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SCHOOL OF INDUSTRIAL AND INFORMATION ENGINEERING

Biomedical Engineering

Design and realization of a table-top robotic game for motor impaired children

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Contents

1. Abstract

Since 1950's playing has been regarded as crucial to proper child's social, personal and physical development. This applies not only to games specifically designed to educate, but also to all forms of playing, that is: "play for the sake of play".

Children with disabilities in particular seem to react in an extremely positive way, although they're often secluded from normal children's activities, and therefore are deprived of a valuable opportunity to develop and overcome some of their limitations.

Our work focused on creating a game environment for children with motor impairments and a table-top interface to play it. The game provides kid-friendly interactions and the possibility to play with another child (whether disabled or not), trying to even the participants abilities.

In this relation we explain the various steps taken to design shape and interaction of the game, prototype construction, in prevision of an eventual trial with patients. Although it may sound obvious, we would like to point out that both the design and construction were entirely carried out by ourselves and almost exclusively with our own means. Therefore, also owing to the little time or poor resources available, we sometimes resolved to solutions different from what we initially planned. This relation separates the design process from realisation, so that it is easy to understand where we had to come to a compromise or alternative solution. Also, options are compared in a future development-perspective, for whoever might like to improve our results.

2. Sommario

A partire da circa la metà del secolo scorso, si è cominciato a prestare un crescente interesse nei confronti della psicologia dei bambini. Ne è emerso che il gioco rappresenta una parte fondamentale per lo sviluppo corretto del bambino, sotto molteplici punti di vista: fisico, psicologico e sociale. Un aspetto importante di questa scoperta è inoltre che il gioco non necessita di avere uno scopo prettamente educativo per sortire il suo effetto positivo, ma può anche essere fino a se stesso.

I bambini con disabilità beneficiano più degli altri di questi effetti, ma paradossalmente, vengono esclusi da questa possibilità spesso, perdendo così l'opportunità di superare le loro difficoltà.

Il nostro progetto si propone di creare un sistema di gioco da tavolo ed un'interfaccia di gioco robotica per bambini affetti da disabilità motorie. Il gioco promuove una comunicazione costruttiva nei confronti dell'utente e fornisce l'opportunità di avere un secondo giocatore (normodotato o meno), cercando al contempo di portare i due giocatori allo stesso livello.

In questa relazione illustriamo i diversi passaggi effettuati per progettare la forma e l'interfaccia del gioco, la costruzione di un prototipo, in vista di un eventuale test con pazienti.

3. Introduction

By now there is strong evidence in literacy that play is not only a purely leisure activity, but that is fundamental to allow children develop properly. Proof of it is the decision of the U.N.O.[1] to make play a right of every child.
Playing:

- develops social, physical, cognitive, abilities;
- improves psychological and emotional strength.

What is even more interesting is that it is not necessary for the game to have a specific educational target, but also playing for its own sake serves the purpose. Moreover, there is evidence that deprivation of playing may affect negatively the child in the future.
Despite this, many children are still denied this opportunity, and this can be due to:

- living conditions (poverty, wars, exploitation ...);
- progressive emphasis on academics in schools and highly scheduled lifestyle trends in middle and upper class families [3];
- children disabilities.

Consequences of this in adulthood and adolescence may be: (only relating to the second and third classes)

- anxiety, depression and lack of self-confidence and self-esteem in general [3];
- lowered motivation, dependence on others, underdeveloped social skills with particular regards to disabled children [9].

Children affected by disabilities seem more prone than the others to suffer the consequences of deprivation of play and proper stimuli. We can define a “physical”deprivation (lack of sensory and motor information received by the child), and a “social”deprivation (secondary disabilities as an indirect result of the former). The reasons for this are various, such as physical limitations of the child him/herself, environmental barriers, and social barriers (integration with peers) [2],[3],[8],[9].

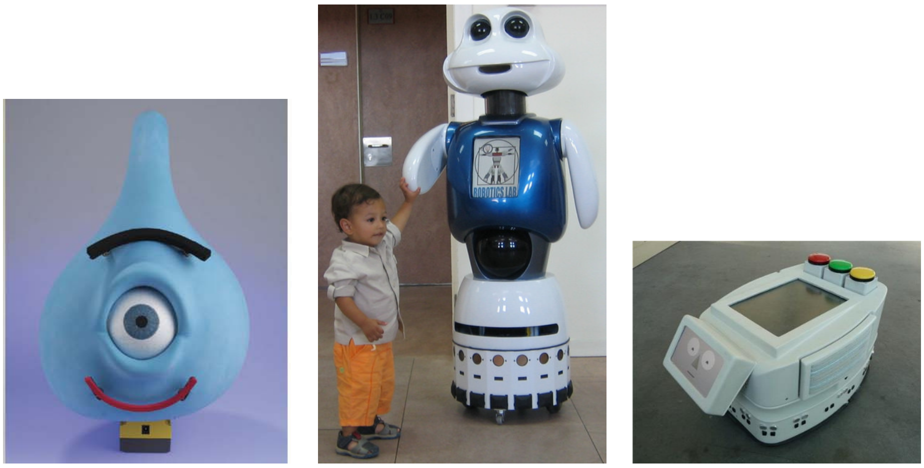
Recently, many efforts have been made to use technology to assist disabled children. Also a 4-year action supported by the C.O.S.T.[2] started in 2014 to connect experts and professionals all over Europe (from 28 countries) and spread concern, to ensure children with disabilities are granted their righteous playing. (LUDI —Play for Children with Disabilities [3]) [4].

3.1 Social Robotics

Robotics seem particularly promising in this case and have been already employed quite successfully in biomedical environment. In particular it is Social Robotics’ aim to develop a natural and productive human-machine interface to improve the quality of playing.

Some encouraging experiments have already been carried out in favour of child-robot interface rather than a bare interaction with a tablet or device (for example to measure children’s ability to develop language).

[1]United Nations Organization
[2]European Cooperation in Science and Technology
[3]http://www.cost.eu/COST_Actions/TDP/Actions/TD1309; http://www.ludi-network.eu



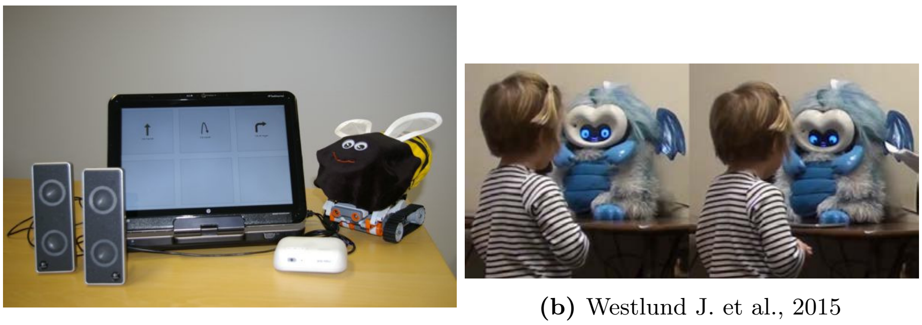
(a) Emuu: Bartneck, C., Reichenbach, J., and Breemen, A., 2004 **(b)** Maggie: Miguel A. Salichs, et al., 2006 **(c)** Van den Heuvel R. et al., 2015

Figure 3.1: Examples of Social Robots.

In fact, children generally react to the robot with more ease as with an adult, for it doesn't look as inquiring or expectant, as long as the robot is fitted with an opportune appearance (that is, it needs to be dressed up to look child–friendly). Therefore children react more enthusiastically to them as they would with simply a tablet [12],[13].

3.2 Related Studies

Social Robotics potential has been evidenced also in experiments/studies involving disabled children. Patients were mainly children affected by ASD[4], motor and generally cognitive disabilities [1],[6],[7],[10], or even diabetes [5], and much more is still in progress [11].



(a) LEKBOT: Ljunglöf P. et al., 2011 **(b)** Westlund J. et al., 2015

Figure 3.2: Examples of social robots used with disabled children(1).

Difficulties encountered by researchers were mainly:

[4] Autistic Spectrum Disorders

1. low playfulness of patients (whether due to physical impairments or to the child's mood);
2. wide range of possible impairments; that is, every patient, especially those affected by ASD or motor disabilities, has his/her own peculiar situation.

The main limitations of the above–mentioned studies (and in general, studies related to the use of social robotics in children playing) were:

1. almost exclusive focus over children with ASD, neglecting other disabilities;
2. excessive focus on the educational purpose of the game;
3. lack of possibility to play with other children and therefore improve social skills;
4. excessively complex/simplified game schemes and rules so that the game may be regarded as too hard/boring;
5. excessive/too apparent facilitation of disabled child that undermines challenge.

3.3 Concept

Playing is good for children, under many aspects of their development (cognitive, relational, psychological, social, physical ...). Although disabled children are deprived of this possibility more often than the others, it seems that playing would even be more productive for them. This project aims to verify this assumption, with particular regards to the social benefits of play for motor disabled children.

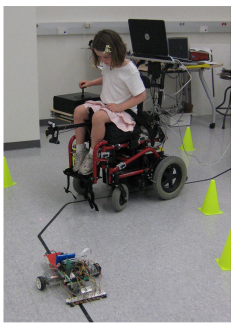
We focused in particular with children with motor disabilities, although some pathologies typically affecting neuromuscular system may also result in sensitive and cognitive issues, e.g. quadriplegia, cerebellar ataxia, hemiparesis ... In fact, up to now, the main addressees of the experiments were children with ASD, and therefore the games were designed for children who could move (in most cases) with little physical restrictions.

Little in comparison has been made for children with motor disabilities, and the employ of robotics up to now hasn't produced the same results as with children with ASD.

This has 4 main reasons:

(a) Charlie: J. Cabibihan et al., 2013

(b) KASPAR: Dautenhahn K. et al., 2009



(c) Marchal-Crespo L. et al., 2010

Figure 3.3: Examples of social robots used with disabled children(2).

1. The range and severity of difficulties in movements is very wide even among patients with the same pathology, and also because of the variety of different illnesses that can result in motor disabilities
2. Often, as the game–rules are extremely simplified to allow children to succeed, the game gets boring and repetitive very quickly. On the other hand, a game should not be too complicated so that the child can play freely
3. Low playfulness of patients (due to the difficult interface with the robot but especially due to the impossibility of playing with peers)
4. Complicated and time–expensive interface needed in the most severe cases (such as quadriplegia) e.g. Eye Tracking Devices, Sip-and-Puff switches, head wands or mouth sticks, Voice Recognition software ...

3.4 Focus on the problem

Since time was short to design interfaces able to deal with all of possible impairments, we needed first to select a specific target of patients.

Inclusion Criteria: We chose to work for children with medium motor impairments, and which do not have severe cognitive and sensitive problems (reserving the option to adapt the interface for other types of conditions, such as tetraplegic patients, at least in a future development–perspective).

Age: 7–12 years (or mentally equal in case of cognitive disabilities).

Limitations:

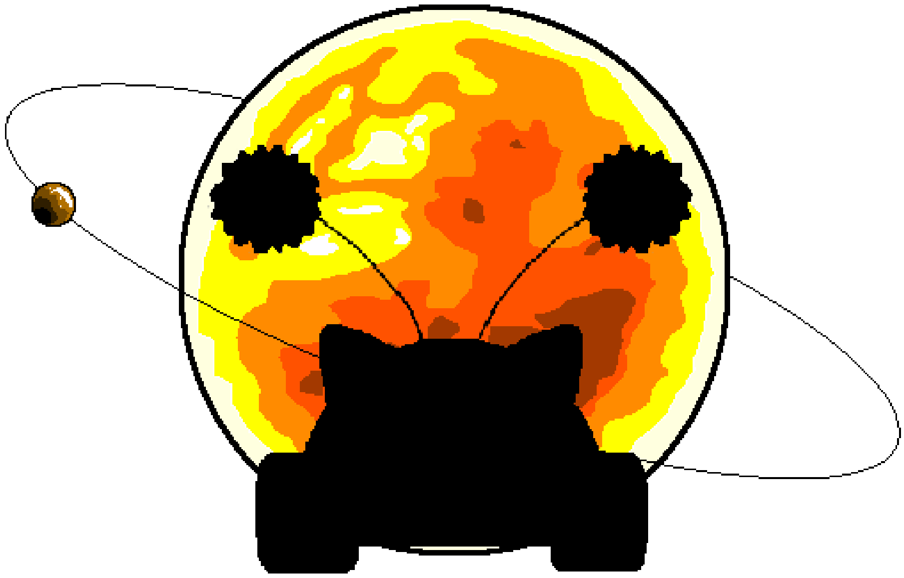
1. the child is possibly sat on a wheelchair and may not be able to move much further from it;
2. his/her movements may be imprecise and/or sudden, he/she may not be able to calculate strength;
3. child is possibly not able to speak properly and may need time to plan the movement as he/she may not hear/see perfectly.

Problems to be solved:

1. the game must not be boring after a few times,
2. at the same time, the game must be simple enough for the child to play even with difficulty in movements;
3. multi–player possibility: the child must be enabled to play with others (whether other disabled children or not) without the game looking fake (too much advantage for the patient) or impossible to win. That is, the game should provide a way to even the possibilities of each; other requirements:
4. the robot must be safe for the child to handle if he/she wishes to, and possibly be satisfactory on the sensory point of view;
5. the robot should possibly give the child feedback when playing, just ad if it was a peer itself.

4. Methods

4.1 Creation of Game/Rules



4.1.1 The Story

ESPer is a little owl–shaped alien, employed at the PIAP Inc. (Pluto is a Planet), a company based on Volcano, in a not so far extendash galaxy. His job is to keep an eye on some old satellites in the orbit of the planet Dabón. These satellites are very old and sometimes their program stops working. The way to fix them is to crash Esper's pod onto their panels. The network of these satellites is owned by Sirocco Studios, that creates cartoons for children, and therefore it is very important to keep it active. When the satellite is lighted up it means it is broken and needs fixing. If the satellite does not start working again in 13 seconds, the whole network crashes and needs a whole day to be brought back to normality. ESPer is short–sighted and needs help to do his job.
Help ESPer keep children happy!

4.1.2 The Game

We took inspiration from pinball and bumper cars to create a game in which the goal is to drive a small vehicle onto a board in order to crash into totems that are light up randomly.

The vehicle (from now referred to as Robot) is controlled by the child with a very simple joystick, while the lighting of the totem is controlled by circuitry inside the board. The board also provides a display onto which the score and time is showed, and is fit with some barriers on the borders that prevent the robot from falling out. Both the robot and the board are fit with sound/light effects to make them appealing.

Single Player Mode: every set time, the board would decide to light up one of the five totems, and the child should try to hit it as quickly as possible. If he/she succeeds before time is over, he/she scores.

The time given to complete the task is 13 seconds for the first 15 points, then 10 for the following 15 points, then 7 seconds for the last 15 points. Is the user manages to hit all of the totems, then he/she wins the game.

Two Players Mode: two children may play one against the other to reach the higher score by hitting totems more quickly. (due to little time available for design and construction, we focused only on single player mode)

In order to even the abilities of the two players, it would be interesting to program robots to randomly not execute the command from players but to go randomly around, as if it was their choice. More details about this can be find in the Robot section.

Simon-Says Mode: playing mode inspired by the popular children's play. It can be suitable for younger children, or if robot batteries are recharging, for it relies on board and joystick only. When the board sees that only the joystick is connected, it asks the user if he/she wishes to enter this mode. The user must confirm he/she wants to enter Simon-Says mode by pushing down the joystick, or wait for the robot to connect.

The game starts with a set of ten lives. The board will tell the user when the sequence is given and when is it his/her turn to repeat it. The sequence is showed lighting up randomly four totems (the one in the middle is excluded). The user must then replicate exactly the sequence shown by tilting the joystick to light up the totems. Each time the user fails, he/she loses one life. The last sequence is then re proposed. The game ends when no lives are left.

The length of the sequence is determined randomly through the following formula, depending on the difficulty.

$L_{max} = \frac{\text{Difficulty}}{5} + 1$

$L = \left\lceil \frac{1}{10} \sum_{i=1}^{10} rand\left(L_{max}\right) \right\rceil$

Difficulty increases linearly with every success in a row (that is, if the user makes a mistake, then difficulty is reset to zero).

The scoring increases as the number of successes in a row: for example, if the user gets three sequences correct in a row, he/she will receive 1 point for the first, then 2 for the second, then 3 for the third. If the user makes a mistake, the score for the following success drops back to one.

4.2 Controller

The controller represents the most interactive part of the game, for it is the connection that allows the child to express his/herself. We developed a few ideas that should cover a wide range of possible impairments, but due to lack of time, we chose only to develop one of them.

4.2.1 Joypad

Controller with 3 very large buttons that order the robot to accelerate forward (middle button), or to spin to the left or right (left and right buttons).

The joypad may be set on the table with the board or secured to the wheelchair armrests using straps.

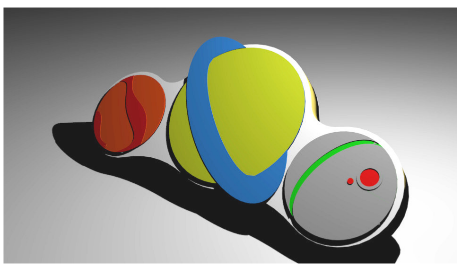


Figure 4.1: 3D render of the joypad

Advantages: this type of controller offers the possibility to patients affected by distonia or spasms to drive the robot without accidentally hitting the wrong buttons. It also can be decorated easily and provided with sounds or lights to make it more appealing, since it is quite large (approximately 50cm wide)

Disadvantages: not suitable if the patient is unable to reach the correct position to press the button (because of spasticity or paresis) or if is very weak, so that he/she tires easily. This controller was not developed because of lack of time and materials needed.

4.2.2 Accelerometer Wrist/Head Band

Wearable controller that can be tied to the child's wrist. The controller is simply an accelerometer and a control circuit that allows the patient to spin the robot on the left or right by swinging the arm (in this case the robot moves forward by itself).

Advantages: useful for patients who cannot reach the joypad/joystick or are too weak to push the buttons.

Disadvantages: may be still not useful if patient is tetraplegic or affected by spasm and sudden movements. Moreover, the use of accelerometers requires an accurate signal analysis. This is especially true when considering the filtering needed to adapt the interface to the movements of the patients, which can be imprecise, jittery or discontinuous.

Therefore, because mainly of lack of time, we chose not to develop such a controller, but it stands as a future development, in the perspective to create multiple interfaces that can cover the widest range of possible impairments.

In the case the patient is tetraplegic, the controller can be adapted to fit on the forehead too (just as if it was a head wand), but in this case the patient may get tired easily.

4.2.3 Joystick

Very weak children may not be able to swing/push the controller long enough to play effectively. If they have sufficient control over at least one upper limb, it is possible to create a joystick. It is sensitive enough to allow the patients to drive the robot without tiring, and has four positions: forward, backward, left and right. There should be also a ON/OFF switch and a slot for batteries. Joystick and its shell are smaller than the joypad and can be positioned where the patients can reach it without difficulty (using straps).

Advantages: can be fit onto wheelchair's armrests, just like normal controls of a scooter. These patients are very practical in driving their scooters and therefore they should fare well with such an interface. It does not need strength.

Disadvantages: the patient needs control over one arm at least. Therefore it is not suitable for tetraplegic or distonic patients.

We chose to develop the joystick for it looked more immediate, since it resembles a well–known interface for wheelchair driving patients.

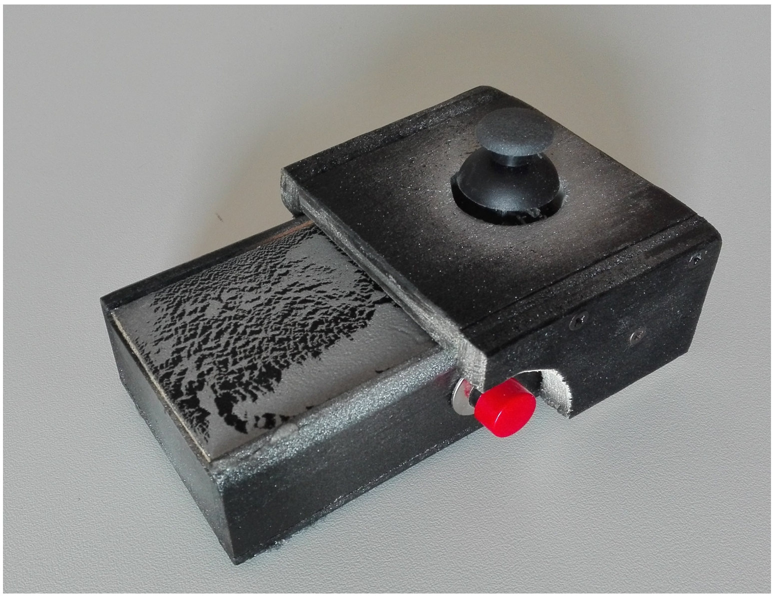


Figure 4.2: Realized Joystick.

4.2.3.1 Mechanical part

The shell provides protection for electronics, support for the joystick and on/off button, and access to battery slot. The shell was realized partly modifying a wooden box, and partly by building pieces ourselves. The shell should not be too large as it needs to be placed ideally besides the wheelchair's armrests, and should not hamper the child's movements. The lid of the shell is made up of two parts:

- a sliding part that can be easily moved and allows to change batteries (which is the part the user should have access to);
- a fixed part that covers circuitry and provides support for the joystick, button and LED. This part can be removed by screws, so that control unit program or circuitry can be modified, but should not be accessible to children.

The joystick is secured to the fixed lid with screws.

4.2.3.2 Electric part [1]

Requirements of this part are:

- provide power;
- interpretation of the inputs given by user (direction of the robot and pause);
- transfer data to board and receive from it (or from/to robot);
- give sensory feedback on the state of the controller;

The circuitry is powered by 3 regular 1.5V AA batteries, provided with their battery slot. We made this choice basing on the ease to find the batteries, size, and possibility to recharge them. Control unit (ESP12) receives right input voltage from 3.3V regulator (AMS1117), that also provides power to Op–Amp (LM378)

[1] For the electric scheme, see Appendix A; for implementation information, see section 4.6 and Appendix E

and analog MUX (PC74HC4053) [2]. The choice was made mainly on order to give the ESP a regulated tension, that should remain stable for a while also when the batteries start running out.

Since the FSR (Full Scale Range) of the ADC on control unit is only 1V, a trimmer connected to the actual joystick reduces power to proper value. The joystick consists of two potentiometers (one for axis and one of y axis), each a $5k\Omega$ resistor. The trimmer value is decoupled by a buffer, then given as input to the actual joystick (which is standard for ARDUINO interfaces). The outputs are given to the MUX, which is controlled by ESP12 that selects inputs from the two axes alternately. Output is then given to ADC input of ESP. The decoupling by the buffer is necessary for otherwise the tension given to the MUX would not depend only on the potentiometers, but also on the. This way we ensure a stable voltage supply for the potentiometers. The joystick also provides a button (which is activated by pushing the joystick down). This input is given directly to ESP and serves as a "everything button ", allowing the user to pause and resume the game, even if he/she cannot reach the everything button on the board.

The circuit is switched on by a spring button switch connected directly to the battery slot. A red LED light signals when power is on, and a RGB LED (blue) signals when the ESP is online. The frequency of the blue LED flashing identifies the state of the controller at the moment:

- idle —doing nothing: off;
- scanning —searching for available networks: slowly blinking;
- connecting —attempting connection with suitable server on the network: fast blinking;
- standard game mode —connected to board and ready to play: alternatively fast and slow (this does not change when game is paused);
- standalone mode —directly controlling the robot: no blinking.

4.2.3.3 Positioning

In order to place the joystick comfortably, we realized a strap (made out of Velcro), that can be tied to the wheelchairs armrest. A complimentary Velcro is glued to the bottom of the joystick shell in order to ensure adjustment of the positioning.

There are two possible configurations, depending on the mobility of the child: the strap can be either wrapped around one armrest (for example, behind the scooter controls), or fastened across the space between the two armrests, so that the box can be placed in the middle. With this system, though sacrificing some stability, we ensure a wide range of positions that can be reached by the patient.

4.2.4 Virtual Interface [3]

In order to test and debug the game while work was still in progress, we created a graphic interface that can simulate both the totem system (with display) and the joystick. From this interface we created a simplified version of joystick that could be used to adapt the controller to different users. By creating an actual virtual controller, the child has the possibility to use his/her own tablet or laptop to play. Patients with most severe restrictions are often provided with personal computer interfaces (e.g. to drive wheelchairs) and a controller application would represent an immediate and flexible approach in order to broaden the range of suitable users.

[2] For more information about ESP, see section B.3

[3] For implementation information, see section 4.6 and Appendix E

4.3 Robot

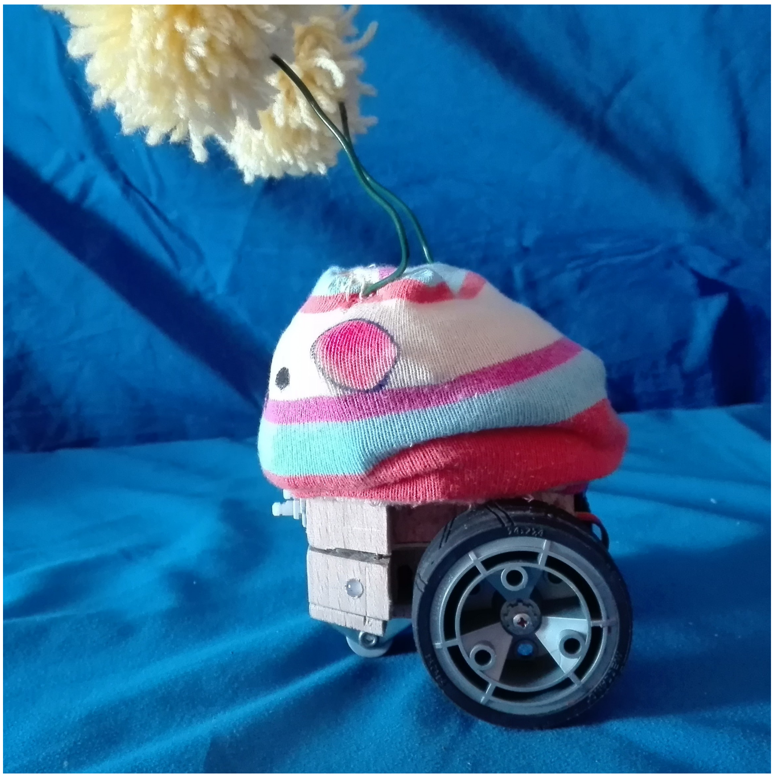


Figure 4.3: Realized Robot.

The second most interactive part of the game is represented by the robot (ESPer). If the controller allows the child freedom of expression, the robot is the part that deals with him/her as a peer. [4]
It consists of three main parts:

- frame (that supports and protects the circuitry and shell), and wheels;
- electronics: batteries, regulation circuitry, lights, motors, control unit;
- outer shell (or “head ”) that can be decorated to form a personalised“outfit ”and provides further protection for electronics;

It receives instructions from the controller through wi-fi connection. The wireless network developed allows the child to control the robot with the controller independently from the board: if the robot sees the board activated, it connects with it and the game can start (standard game mode), while if the board is not active (its network is not on), the robot can used alone (stand alone mode). We chose to create also this second mode in order to allow the child to use the game even when the board is charging batteries, or if the board set-up is made difficult, due to its dimensions. In this mode the robot can be used on the floor as well.

The batteries are accessible by removing the outer shell from the top of the robot. To prevent the user from touching the circuitry inside, the batteries are stored in a separate section of the robot and only the connectors are accessible. Ideally, the best approach would be to have the batteries placed on the bottom and removable

[4]For implementation information, see section 4.6 and Appendix E

using their own slot, without having to remove the outer shell. This was not done due mainly to lack of material.

Moreover, the robot needs to be small enough to move freely on the board (approximately 7cm in diameter). The problem of the size is particularly pressing when approaching the corners of the board, for the space left between edges and totems is very narrow. This is due mainly to the size of the wheels. To reduce the effect of this, the robot is programmed to stop progressing while the bumper is pushed. That is: the robot ignores the command “forward ”while it is pushing against and obstacle and only turns on the spot to avoid it.

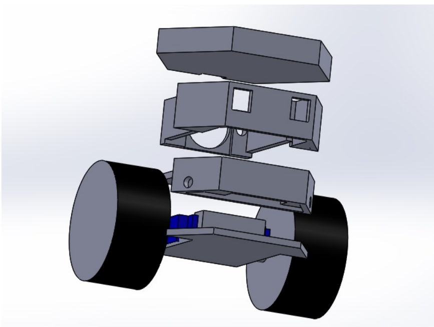
4.3.1 Frame

The frame is made up of four layers (from top to bottom):

- Battery slot —ensures that the user’s only contact with batteries is through the connectors pinned on the wood;
- Circuitry slot —accommodates all circuitry and it is connected above to batteries and below to motors. Also lodges rear LEDs, ON/OFF switch and bumper structure (micro switches with plaques on the outside);
- Motor slot —used to store the two motors, which are secured to the wood to ensure stability, and front LEDs;
- Bottom layer —serves as lid for the stack and as a base for a small spinning wheel that allows the robot to be balanced.

Sections are carved in lightweight wood and secured by screws, the shape is hexagonal, inscribed in a circle approximately 7cm in diameter. The mask is set on top of everything. The strict detachment of compartments is needed both to minimize the eventuality of accidental electric contacts and to increase stability. The motors are actually servomotors that have been modified so that they can spin at 360°. This is due to lack of time, poor information supplied by data–sheets on online markets, and cost of components. This arrangement causes the two motors not to spin at the same rate, so that it may be useful to verify that this problem does not affect manoeuvrability too much. Anyway, considering the size of the board (70cm) and placement of totems, the robot needs not to move on straight line for more than 30cm, so that we can accept some deviation without the game to suffer from this.

On the other hand, an advantage of using servomotors is that speed con be selected directly from the control unit, with no need for a driver.



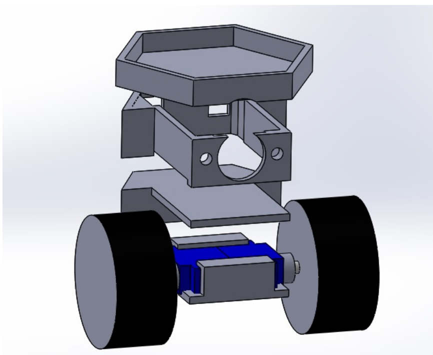


Figure 4.4: CAD models of the inner structure of the robot.

To simplify the game, we chose to set the wheels only to spin at one speed, both clockwise and counter-clockwise. Steering is achieved in two different ways, depending on the inputs from the controller (in this case, the joystick):

- by blocking one of the wheels, so that the robot turns while progressing (either forward or backwards). This corresponds to tilting the joystick to upper/lower left and to upper/lower right;
- by spinning the wheels in opposite directions, so that the robot turns on the spot. This corresponds to tilting the joystick to the left or right;

4.3.2 Electronics

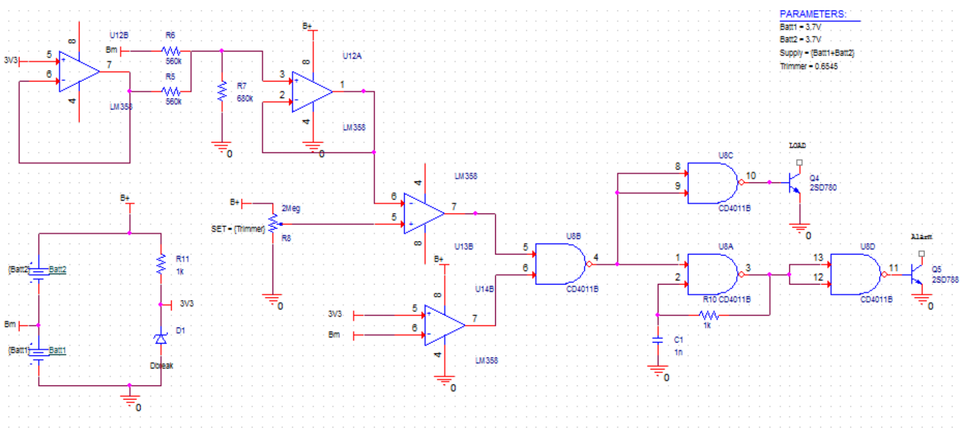


Figure 4.5: Electric scheme of robot circuitry

The robot is powered with two 4.7V LIPO batteries, and can be switched on/off through a switch on the rear part. We chose to use LIPO batteries because, although more expensive, they are rechargeable and —compared to the alternatives (such as Stilo) —provide a better “power-to-bulk ”ratio, for they are lighter and smaller than the others. The control unit (ESP12[5]) requires 3.3V input voltage, given by the same regulator used in the controller (AMS1117).

The circuitry also provides a way of monitoring the voltage of the single battery through two triggers. When one of the two batteries drops below a threshold (set at 3.3V), the circuit cuts them off from the rest of the more power-consuming electronics (such as motors), preventing degeneration of batteries. The circuit provides connections between motors, LEDs, and bumpers, and ESP12 as well as access for programming.

The circuit was designed entirely by us and printed as PCB by a Chinese manufacturer.

4.3.3 Head

The role of the outer shell is mainly decorative, but is it also useful to dampen impacts and protect the inner part. In this case, we gave Esper a colourful look to appeal kids, and to ease realisation but also more “technological”outfits could be considered, such as space saucers etc. This is particularly true if we consider the possibility to play with another child, so that the two ESPers are recognizable. The shell consists of a papier–mâché mask under a painted striped tissue cover fitted

[5]For more information about ESP, see section B.3

with an elastic band. There are also a couple of antennae that can be bent as one pleases fixed on the head. These were realised in metal wire and wool. Ideally, the outer shell could also provide sensory feedback for the child, in case he/she wishes to handle it. This requires also the frame to be robust. Unfortunately, we had to neglect this side, due to lack of time/materials but especially owing to the need to continuously revise the circuitry and programming. Therefore the head is designed more to be easily removable (also because the batteries are accessible only from above) than to be sturdy.

4.3.4 Interaction and Feedback

Being responsible for an important part of interaction with the patient, it should have a range of sound/lighting effects.

- green and red LED lights (2 couples) that signal the state of the robot, like they are used in the controller;
  - **idle** green on, red off;
  - **scanning** searching for available networks: green on, red slowly blinking;
  - **connecting** attempting connection with suitable server on the network: green on, red quickly blinking;
  - **standard game mode** connected to board and ready to play: green and red alternately blinking (this does not change during the pause);
  - **standalone mode** directly controlling the robot: green and red both on.
- Buzzer that emits sounds when the robot crashes, etc. We decided to delegate this part to the board as well, for the RPi can control the buzzer more efficiently than the ESP in the robot, providing more effective interaction, although sacrificing realism.

In a future development perspective, it was our intention to give the robot the possibility to disobey the user's commands from time to time, and randomly act on its own decision. This should not be as if openly helping the disabled child (in case the other player in not disabled).

It also should give the impression that the robots have actually their own will, but are not capable of doing thing on their own, so that the child perceives that he/she must help them (in the story, we justify this by saying that ESPer is short-sighted). We believe this is very important to develop self-confidence and social skills.

The sounds from the robot are provided by the board, and they are divided according to the situation in which they occur: [6]

1. entering the game from main menu;
2. resuming the game from pause menu;
3. scoring (hitting the totems);
4. running out of time (last 5 seconds of time allotted, when the totem starts flashing);
5. failure (not hitting the totem in time, or not hitting the right one in Simon-Says mode);

Figure 4.6: Realized board with totems.

4.4 Board

The board offers mechanical support the robot and totems, as well as central control unit and Wi-Fi network connection. Also, it provides lighting and sound effects to the whole interface and it is decorated accordingly to the theme.
It consists of three main layers:

- top layer, that can be open to operate on inner circuitry, and in which there are holes for the totems and for the removable boundaries. It is punctuated with white LEDs to mimic a starry sky, and it is covered by black plastic to simulate background;
- middle layer, that creates the room for inner circuitry and power supply and creates the connection between the sections;
- bottom layer, that provides basis for the totem mating and onto which middle layer is secured.

The display for scoring is located on the sides, as well as LEDs signalling the state of game, ON/OFF switch, and the "everything button". On the top there are also small holes that show the battery charge (being located above the battery pack).

The board was designed to be divided in four quarters that could be disassembled and transported more easily. The pieces are not the same size because of the middle totem: it would have been extremely difficult to create the basis for the mating if we had had to split it into fourths.

When assembled the body is 70x70cm wide and the thickness (mostly made up by middle layer) is about 5cm.

The sections are made out of lightweight wood and plastic and are connected with each other:

- mechanically (through wooden nails);
- electrically (through 4 channel 3.5mm jack plugs);

[6] See also section B.4

In order to ease the use of the game, all the circuitry and control unit (Raspberry Pi or RPi[7]) are located in the largest plaque (the one with two totems), from now referred to a “main section ”.

The main section contains also a battery pack and a pin (micro USB) to access it. This ensures the RPi to receive its proper input voltage (5V) and that the board can be recharged without extracting batteries but simply by plugging in the main section.

Moreover, this way the entire game could be played with power provided directly from electric distribution (for the battery pack does not need to be disconnected to be recharged, unlike LIPO batteries).

There is also another jack input to connect to game to an audio system (e.g. headphones, speakers . . .). The board on its own does not provide sounds if not connected to external device. Since it is lacking its own volume regulation, this allows the user to adjust it to his/her own preference, or even to exclude completely the audio.

The main section receives information from all other game components (robot and controller) via Wi-Fi, and from the totem via cables.

We chose Wi-Fi over other type of connections (e.g. Blue-tooth) for:

- ESPs and RPi provide built-in Wi-Fi connection;
- Wi-Fi connection is supported by a wide range of devices: laptops, tablets, cellphones . . . while others may not always be.

The drawback is that this kind of procedure is more energy consuming compared to Blue-tooth, for example. The RPi is responsible for collecting this information, processing it and sending it back.
These processes include:

- detecting the impacts between totems and robot;
- updating the score and reset when needed;
- lighting totems;
- counting time to the next target;
- transfer information from controller to robot;
- management of display;
- management of sound effects[8] (when connected to output).

The implementation needed in this process is extensive and so we describe in a separate chapter[9]. Battery pack, RPi and circuitry are secured into their positions by screws and metal bands. All pieces contain the basis for the mating with the totems (described in the totem section).

The board also provides some boundaries to prevent the robot from falling off the top. They come in the form of wooden planks (5cm wide) with hinges that allow them to be folded and stored. They are secured to the top layer by wooden nails as well.

[7]For more information about Raspberry Pi, see section B.1
[8]See section B.4
[9] See section 4.6

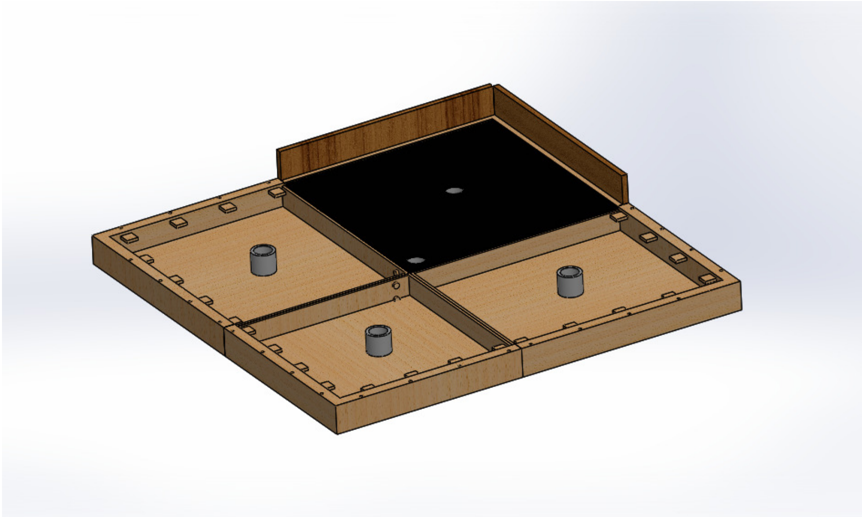


Figure 4.7: CAD of Assembled board with detail of section.

4.4.1 Display [10]

The display is a LTC4727G 7-segment common cathode, with four digits and seven points. It is controlled directly by ARDUINO UNO[11], that receives serial instructions from RPi. This is because, having many processes concurrently running, the Raspberry Pi does not manage to control the display most effectively, so that it tends to flicker quite visibly if directly controlling the display.

Apart from keeping track of the score and time countdown, the display is also used as a way to give more information about the game state and to improve appearance, contributing to the "space adventure "atmosphere.

For example, the display shows "FlipperBot "sliding from right to left in the main menu, or "LOSE "when time runs out, as well as some animations in between the various states.

4.4.2 LEDs

There are three lights:

- ON/OFF LED —red light signalling when the board is turned on;
- Player LEDs —two yellow LEDs lights, one for each player. The state of game is represented by the frequency of flashing:
  - LED is off —both controller and robot are not;
  - LED is on, no blinking —both robot and controller are online, ready to play standard game mode;
  - LED slowly blinking —robot is online, but not controller;
  - LED blinking fast —controller is online, but not the robot.

4.4.3 The "everything button"

The big round button besides the ON/OFF switch allows the child to:

[10] For details on implementation, see section 4.6 and Appendix E
[11] For more information about ARDUINO, see section B.2

1. start the game —by pushing once from the main menu (that starts automatically when turned on and to which the player returns in case of loss);
2. pause the game —by pushing once from the game session. This stops the countdown and disconnects the robot;
3. resume the game —by pushing once from pause menu;
4. return to main menu —by holding the button 3s at least during pause.

All of these passages are supported by the change in music themes [12].

4.5 Totems

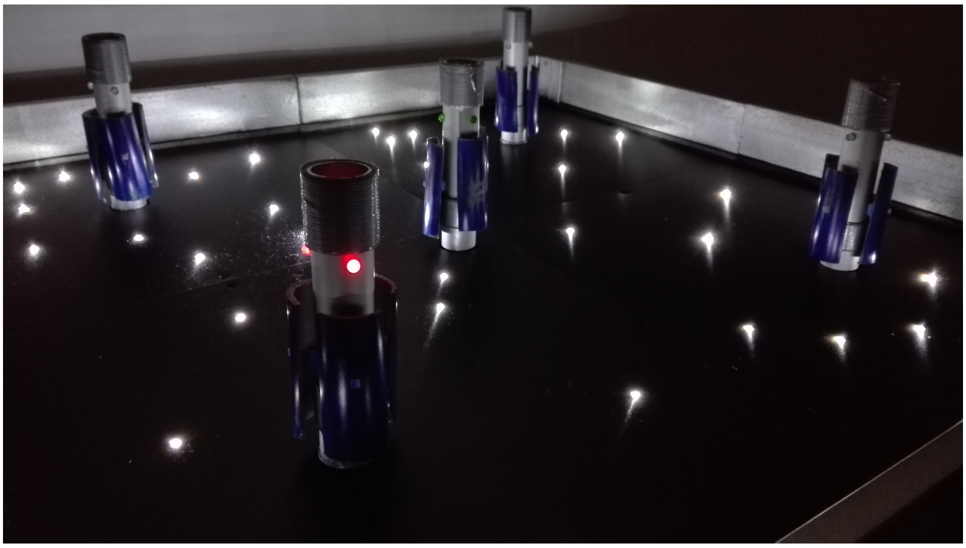


Figure 4.8: Realized Totems.

Totems are the targets into which the robot must crash in order to score.

They consist of cylinders containing the light set and switches (to detect impacts through plaques). The outside of the cylinder be decorated accordingly to the theme (e.g. as a satellite as we chose). In order to move the game more comfortably they are designed to be easily removable from the board.

4.5.0.1 Mechanical Part

The core consists in aluminium cylinders (inner diameter 2cm). On the lower part of the core, there are three tough plastic plaques. The plaques transfer impact to the switches to which there are connected.

On the upper rim of the core three LEDs are positioned in the upper half of the structure and provide colour and feedback (two sets are blue, two are red and one is green).

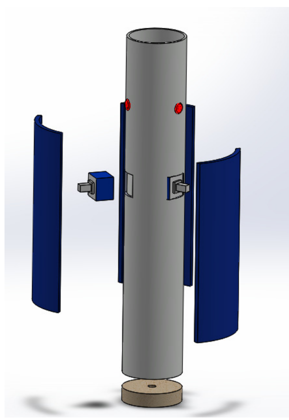


Figure 4.9: CAD model of the struction of totems.

[12] See section B.4 for more information

4.5.0.2 Electric Part

LEDs sets signal the totem that is active in that moment, and blink when the target is hit. The target blinks faster and faster as time left runs out. In the menu mode, totems are lit in a circle, waiting for the user to push the "everything button".

Lighting is controlled by the board onto which they are plugged, so totems do not need complex circuitry. The electronic part includes the contacts for the switches and LEDs (which are lighted up by RPi through a simple pull-up resistor) and power supply. [13]
The choice to defer the control of the lighting to the board is preferable for:

- there is little space to work with inside the totem;
- allows saving of materials;
- allows to modify easily the connection if needed by operating only on the main section (for the board collects everything there).

4.5.0.3 Mating

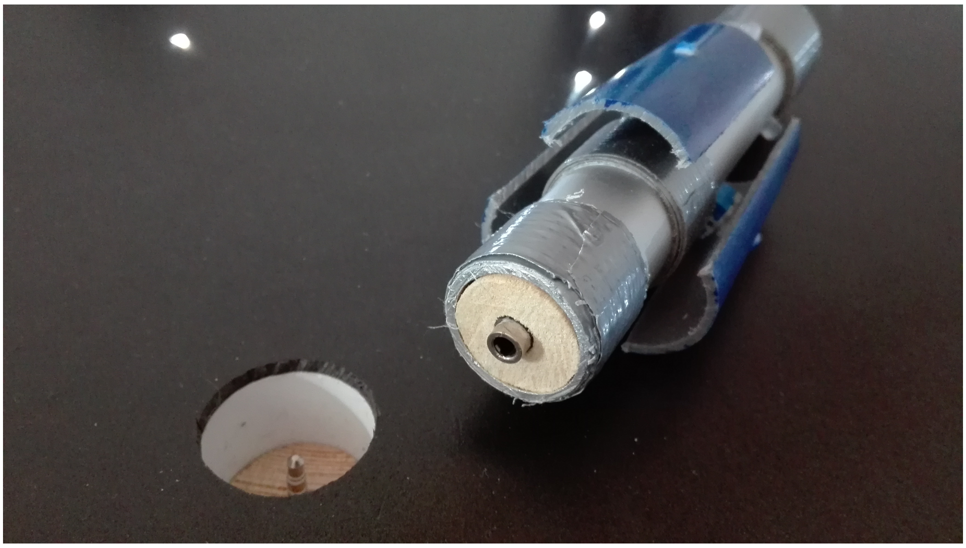


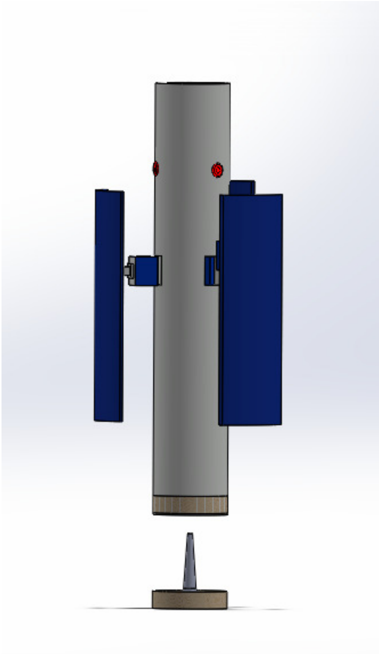
Figure 4.10: Detail of realized totem base and mating.

The mating provides ease of use, mechanical stability, electronically safe connexions. These are ensured by using the same 4 channel 3.5mm jack plugs as used to connect the board sections. They are stiff enough to ensure the totems do not tilt when hit by the robot. Moreover, they are quite a common component, so it is easy to find and replace them if needed.

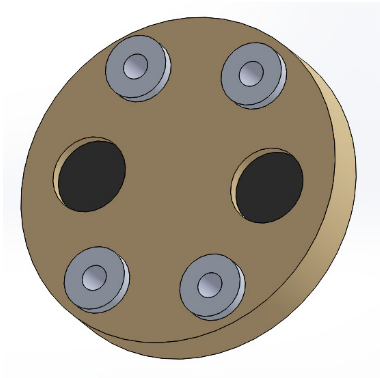
Further stability is provided by a cylinder of though plastic secured onto the bottom of the board, that prevents tilting and accidental contact among other wires in the board section. The complimentary plug is glued to a wooden disc from which the wires are gathered to be sent though connections to the main section.

In a future development perspective, it would be interesting to develop a mating system that should allow the child to insert the totems him/herself. We designed

[13] For the electrical scheme, see Appendix A



(a) Model of totems with mating



(b) Detail of the magnetic contact plaque.

an alternative based on magnets: two complimentary plaques would be fixed to the totems and board bottom. They would contain:

- **Magnets**: 2 small button magnets (6mm diameter) with opposite polarity. When totem is connected, only appropriate orientation (corresponding to the complimentary magnets on the board) would allowed;

- **Electric contacts**: The connection would be provided by small screws and flat nuts for two contacts, while for the other two contacts it would be possible the magnets themselves.

On the board the corresponding plaque would be secured to the bottom layer. The plaque is lightly raised so that wires from the contacts can be gathered together and transferred to the pins, as with the current solution.

We tried to realize one of this plaques, but we had significant contact losses, especially when the totem was hit, for it tended to tilt and rotate. This is due to the facts that the magnets were not perfectly in contact, and also to the not exact alignment of the nuts. This is mainly dued to the availability of technical means we had, since this mating requires such a precision we cannot reach with manual construction alone.

On the other hand, this development is potentially very interesting, since the child is provided with the possibility to assemble part of the game him/herself, and guided in a way that does not seem to facilitate him/her excessively (for the intervention of magnets is less apparent than, say, guiding lines traced on the core that point to the right orientation). This is very useful to give the child self confidence in his/her manual ability.

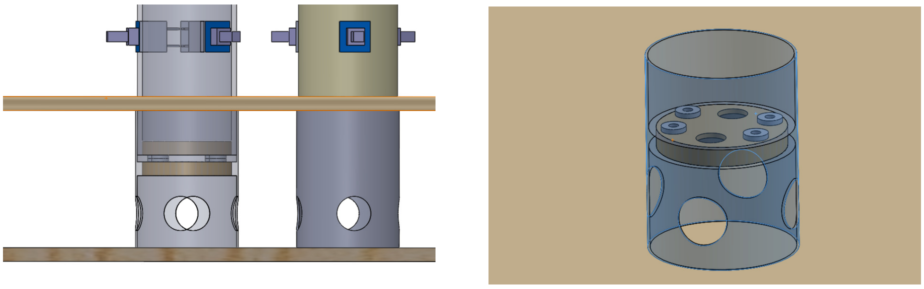


Figure 4.12: Detail of the magnetic mating.

4.6 Software

In addition to designing and building the physical parts of this project, a considerable amount of work was put in developing the software needed to make the various devices operate as wanted.

The main programming languages used were C++ and Python, with some utilities written as Bash scripts.

Snippets of the code contained in this project can be found in Appendix E, together with examples of use of the various tools.

4.6.1 Scheduler Module (ScheMo)

Both the robot and the controller (as will be clear later) need to execute multiple tasks simultaneously to work properly, however the ESP8266 includes only a one-core CPU, allowing for only one process to run at a time.

The SDK[14] available to be used with the Arduino IDE[15] implements a simple scheduler to allow the correct functioning of the WiFi communication while the main program runs. Unfortunately, the related API are hard to use, badly documented and their use is discouraged by the developers.

For these reasons, we developed our own scheduler, written in standard C++ and thus compatible with various platforms other than the ESP8266. It is, however, only a barebone implementation useful for this specific application but lacking of various features common to modern schedulers.

4.6.1.1 Control flow

To better understand how ScheMo simulates parallel processing, we first have to define some of its terminology[16]:

Job it represents a single (pseudo-)process that can be started, stopped, paused and resumed at will. Different processes are represented by different jobs.

Task it's a continous, non-interruptable part of a job; that is, the scheduler can switch control from a job to another only after a task of the first job has terminated and before the next task starts. This means that it is vital to split jobs in as many tasks as possible and to make sure that tasks always halt (this condition is not required for jobs)

[14]Software Development Kit

[15]Available at *https://github.com/esp8266/Arduino*

[16]Note that these definitions are specific for ScheMo and do not necessarily correspond to the meanings that the same words have in other contexts of Computer Science

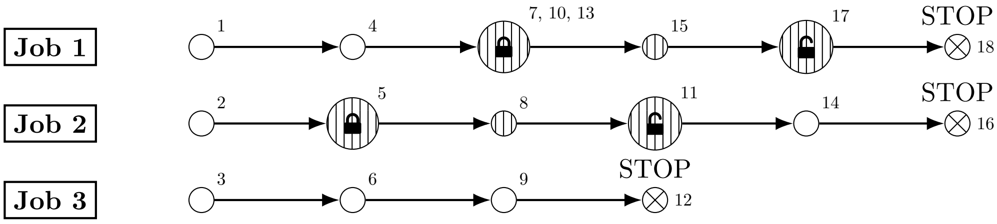


Figure 4.13: Example flow diagram of a ScheMo program.
Each job has a distinct flow diagram, where tasks are represented by circles.
The padlocks indicate if a mutex is locked/unlocked inside a task and they delimit the critical sections of the program (the same kind of hatch means that both critical sections refer to the same mutex).
The small numbers near the tasks show the order with which they are executed, alternating between jobs and remaining stuck at the start of critical sections when the related mutex is busy.

Function it's similar to a job in that it can run concurrently with other processes, but it has some important differences:

- it can't be scheduled by itself, it must instead be called inside a job (that passes control to the function until completion[17])
- when called, it can accept parameters that change its behaviour
- once finished, it returns a value that can be used for subsequent computation[18]
- multiple instances of the same function can be run at the same time without conflicting with each other

Cycle it represents the order of execution of the various tasks. The name comes from the fact that, at any one time, it only contains a small portion of the tasks necessary for the program and its content is updated by a loop inside the core function of the scheduler.

ScheMo manages execution of tasks in a very simple way: it has a loop that, at each iteration, cycles through all started jobs and adds the current task of each to the Cycle (potentially skipping some jobs if they are locked[19] or defined to be run less often) and then proceeds to execute them. Once all jobs have terminated, the scheduler stops[20].

A new job can be started by informing the scheduler of its first task and asking for it to be executed.

Each task, then, must tell the scheduler what the next task in the job is before terminating (this process can be automated by `schemop`[21]).

ScheMo also incorporates a system to manage shared memory between jobs by using mutexes.

A mutex is a dummy variable associated to a block of memory that keeps track of whether or not that block of memory is being used by some job. A job that wants to access that data must make a request to the related mutex, with two possible outcomes:

1. the mutex changes state from *free* to *busy* and the job continues its execution

[17] Asynchronous function calling has not been implemented yet
[18] `void` functions are not implemented as of now
[19] See below
[20] It is therefore important to schedule at least one job before starting the scheduler
[21] See 4.6.1.2

2. the mutex remains in the *busy* state and the job locks until the mutex is freed

To allow other jobs to use the same resources, a job must free the mutex once it has finished accessing the data.

See Figure 4.13 to see a graphical representation of how ScheMo operates.

Note: ScheMo's management of shared resources is very basic and it is not able to prevent deadlocks or other similar problems related to mutexes.

4.6.1.2 ScheMo Preprocessor (`schemop`)

Even if the C++ library offers various functions and macros to ease the writing of a multithreaded program, complex applications still result in hard-to-read and cluttered code.

To avoid this, we developed a custom preprocessor (`schemop`) that lets the developer write a cleaner code, focusing on the control flow of each job without worrying about defining the various support variables and functions that make the program run smoothly.

`schemop` is written in Python and offers a list of directives[22] that can be used in the source file in place of ScheMo's C++ macros or more complex statements.

The preprocessor also tracks all used jobs, tasks, functions and related variables, automating their definition and initialization.

Lastly, `schemop` allows the management of shared memory by defining *critical sections*, blocks of code that need to access a particular resource. This way, the developer need not to worry about defining, locking and unlocking mutexes since the preprocessor automatically generates the right code to do that.

It is however worthy of note that only statically defined jobs and tasks can take advantage of the full capabilities of this tool, since it can not reliably predict runtime behaviour. ScheMo allows dynamically created jobs and tasks, but mixing `@`-directives and normal macros is an operation that necessitates a clear understanding of the library and the preprocessor.

Once the source file is given to `schemop`, the latter converts it to a standard C++ source file, ready to be compiled normally with `g++` or any other C++ compiler.

For an example of ScheMo's features, see Appendix E.

4.6.1.3 ScheMo Profiler

A deeper understanding of the structure of a ScheMo program and the way it is executed can help in its design and optimization.

Because of this, we created a tool (called ScheMo Profiler) that can analyse the program both by looking at the source code and at run-time[23]. The result is a `.profile` file, a text file that is both human-readable and easy to parse automatically.

ScheMo Profiler isn't made of standalone programs but it is a set of optional features built-in in both the ScheMo Preprocessor and the ScheMo C++ Library.

When used in conjunction with the ScheMo Preprocessor, it:

- counts the number of jobs, functions, tasks and mutexes used
- assigns a name and ID to each job, function and task for additional analysis
- builds a flow graph of each job and function

[22] See Appendix C

[23] The current C++ implementation of the profiler uses the `ctime` and `cstdio` libraries, not available in all platforms. Some useful information can still be gathered by using it on the computer used to develop the software instead of the real device.

If the profiler features have been enabled during compilation, when the resulting program is run it records in a `.profile` file (either an already existing one or a new one) data about how the scheduler executed the various parts of the program. Each time the scheduler passes control to a different job, in fact, it adds to the file:

- the ID of the currently running job
- the ID of the task the job is currently on
- a timestamp[24] of when control is passed *to* the job
- a timestamp[24] of when control is passed *away from* the job

Using this information it is possible to:

- reveal superflous pieces of code that are never accessed
- decide whether or not it is convenient to merge or split certain tasks based on their running time
- identify bottlenecks in the program execution
- recognise errors in the structure of the program
- etc...

As of yet, no memory-related profiling has been implemented.

We also created a tool called SCHEMOTEX (and in particular the Python script `smp2tikz`[25]) that converts ScheMo Profiler's `.profile` files in LaTeX `.tex` files, making it possible to visualize the whole program and more intuitively analyse its structure. Figure 4.13 and the diagrams in Appendix E are examples of SCHEMOTEX's output.

4.6.2 Network topology

FlipperBot is made of different devices that need to communicate among themselves and for this reason they have to be connected in a suitable network. In particular, the devices can be connected in different ways depending on the current mode: standard game or standalone.

4.6.2.1 Standard Game Network (SSID starting with `FlipperBot-Board-`)

In game mode, the board acts as access point for all other devices and all communications go through it.

In particular, in this mode controller and robot are not directly connected, instead there is a client-server connection between controller and board and another one between board and robot. This way, the board is able to block or modify the commands given by the controller before sending them to the robot, as suited to make the game work as expected.

The first connection is also used to manage the Everything Button on the controller.

Another client-server connection exists between the robot and the board to allow the transmission of impact information.

See Figure 4.14

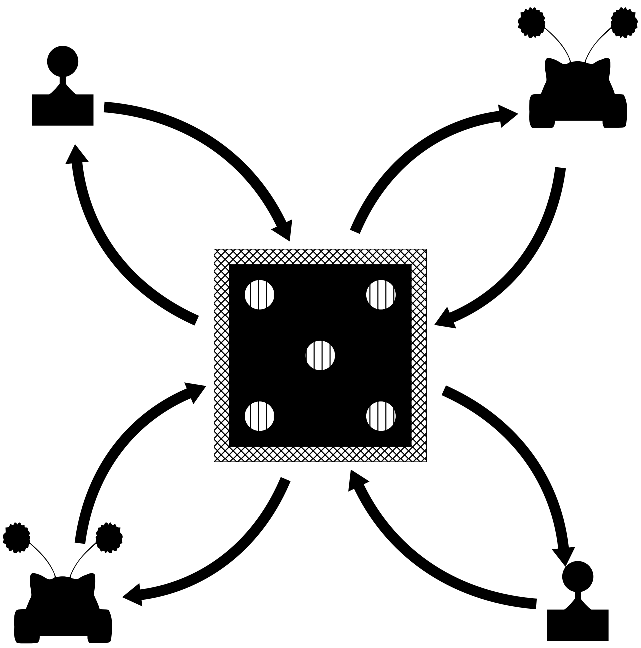


Figure 4.14: Standard Game Network

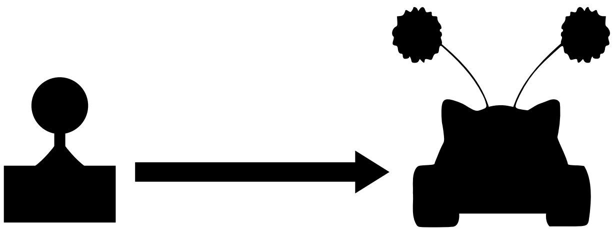


Figure 4.15: Standalone Network

4.6.2.2 Standalone Network (SSID starting with `FlipperBot-Robot-`)

When no boards are available for connection, a robot can become an access point to create a new network.

A single controller can join this network and create a client-server connection with the robot, directly controlling it.

See Figure 4.15

4.6.2.3 Isolated Network

In the case in which neither boards nor robots are available, the controller simply doesn't connect to any other device while waiting for a suitable network to appear.

The board always uses the game mode, broadcasting the network SSID[26] to make its presence known. Robots try to connect to a game network if they can find it, otherwise they get into standalone mode. Controllers connect to whichever suitable network they can find, giving priority to the ones created by a board.

In some cases, a WiFi network can exist and be accessible while it is already *full* (all devices of the previously defined topologies are already present). Such cases are managed by FBCP[27] and lead to changes in topologies.

4.6.3 FlipperBot Communication Protocol (FBCP)

In order to create the above networks and share data through them, all devices must use a common language to communicate. For this reason, we created the FlipperBot Communication Protocol (FBCP for short).

It is a plain-text, application-level protocol in which each packet is made of:

- a command identifier
- zero or more[28] mandatory parameters separated by spaces
- trailing data that can contain optional parameters but is often ignored
- a newline character (`0x0A`) to end the packet

The various FBCP commands are divided in the following groups:

- **generic**: common commands that can be used with other groups of commands
- **network building**: manages requests of permission to join a network and grant/denial of it, in addition to changes of network topology
- **robot** and **controller**: commands specific for communication with robots and controllers
- **debug**: utilities to thelp in the development of new FBCP-compatible software

[24] Milliseconds elapsed since the program was launched.
[25] PGF/Ti*k*Z is a LaTeX package used in the output files to visualize the graphs
[26] Service Set IDentifier: the *name* of the WiFi network
[27] See 4.6.3
[28] The exact number is dependent on the command

To make the use of this protocol as easy as possible, we developed a C++ library and a Python module that implement it.

These tools, however, are only concerned with the creation and parsing of correct FBCP packets, completely ignoring how the device should react to them. In fact, a program that uses FBCP need not implement all supported commands but only the ones it is supposed to use, giving an error for everything else.

The C++ library and the Python module are also built so to be easily extendible, making it simple to add new commands to the protocol.

A full list of currently supported commands with a short description of each can be found in Appendix D.

4.6.3.1 Controller modes and options

Given the wide range of possible controllers that could be used with this game (the ones described in this text being only a part of them), it can be useful to also have different ways of managing the sharing of information between controller and server (whether it's a robot or a board).

To this end, it's possible to set or unset certain *options* for the connection, flags that indicate if certain modifications must be applied to the normal way of communicating. As an example, for the accelerometer-based controller described in 4.2.2, an useful option could be one that removes the need for the controller to send a command to make the robot go forwards, having the server assume that that is the desired direction when no command is sent.

Other than being set or unset, options can, if needed, take a particular value, making them more generic and versatile. There could be, for example, an option called `timeout` that contains information about how long the server should wait for a command before considering the controller disconnected.

In the case that there are many options to be set or unset for the correct use of a controller, it's easier to use *modes*. A mode is nothing more than a predefined collection of options, with their set/unset states (and their additional values if needed) already decided.

Enabling a mode is in no way different from setting the individual options one by one from a functionality point of view, but:

- it is quicker
- it requires fewer package exchanges
- it makes it possible to modify the options needed by the server to make a particular controller work without editing the code of the controller (if the name of the mode doesn't change)

A server isn't required to support all possible modes and options, so a controller should:

1. try to select all suitable modes, from the one that allows the best performance to the worst
2. try to set the necessary options one by one, if the previous point failed
3. fall back to the standard way of communicating (with direct robot or motor commands) if the available options aren't sufficient

4.6.4 Robot

Table 4.1

a
b
c

Table 4.1: CIAO

4.6.5 Controller

4.6.6 Board

4.6.6.1 `demo` module

4.6.7 Virtual controller

4.6.8 Utilities

4.6.8.1 Projects management

4.6.8.2 Makefile

5. Method Evaluation

Some of these tests either would require too long time or cannot be performed due to difficulties in organisation (e.g. too small a sample to have statistically relevant results). We propose here some ideas to verify our assumptions, but unfortunately was not possible to carry out them all.

Since we chose to focus on realization, we tried to finish the projects by the time given, neglecting a proper planning of measures of success and tests.

5.1 Proposed tests

5.1.1 Tests During Realization

Battery Regulation Circuit Accuracy

The regulatory circuit should disconnect robot batteries only when power supply drops under 3.3V.

Accuracy could be tested by monitoring at various inputs the outputs of the two triggers (separately). The inputs would be provided by connecting the batteries (individually) to a trimmer and regulating the tension to the circuit. It should be calculated standard deviation and RMS of error (as the difference between the tension at which triggers are activated and 3.3V)

Impact Detection

Switches on the robot as well as on the totems should be effectively pushed (except very slow ones) and signal should reach the board at every impact. The board itself should recognize as effective only simultaneous impacts on both robot and selected totem (with a minimum lag).

Impacts would be simulated on separate parts: robot (1), totem(2) and between the two of them (3). These would be given randomly (e.g. totem, totem, totem/robot, totem, robot, totem/robot etc.) and we record the counting of the programs. We would define accuracy as the percentage or recognized impacts over the total. Robot and totem should recognize respectively (1) and (2) type of impact, while the board should recognize and update score only with type (3).

$Accuracy = \frac{\#Recognized\ impacts}{\#Total\ impacts\ given}$

Wi-Fi Network Robustness

The network among robot, board and totem should be robust to interferences from other sources (such as nearby computers, cellphones etc.). To test this requirement we would count the logs during the game on the various components and check at the end of the match the number of misunderstood packets.

The protocol created should minimize this problem for every time a packet is sent there has to be an answer for the receiver, and if there is not, the packet is sent again. Since the network is simple and does not need to protect possibly private information, there was not need to provide it with protection from possible hackings.

5.1.2 Tests After Realisation

Measurement of time played (in minutes)

For the same person, trend in playing time over sessions should be calculated (if the game is not boring it should not be negative);

For the two populations (single and double player) the playing should be tested to be significantly different (our thesis is that double player population should have a longer playing-time).

Measurement of the percentage of active interaction of the child in the conversation (not necessarily speaking)

$PAIT(Percentage\ of\ Active\ Interaction\ Time) = \frac{T(active\ interaction)}{Total\ time}$

For the same session, difference in mean PAIT between the registrations taken before and after every session should be checked (our thesis being that if the child is happy with the game, the active interaction time should be longer after sessions).

For the same person, we also should calculate trend, as with playing tome. Our thesis is that is the game is boring, trend should be negative, for the child may loose enthusiasm.

The same considerations for the two populations as B.1 can be applied here to verify if double player extendash mode is more effective in promoting social skills. In this case the coefficients in the trend of PAIT after game session should be confronted.

Questionnaire

Questionnaire should be possibly with some numerical responses (such as "How would you rate the child's enthusiasm for playing with others? From 0 (no enthusiasm at all) to 5 (very eager to)"). However, the rating here are personal ad rather qualitative, and probably should be used only to support statistic results.

5.2 Performed tests

Motor Coordination

As previously said, motors on the robot are actually modified servomotors. This may undermine the required synchronism. Therefore, we decided to test both coordination between wheels and, for the same wheel, coordination between clockwise rotation (from now CW) and counter clockwise rotation (from now CCW).

Protocol: The procedure for the evaluations is here described:

1. it was recorded the period of rotation (in s) for each wheel for both CW and CCW, for 1 minute of observation;

2. to test normality of the four populations, an Anderson Darling test was performed;

3. for the same wheel, it was performed a T-test (in case the distribution resulted normal), or a Wilcoxon Test (in case the distributions deviated from normal) to verify the means of CCW and CW to be equal;

4. for the separate wheel, the same test as above were performed, in order to verify the coordination between left CW and right CCW (forward) and left CCW and right CW (backwards);
5. box plots were drawn to exemplify conclusions for each of the four tests;
6. the same passages were performed after removing outliers using Chauvenet's criterion.

Data were acquired using a Python program written by us to analyse video clips of rotating wheels. The program used red colour marks placed on the centre and on the rim of the wheel to determine in which frame a rotation was completed. Knowing the frame rate of the camera (50fps), it was possible to estimate period of rotation, and the maximum error of measures (20ms).

Results: Observations were:

- for left wheel: 74 CW (no outliers), 81 CCW (10 outliers);
- for right wheel: 60 CW (1 outlier), 87 for CCW (1 outlier);

Unfortunately it appears that motors are not well coordinated. None of the distributions appeared normal, and the situation did not improve after removing outliers. P-values were all in the range of 0.05%.

Also, it appears that the distributions medians are significantly different, and this applies both to the comparison of the same wheel CW and CCW rotation, and in the comparison of the opposite wheels.

Observations and Conclusions: It can be inferred that the scarce quality of the result can be ascribed to a consistent slowing in the rotation as time passed by, as shown in the graph above.

Nevertheless, since for the purpose of the game the robot does not need to move in a straight line for 1 minute, this does not affect the use of it too heavily. In conclusion, we can say that modified servomotors do not make a suitable substitute for regular motors, although it is not so patent during the playing of the game.

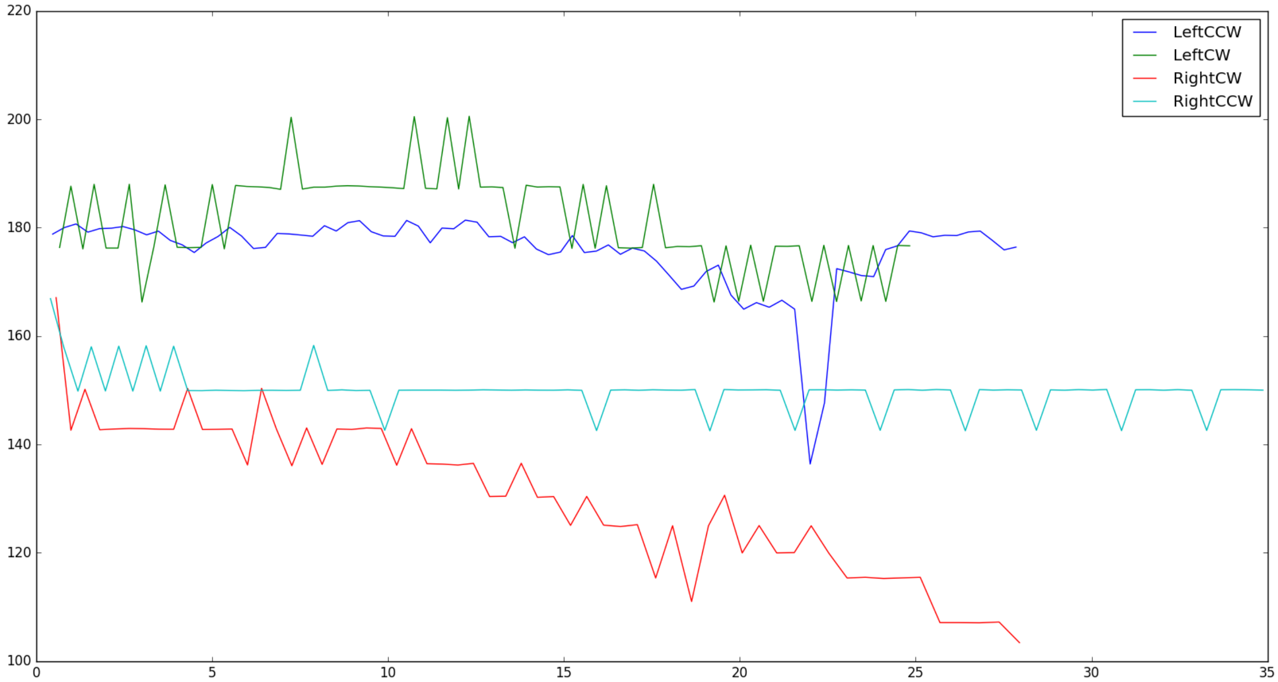


Figure 5.1: Plot of the periods of rotation for each sample.

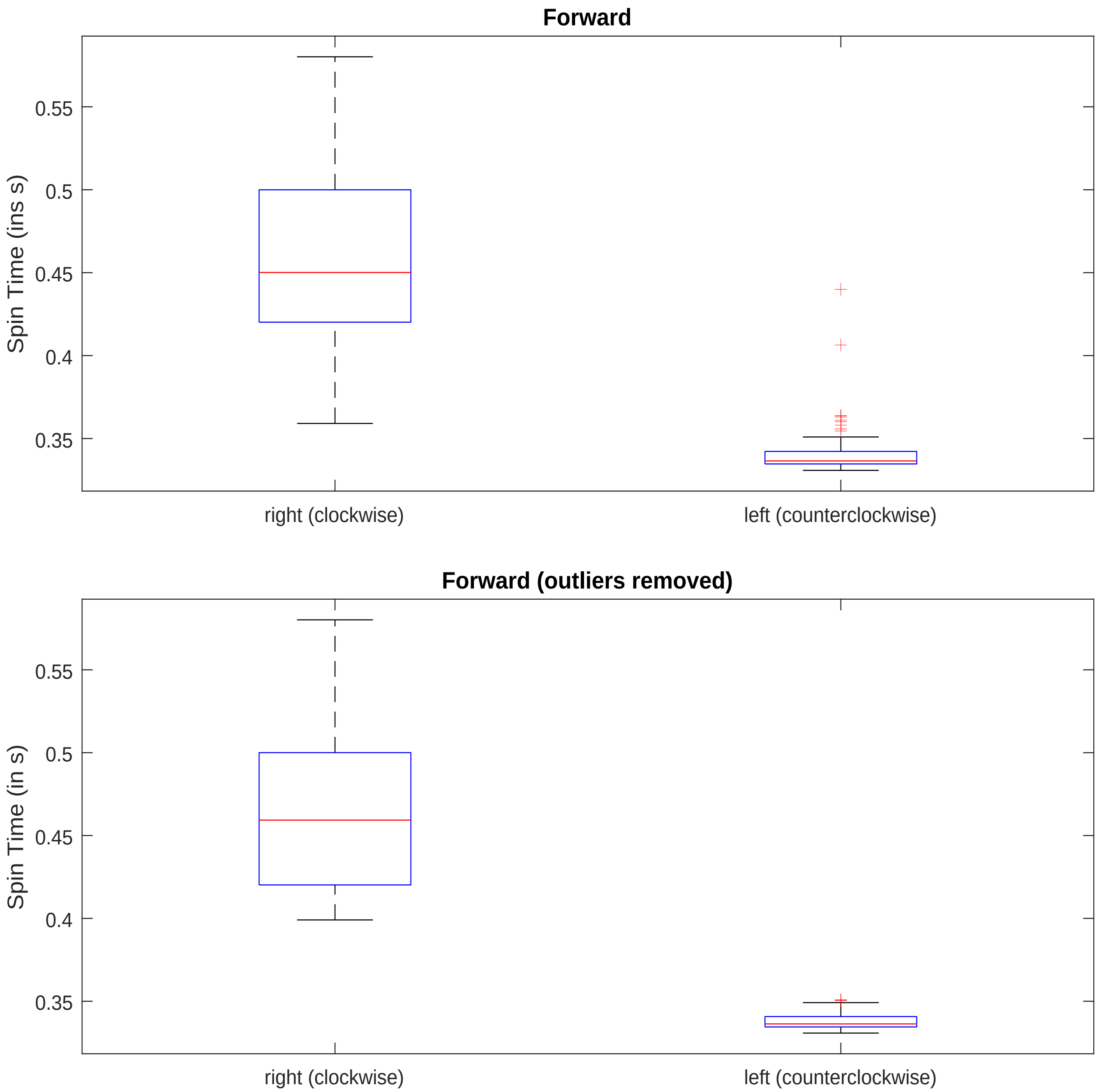


Figure 5.2: Boxplots of rotation for forward progression.

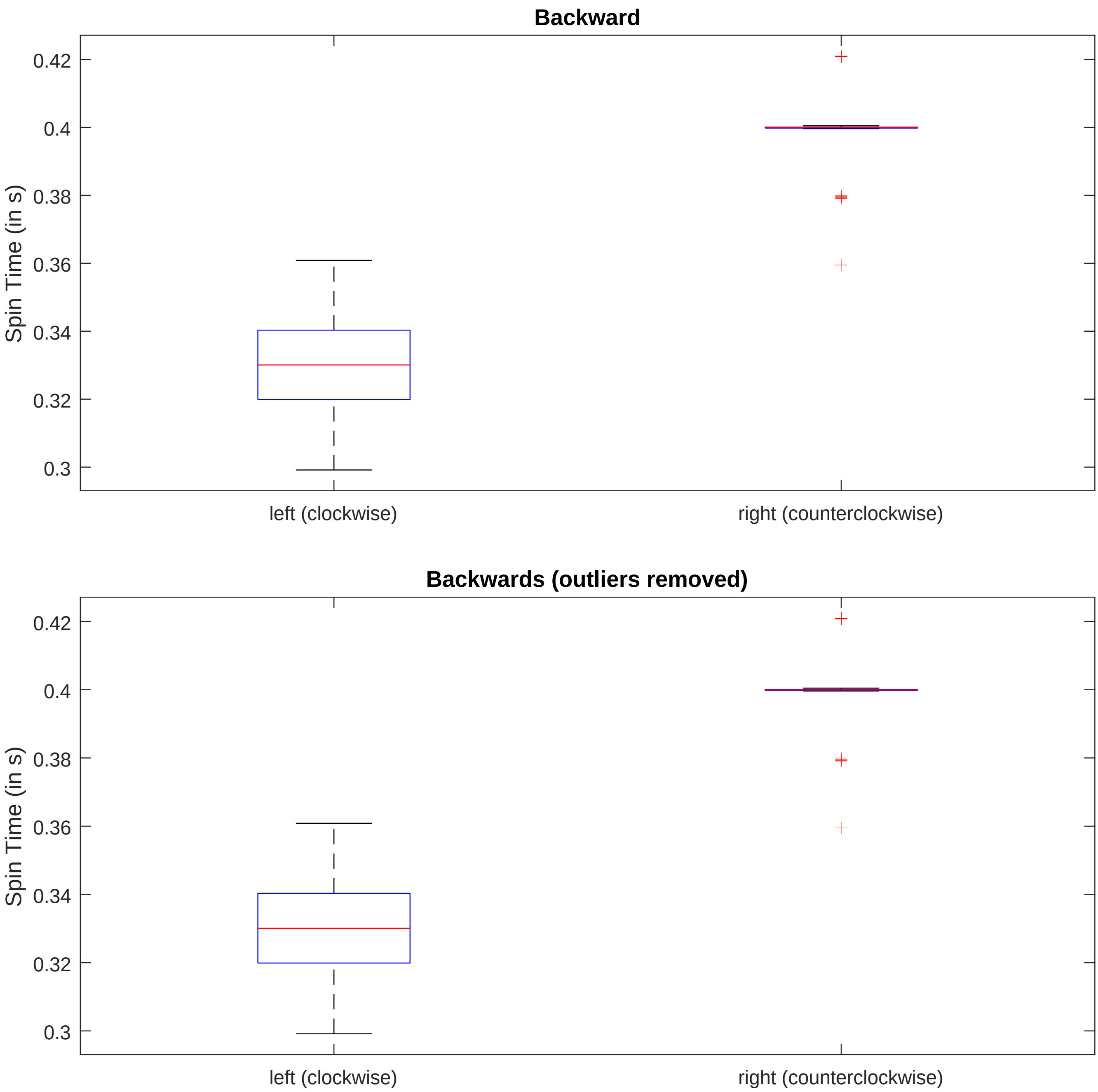


Figure 5.3: Boxplots of rotation for backward progression.

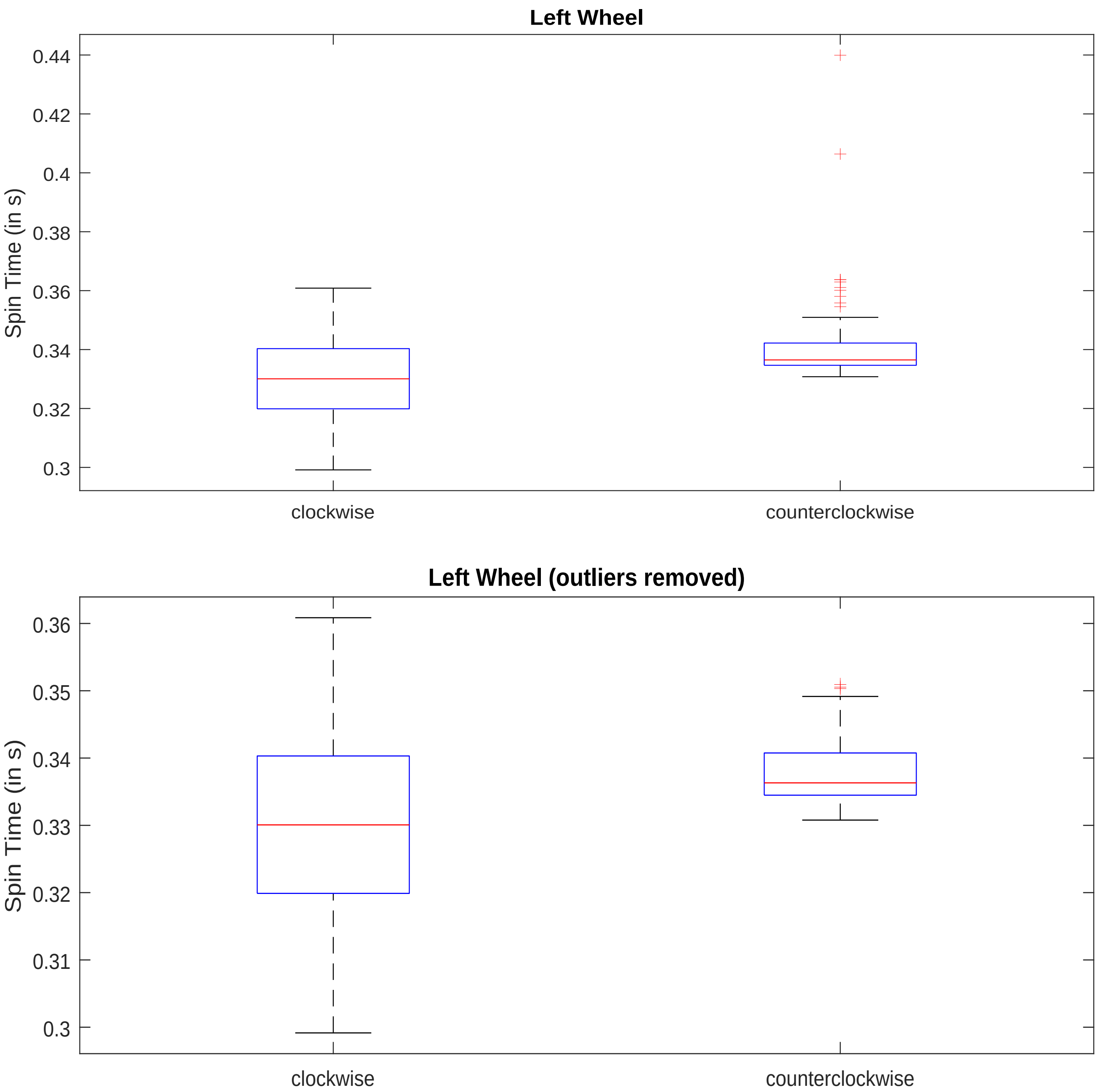


Figure 5.4: Boxplots of rotation for left wheel.

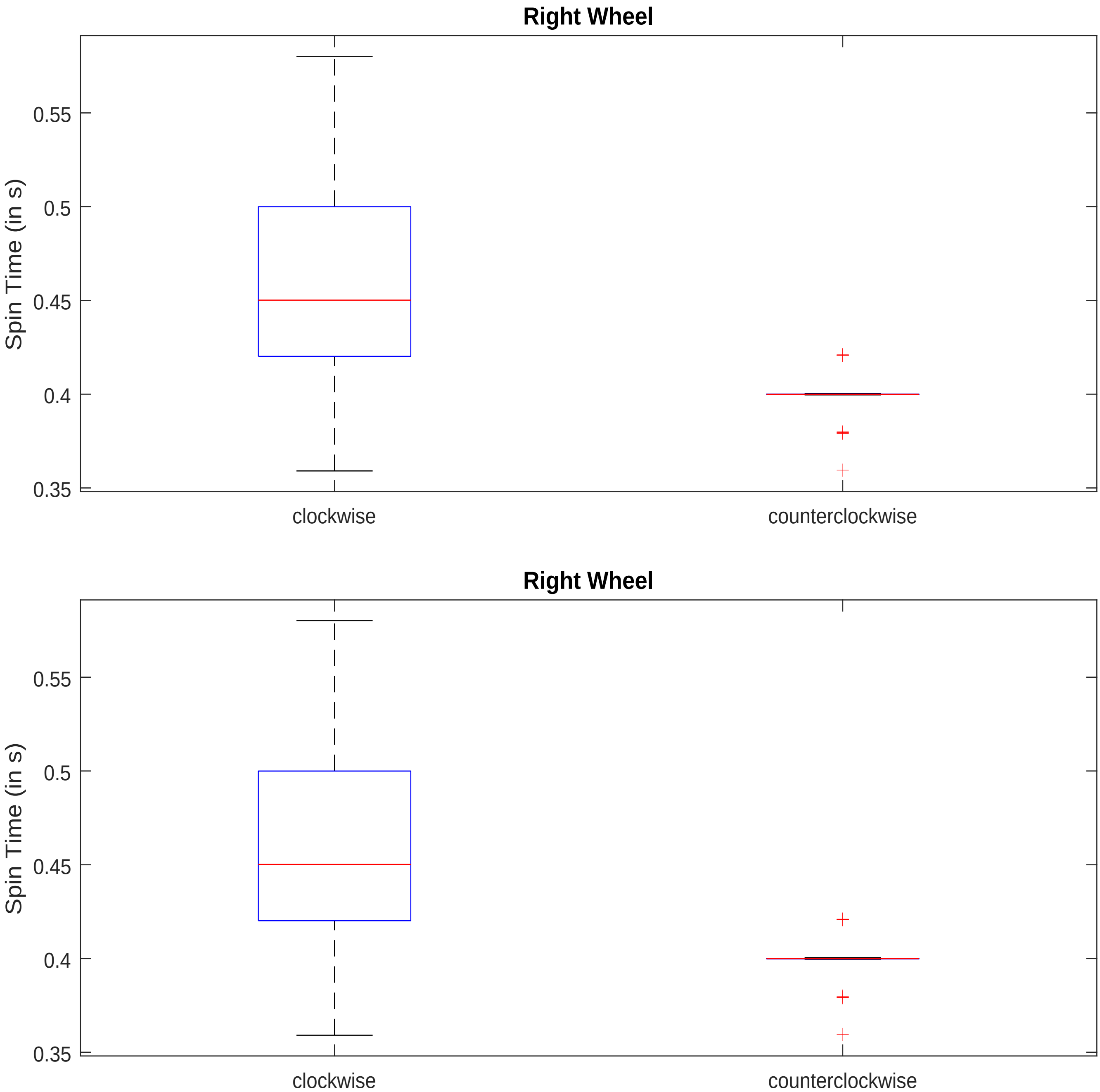


Figure 5.5: Boxplots of rotation for right wheel.

6. Future Developments

As said in Abstract, sometimes we had to deviate from what we planned in order to have a functioning prototype in time for the deadline. These changes were due to a number of reasons:

- little time available;
- faulty components;
- poor resources available (both because of monetary costs or because of long time needed for components to be shipped);
- programming needed was too complex or too time-consuming;

  Nevertheless, it seemed fair to point out where it happened so that it could be discerned what was due to mistakes in design and what difficulties could be avoided instead with more time/resources. Also, this may be useful to anyone who would like to improve our achievements.

6.1 Possible Improvements

The Game

Due to little time, we chose not to develop the second player interface. All the considerations made for the single player mode still apply, the changes should be made mainly to the program.

The Controller

The controller is the component that resulted most affected by the large variety of possible impairments found in patients. Due mostly to the little time, and second extendash handedly to the delay in shipping of components, we decided only to fully design and realise the joystick interface, which looked to us as the one who could cover the widest range of limitations.

Extended considerations over the other options are provided in the dedicated chapter.

The Robot

The second player uses a robot and a controller exactly like Esper's. These were not realised mainly due to lack of time. Another good idea would be to create multiple "outfits"for the robots, so that players can personalise their own own ESPers.

The current external shell was made to be removable, also to recharge batteries, and could be easily replaced with a different one. This was not done also due to lack of time.

Another interesting development would be to implement a program that allows the robot to choose to disobey to the child sometimes, to give the idea that it is acting on its own will. This should give the child the idea that ESPer is just like a child itself, and needing of his/her support, improving empathy and self-esteem.

The Board and Totems

We managed to realise the board the way we designed in the time allotted. A possible improvement could be to create a box were to store it properly when disassembled.

We also designed a Totem-Board mating based on magnets to make it more appealing and fun for the child to assemble this part on his/her own. We also tried to realise one of this matings, but we encountered a number of difficulties and resolved to using jack plugs. These difficulties are due, in our opinion, mostly to the precision needed in the construction and to a lesser extent in finding the right magnets. It could still be made in the right conditions.

Method Evaluation

We chose to put realization at the top of priorities, and moreover there was physically no time to perform a proper testing of the game performances. Our intention is to carry out a global testing by letting users play with the game to see if they liked it and how well the various parts behaved.

We would contact an association, “L’Abilità”, that dedicates itself to enhance the quality of life of disabled children, and that was recommended to us by our supervisor. Should this fail to happen, also testing the game with non–disabled children would be a good result already.

7. Aknowledgements

We would like to set aside this little space to thank those who contributed to our effort.

First of all, our supervisor professor Andrea Bonarini for the precious advice, and Elena De Momi, the teacher responsible for the “Project in Instrumentation and Functional Assestment ”, as well as the course tutors, Elisabetta Peri and Noelia Chia Bejarano.

We would like to thank Dr. Giulio Fontana from AIRLab for helping coordinating our work.

A special thank to professor Franco Zappa for helping us out with a faulty component.

Thanks also to Greta, Giada and Giammarco, who contributed to give voice to ESPer.

Finally, we would like to thank all those people that started doubting our own existence during the months dedicated to the FlipperBot experience. Thank you, your patience was priceless.

Appendices

A. Circuits and Electric Schemes

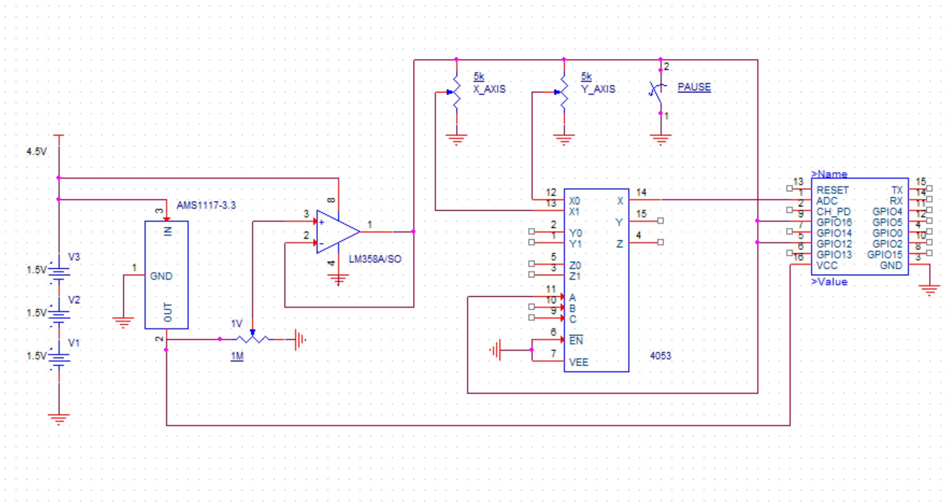


Figure A.1: Scheme of Joystick Circuit.

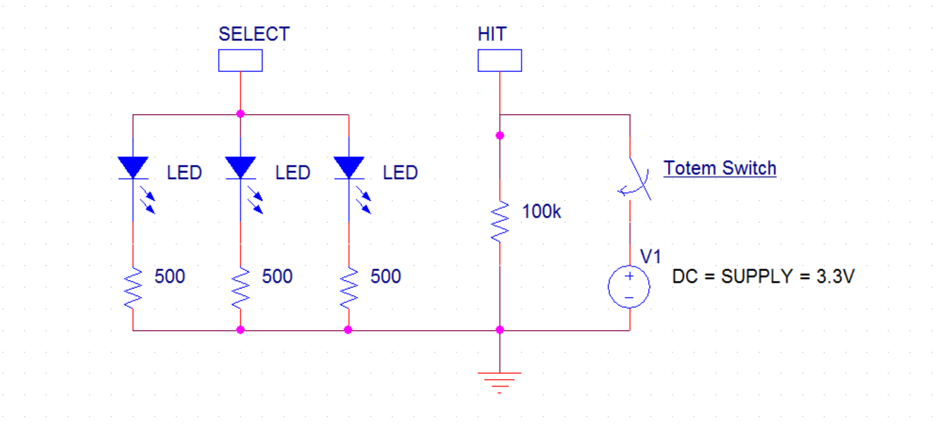


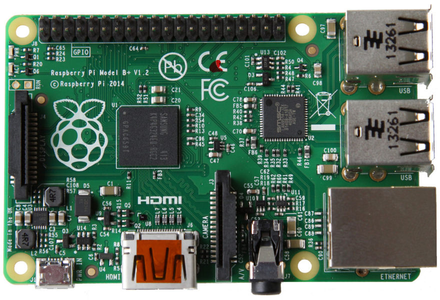
Figure A.2: Scheme of Totem Circuit.

B. External Resources

B.1 Raspberry Pi (RPi)

Raspberry Pi is responsible for the main part of game-management, being the true centre of the interaction. It deals with:

1. totem lighting;
2. scoring and impact detection;
3. countdown;
4. sound effect;
5. display effect (through ARDUINO);
6. Wi-Fi communication, receiving from and transmitting to both robot and controller;
7. management of game states;

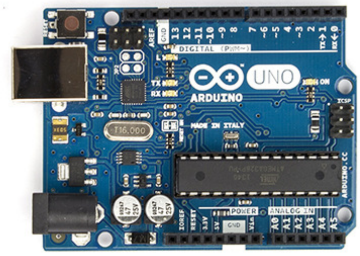


Raspberry Pi is a single-board computer with a voltage supply of 5V (from the battery pack). The embedded operating system is Raspbian Wheezy.
The model used in the game is Raspberry Pi B+.
Features:

1. 40 GPIOs (General Purpose Input/Output);
2. 4 USB ports;
3. audio output (3.5mm TRRS jack);
4. 15-pin MIPI camera interface (CSI);
5. HDMI, composite video (3.5mm TRRS jack);
6. 10/100 Mbit/s Ethernet (8P8C);
7. 512MB RAM;

GPIOs are used to manage totem lighting and impact detection, as well as LED lights, "everything button ", while 2 USB ports are used for Wi-Fi network and serial communication with ARDUINO, the audio output is dedicated to sound effects. All programming was done in Python 3. [1] It is located in the main section of the board.

[1]For details on implementation, see section 4.6 and Appendix E



B.2 ARDUINO

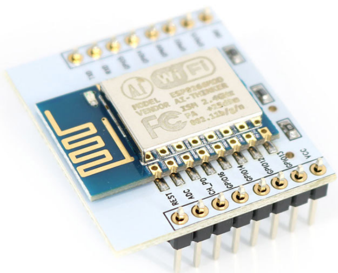
ARDUINO is a micro controller with its own dedicated IDE and can be programmed using C++. Power supply is 5V. In the project, we used a ARDUINO UNO as a dedicated controller for managing the display in the main section of the board. Features:

1. 14 digital input/output pins (of which 6 can be used as PWM outputs);
2. 6 analog inputs;
3. 16 MHz internal clock;
4. 1 USB port;
5. 1 power jack;
6. ICSP header;
7. reset button.

It receives serial inputs from one of the USB ports on the RPi, and uses digital outputs to control display. Inputs correspond to string of characters that should be printed on the display. The deconding of the string is left to the ARDUINO. It is also placed on the main section of the board.

B.3 ESP

ESP-12 is an ultra-low power Wi-Fi module, and can be programmed in the same way as ARDUINO. Its voltage supply is 3.3V, and offers:



1. 16 digital input/output pins (that can be used as PWM outputs);
2. Wi-Fi module;
3. ADC;

We chose a separate controller to use on both robot and controller, for it offered:

- low power consumption;
- smaller dimensions and reduced weight;
- little cost (approximately 2€ apiece);
- embedded Wi-Fi (without having to use an external adapter as in Rpi).

ESP on the controller
The unit on the controller is responsible for:

- search for connection and transmitting information to the board;
- interpretation of signals from the joystick;
- management of LED lights.

ESP on the robot
The unit on the robot is responsible for:

- search for connection and transmitting/receiving information to and from the board;
- driving wheels;
- management of impact detection;
- management of LED lights.

Because of the need to have multiple processes concurrently running, we created a scheduler to simulate parallelism on a single processor. [2]

B.4 Themes and Sounds Effects

All music themes come from royalty free sources:

1. from Creative Common Music Archives:
   - "Nachtwandel ", by Andy G. Cohen —*pause*;
   - "Rainbow Street ", by Scott Holmes —*active play*;
   - "Space Outro ", by Andy G. Cohen —*game over*;
2. "Acquarium"from "Carnaval des Animaux", by Camille Saint-Saëns —*menu*.

Sounds effects (such as beeps and robot squeaks) were created by us by elaborating voice recordings using Audacity. The format used for audio files is Ogg Vorbis, and is reproduced using VLC Media Player.

[2]For details on implementation, see section 4.6 and Appendix E

C. `schemop` directives

Table C.1 shows a list of directives currently supported by the ScheMo Preprocessor.

Each directive is identified by a string name (shown in the first column of the table[1]) that is used in conjunction with a prefix to be recognized by `schemop`. There are two default prefixes:

- a *full prefix*: `@SCHEMO_`
- a *shorthand prefix*: `@`

The desired prefix (either one of the default ones or a user-defined one) can be selected using a command-line option of `schemop`.

In the table, the usage strings are written using the shorthand prefix for brevity, but they apply to any other prefix as well.

Inside the usage strings, italicized names are to be replaced with suitable to get the desired result.

[Table C.1]

Directive	Usage and description
	Automatic code generation
`DECLARE`	`@DECLARE` Must be placed in the global space before any other directive. The preprocessor replaces it with the declarations of all the variables and functions needed to make the code generated by the other directives work.
`INIT`	`@INIT` Must be used before any scheduling occurs. It initializes all needed variables and the scheduler itself.
`SCHEDULE_ALL`	`@SCHEDULE_ALL` Shortcut command to schedule all recognized jobs. Jobs that have been defined without the use of the ScheMo Preprocessor are not automatically scheduled this way. To schedule jobs individually the C++ function `schemo::schedule_job(`*name*`)` can be used.
	Job definition
`JOB[1]`	`@JOB (`*name*`) {`*code*`}` Defines a new job called *name*. The *code* part contains the definition of the job similarly to a normal C++ function, with the added possibility to use special `schemop` directives.
`JOB[2]`	`@JOB {`*code*`}` Like the one above, but the job name is autogenerated by the preprocessor. Because of this, the job can only be scheduled by using the `@SCHEDULE_ALL` directive.

[Table C.1]

[1] When present, a number between square brackets is used to distinguish between different uses of the same identifier, but it is not to be considered part of the name

[**Table C.1**]

Directive	Usage and description
`JDELAY`	`@JDELAY (`*`delay`*`)` If used, it must be placed inside a `JOB` block. Defines how many cycles the job must skip between the execution of one of its task and the next. It can be useful if some tasks need to get control less often than others to work properly. If this directive is not used, a *`delay`* of `0` is assumed (meaning that no cycles are skipped).
	Control flow[2]
`TBREAK[1]`	`@TBREAK (`*`name`*`)` Explicitly ends a task and starts a new one called *`name`*. It's useful to add break-points where the scheduler can pass control to a different job when long linear pieces of code without interruptions are present.
`TBREAK[2]`	`@TBREAK` Like the one above, but the task name is autogenerated.
`WHILE[1]`	`@WHILE (`*`condition`*`) {`*`code`*`}` `schemop`'s counterpart of a C++ `while` loop. The differences with a normal C++ `while` loop are that: • a break-point is added before the first condition check and before each loop-back, meaning that control is passed to a different job after each iteration • using other control flow directives or a `CALL` directive inside a normal C++ control flow statement would break it
`WHILE[2]`	`@WHILE {`*`code`*`}` Like the one above, but a `true` condition is assumed. It effectively generates an infinite loop.
`IF`	`@IF (`*`condition`*`) {`*`code`*`}` `schemop`'s counterpart of a C++ `if` statement. The reasons to use it instead of a normal C++ `if` are similar to those in favour of `WHILE` statements.
`ELSE`	`@ELSE {`*`code`*`}` `schemop`'s counterpart of a C++ `else` statement to be used after an `IF` block instead of the standard C++ statement.
`CONTINUE`	`@CONTINUE` `schemop`'s counterpart of a C++ `continue` statement to be used inside a `WHILE` block instead of the standard C++ statement.
`BREAK`	`@BREAK` `schemop`'s counterpart of a C++ `break` statement to be used inside a `WHILE` block.
`EXIT`	`@EXIT` Stops the execution of the current job.

[**Table C.1**]

[2] These directives can only be used inside `JOB` and `FUNCTION` blocks.

[**Table C.1**]

Directive	Usage and description
`SHUTDOWN`	`@SHUTDOWN` Stops the main scheduler loop and thus the execution of all scheduled jobs.
	Memory management[2]
`MEMORY`	`@MEMORY {`*`variables`*`}` Defines the variables available to all tasks of a job. Multiple `MEMORY` blocks can be defined for the same job. *`variable`* is a list of `VAR[1]` directives.
`VAR[1]`	`@VAR (`*`name`*` : `*`type`*`)` Used inside a `MEMORY` block to declare a job-wide variable called *`name`* of type *`type`*.
`VAR[2]`	`@VAR (`*`name`*`)` Used outside a `MEMORY` block to refer to a previously declared ob-wide variable.
`CRITSEC`	`@CRITSEC (`*`name`*`) {`*`code`*`}` Protects a block of code with a mutex called *`name`* (defining the latter if it is its first appearance in the code).
	Functions
`FUNCTION`	`@FUNCTION (`*`name`*`) `*`options`*` {`*`code`*`}` Defines a function that can be used with the `CALL` directive and can contain control flow directives, similarly to a `JOB` block. *`options`* is a list of zero or more `PARAM[1]` directives and exactly one `RETURN[1]` directive.
`PARAM[1]`	`@PARAM (`*`name`*` : `*`type`*`)` Defines a parameter for a function when placed among its *`options`*. *`type`* and *`name`* represent respectively the type of the related variable and the name with which it can be referenced inside the function.
`RETURN[1]`	`@RETURN (`*`type`*`)` Defines the type of variable returned by the function when placed among its *`options`*. ScheMo functions can not be declared `void`.
`PARAM[2]`	`@PARAM (`*`name`*`)` Used inside a function to refer to the parameter with the same name.
`RETURN[2]`	`@RETURN (`*`value`*`);` Used inside a function to stop its execution and return *`value`* to the caller.
`CALL[1]`	`@CALL (`*`function`*`) : `*`result`*`;` Calls a ScheMo function with name *`function`* without parameters and places the returned value in a new variable called *`result`*. The type of the variable is inferred from the function definition. *`result`*'s scope is limited to a task that starts right after the `CALL` statement.

[**Table C.1**]

[**Table C.1**]

Directive	Usage and description
`CALL[2]`	`@CALL (`*`function`*` ; `*`parameters`*`) : `*`result`*`;` Like the one above, but semicolon-separated parameters are passed to the function. The parameters must be passed in the same order with which they were defined in the function's *`options`*.

Table C.1: List of ScheMo Preprocessor directives

D. FBCP commands

Table D.1 lists all currently supported FBCP commands.

The first column contains the name with which each command is referred to in code (both using the C++ library and the Python module). The first letter indicates wether the command should be sent from the client (**Q**uestion) or the server in response to a previous command (**A**nswer).

The second one shows how a packet must be written to be understood as the related command (the words in italic are mandatory parameters and should be replaced with appropriate strings). The terminating *newline* character has been omitted for the sake of readability.

The last column briefly explains how each command is used.

The various commands are divided in the groups described in 4.6.3.

[Table D.1]

Command name	**Packet structure**	**Description**
	Generic	
`A_ACCEPT`	`ON_IT!`	Sent if the previous command was accepted and correctly handled.
`A_REFUSE`	`NOT_NOW`	Sent if the previous command was not handled as requested.
`A_ERROR`	`WHAT?`	Sent if the previous command couldn't be understood or wasn't a correct FBCP packet.
	Network building	
`Q_SINGLE_PRESENTATION`	`I'M` *`serial`*	Asks for permission to join a network. *`serial`* is an unique identifier of the device[1].
`Q_MULTI_PRESENTATION`	`WE'RE` *`serial friend`*	Asks for permission of the requesting device and another one to join a network. Used when already connected robots and controllers want to join a game network. The *`friend`* device will have a reserved place in the network but will stillr need to send a `Q_SINGLE_PRESENTATION` to the server.
`A_GRANT_ACCESS`	`WELCOME`	Sent if a request to join a network is accepted.

[Table D.1]

[1] It must be in the form `FlipperBot-Board-...` for boards, `FlipperBot-Robot-...` for robots and `FlipperBot-Controller-...` for controllers

[**Table D.1**]

Command name	**Packet structure**	**Description**
A_DENY_ACCESS	BUSY	Sent if a request to join a network is refused. Usually because there are already enough devices connected.
Q_HEARTBEAT	STILL_THERE?	Used to avoid timeouts.
A_HEARTBEAT	YEP	
Q_CLEAN	GOODBYE	Used to disconnect a device from the network.
A_CLEAN	BYE	
A_REQUEST_PRESENTATION	WHO?	Sent if the previous command was sent without a prior proper connection.
Q_CHANGE_NET	MOVE_TO *net*	Used by a robot to inform a connected controller of the wish to change network. The robot must have already sent a Q_MULTI_PRESENTATION command to the new network to reserve a place in the new network for the controller. The *net* parameter must be set to the SSID of the new network.
A_CHANGE_ACCEPT	OK	Sent by a controller to accept a change of network. It must then send a Q_SINGLE_PRESENTATION to the new network to effectively join it.
A_CHANGE_DENY	NO	Sent by a controller if it isn't willing to join the new network. In answer to this, the robot must leave the new network (that was joined in combination with the controller) and then either: • leave the old network too and rejoin the new one alone • remain in the old network
	Robot	
Q_MOTOR_COMMAND [2]	MOTOR *motor direction*	Sets the direction of rotation of a specific motor[3].

[**Table D.1**]

[2] These commands are also part of the *Controller* group
[3] See Table D.2 to find available parameters

[Table D.1]

Command name	Packet structure	Description
`Q_ROBOT_COMMAND`[2]	`BOT` *`direction`*	Sets the direction of motion of the whole robot[3] by changing the speed of both motors (not necessarily in the same way).
`Q_HIT`	`OUCH`	Sent when the bumper of the robot hits something.
	Controller	
`Q_OPTION`	`OPT` *`option value`*	Sets/unsets (based on *`value`*[3]) an option. For certain options, the value parameter can contain additional information.
`A_OPTION_ACCEPT`	`OK`	Sent if the requested option was recognized and correctly set/unset.
`A_OPTION_DENY`	`DUNNO`	Sent if the requested option wasn't recognized or its state couldn't be changed as wanted.
`Q_MODE_SELECT`	`MODE` *`mode`*	Enables a certain mode[3].
`A_MODE_ACCEPT`	`OK`	Sent if the requested mode was recognised and enabled.
`A_MODE_DENY`	`DUNNO`	Sent if the requested mode wasn't recognised or couldn't be enabled.
`Q_EVERYTHING_ON`	`PRESSED`	Asks to set all available options.
`Q_EVERYTHING_OFF`	`RELEASED`	Asks to unset all available options.
`Q_RAW_COMMAND`	`RAW`	Used to send any kind of data with the assumption that the server will correctly handle it and use it to guide the robot. The right mode/options should be selected in advance.

[Table D.1]

[3] See 4.6.3.1 for an explanation of options and modes

[**Table D.1**]

Command name	**Packet structure**	**Description**
	Debug	
`A_DATA`	`DATA`	Can be used in various contexts and there isn't a specific way of handling it. It can contain any kind of data as optional parameter with the assumption that the requesting device knows how to interpret it.
`A_ALIKE`	`MAYBE` *`command`*	Suggests a command similar with a similar signature to the received one in case the latter is not recognized. It makes recognizing typos easier.
`Q_LIST`	`LIST` *`type`*	Requests a list of supported commands or options, depending on the *`type`* parameter[3]. The answer should be a `A_DATA` command with a list of comma-separated commands/options as optional parameter.
`Q_HELP`	`EXPLAIN` *`command`*	Requests a description of how to use the command and/or what it does. The answer should be a `A_DATA` command. The implementation can give a more or less detailed answer that isn't usually suitable for automatic parsing but is more useful for interactive interfaces during debugging.
`Q_LOG`	`LOG`	Requests the addition of some data to the server logs.

Table D.1: List of supported FBCP commands

Table D.2 contains a list of all predefined parameter strings to be used in conjunction with the commands in Table D.1.

The first column contains the name with which each parameter is referred to in code (both using the C++ library and the Python module).

The second one shows what the corresponding string is.

The last column explains the meaning of the parameter.

The various entries are divided based on the commands with which they are supposed to be used; the mandatory parameter to which the string refers is indicated in parenthesis.

[**Table D.2**]

Parameter name	**String**	**Description**
`Q_OPTION` (*value*)		
`OPTION_SET`	`ON`	Indicate whether the related *option* must be set or unset.
`OPTION_UNSET`	`OFF`	
`Q_LIST` (*type*)		
`LIST_OPT`	`OPT`	Used to list options.
`LIST_CMD`	`CMD`	Used to list commands.
`Q_MOTOR_COMMAND` (*motor*)		
`MOTOR_LEFT`	`ML`	Indicates that the left motor speed must be changed.
`MOTOR_RIGHT`	`MR`	Indicates that the right motor speed must be changed.
`MOTOR_BOTH`	`MLR`	Indicates that both motors speed must be changed to the same value.
`Q_MOTOR_COMMAND` (*direction*) and `Q_ROBOT_COMMAND` (*direction*)		
`DIRECTION_FORWARD`	`FW`	Changes the speed of the motor/motors to move the robot forwards.
`DIRECTION_BACKWARD`	`BW`	Changes the speed of the motor/motors to move the robot backwards.
`DIRECTION_STOP`	`STOP`	Stops the motor/motors.
`Q_ROBOT_COMMAND` (*direction*)		
`DIRECTION_FORWARD_LEFT`	`FL`	Changes the motors speed to make the robot turn left while moving forwards.
`DIRECTION_FORWARD_RIGHT`	`FR`	Changes the motors speed to make the robot turn right while moving forwards.
`DIRECTION_BACKWARD_LEFT`	`BL`	Changes the motors speed to make the robot turn left while moving backwards.
`DIRECTION_BACKWARD_RIGHT`	`BR`	Changes the motors speed to make the robot turn right while moving backwards.
`DIRECTION_LEFT`	`SL`	Changes the motors speed to make the robot turn left in place.
`DIRECTION_RIGHT`	`SR`	Changes the motors speed to make the robot turn right in place.

Table D.2: List of standard FBCP parameters

E. Code Snippets

```
#include "schemo.h"
#include "fbcp.common.h"
#include "FBNet.h"
#include <ESP8266WiFi.h>
#include "ssidheap.h"

fbcp::string fbcp::serial;
fbcp::string ssid;

WiFiClient sockOut;

enum
{
  MODE_IDLE,
  MODE_CONNECTING,
  MODE_GAME,
  MODE_STANDALONE
} mode = MODE_IDLE;

typedef enum
{
  READ_TIMEOUT,
  READ_SUCCESS,
  READ_FAIL
} READ_RESULT;

@DECLARE

@FUNCTION(read_command)
@PARAM(sock:WiFiClient*)
@PARAM(cmd:fbcp::COMMAND_LINE*)
@PARAM(timeout:unsigned long)
@RETURN(READ_RESULT)
{
  @MEMORY
  {
    @VAR(msg:fbcp::string)
    @VAR(t:unsigned long)
  }

  @VAR(msg) = "";
  @VAR(t) = millis();
  @WHILE (millis() - @VAR(t) < @PARAM(timeout))
  {
    int nc = @PARAM(sock)->available();
    for (int i = 0; i < nc; ++i)
    {
      char c = @PARAM(sock)->read();
      @VAR(msg) += c;

      if (c == '\n' or c == '\0')
```

```
      {
        @BREAK
      }
    }
  }

  @IF (millis() - @VAR(t) >= @PARAM(timeout))
  {
    @RETURN(READ_TIMEOUT);
  }

  @IF (@VAR(msg)[@VAR(msg).length()-1] == '\0')
  {
    @RETURN(READ_FAIL);
  }

  @RETURN(fbcp::parseCommand(@VAR(msg), *@PARAM(cmd))?READ_SUCCESS:READ_FAIL);
}

@FUNCTION(wait)
@PARAM(dt:unsigned int)
@RETURN(char)
{
  @MEMORY
  {
    @VAR(t0:unsigned int)
  }
  @VAR(t0) = millis();
  @WHILE (millis() - @VAR(t0) < @PARAM(dt)) {}
  @RETURN(0);
}

@JOB (job_network)
{
  @MEMORY
  {
    @VAR(i:byte)
    @VAR(n:int)
    @VAR(boardrobot:bool)
    @VAR(cmd:fbcp::COMMAND_LINE)
  }

  @WHILE
  {
    @IF (mode == MODE_IDLE)
    {
      mode = MODE_CONNECTING;
      @VAR(n) = WiFi.scanNetworks();

      @VAR(i) = 0;
      clearSsidHeap();
      @WHILE (@VAR(i) < @VAR(n))
      {
        insertSsid(@VAR(i));
```

```
        ++@VAR(i);
      }
      @WHILE ( (@VAR(i)=popSsid()) < @VAR(n))
      {
        ssid = WiFi.SSID(@VAR(i)).c_str();
        if (ssid.startsWith(fbcp::BOARD_PREFIX))
        {
          @VAR(boardrobot) = true;
        }
        else if (ssid.startsWith(fbcp::ROBOT_PREFIX))
        {
          @VAR(boardrobot) = false;
        }
        else
        {
          @CONTINUE
        }

        WiFi.begin(ssid.c_str());
        sockOut.connect(IPAddress(192,168,1,1), FBNet::PORT);

        @VAR(cmd).command = &fbcp::Q_SINGLE_PRESENTATION;
        @VAR(cmd).params["serial"] = fbcp::serial;
        fbcp::string s = fbcp::writeCommand(@VAR(cmd));
        sockOut.print(s.c_str());

        @CALL(
          read_command;
          &sockOut;&@VAR(cmd);
          fbcp::HARD_TIMEOUT
        ) : understood;
        if (understood == READ_SUCCESS && @VAR(cmd).command->code == fbcp::A_GRANT_ACCESS
        {
          if (@VAR(boardrobot))
          {
            mode = MODE_GAME;
          }
          else
          {
            mode = MODE_STANDALONE;
          }
          @BREAK
        }
        mode = MODE_IDLE;
      }

      @IF (mode != MODE_GAME && mode != MODE_STANDALONE)
      {
        mode = MODE_IDLE;
        @CALL(wait;10000):null;
      }
    }
  }
}
```

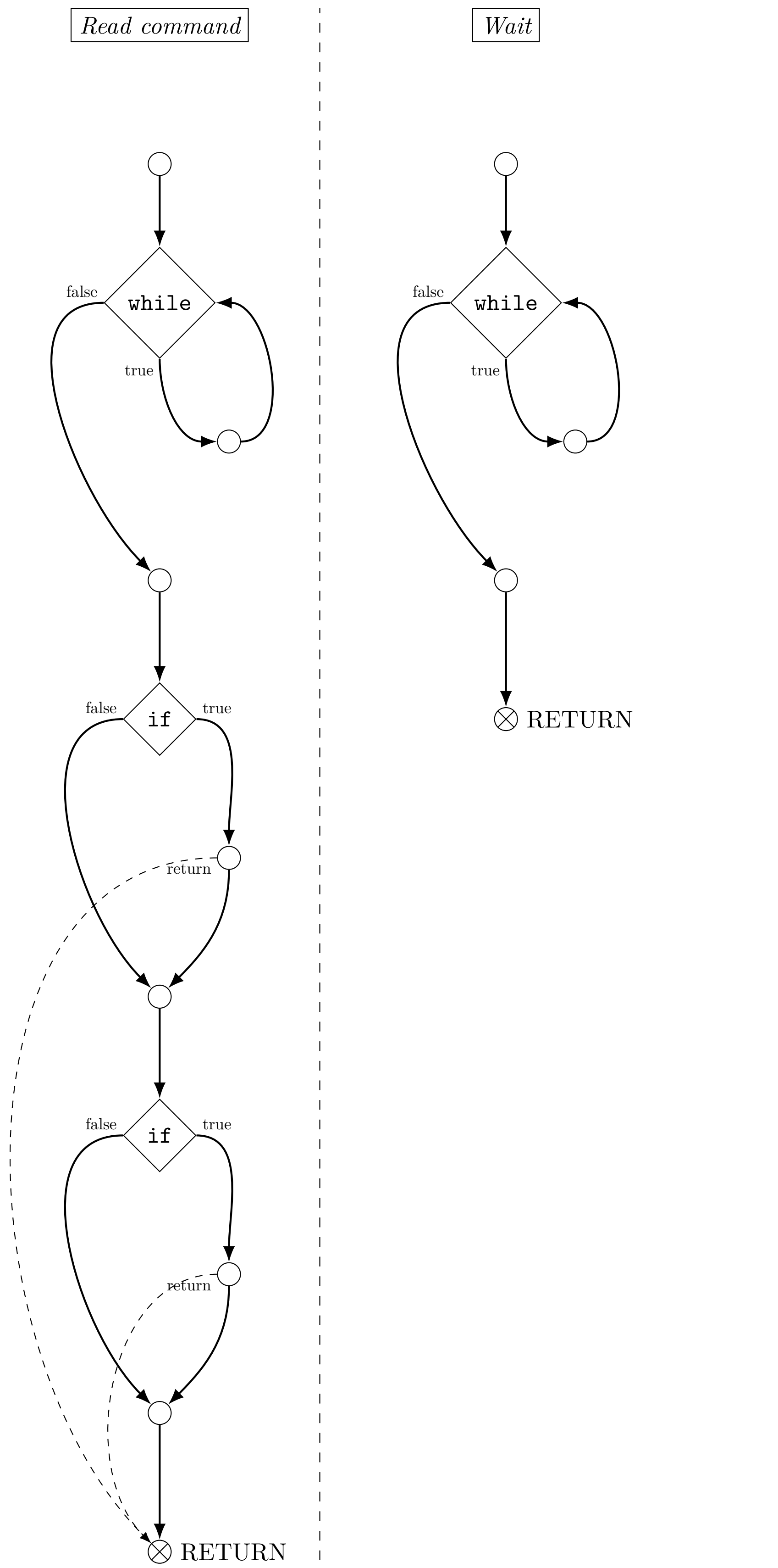
```

void setup()
{
  // FBCP
  fbcp::serial = fbcp::CONTR_PREFIX;
  fbcp::serial += "00001";
  mode = MODE_IDLE;

  //ScheMo
  @INIT
  @SCHEDULE_ALL

  schemo::start_cycle();
}

void loop(){}
```



Read command
Wait
while
false
true
if
return
RETURN

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