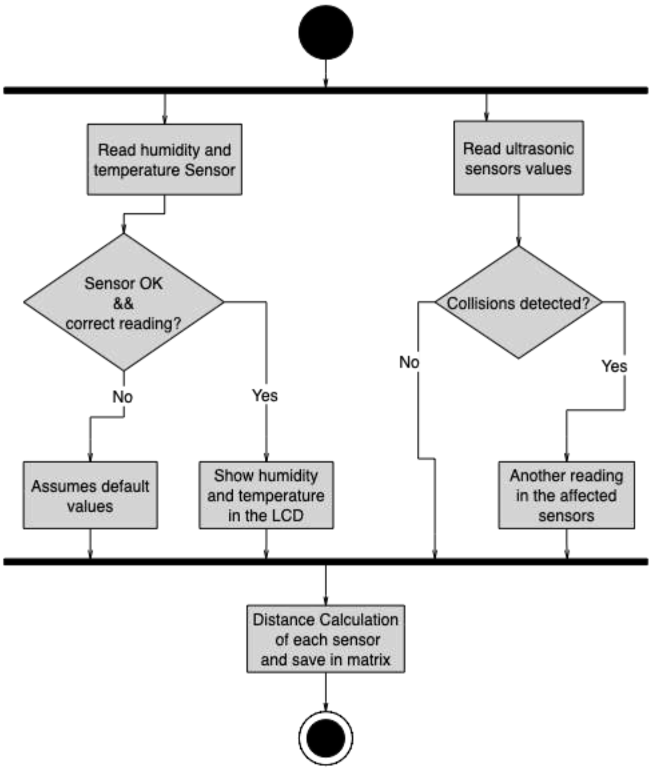

Figure 3.30: Read sensors Activity Diagram

In the figure 3.31 the algorithm will use the previous captured distance matrix provided by the figure 3.30, to convert it in a binary matrix, and then verify the similarity with the matrix database to find a recognizable gesture. This comparison algorithm can be considered as a narrow weak AI: only can handle one task and behave looking for similarities.

The gestures recognized by the algorithm will be explained in the next chapter four.

As an example of the console output when a real gesture is found to decrease the volume:

```
$ Lower sensor in vector: 6
$ Vector in boolean: 000111000
$ Compared command : 1 wrong!
$ ...
$ Not command: 1
$ ...
$ Compared command : 000111000 Action Command: 8
$ Command to execute: 8
$ Real Exectute switch command 8: VOLUME DOWN!
```

If a match is found, a command will be sent from the Mega2560 microcontroller to ATtiny85, in the figure 3.32, is shown how ATtiny85 handles when receive information.

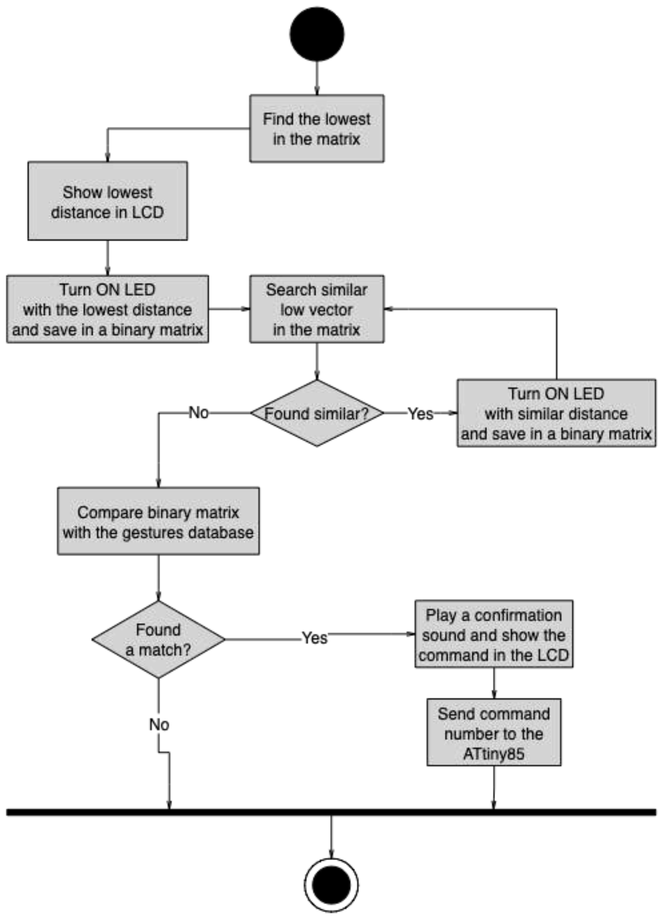

Figure 3.31: Matrix Similarity Activity Diagram

3.3.1.3 Interaction Diagrams

The sequence diagram show how process interact between the user and the host computer. The figure 3.33 presets the connection between the prototype in the 2nd column, in the 3rd the optional Debug connection over USB, and the 4th column the host computer that will receive the commands.

The prototype allows executing commands on different OSs, in the host computer, the test was successfully performed on: Microsoft Windows 10, Apple macOS 10.15.6, Ubuntu 18.04 and Android 6 (over USB On-The-Go (OTG) B-device).

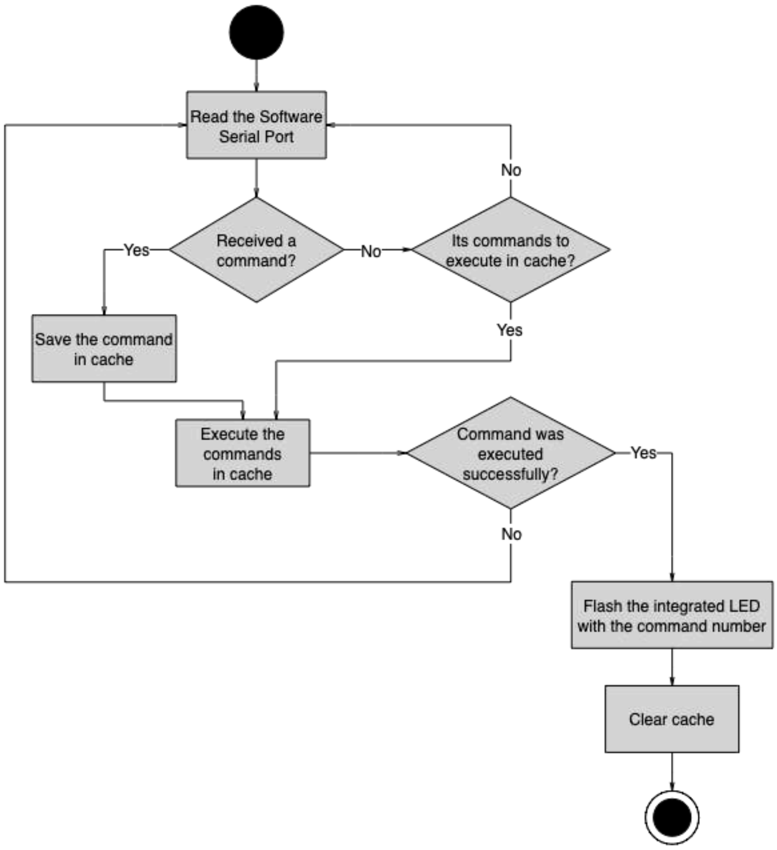

Figure 3.32: Microcontrollers Communication Activity Diagram

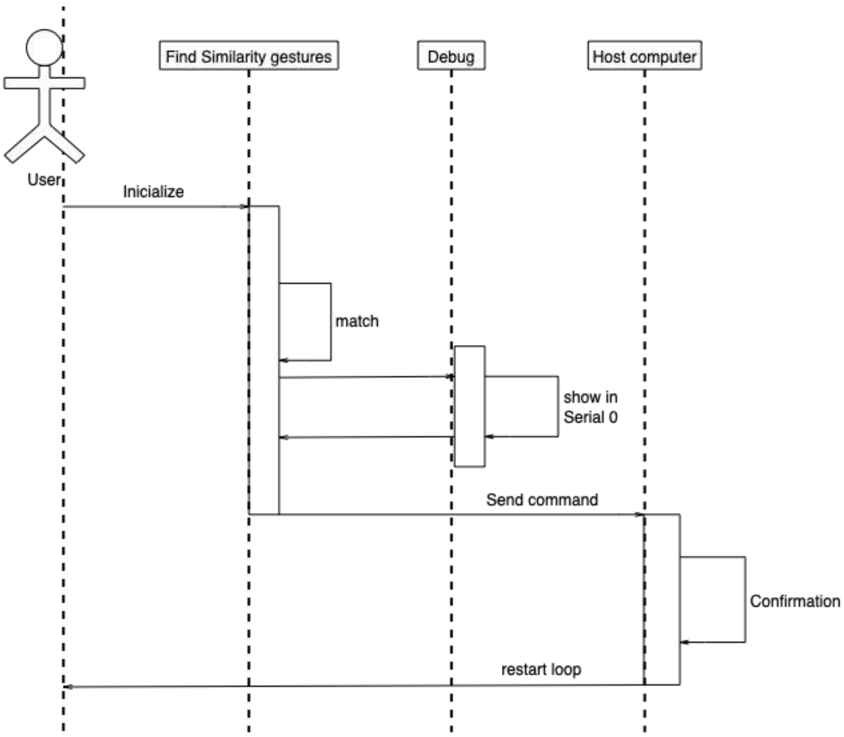

Figure 3.33: Sequence Diagram usage

4. Gesture Identification

In this chapter is shown the gestures that can trig a command to executed by the host computer.

For proof of concept, 8 possible commands were considered, with 5 possible variation of the command, in which 9 conditions that define the command must be fulfilled, concerning the number of sensors present in the prototype grid.

Each command has a number that identifies it in the source code, which Mega2560 sent to ATtiny85, as the corresponding gesture is identified. In turn, ATtiny, when receiving the command number, executes a standard hexadecimal command [25] recognized by the OS, as shown in table 4.1.

Table 4.1: Media keys commands List

Command #	Media key	Consumer HID Code
0		Nothing to execute
1	Pause	0xCD
2	Play	0xCD
3	Stop	0xB7
4	Next	0xB5
5	Previous	0xB6
6	Mute	0xE2
7	Volume Up	0xE9
8	Volume Down	0xEA
9		Reserved for furture use

Although the gestures chosen were based on multimedia commands, these serve only as proof of concept, and may have been chosen simple keystrokes, a string or even set of keys pressed in a certain order, called macro. The gestures that were identified for this experiment, were selected as the easiest to identify by a user, trying to approximate the forearms position more identical to the standard multimedia icons. However, there is still space for the creation of more gestures that can be recognized by the prototype without overlapping.

4.1 Pause

This gesture is performed by keeping both forearms vertically parallel, in front of the prototype, as it show the figure 4.1. For the recognition to be carried out in the best way, the arms must be consistent with the sensor grid, as represent the figure 4.3, that way with the forearms closest to the sensors, they will trigger the respective sensors, as show the figure 4.4, the rest of the user's body will be ignored, because it will be at a higher distance, and different from the distance of the forearms.

This gesture will execute a command to pause the playback of multimedia content, whether audio or video, in the last application in use capable of recognize this command on the host computer. When the gesture is recognized, a message is displayed on the LCD screen, as in the example in the figure 4.2.

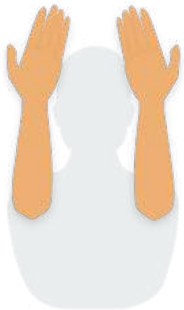

Figure 4.1: Pause Gesture

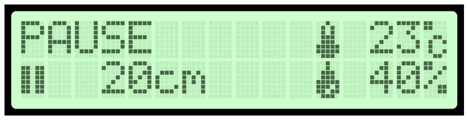

Figure 4.2: Pause Gesture triggered in LCD

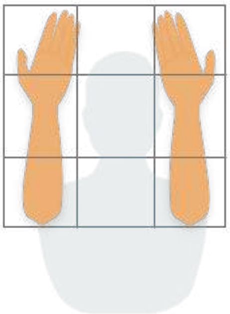

Figure 4.3: Pause Gesture in the Prototype grid

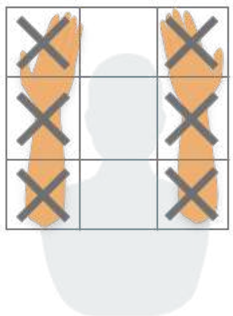

Figure 4.4: Pause Gesture triggered in the Prototype grid

4.2 Play

Some of the gestures will appear unnatural in this document, but only because they are mirrored, as is the case with play gesture, shown in the figure 4.5, to the user will have a natural perception of the direction of the standard formed by the play icon.

Only at the conclusion of the project was it verified that the multimedia play and pause key, share the same hexadecimal reference on a keyboard. As the prototype will be recognized as a HID physical keyboard, the command sent will be the same, but in the source code it will be treated as different commands, in a future work it can be understood and changed without modifying the switch algorithm.

Therefore, this command will execute the same as presented in section 4.1, playback or pause will be performed.

Figure 4.5: Play Gesture

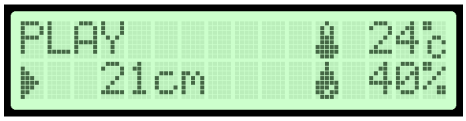

Figure 4.6: Play Gesture triggered in LCD

4.3 Stop

This gesture will execute a command to end the playback of multimedia content, whether audio or video, in the last application in use capable of recognize this command on the host computer. It is executed with both arms parallel horizontally, as it show the figure 4.7.

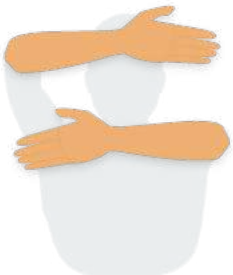

Figure 4.7: Stop Gesture

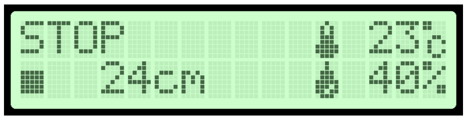

Figure 4.8: Stop Gesture triggered in LCD

4.4 Next

Such as Play gesture, detailed in the section 4.2, the Next gesture is also mirrored, and is represented in the figure 4.9. As a command allow to skip the current multimedia content and reproduce the next one in the list, if exist.

Figure 4.9: Next Gesture

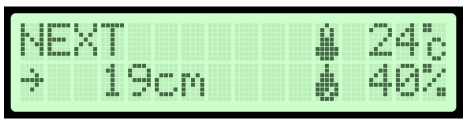

Figure 4.10: Next Gesture triggered in LCD

4.5 Previous

Such as Play and Next gesture, detailed in the section 4.2 and 4.4, the Previous gesture is also mirrored, and is represented in the figure 4.11. As a command reproduce the antecedent multimedia content.

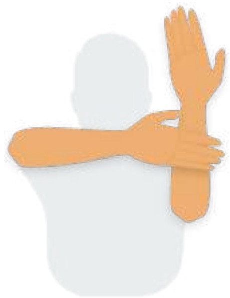

Figure 4.11: Previous Gesture

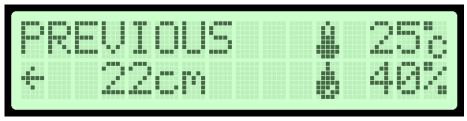

Figure 4.12: Previous Gesture triggered in LCD

4.6 Mute

To perform this gesture the user must cross both forearms, as shown in the figure 4.13. Unlike previous gestures, Mute interacts with the OS, instead of specific applications. This command allows you to silence the output sound of the sound card predefined by the OS. If performed again, the volume is restored to the same level before being silenced.

Figure 4.13: Mute Gesture

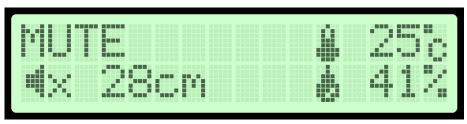

Figure 4.14: Mute Gesture triggered in LCD

4.7 Volume Up

Such as Mute gesture, detailed in the section 4.6, this command allow to increase the sound of the OS, and should be performed as shown in the figure 4.15.

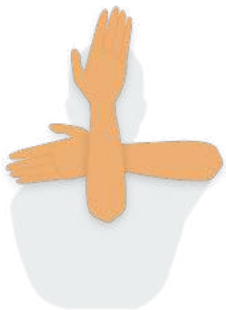

Figure 4.15: Volume Up Gesture

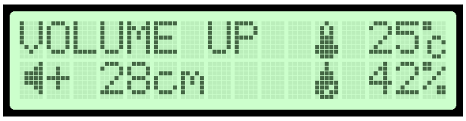

Figure 4.16: Volume Up Gesture triggered in LCD

4.8 Volume Down

The gesture to decrease the volume will be the only one that can be performed with just one forearm, as shown in the figure 4.17. Such as Mute and Volume Up gesture, detailed in the section 4.6 and 4.7, this command allow to decrease the sound of the OS.

Figure 4.17: Volume Down Gesture

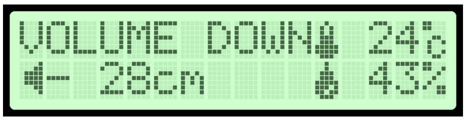

Figure 4.18: Volume Down Gesture triggered in LCD

5. Implementation and Results

The implementation of the project was due to the previous research of state of the art and the combination of the methods studied in the previous chapters. In this chapter will be presented the results after the finalization of the prototype: how to work with it, experiments to

- 5.1 Instruction Manual - how to work with it: positioning and switch on
- 5.1.1 Initialization and Diagnostic - Integrity validation of components
- 5.1.2 Troubleshooting - Some experiments were carried out to cause problems and possible solutions.
- 5.2 User Survey - User experience and performance
- 5.3 Discussion - Compare systems and identify qualities and flaws

5.1 Instruction Manual

The prototype it must be adjusted in height to first bottom row of the grid matches the user shoulders, this can be done with the help of a tripod mounted on the central base support, presented in the section 3.2.2, and how it is represented in the figure 5.1.

The prototype must be connected using the blue button on the power supply, as shown in figure 3.7, located at the rear of the prototype, in the lower right corner, as shown in the figure 5.2, also ensuring that the battery cell holder is charged and is connected to the DC source. Then connected the USB cable from ATtiny85 to the host computer. It must be disconnected from the same information inversely, removing the USB cable and only then disconnecting the power supply.

The user must perform the gestures in accordance with chapter four, when they are recognized, the user will hear a confirmation sound, in addition to the information presented on the prototype's LCD.

5.1.1 Initialization and Diagnostic

When connecting the prototype, it performs a series of commands to show the user the good condition of some components.

1. Turn ON the the backlight of LCD screen and show the text: ”Non Invasive Gesture Recognition”;
2. Play a sound test in the inside buzzer speaker;
3. Turn all the LEDs ON during 2 seconds;
4. Welcome message is Removed from the LCD and exhibit room temperature and humidity;
5. After 5 seconds, the bootloader will be complete and a red LED should stop blinking in the ATtiny85;
6. From this moment the USB port can be connected, it must be detected by the host computer;
7. The lowest distance between the prototype and the user should appear on the screen in centimeters;

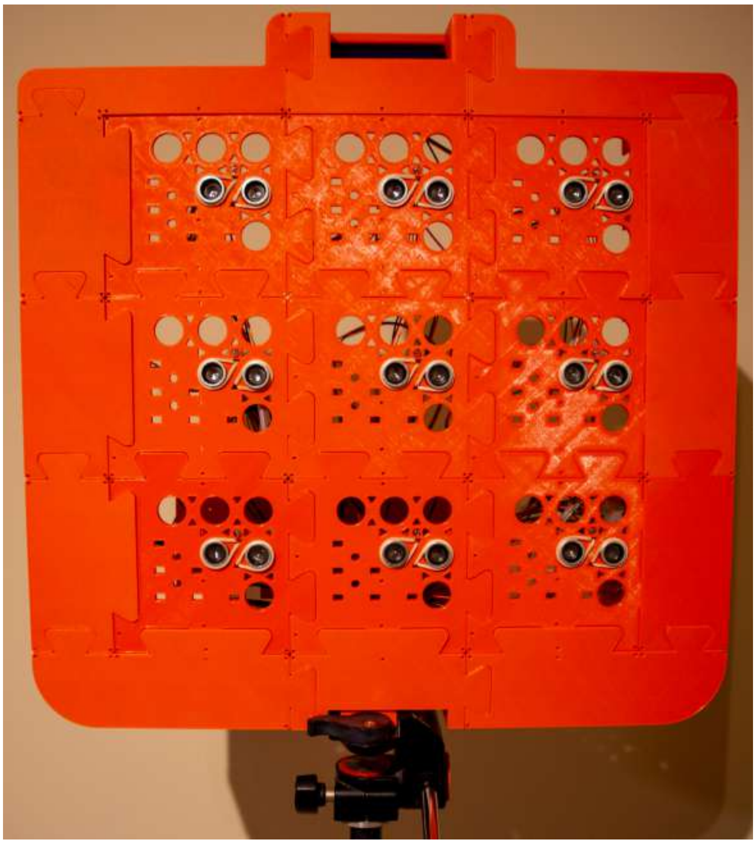

Figure 5.1: Prototype frontal photo

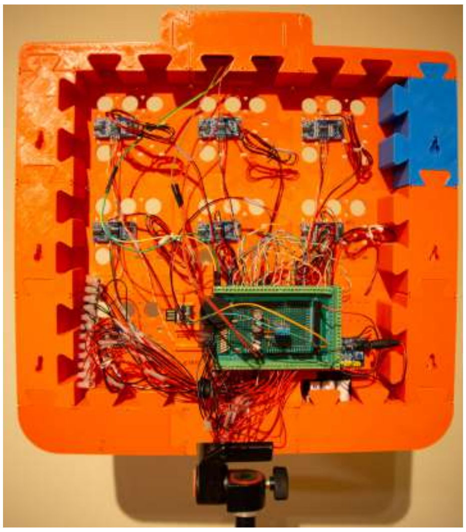

Figure 5.2: Prototype back photo

Figure 5.3: Prototype LCD photo

5.1.2 Troubleshooting

The table 5.1 presents some problems during development and possible solutions.

Table 5.1: Troubleshooting table

Problem description	**Solution**
The operating system does not recognize the device	Install Digispark drivers[1]. Install Mega 2560 drivers[2].
One or more LEDs didn't turn on during the initialization	Verify the wire connection from A7 to A15
In the LCD the shortest distance is 0 cm	The sensor that is reporting this error, should have the LED on, check if the echo/trig rigid cables are broken.
No sound	Check the tightness between the Arduino Mega 2560 and the Shield.
Operating System does not execute commands	Each command is numbered, the red LED of ATtiny should flash the number of times of the respective command during execution. Otherwise, check the connection.
Irregular and inconsistent sensor values	Measure the battery electric current, if it is discharged or the power supply is disconnected, there will be no current to supply the sensors.

It is possible through serial port 0, to send the number for the command to be executed, without having to perform the gesture. It only serves to debug, and verify that the connections between the microcontrollers are correct. As an example of the console output when a debug command is send it to increase the volume:

```
$ Nothing detected!
$ Command to execute: 0
$ Echo of debug input: 7
$ Debug Execute switch command 7: VOLUME UP!
```

[2]Download from: `https://github.com/digistump/DigistumpArduino/tree/master/tools`
[2]Download from: `https://learn.sparkfun.com/tutorials/how-to-install-ch340-drivers/all`

5.2 User Survey

The surveys where made in Google Forms with provides a free online questionnaire. The questionnaires were carried out after the use of the prototype, it was already properly recognized by the host computer, and installed in the tripod, and adjusted to the height of the subjects shoulders. The front area of the prototype was far from any object, with a free 90 cm radius.

Regarding quantitative results, a total of 22 volunteers subjects conducted the survey, 12 men and 10 women, between 22 and 35 years old, the summary of results are shown in table 5.3. Accepting in the same anonymous form the consent for data collection will only be used for treatment in the context of the dissertation, also the study would not contain any information that could be used to identify them.

All study participants were also asked to remove jewelry that could cause reading disruption, like watches and bracelets, only the use of rings was allowed. Also rolling up the sleeves, due to some fabrics not correctly reflecting ultrasounds.

Were presented the gestures recognized by the prototype, on the host computer screen where the experience were being carried out, and were asked the subject to perform 3 times the 8 available gestures, in a distance between 2-20 cm from the prototype, each gesture perform during a maximum time of 12 seconds. The subject could control the music that was being played in the VLC media player application, also known as VideoLAN Client, is open-source and cross-platform. Where 10 songs were randomly selected and inserted in the playlist, users could follow the result on the host computer's monitor, listen to the playlist being played, and confirm the changes that were being made.

Table 5.2: User experience survey questions

	Description
Question 1	Has the prototype an original design?
Question 2	Has the prototype a suitable size?
Question 3	The prototype is easy to use without review the instructions?
Question 4	Is the gesture recognition time adequate?
Question 5	The visual feedback is enough?
Question 6	Did you consider change your television remote control by a gesture recognition?

The questions in the survey are in table 5.2. Some criticisms were received during the survey regarding the lights, it is too strong, not only the LEDs on top of the sensors, but also the backlight of the LCD screen, as it show the figure 5.3. In a future design, the LEDs circuit resistors must be increased, and it will reduce the luminous intensity.

During individual observation, it was found that some men subjects with broader shoulders had difficulty performing gestures such as pause and play, due to the need to approach their elbows to be perpendicular to the sensor. However, was noticed that they overcame this difficulty by using the palm of their hand to activate the sensor. In the case of women subjects, it was observed that they quickly understood the concept of the performance grid, ensured the forearms were triggering the sensors, and were able to memorize the vast majority of the gesture table, without the need to review it. However both genders subjects had difficulty understanding the figures that were mirrored (play, next, previous gestures).

In the graphical analysis of the survey, as shown in figure 5.4, the low acceptance value in question 4, is due to some subjects get tired of waiting for the recognition of the performing gesture. As for the need to review the possible gestures, in question 3, most found the experience positive, however there is room for improvement, especially in the gestures that are mirrored.

In question 6, some questions have been raised about the location/installation of the prototype, to those who asked the question, it was indicated that it would be installed over the television. Which led users to protest that they would not stand up to carry out operations, that they could do sit down with a remote control.

For the hardware questions (1, 2 and 5) were very positive, most agree with the originality, size and visual information that the prototype presents.

Table 5.3: Survey results table by Questions

	Q1	Q2	Q3	Q4	Q5	Q6
Strongly agree	18	5	3	1	16	1
Agree	4	11	10	4	5	10
Neutral	0	4	5	14	1	6
Disagree	0	2	3	2	0	4
Strongly disagree	0	0	1	1	0	1

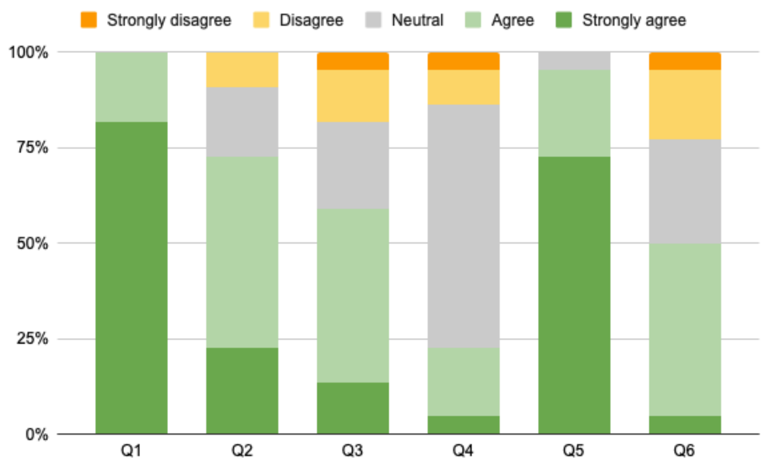

Figure 5.4: Survey graphic results

5.3 Discussion

After validate the quality of the prototype system by conducting a user test, were verified some points that are at a disadvantage in relation to the equipment's presented in the section 2.1, the *Kinect* and the *Leap Motion* are both much smaller in size and faster in obtaining the data, and subsequent gesture recognition. The *Leap Motion* having the possibility to recognize 3D gestures, the possibilities of creating and adapting new gestures

Table 5.4: Prototype Specs and results

Hardware	Prototype
Size	43 x 43 x 55 cm
Type of Source	9 Ultrasonic sensors 40 kHz
	Humidity and Temperature Sensor at 250 ms
Depth Resolution	3x3 px at 0.25 fps
Field of view	15º Horizontal
	15º Vertical
Mapping	ToF
Tracking capacity	Forearms
Tracking in focus	Forearms
Recommended Distance	2 - 20 cm
Range of gestures in Study	8 - Static
Acuracy	59.09% - 84.85%
Data Provided to the Host	USB: Execute commands Serial 0: Sensors distances, Temperature and Humidity
Consuption	2.8 w
Mininum latency	4 seconds

is enormous. In the case of the prototype, you will have a much more limited number of gestures that can recognize, and may have overlapping sensors or even ultrasonic echo sound collisions, even with different gestures.

As advantages these devices do not perform this image treatment, and recognition in isolation. But using the computational power of the host computer, and even the recommended requirements specifically for the *Leap Motion*, involves a medium-high performance Graphics processing unit (GPU) for that processing. While in the prototype, all this processing and calculation is performed in the installed microcontrollers.

Regarding security, since no system is completely safe, in the hypothetical hypothesis that the systems in the section 2.1, get compromised, the attacker may have access to the source cameras images, in the *Kinect* can capture the user's full body and in the *Leap Motion* the user's face. The *Kinect* also have microphones so the audio in the room, can be intercepted and harken. Regarding the developed prototype, in a scenario where the attacker had access to the source values, none of these attacks can compromise sensitive user data, and the only information they can obtain from the sensors will be distances, temperature and humidity.

Based on these results, it is possible to compare the results of the table 5.4 with the table 2.2 created at the beginning of the study. To obtain the accuracy results, was used the number of times the prototype correctly triggered the intended gesture, during the experiment for the user experience survey, failed attempts and false positives.

The percentage results are shown in table 5.5, where it can verify that the "mute" ges-

Table 5.5: Accuracy percentage results per gesture

	Pause	Play	Stop	Next	Previous	Mute	VolumeUp	VolumeDown
Triggered	71.21%	66.67%	74.24%	77.27%	78.79%	59.09%	84.85%	81.82%
Undetected	21.21%	30.30%	10.61%	22.73%	13.64%	37.88%	9.09%	16.67%
False Positive	7.58%	3.03%	15.15%	0.00%	7.58%	3.03%	6.06%	1.52%

ture was the most difficult to be recognized, getting 59.09% of accuracy, due to the need to have to activate more sensors simultaneously.

Although these results were obtained during the final phase of the project's development, during the time improvements were made to the algorithm, and consequently the number of false positives tended to drop significantly. The graph of figure 5.5 shows the raw data of the results, used to calculate the accuracy.

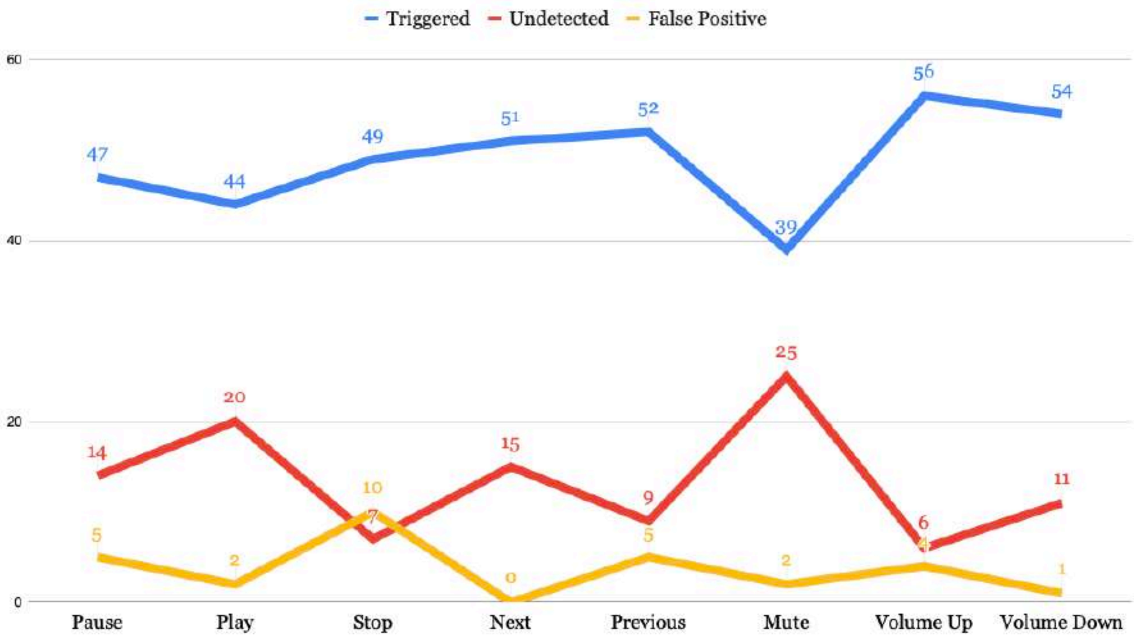

Figure 5.5: Accuracy numerical graphic results

6. Conclusion and Future Work

6.1 Conclusions

This Chapter presents a synthesis of the main achievements and points to several directions for future work.

The objective of this dissertation was initially to identify human actions in the controlled environment, however it became an recognition of a limited similar gestures previously studied and stored in the microcontroller, and triggered a recognized command on the host computer as an HID. Therefore all the dissertation objectives were successfully accomplished.

The section 3.1.2 and 3.1.3 shows some possible improvements to the response time were presented if other sensors were used, and even the possibility of using a single board for the entire project. Section 3.2 it was possible during the printing process optimize it: reduction of the filament used, adjusting the printing characteristics (temperature, speed and number of layers) and as a result a printing time decreasing.

In the section 5.2 after the user experience survey it was verified that the prototype is far from perfect, but that it has the potential to be used in the replacement of other input devices. In short the feedback received was good, and the evaluation points in the survey were answered with a positive note.

6.2 Future Works

To improve this prototype it just remains to suggest future research directions based on current work:

The current prototype only allows interaction with an operating system, by USB cable. Modifying the code of ATtiny85 microcontroller it would be possible to replace it and compile it for a HID Bluetooth device microcontroller, and this way expand the range of compatible devices (e.g. iPadOS and iPhone devices). Ideally, using only a single microcontroller board having all these features.

As indicated in the section 3.1.2 replacing ultrasound with lasers sensors would be an improvement for the response time of the command execution, and it would be translated into a better user experience.

Focusing on feedback given by users after conducting the survey in the section 5.2, to expand the prototype horizontally, having the advantage of being modular, printing a column of supports, and the respective sensors were added, in order to facilitate and allow the use of the device by users with a greater shoulder distance.

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A. Annex

A.1 RS-Components Shopping list

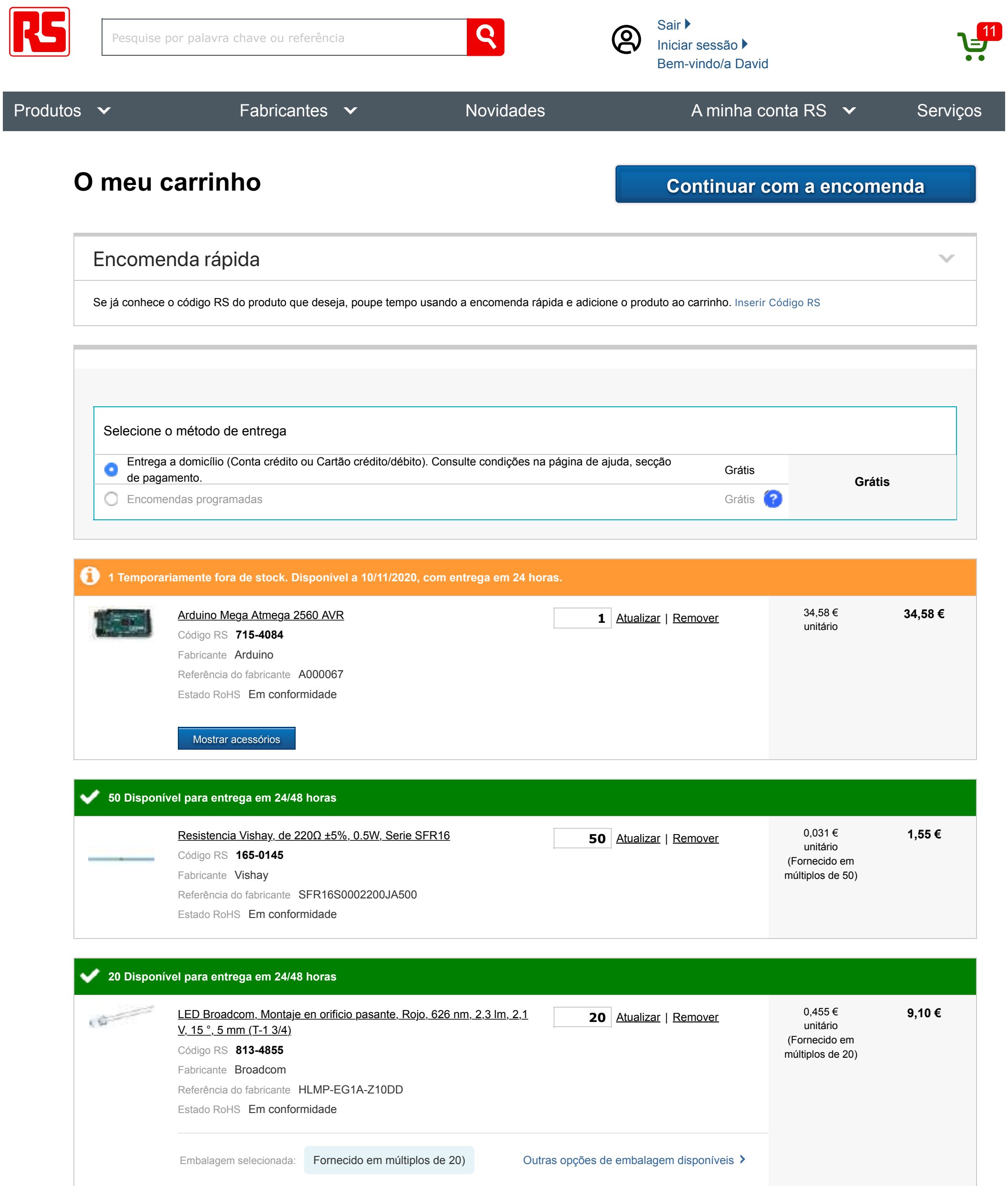
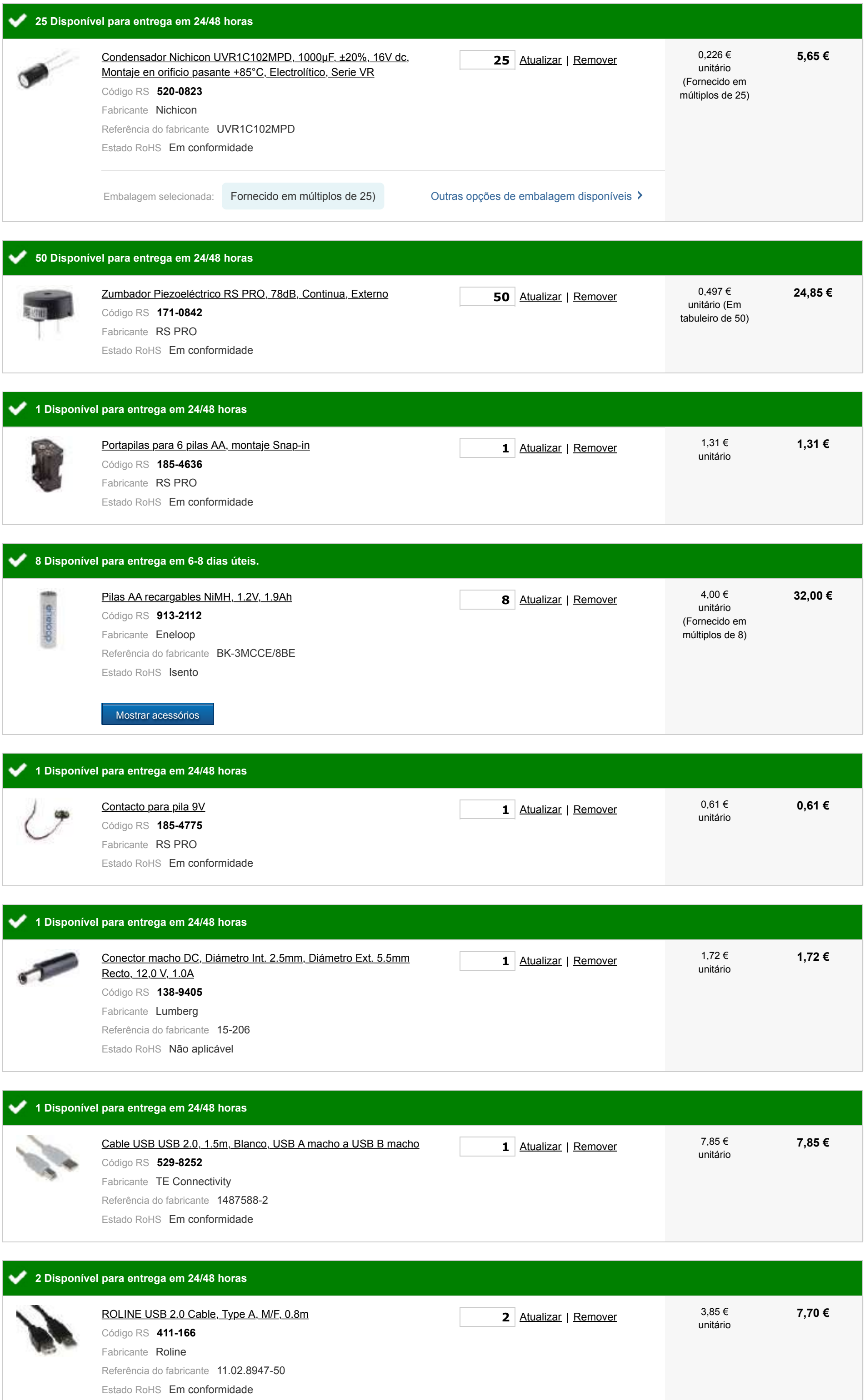


Figure A.1: RS-Components Shopping list Page 1 of 2



Disponibilidade	Produto	Quantidade	Preço unitário	Total
25 Disponível para entrega em 24/48 horas	Condensador Nichicon UVR1C102MPD, 1000μF, ±20%, 16V dc, Montaje en orificio pasante +85°C, Electrolítico, Serie VR Código RS 520-0823 Fabricante Nichicon Referência do fabricante UVR1C102MPD Estado RoHS Em conformidade Embalagem selecionada: Fornecido em múltiplos de 25) — Outras opções de embalagem disponíveis	25 Atualizar | Remover	0,226 € unitário (Fornecido em múltiplos de 25)	5,65 €
50 Disponível para entrega em 24/48 horas	Zumbador Piezoeléctrico RS PRO, 78dB, Continua, Externo Código RS 171-0842 Fabricante RS PRO Estado RoHS Em conformidade	50 Atualizar | Remover	0,497 € unitário (Em tabuleiro de 50)	24,85 €
1 Disponível para entrega em 24/48 horas	Portapilas para 6 pilas AA, montaje Snap-in Código RS 185-4636 Fabricante RS PRO Estado RoHS Em conformidade	1 Atualizar | Remover	1,31 € unitário	1,31 €
8 Disponível para entrega em 6-8 dias úteis.	Pilas AA recargables NiMH, 1.2V, 1.9Ah Código RS 913-2112 Fabricante Eneloop Referência do fabricante BK-3MCCE/8BE Estado RoHS Isento Mostrar acessórios	8 Atualizar | Remover	4,00 € unitário (Fornecido em múltiplos de 8)	32,00 €
1 Disponível para entrega em 24/48 horas	Contacto para pila 9V Código RS 185-4775 Fabricante RS PRO Estado RoHS Em conformidade	1 Atualizar | Remover	0,61 € unitário	0,61 €
1 Disponível para entrega em 24/48 horas	Conector macho DC, Diámetro Int. 2.5mm, Diámetro Ext. 5.5mm Recto, 12.0 V, 1.0A Código RS 138-9405 Fabricante Lumberg Referência do fabricante 15-206 Estado RoHS Não aplicável	1 Atualizar | Remover	1,72 € unitário	1,72 €
1 Disponível para entrega em 24/48 horas	Cable USB USB 2.0, 1.5m, Blanco, USB A macho a USB B macho Código RS 529-8252 Fabricante TE Connectivity Referência do fabricante 1487588-2 Estado RoHS Em conformidade	1 Atualizar | Remover	7,85 € unitário	7,85 €
2 Disponível para entrega em 24/48 horas	ROLINE USB 2.0 Cable, Type A, M/F, 0.8m Código RS 411-166 Fabricante Roline Referência do fabricante 11.02.8947-50 Estado RoHS Em conformidade	2 Atualizar | Remover	3,85 € unitário	7,70 €

Figure A.2: RS-Components Shopping list Page 2 of 2

A.2 Amazon Shopping list

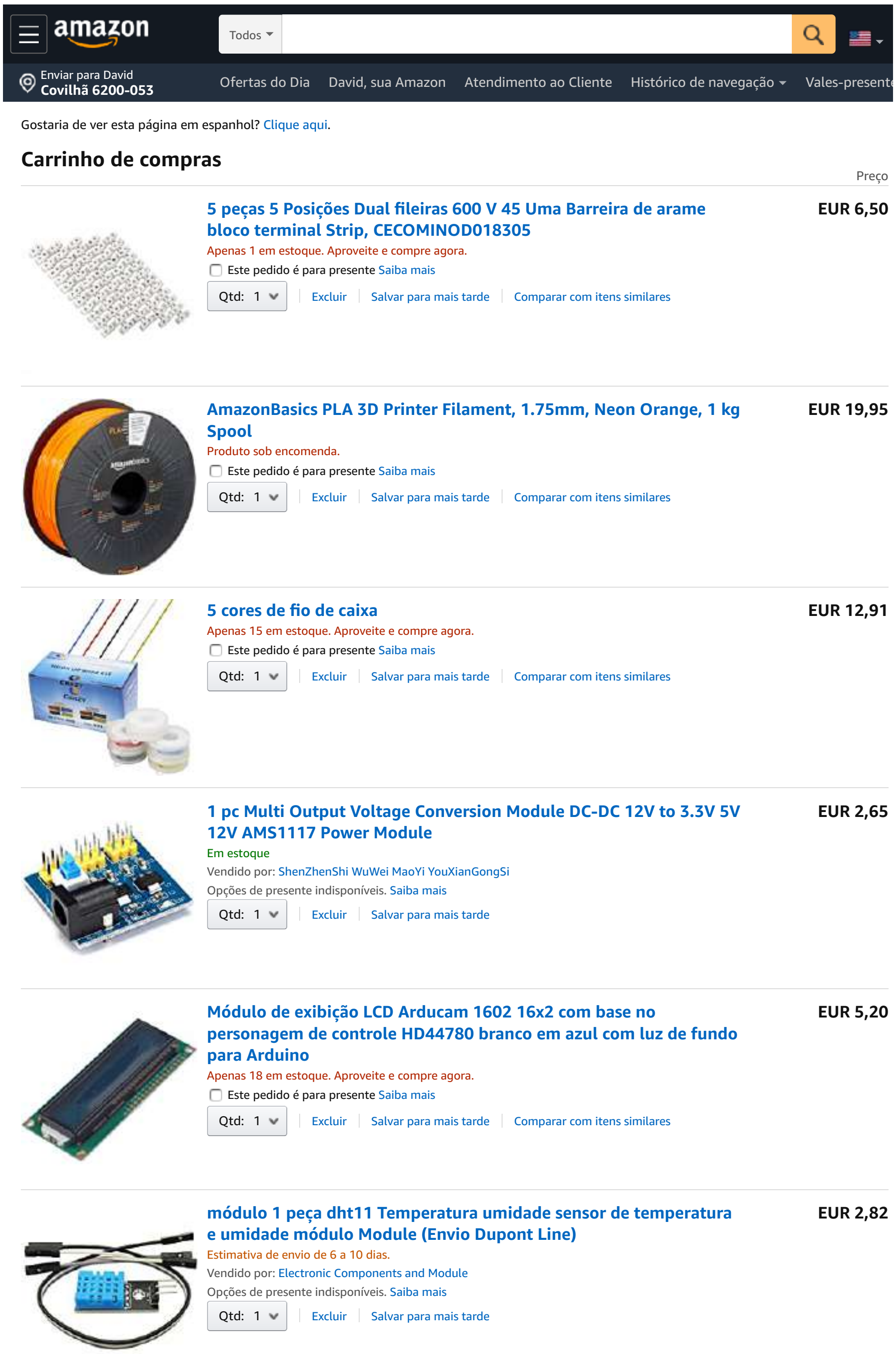


Figure A.3: Amazon Shopping list Page 1 of 2

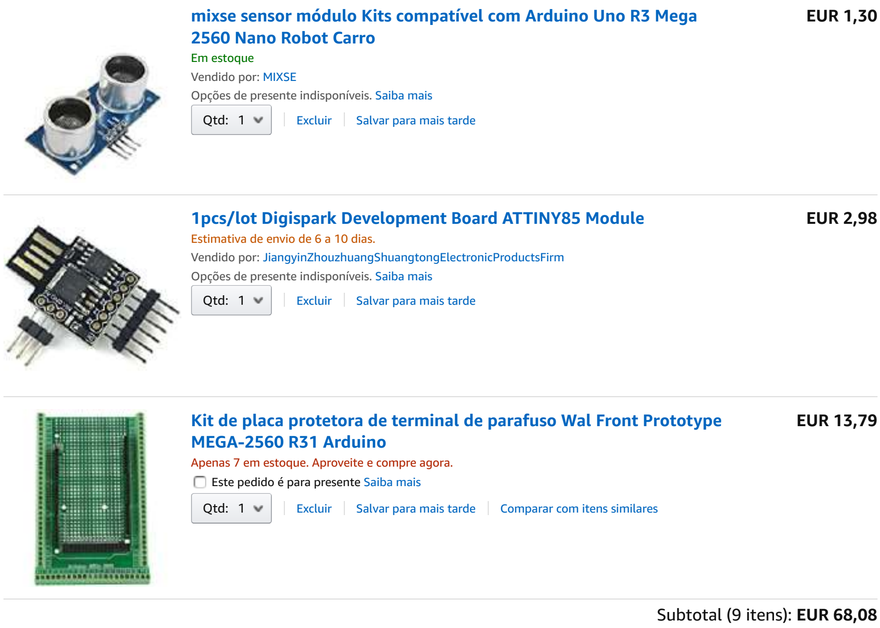


Figure A.4: Amazon Shopping list Page 2 of 2