Department of Information Systems and Computing

"A Usability Study of a Tactile-Tangible User Interface for the Remote Control of a Robotic Element on Interactive Surfaces"

Master's Degree Thesis

Master's degree in Software Engineering, Formal Methods and Information Systems.

Author: Julio Fernández

Director: Dr. Francisco Javier Jaén Martínez

September 2015

Abstract

With the turn of the decade, there has been a powerful shift in the way gaming is perceived and its potential impact. With the rise of Tangible User Interfaces (TUI), the advances in the field of Gamification and the willingness of users to accept new technologies in the field of gaming, more studies, projects and academic research papers are looking into the possibility of combining the three in a more day to day way.

On the heels of the work on "Tangibot" done by ISSI Group, Department of Computer Systems and Computation (DSIC), we now bring in this work a possible next step in the evolution of said project, one that can not only potentially improve the results of the original project, but that can potentially expand its possible fields of application. Similar tests to those used in the original Tangibot are applied as well as groundwork for a new method of virtual and real world interaction. The tests are meant to test the viability of this new form of interaction, using an AppMATe and an android tablet to control the Tangibot. Unity is used to create a virtual duplication of the real world board used originally in the first incarnation, which is to be expanded on in future work.

Keywords

AppMATe, cognitive games, Tangible User Interfaces (TUI), robots, usability, Gamification, Tangibot

Resumen

Con el paso de la década, ha habido un cambio significativo en la manera en que los videojuegos son percibidos y su impacto potencial. Con el surgir de las interfaces tangibles, los avances en el campo de la Gamificación y la aceptación de nuevas tecnologías por parte de los usuarios además de proyectos e investigaciones académicas. Los mismos exploran la posibilidad de combinar todos estos elementos.

A partir del proyecto Tangibot, que fue realizado por el grupo ISSI del DSIC de la Universidad Politécnica de Valencia, con nuestro proyecto, intentamos traer el siguiente paso en la evolución del mismo, abriendo las puertas no solo a la posibilidad de mejorar su sistema de control, sino además expandir los posibles campos de aplicación. En este trabajo se presentan pruebas de usabilidad y se considera una nueva inclusión de un elemento virtual. Las pruebas están diseñadas para comprobar la viabilidad de controlar el Tangibot con un AppMATe y una tableta android. Unity es utilizado para crear una duplicación del mapa físico en digital y será expandido en trabajos futuros.

Palabras claves:

AppMATe, Juegos cognitivos, Interfaces tangibles, robots, usabilidad, Tangibot.

Contents

1-Introduction

1.1-Motivatiation

In today's world, the videogame industry has broken from the realms of pure entertainment into virtually every field. This should come as no surprise though, as games in general have the central purpose of stimulation, in vastly different ways no doubt, the mind of the participants. Board games like chess help with pattern recognition, card games can help with memory stimulation. Videogames have been suggested to be capable of doing the same.

It is not a surprise the videogames have been studied as more than simple entertainment, and the undeniable strides in fields like "Gamification", have made it clear that videogames have a very real future in fields as education and therapy. It has also become clear that the video game industry has evolved at an incredibly rapid rate, in the better part of forty years, video games have gone from small colored squares on a screen to the juggernauts of cinematics we know today, and that more and more we are seeing spill into other industries as well.

Tangible User Interfaces are the logical next step in the videogame development, and has shown to be on the mind of the industry for some time. With the Nintendos 3DS, Amiibo, The Wii U, Skylanders, Disney Infinity and more, it has become clear that not only is there a place for Tangible User Interfaces in the industry, but a growing demand for them.

The potential of Tangible User Interfaces seems endless and its applications incredibly diverse. With the work of ISSI Group, Department of Computer Systems and Computation (DSIC) with Tangibot[1], we were inspired to explore new methods of developing games with a robot by adding on to their body of work the implementation of a TUI.

Having a Tangible User Interface in place, we believe we can deliver a more intuitive control scheme and will also attract a new user base as well as expand Tangibot's original scope. The main draw of adding a Tangible User Interface is that it bridges the gap between those with video game experience and those without it. Basing ourselves off of the success of Nintendo's original "Wii", we firmly believe that this new control scheme removes the need to have any need for complex instructions and rather relies on the user's intuition and simple controls to execute complex tasks.

It is also fair to state that oversimplification of user interactions can lead to limited game design choices. However, in the case of our modifications to Tangibot, we believe we have not only stricken the necessary sweet spot: the control scheme not only does not limit the potential of what games can be designed, but we believe that it in fact expands in this area.

Additionally, we present the groundwork for including a new element into Tangibot: the ability to create virtual environments. Thanks to Unity 3D, we have added an element meant to make game design with Tangibot easier and expand on the potential applications. By adding a virtual element, the user can have both a virtual and real experience, this is what truly blends the "video game" element that Tangibot previously did not poses.

1.2- Problem statement

The main issue with our proposed modifications boils down to whether or not, users with no experience with Tangible User Interfaces can successfully adapt to the control scheme in a timely fashion. Furthermore, how much precision can be expected of these new users and how will this impact their interaction with Tangibot.

Difficult control schemes have been a huge problem in the past in the field of game development, and complex unintuitive rules have been a hamper for games of all fields. If either of these failures is present in any kind of game, the casual, less experienced user, will become disinterested. In the case of Tangible User interfaces, an additional challenge is presented: if responsiveness is an issue. There have been failures in the past because of this, for this reason, we intend to test all three categories.

For our proposal to be successful, it will be important to prove that these controls are intuitive enough that users won't require manuals or long tutorials. The reason for this is twofold:

1- If the user cannot intuitively understand the controls, it will break immersion which in turn will reduce any potential beneficial effects, since users will have to dedicate a portion of their attentions to controls whether then the task at hand.
2- If the control scheme is too difficult to easily adapt, it will add an unwanted layer of complexity to game design, as it will require the developer to simplify the task to compensate.

Our proposal is ambitious, we do not aim to experiment with each of the possible areas in which our idea can be applied, and rather, we intend to keep the scope of this thesis on the overall usability of this modification.

Our proposal also hinges on whether or not the proposed controls being sufficient to create a true, quasi natural connection between the user and the game, or more specifically in this case the robot. Oversimplified controls have caused problems for platforms such as Xbox Kinect, as this has resulted in unnatural and unintuitive movements required to the player. How natural our project feels in the hands of the user is an intangible that can make or break the proposal.

Furthermore, we intend to explore unexpected results to narrow down if there is a specific niche group that would require certain modifications or adjustments that originally were not taken into consideration.

1.3- Aim and Objectives

It is clear, being our thesis so heavily based on a user adaptability that our main objective is to determine if a user can effectively learn how to use the interface in a small period of time.

We will also explore how users can adapt to increasingly complex challenges in a very short amount of time and with minimal training. It is important to determine if users can not only quickly understand this no mechanism but quickly master it, ad least to the point that basic challenges become second nature to them.

Another key point we would like to determine is if user adaptability is independent to the user profile. More specifically, we are interested to see if the user background does not hamper said user in mastering the Tangible User Interface, to the point that they can achieve high level tasks.

A key intangible is how much a user progresses on his own by simply using the Interface. We aim to find out if continued use of the system will improve the skills of the user, without the need of outside interference.

We also do not intend to discard the possibility of using Tangibot's previous control scheme, rather, demonstrate whether or not Tangible user interfaces can be a viable alternative, allowing the project to move beyond its initial intended bonds. We also intend to find out which specific factors hinder or facilitate the user in the learning process of this new control scheme.

1.4- Methodology

To answer the previously proposed questions, we must first set up the controls themselves. The controls in question were designed keeping in mind simplicity first. After defining our control scheme we now needed to set up a method of testing whether or not the user could learn "on the fly".

To answer our questions, we decided to create three levels of testing with four sub challenges each. This would involve breaking down the control scheme into separate, simple chunks and then require the user to use all of the skills combined.

We designed the tests with the intention of finding out not only if users could easily adapt to controls, but how they would progress with the system when increasingly difficult challenges were presented. Before having the users go through the tests, we have an expert, i.e. someone involved with the project, go through the tests after having practiced with the control schemes. These results resemble the ideal results as each test was created with a number of actions and ideal time limit in mind. The results of the expert are then compared to the average results of the participants and these results are compared.

Small subsets of interesting groups that were relevant from a statistical perspective were also included in the analysis.

We also spoke to each participant to grasp their feelings both during and after the test. This helped us understand the intangibles that cannot be reflected in tests, as an important aspect in any user interface is user feedback.

2-Related Work

2.1 State of the Art

It is difficult to point to a single term or topic that would objectively define the scope of not only this thesis, but the state of the art regarding tangible user interfaces. The range of both the possible implementations of this thesis as well as Tangible User Interfaces is as versatile as the gaming industry itself.

Gamification has shown us that information learned in a virtual environment can be retained, this has lead to an increased interest in including gaming in education. Of course, there are certain tasks that the traditional virtual environments are not well suited for when it comes to transmitting information. One can easily point at traditional home consoles and realize that racing games don't actually improve a user's driving ability (an exception can be drawn for highly targeted simulation pods, but these do not intersect with the realm of home consoles very often).

However, studies have shown that by including semi real world interactions, more information can be retained and henceforth a greater impact on the user can be expected. Tangible User Interfaces are the method to achieve this. Its impact on the video game market is obvious, as previously implied. An interesting example that is relevant to our thesis is the Nintendo Wii U, a product that incorporates a tablet with the console, which is used in conjunction with specific game mechanics to create a Tangible User Interface environment. The main interest of this example is not its commercial success or failure, it is how users have quickly been able to "pick up and play" the console due to its extremely intuitive nature.

An interesting example of a TUI is the work by Suzuki and Kato[2] with AlgoBlock which is an educational tool where users use physical block-like pieces that can be arranged all together to program the movement of a submarine within a labyrinth. Each physical block represents an instruction for the submarine (e.g. go forward, turn left, turn right, etc.). The result of the program execution is shown on a CRT monitor by means of an animated submarine moving on a map. The system is primarily aimed at programming languages learning by K-12 students. Moreover, it allows students to improve their skills in problem-solving by means of some sort of collaborative programming tasks. By working with tangible tools, which can be shared in a collaborative workspace, AlgoBlock provides physical interaction and collaboration.

Another interesting example is the work by Cockburn and Bryant [3]. Cleogo is a programming environment for groups based on the Logo programming language. It allows several users to collaborate in real time in the development of programs and check their execution. The users work with different personal computers that are interconnected through a network. Cleogo uses a graphical user interface based on WIMP to program the movement of the turtle in Logo.

However one of the works that truly opened the door for our investigation was the work by Cheng Guo and Ehud Sharlin [2]. In this paper they suggest the use of tangible user interfaces (TUIs) for human-robot interaction (HRI) applications. They discuss the potential benefits of this approach while focusing on low-level of autonomy tasks. They present an experimental robotic interaction test bed to support our investigation. They use the test bed to explore two HRI-related task-sets: robotic navigation control and robotic posture control. We discuss the implementation of these two task-sets using an AIBO robot dog. Both tasks were mapped to two different robotic control interfaces: keypad interface which resembles the interaction approach currently common in HRI, and a gesture input mechanism based on Nintendo Wii game controllers. They discuss the interfaces implementation and conclude with a detailed user study for evaluating these different HRI techniques in the two robotic tasks-sets.

When giving context to our thesis, it is imperative we talk about the project that inspired this investigation: Tangibot A tangible-mediated robot aimed at enabling more intuitive and appealing interactions. This project was aimed at the senior citizens with cognitive impairment, with the intent of improving their capacities through cognitive games. The project used a robot, controlled with four small paddles, with RFID tags attached to them. These RFID tags would communicate via Bluetooth with a phone that was attached to the robot. The phone would process the commands and send it to the robot.

This project, being targeted at a specific audience, only took into account said audience when performing tests specifically in the age range of 57-95. Its study aimed to see how the three previously, more specifically those with cognitive disorder ranging from low, mild and high, would handle the controls presented to them. What's interesting here is the results showed that those in the low to mild range of cognitive impairments were able to successfully use the control scheme. It was clear, however, that the use of four paddles added a certain layer of complexity; because this study was done with a control group previously mentioned, there is no doubt that a younger audience would easily adapt to it.

3-Technological platform

3.1 -Overview

The new Prototype worked with on this project is meant to improve on the previous incarnation of the Tangibot. It consists of three major parts: the mobile robot, an android tablet and an AppMATe.

The Robot receives its commands via a Bluetooth link with the android tablet. Which commands are determined by the user interaction with the tablet using the AppMATe. A general overview can be seen in figure 3.1

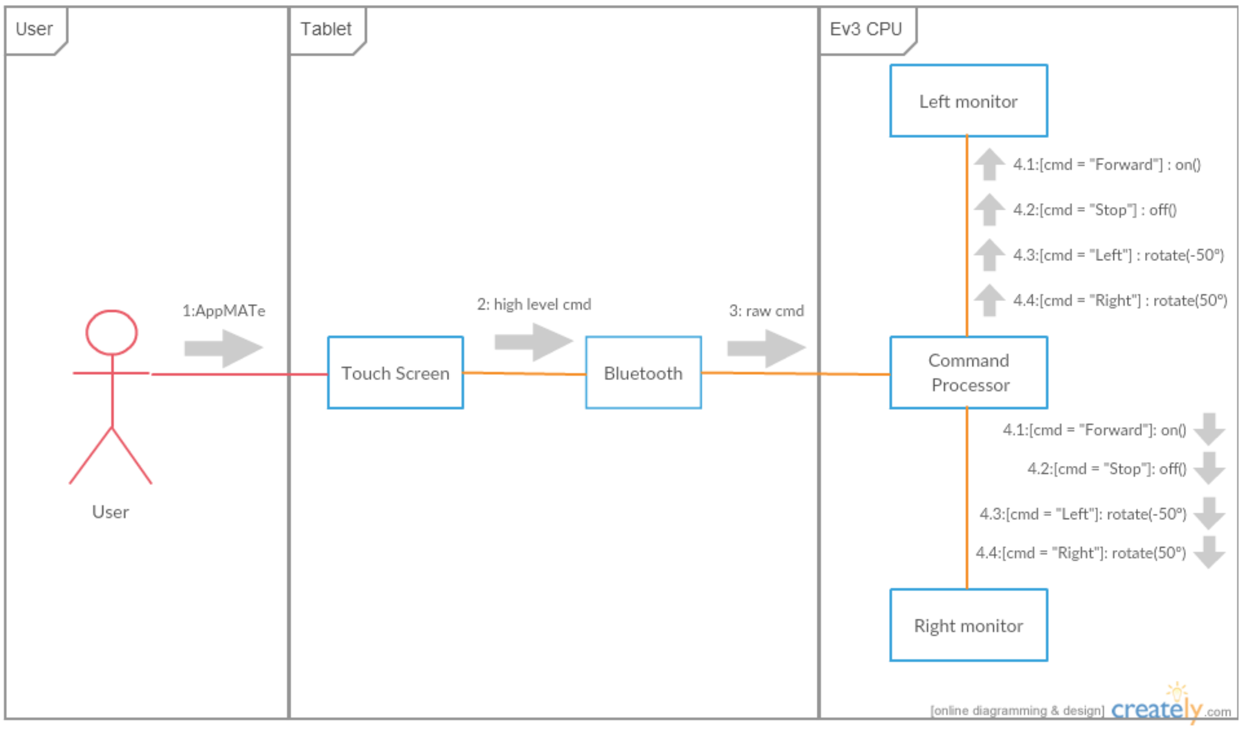


Figure 3.1 General Overview of the new system

3.2 The Robot

The robot is a modified version of the Tangibot, constructed using the LegoTM Mindstorms® Ev3 platform, which facilitates rapid prototyping of multiple versions. It communicates by Bluetooth with an android tablet.

The robot is using the same program used in the “Tangibot” project, which was made with the Mindstorm EV3 visual programming environment, as can be seen in figure 3.2. The robot has gone through some very minor cosmetic modifications as it no longer has need of the RFID reader nor does it require the mobile phone. These differences are visible in figure 3.3

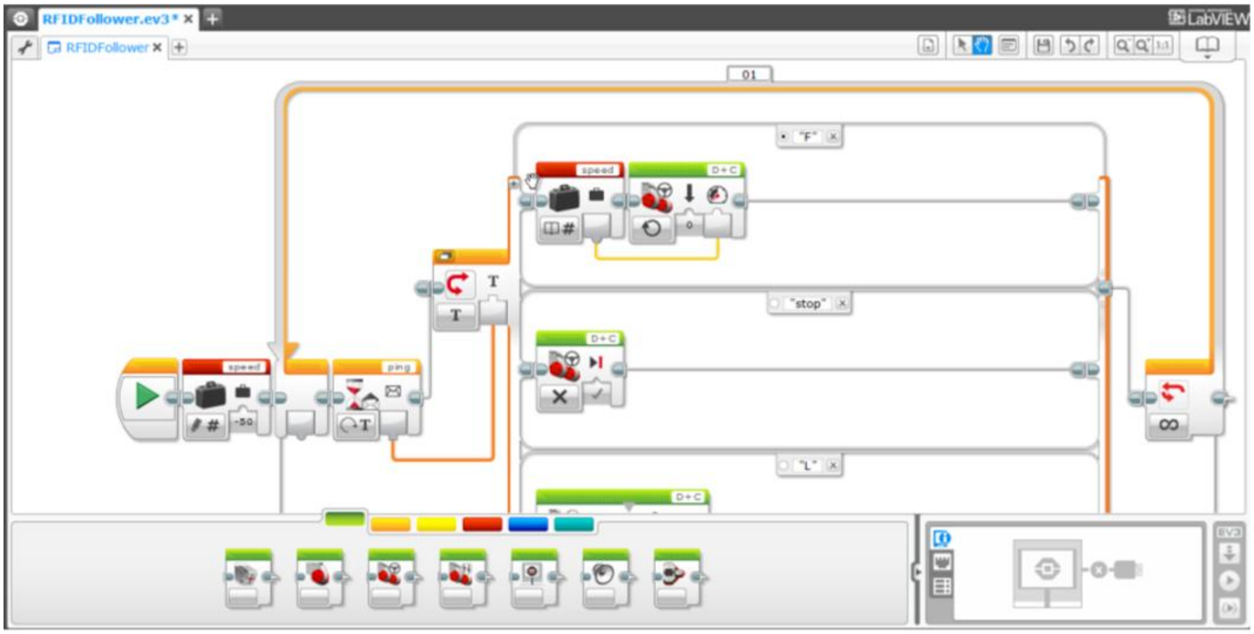


Figure 3.2.1 Minstorms™ EV3 Visual Programming Environment.

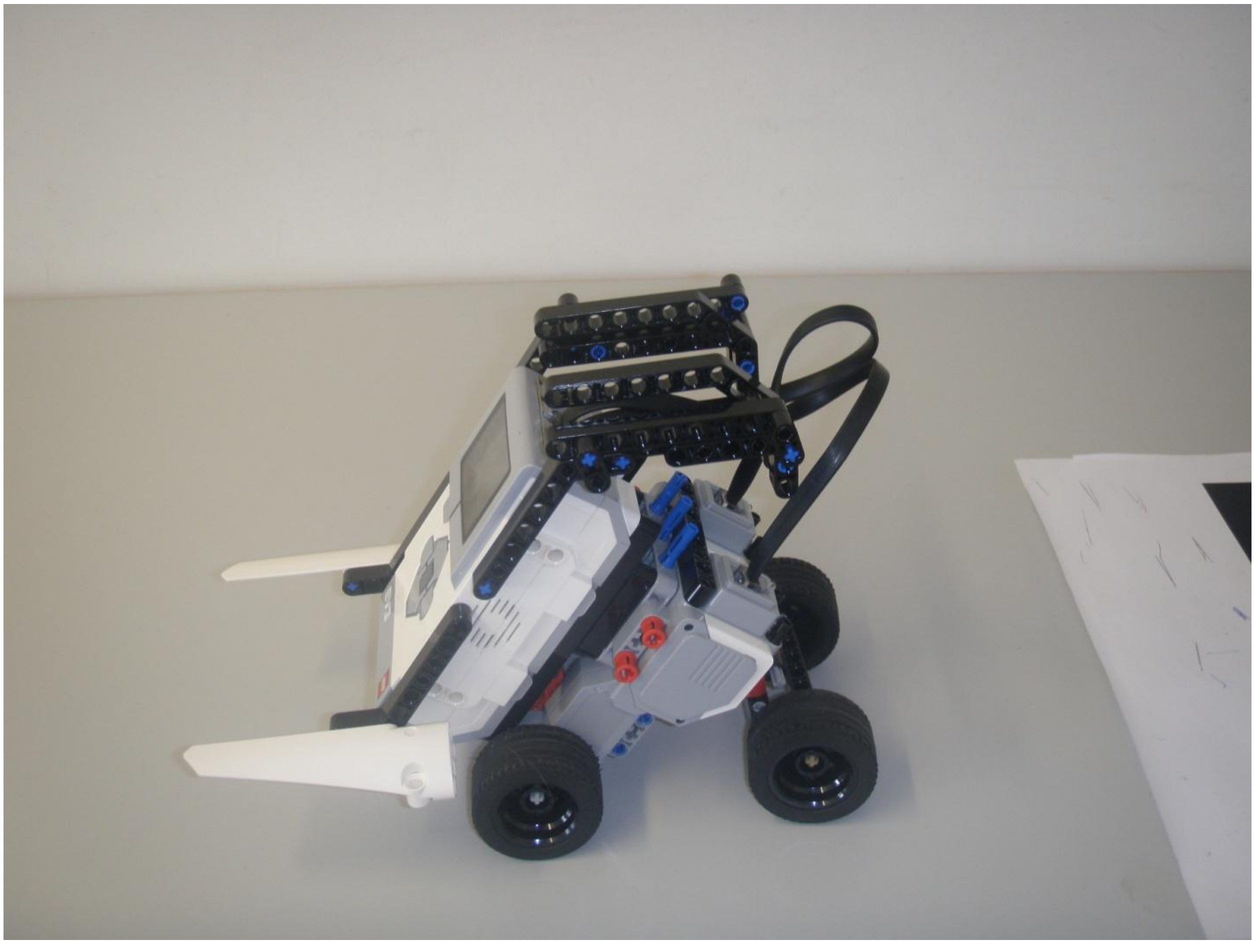


Figure 3.2.2 Robot physical appearance.

3.3- Android Tablet program.

The android Tablet is running an application which leaves a black screen for the user to use as a movement board. The AppMATe is then placed on the screen, in whatever position chosen by the user. The program in the android tablet tracks the AppMATe's placement on to the tablet's screen, calculates its angle at this moment and uses it as a reference. When the user moves the AppMATe, i.e. changes the position in a turning motion, right or left, the program calculates this new angle and compares It to the original reference angle and chooses the appropriate direction. When a command is received, the tablet sends the robot the information via

Bluetooth. A general overview can be seen in figure 3.3.1 and is further detailed in figure X.X. The exact commands the tablet can process are as follows:

3.3.1 Advance

Whenever the AppMATe is placed on the screen in the appropriate manner the message to advance is continuously sent to the robot while this condition is met. A reference angle is obtained by calculating the resulting normal vector of the contact points of the AppMATe. The reference angle is used by the program to determine the direction to turn when the AppMATe's position is shifted. While the AppMATe remains on the screen and the current angle of the AppMATe remains the same as the fore mentioned reference angle, the message to Advance is sent. While the "stop" message is not sent, if the AppMATe's angle becomes the same as the reference angle, the "advance" message is resumed.

3.3.2 Stop

When the AppMATe's contacts are removed from the screen, the program sends the "stop" message to the robot. It then clears the aforementioned angle and enters a "wait" state. It also clears the previous reference angle.

3.3.3 Right

While the AppMAte is pressed on the screen, if it is moved 15 degrees or more to the right, in comparison to the reference angle, the program will cease sending the "advance" message and instead send the "Turn Right" message. While the angle of the AppMATe is not restored to the reference angle (or an approximate of 15 degrees or less) the "Turn Right" message will be continuously sent.

3.3.4 Left

While the AppMAte is pressed on the screen, if it is moved 15 degrees or more to the left, in comparison to the reference angle, the program will cease sending the "advance" message and instead send the "Turn Left" message. While the angle of the AppMATe is not restored to the reference angle (or an approximate of 15 degrees or less) the “Turn Left” message will be continuously sent.

The following Diagrams explain the functionality of the program in the android tablet in a more visual way, the first diagram shows interconnectivity of the commands. The second is a more classical control flow diagram.

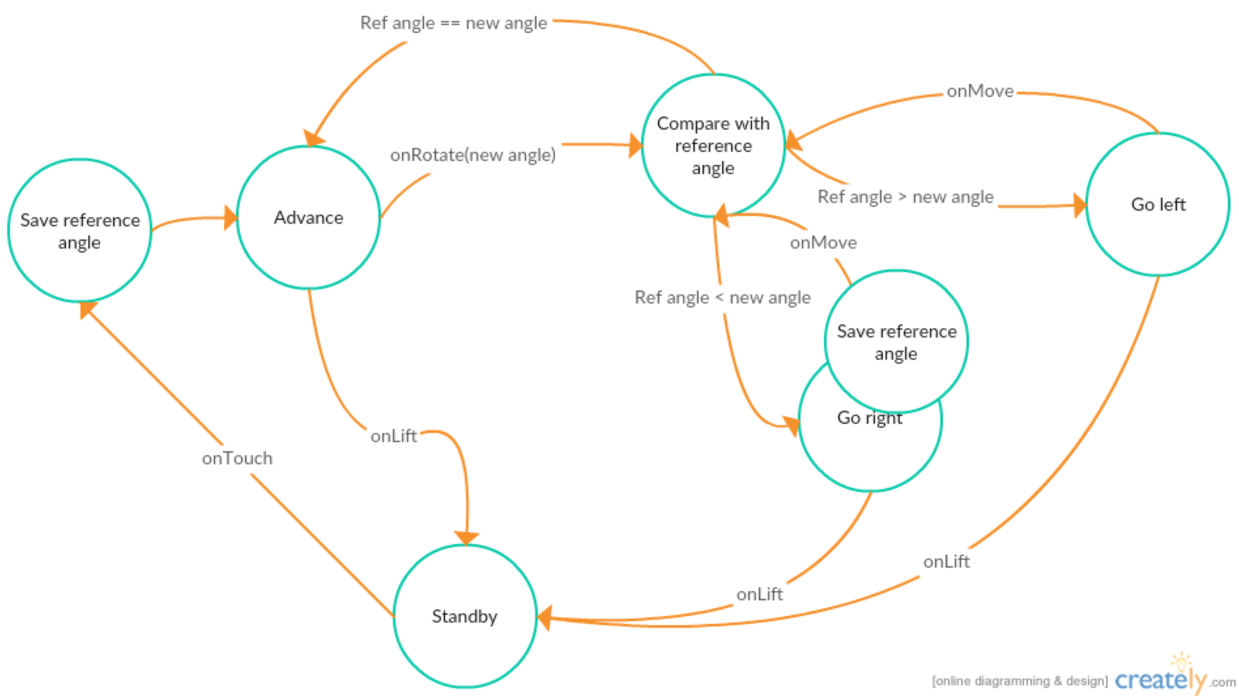


Figure 3.3.1 Diagram explaining program functionality

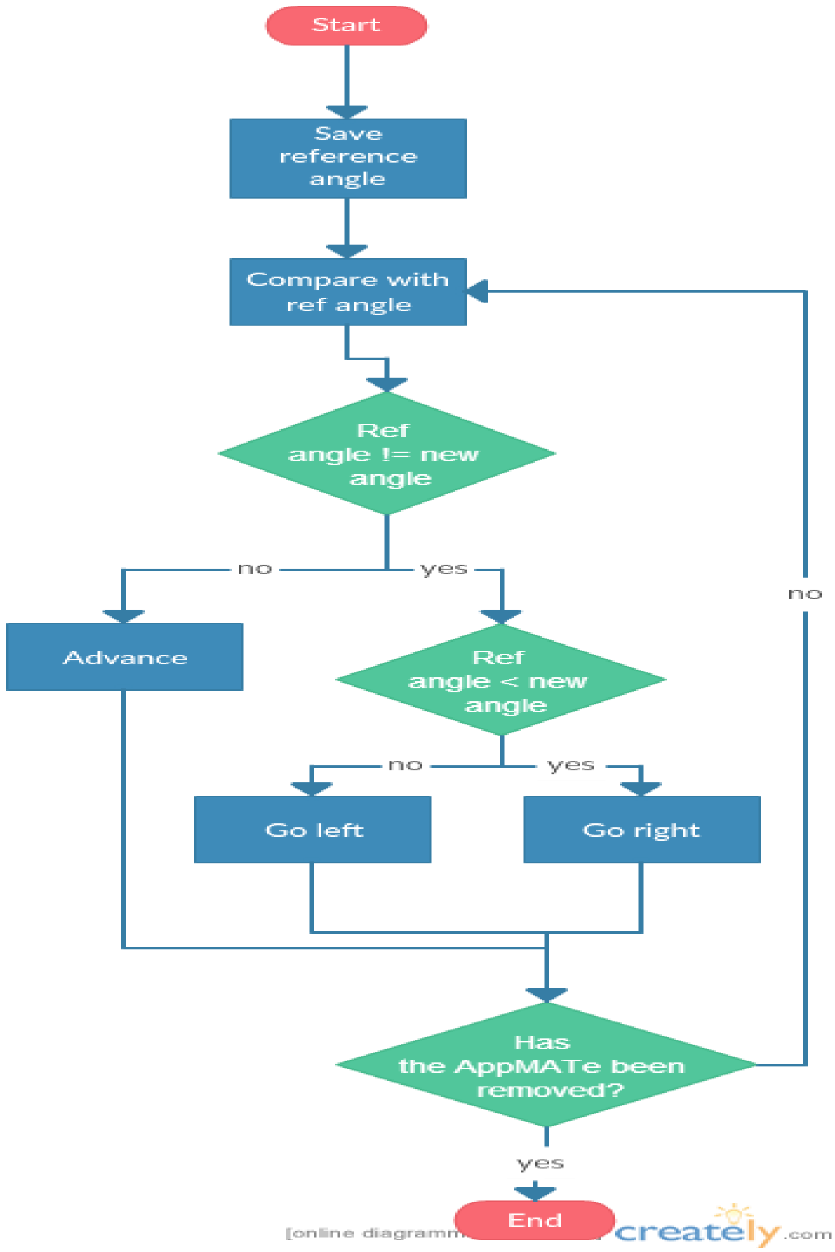


Figure 3.3.2 Algorithm diagram

3.4-The AppMATe

The AppMATe[6] is a toy designed for more hands on interactions with tablet games. We are using Disney's "Cars 2" AppMATes.

The AppMATe should be gripped in the way shown in figure 3.4.1 for ideal pressure to be applied. The AppMATes have three contact points on the bottom side of the toy, which are the only points that, during gameplay, interact with the tablet screen. These three contact points are set up as shown in figure 3.4.2.

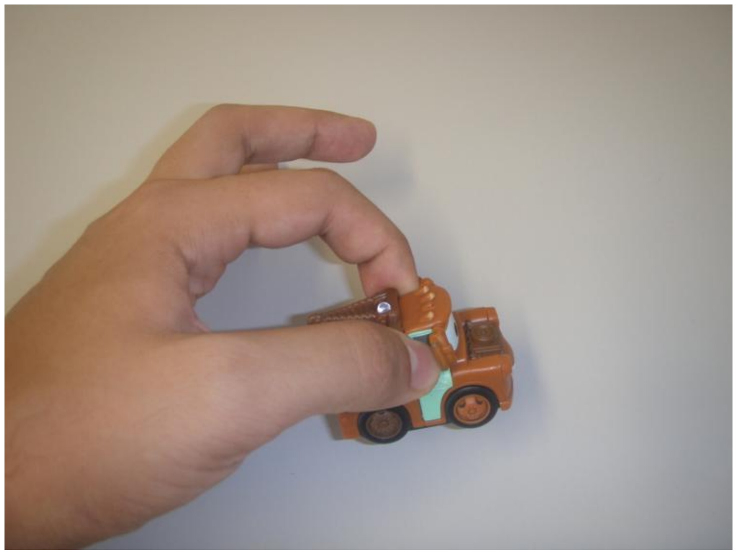


Figure 3.4.1 AppMATe

Figure 3.4.2 AppMATe contact points

4-Usability evaluation

4.1- Overview

Before any actual game design can take place, it is necessary to determine if the modifications to the Tangibot project actually have the desired effect of simplifying usage of the robot as well as making it more intuitive to users. The tests were refined versions of those used in Tangibot as the target audience is not exclusively the elderly.

The tests were meant to verify how easy to learn and handle the controls of the robot were. For this, three tests, with four challenges each, were implemented in order to test three main attributes:

- Handling: How well the user could get the robot from one point or position to another one.
- Precision: How accurate could the user be with the robot, where it wanted to go and how it got there.
- Comfort: How easy was it for the user to adapt to the controls and how quickly it became second nature to them.

Before beginning the tests, the user was taught how to control the robot and allowed approximately one minute to test the controls out for himself in a free roaming situation. Immediately after, the user was presented with the first of the tests.

4.2 Distance control tests.

This test required the user to move the robot a specific distance and stop the robot in a precise location. This was measured using the tips of the robots plastic “arms”. No orientation was evaluated. If for whatever reason the robot was turned slightly during the test, the arm that was further forward was used for the measuring.

Specifically, the objective was to place the tips of the robot's arms at the beginning of a 3 centimeter thick, black line. Each of the four challenges was meant to test and improve a different skill related to precision:

80 centimeters

This was the first challenge the user was presented. This purpose of this challenge was twofold: to test how precise the user could be over large distances and to help familiarize the user with the controls.

Figure 4.2.1 80 centimeters distance test

50 centimeters

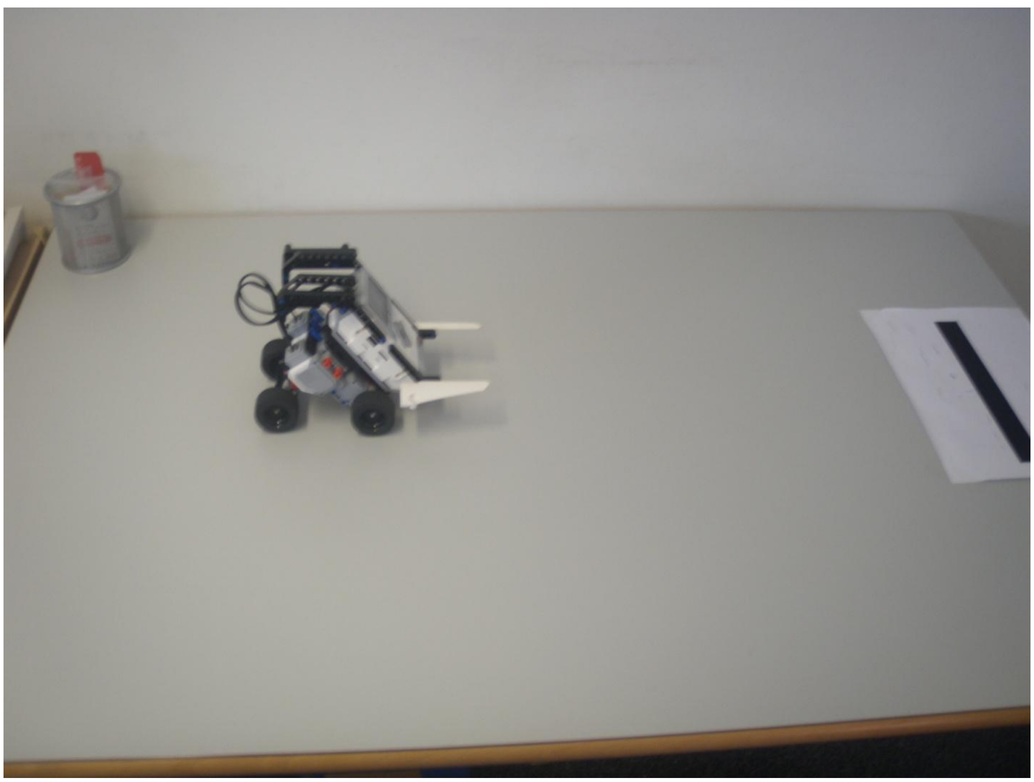


Figure 4.2.2 50 centimeters distance test

The second challenge, gave the user the ability to apply what they had learned in the previous challenge. It demanded a little more precision as the distance was reduced.

40 centimeters

The third challenge, which was now half the distance of the original interaction the user had, was meant to place a stronger emphasis on control. Being only ten centimeters less than the previous test, it is a good way to view the progress the user has made, as well as a higher demand for precision.

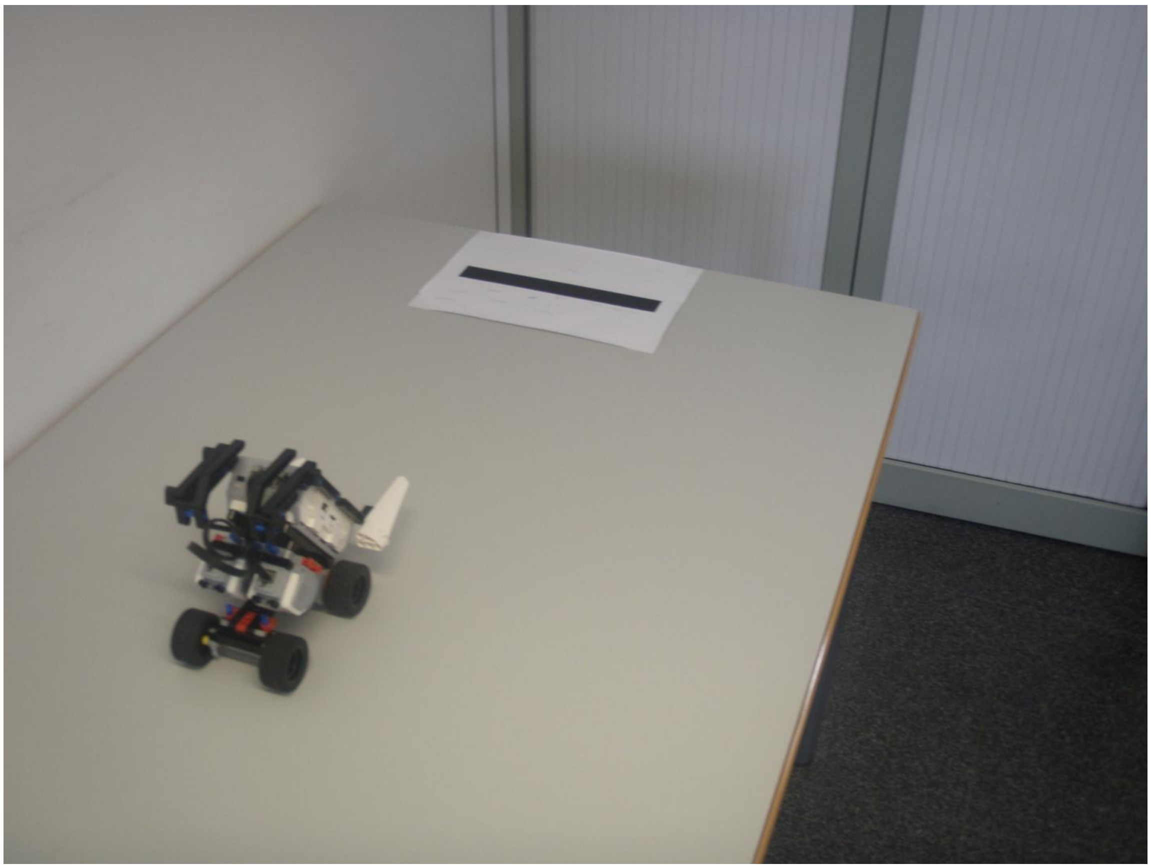


Figure 4.2.3 40 centimeters distance test

10 centimeters

The final challenge was meant as the most challenging test of precision the user has faced. It required the user to very briefly advance the robot.

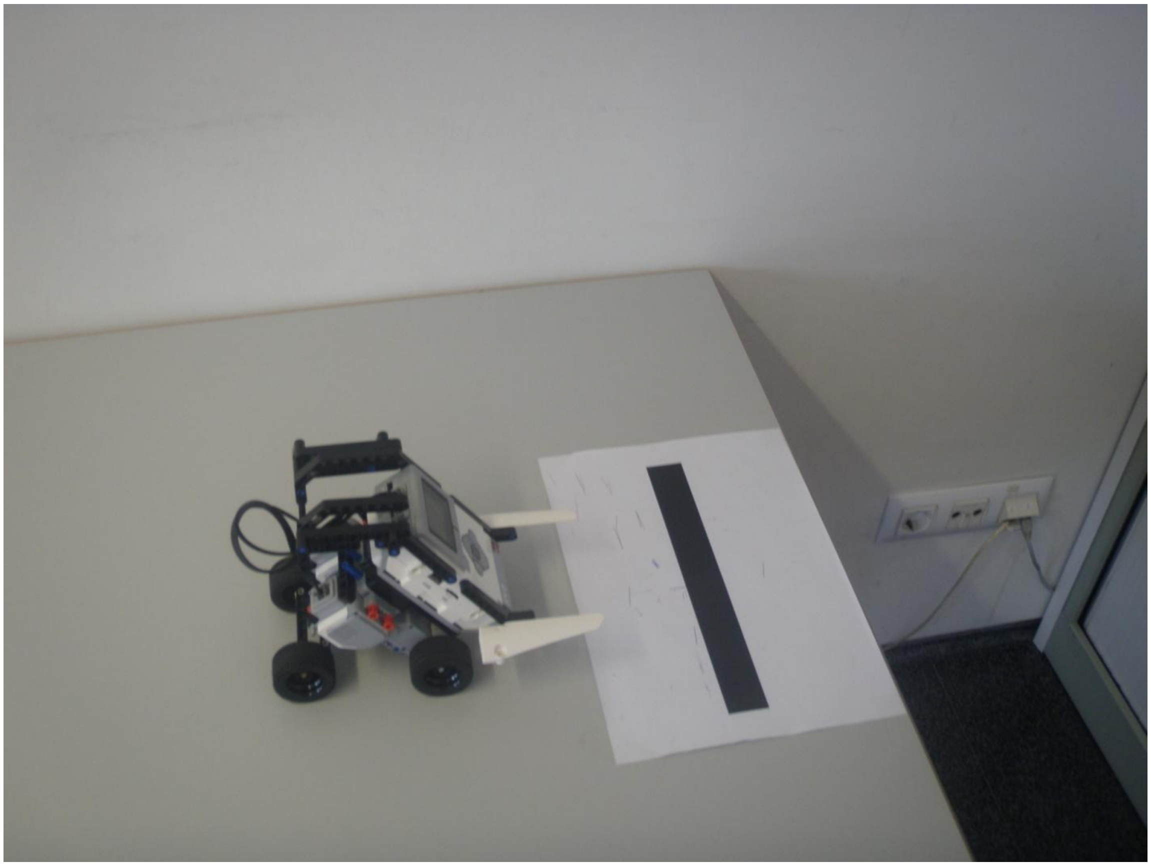


Figure 4.2.4 10 centimeters distance test

4.3 Orientation test

The orientation test was meant to both familiarize the user with the robot's turning mechanics and at the same time, determine how precisely the user could handle the turning mechanism. The robot turns at increments of ten degrees, which was kept in mind at the moment of revising the results. The user was allowed to attempt to adjust the angle if they felt that. Four different turning angles were presented as challenges in the same order as detailed bellow.

90 degrees

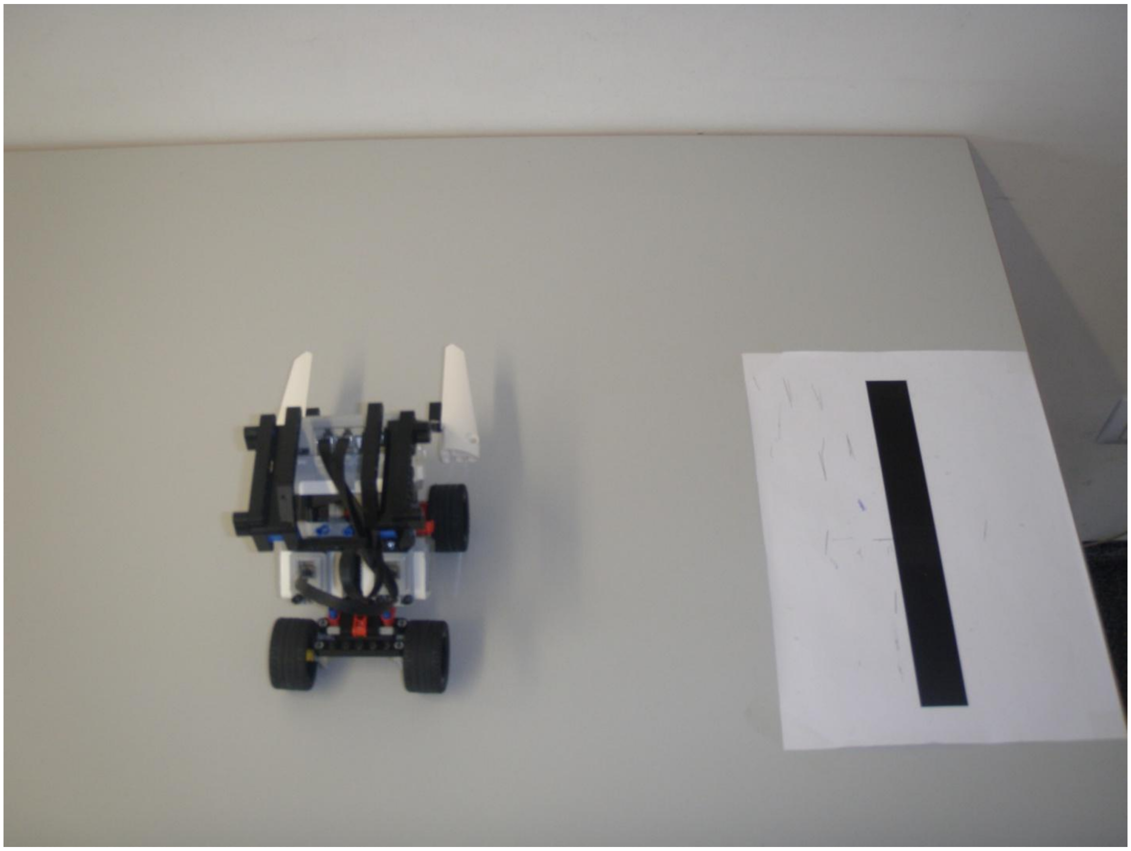


Figure 4.3.1 90 degrees rotation test

The first challenge was a simple 90 degree turn to the right. The user was allowed to attempt to adjust the angle if they turned too much. The objective of this challenge was to determine how a new user, with no prior experience with the prototype, can handle turning in a moderately closed arc.

180 degrees

The second challenge gave the user the freedom to choose which direction they wanted to turn it. Being a larger arc than the previous challenge, this time the user's confidence in handling was key.

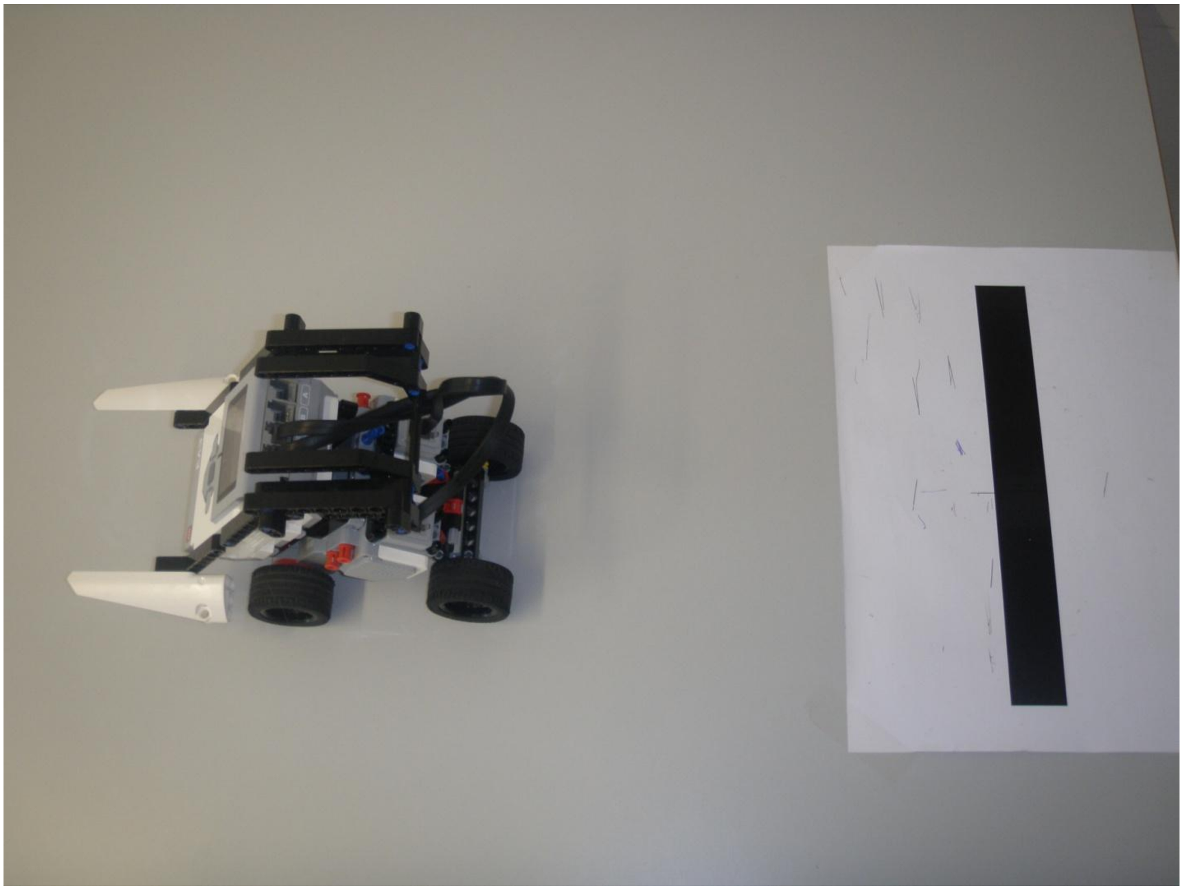


Figure 4.3.2 180 degrees rotation test

270 degrees

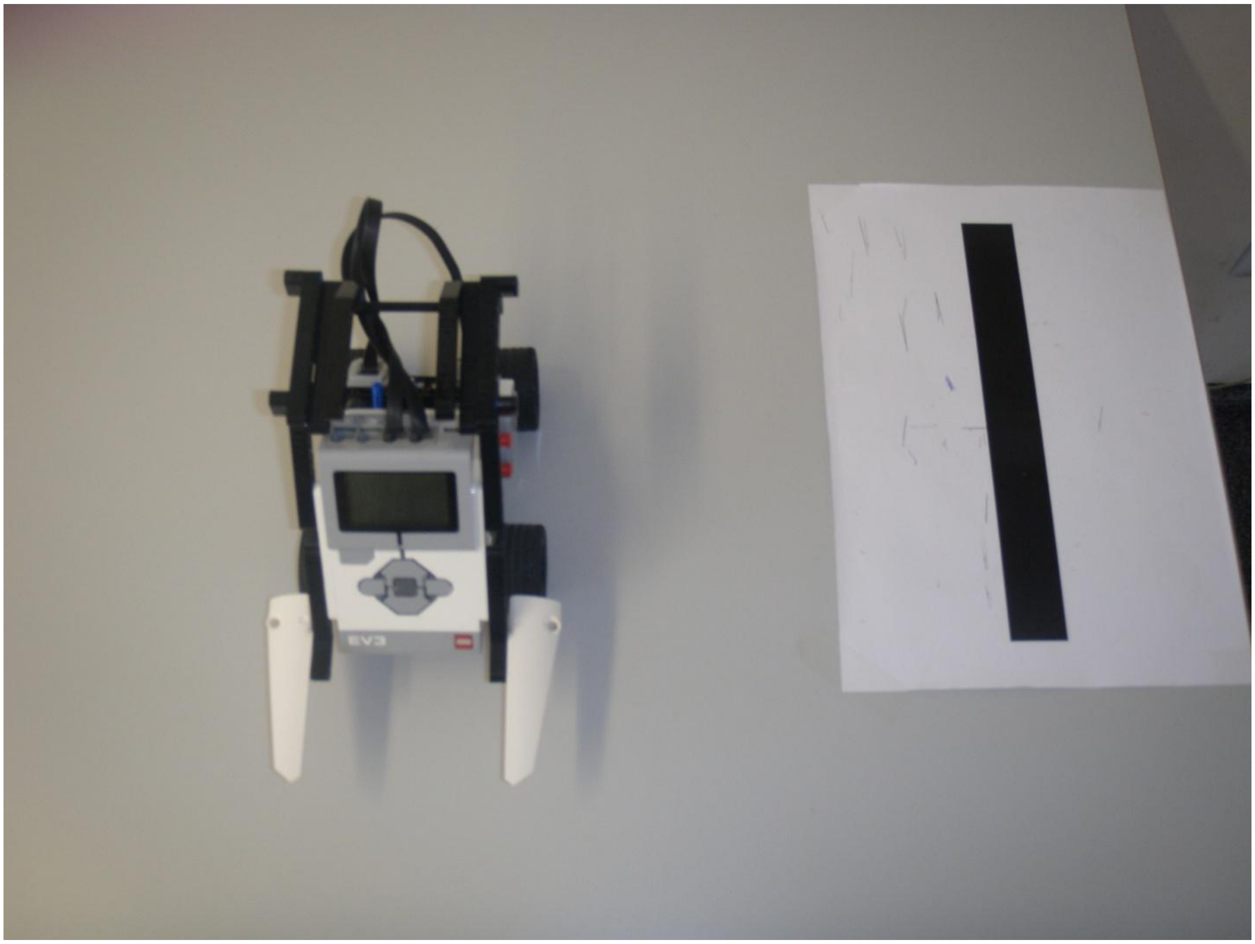


Figure 4.3.3 270 degrees rotation test

This challenge had the user turn to the right, 270 degrees. This is the largest turn in the test. It is meant to see how well the user has adapted to the robots turning algorithm. If the user overshoots, they are allowed an attempt at fixing the angle.

30 degrees

In contrast to the previous go, this challenge is meant to test the users' precision. After completing the other three challenges in this test, this one aims to answer the question: Has the user now adapted to the turning algorithm to the point that they can now execute precise, difficult maneuvers?

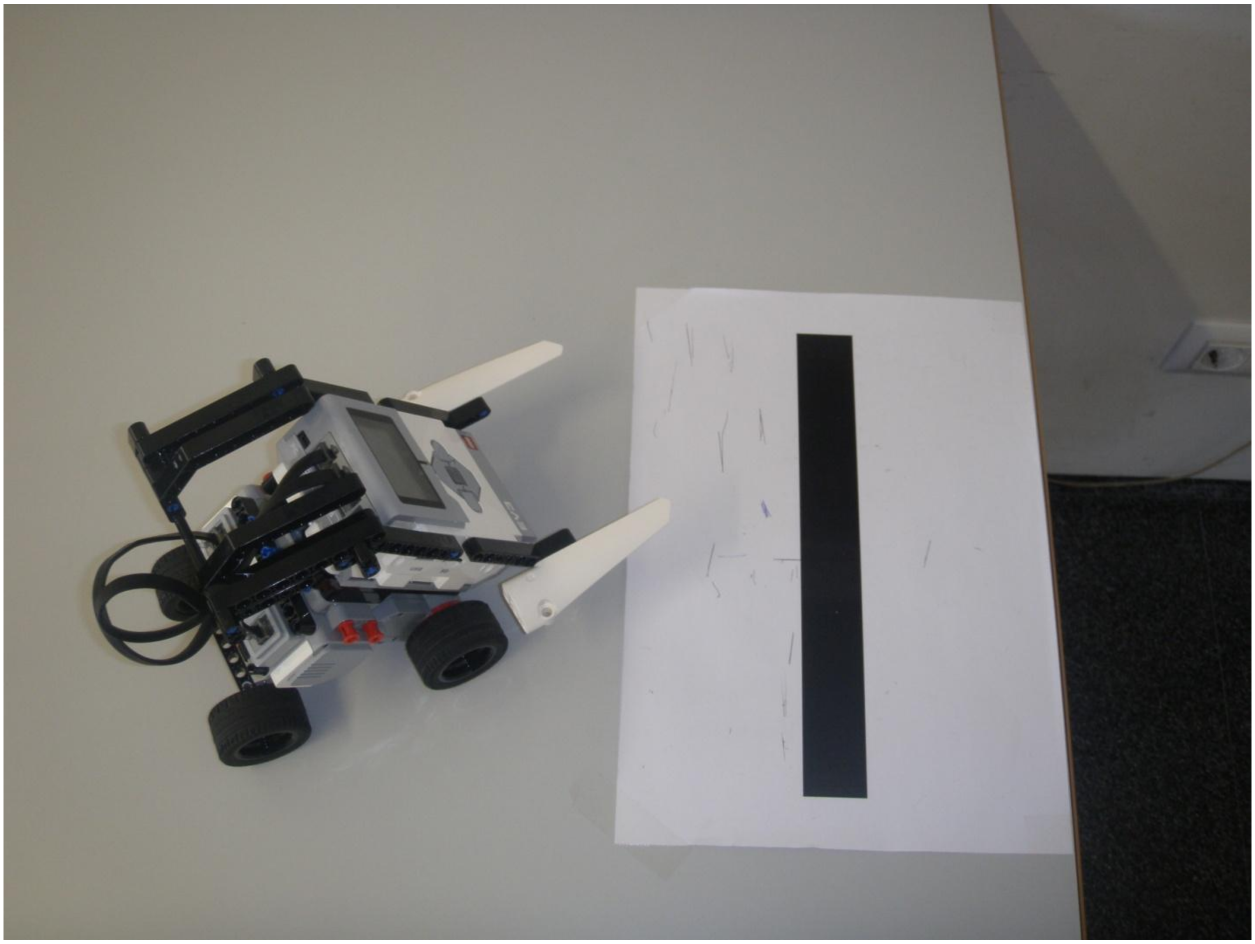


Figure 4.3.4 30 degrees rotation test

4.4 Combination test

The combination test had as its main objective testing the ability of the user to use the skills they had just learned from the previous tests simultaneously. This test reflected a more real scenario in which the robot’s controls would have to be used to its fullest to achieve the goal. This test is, by comparison, the most similar to real gaming conditions. In this test, the same distances as the first test are used, with the difference that the starting position of the robot was always 90 degrees, forcing the user to rotate the robot as well as get to the target spot. The reason the angle is not changed is to give the user multiple attempts to become used to the combination of both tests. There was no restriction when it came to turning the robot.

Distance: 80 centimeters, 90 degrees

This first challenge was meant as a way to introduce the user into real game situations. The familiar distance had two purposes: to allow the user a large distance to adjust the robots angle to zero degrees as well as quick fire way to test the users newly gained skills.

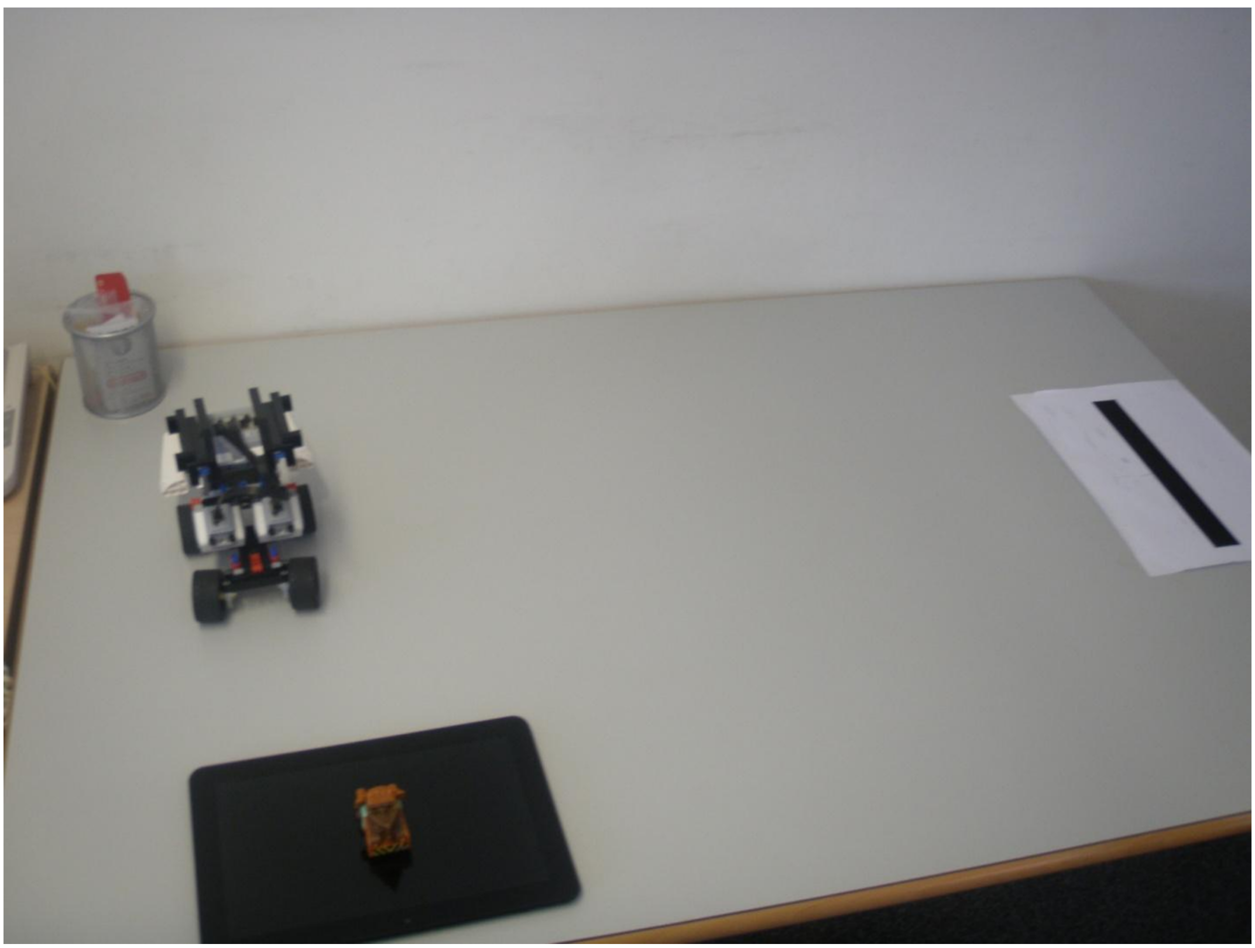


Figure 4.4.1 80 centimeters distance and 90 degrees rotation test

Distance: 50 centimeters, 90 degrees

Challenge number two increased the difficulty by allowing less room for error yet at the same time still giving the user large room for adjustment.

Figure 4.4.2 50 centimeters distance and 90 degrees rotation test

Distance: 40 centimeters, 90 degrees

At half the distance of the first challenge of this gauntlet, the user now has to be more precise with their movements, as now they are working with much less space.

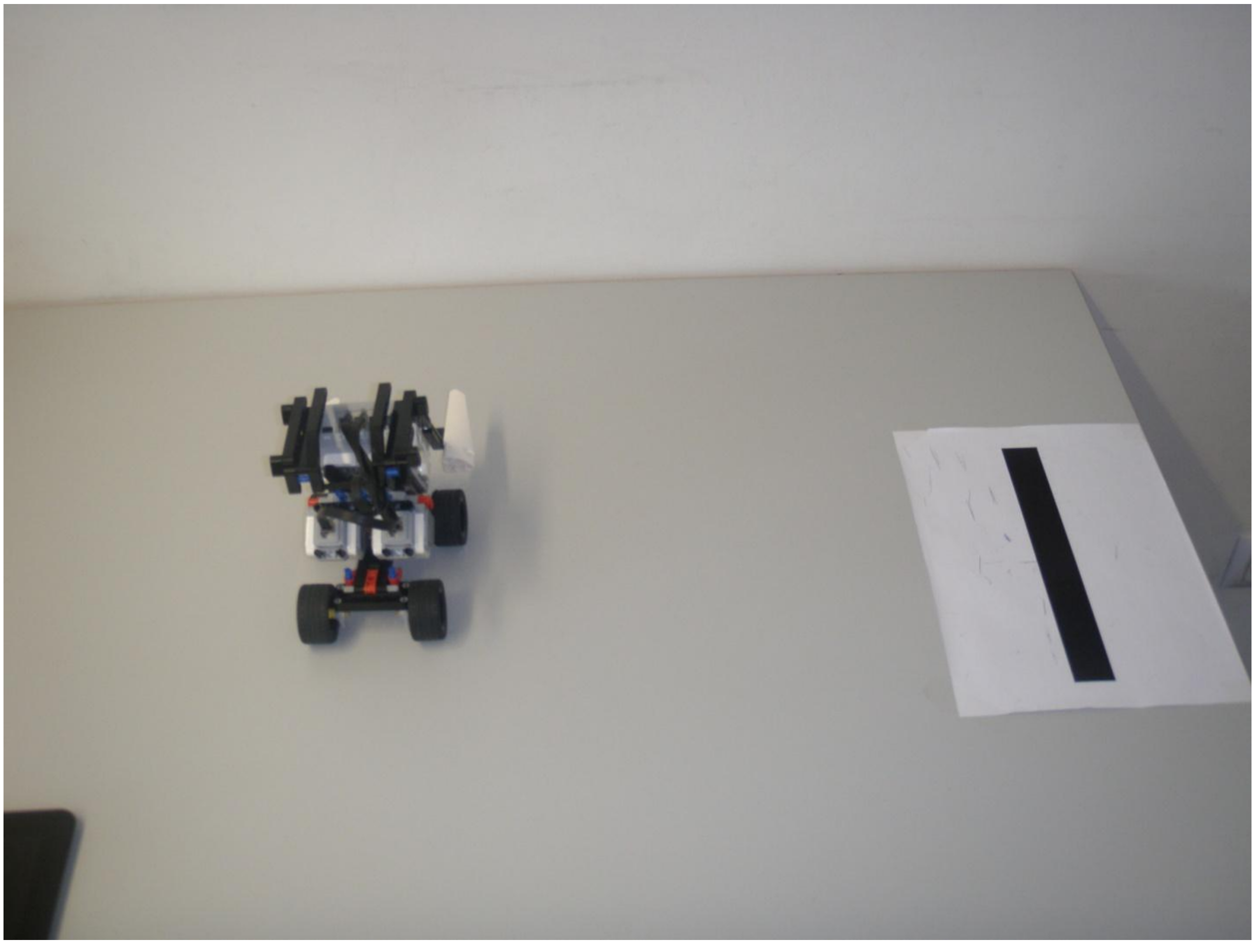


Figure 4.4.3 40 centimeters distance and 90 degrees rotation test

Distance: 10 centimeters, 90 degrees

By far the most challenging task in this entire experiment, with little room to navigate this challenge shows how far the user has come. It was also meant to answer the question: How precise can this method of control be with the robot at hand?

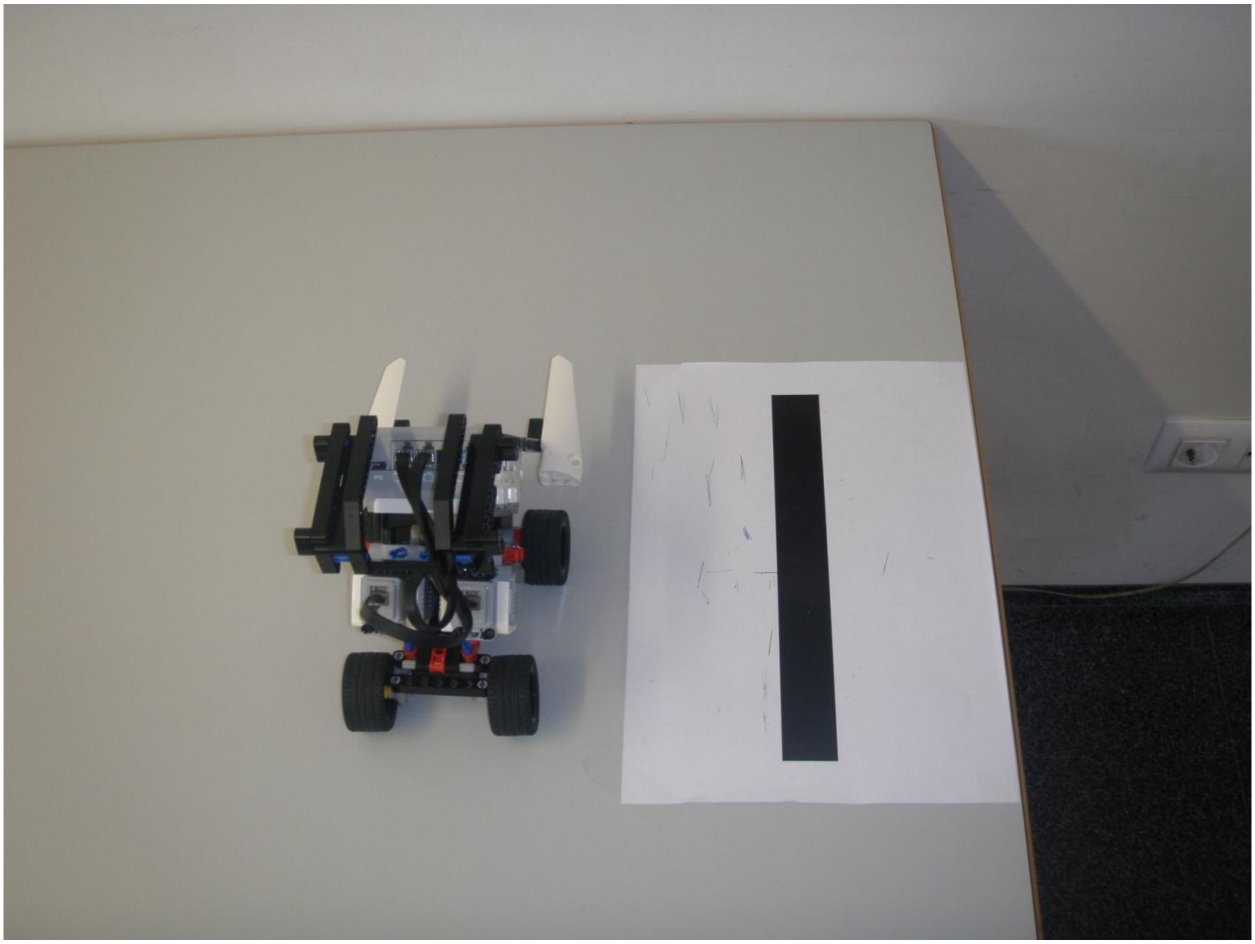


Figure 4.4.4 10 centimeters distance and 90 degrees rotation test

4.5- Results

As previously stated, the test results were compiled and compared to an ideal situation, compared both to the planed amount of moves and, in cases such as time, compared to an expert who was given a lot of time to practice before his stats were recorded. The results are broken up into the different categories of each test: Actions, Time, Distance and degrees. The last two are specific to two tests each. We also take an interesting case regarding male and female performance.

Figure 4.5 Example of a user using the system

It is also important to keep in mind that the users had no experience with the system beforehand, they were given around a minute to simply test the controls and were then thrown into the tests immediately. We answered basic questions but mostly it was intended that users find the answers for themselves by using the system.

Users were suggested the most important thing was precision, neither time or actions was told was even a relevant statistic. Even so, we still evaluated it. This is noticeable when the results were looked at, the best results were in the distance and degrees department (precision) the worst were time and actions. However it is very telling how even these results turned out.

4.5.1 Actions results.

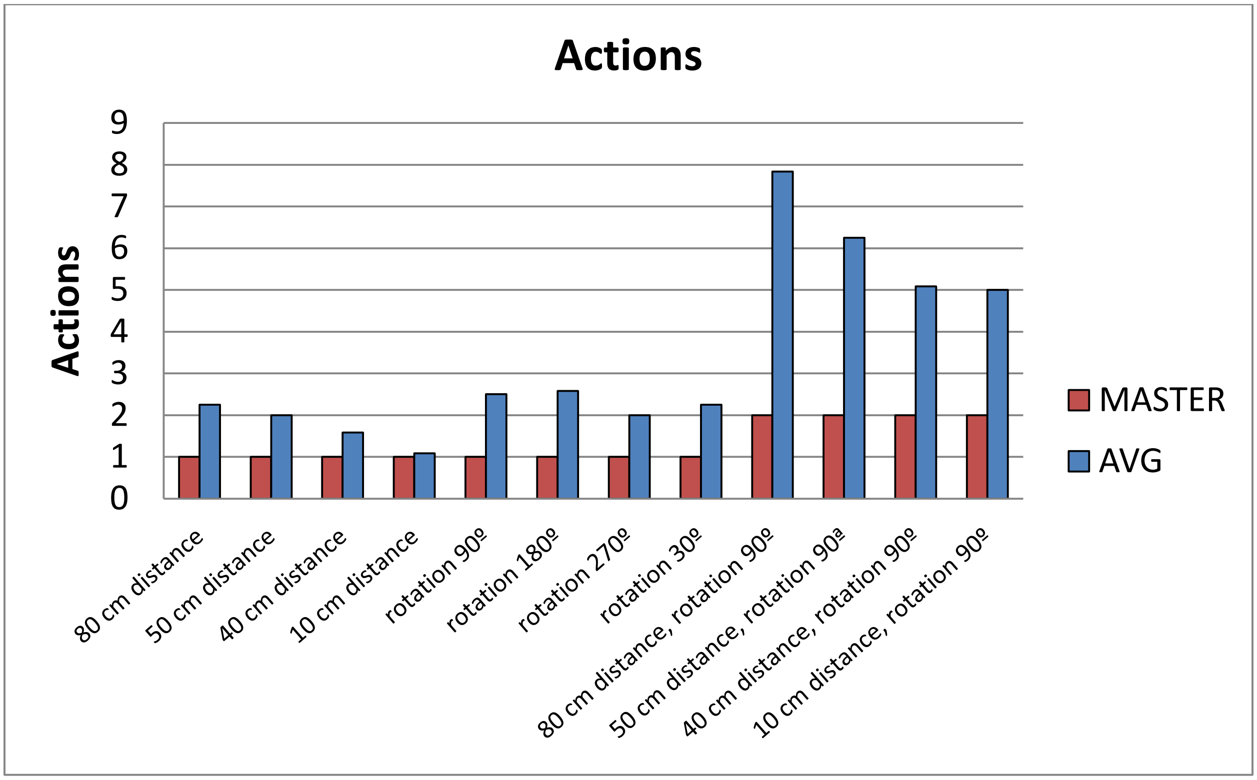


Figure 4.5.1.2 Comparation of the average actions number against the best case

When analyzing the amount of actions taken by the users, it is clear that the users were not equal to the reference one, however it is very encouraging how the users got better in most cases. Also from an objective standpoint, it is interesting how the users were not very off from the ideal action scenario, the obvious exception being the third test, the combination test. Overall, the amount of actions improved with each test and is an encouraging sign as users were not giving it priority.

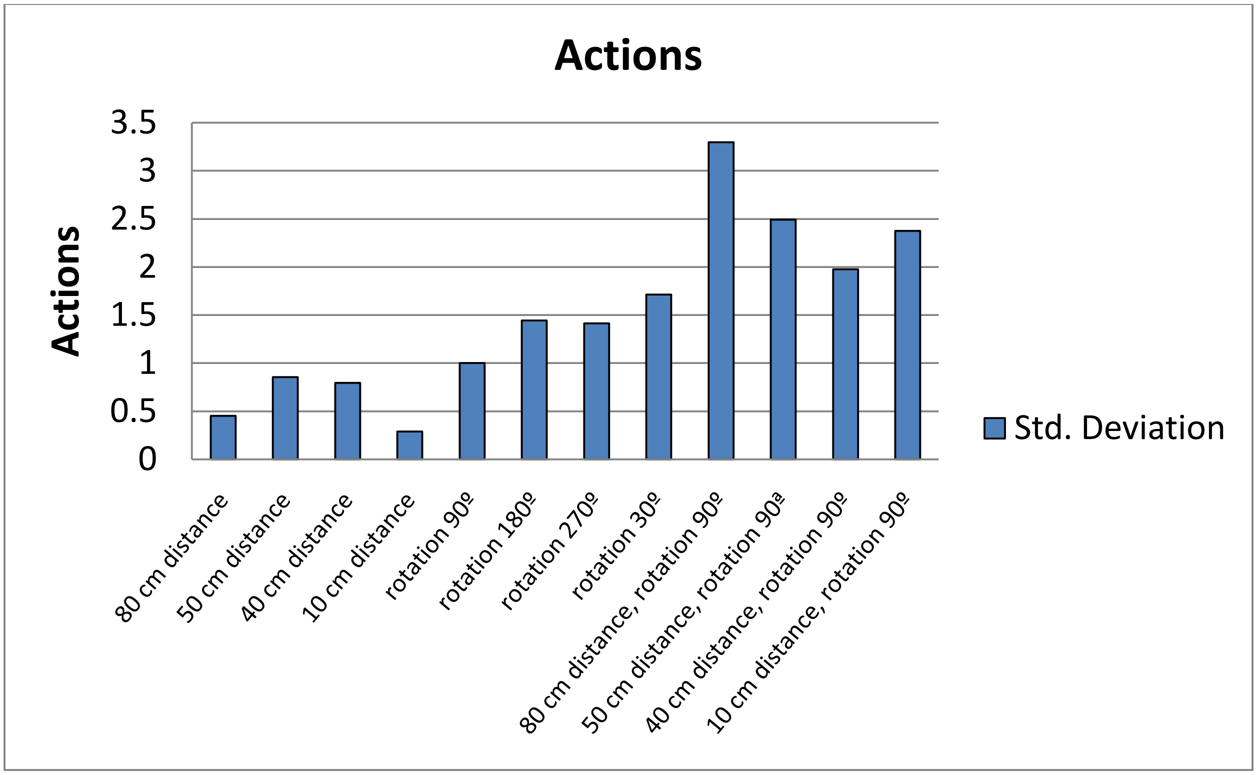


Figure 4.5.1.2 Actions standard deviation

The relatively small deviations can be interpreted as good news. It is clear that users all required around the same amount of actions, this shows that the learning curve was similar for most users. If the system were difficult to master, we would see the user numbers all over the place, it is even more encouraging that the deviations are not very large.

4.5.2 Time results.

The time parameter was also not stressed to the individual when performing the task. It was measured once again in comparison to an expert using the system, the results were as follows:

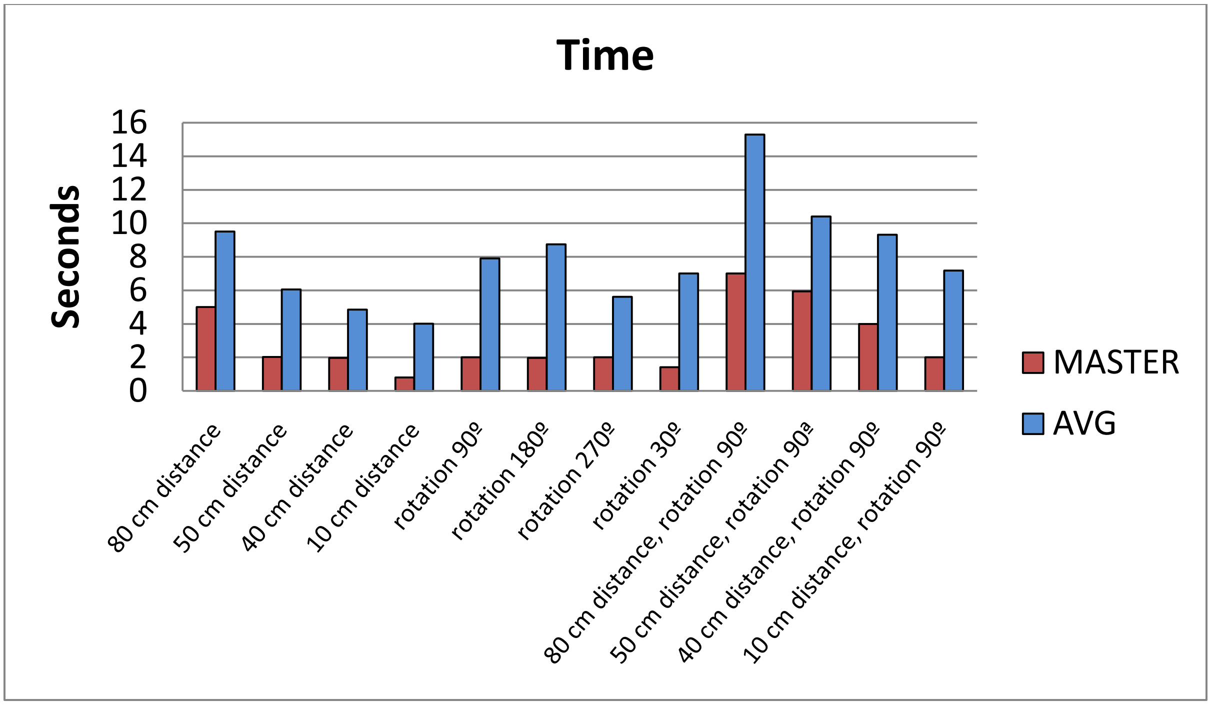
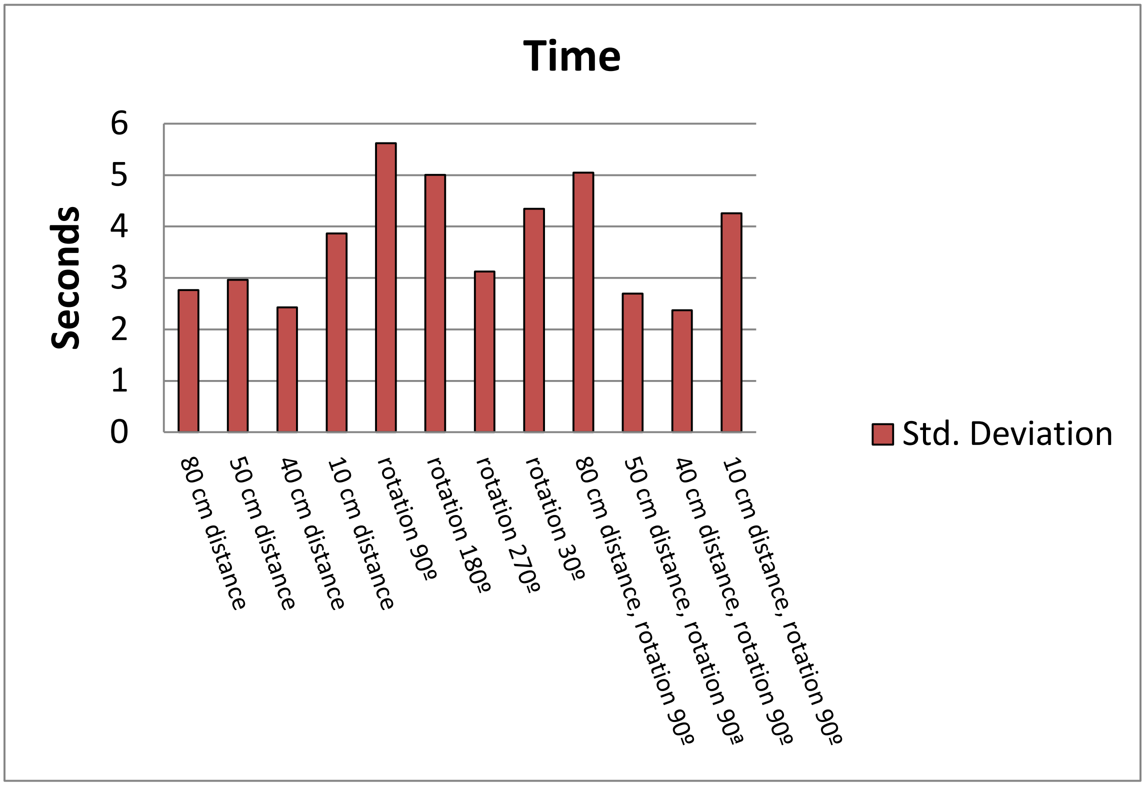


Figure 4.5.2.1 Comparation of the average time against the best case

With the exception of the rotation test, each challenge resulted in the users requiring less time to perform their actions. Since they were encouraged to try to be as precise as possible, it should not come as a surprise that the times were much larger than those performed by an expert. Still, from a progression standpoint, it is clear that users only got better as the challenges went on. It is also clear that the rotation test took the most time to get right for the user. Though the times being as off as they are here may seem like a negative result, it does show that users actively strived for perfection and were not easily frustrated by this. The deviation described below can easily confirm this.

Figure 4.5.2.2 Time standard deviation



As we can see in this graph, the deviation was largest when the user was first introduced to the concept of turning. This is an unsurprising find if we take two factors into consideration: a) Users were encouraged to pursue precision, this meant they would naturally take their time. B) As mentioned before, the robot can only turn in ten degree increments, which meant that on certain instances, users could not perfectly adjust due to human placement error by the test giver. It also shows that users were not easily frustrated and actively wanted to continue using the robot rather than “give up”.

4.5.3 Distance results

These results were measured in comparison to the actual objective. The results of distance and the results of degrees are easily the most important all around.

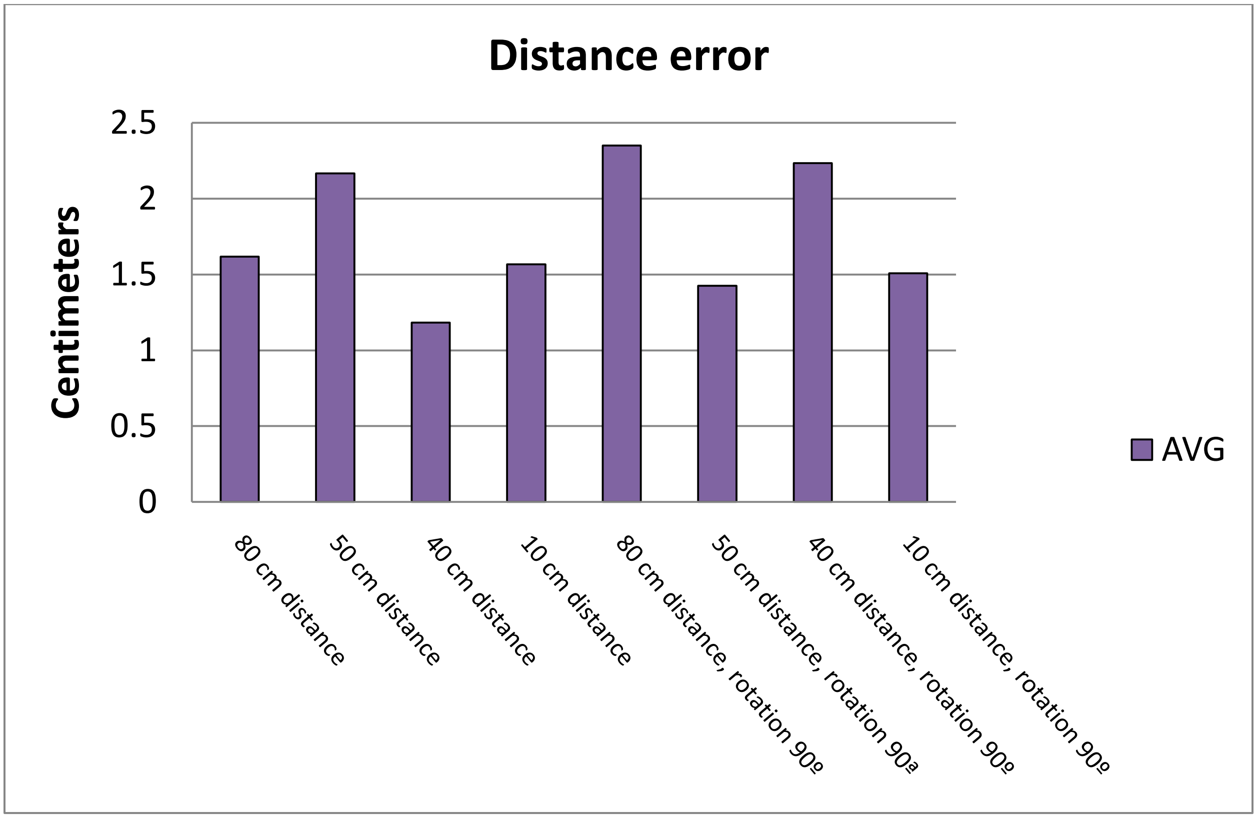


Figure 4.5.3.1 Distance error average

The overall distance results are very encouraging. Less than 2.5 centimeters off from the target is very encouraging. It is also clear that the most difficult challenge was when both distance and orientation was asked of the user. Even so, in most cases the user improved with each test. An interesting note is that users seemed to be consistently off by around the same amount in both ten centimeters tests. This shows that precision from short distances is overall the same, regardless of additional conditions.

Figure 4.5.3.2 Distance error standard deviation

The deviation is very encouraging in the sense that users were not too far apart from each other. It also seems to support the idea that the user error may have had more to do with the physical limitation of the robots movement then lack of skill from the user. This small deviation shows that users, ad least in the distance department, all seem to learn at very similar pace, this clearly supports the theory that the interface has an easy learning curve.

4.5.4 Degree results

Degrees were measured after every challenge that required it, using the robots arms as a reference. It must be kept in mind that the robot has a limitation of only being able to move in ten degree increments.

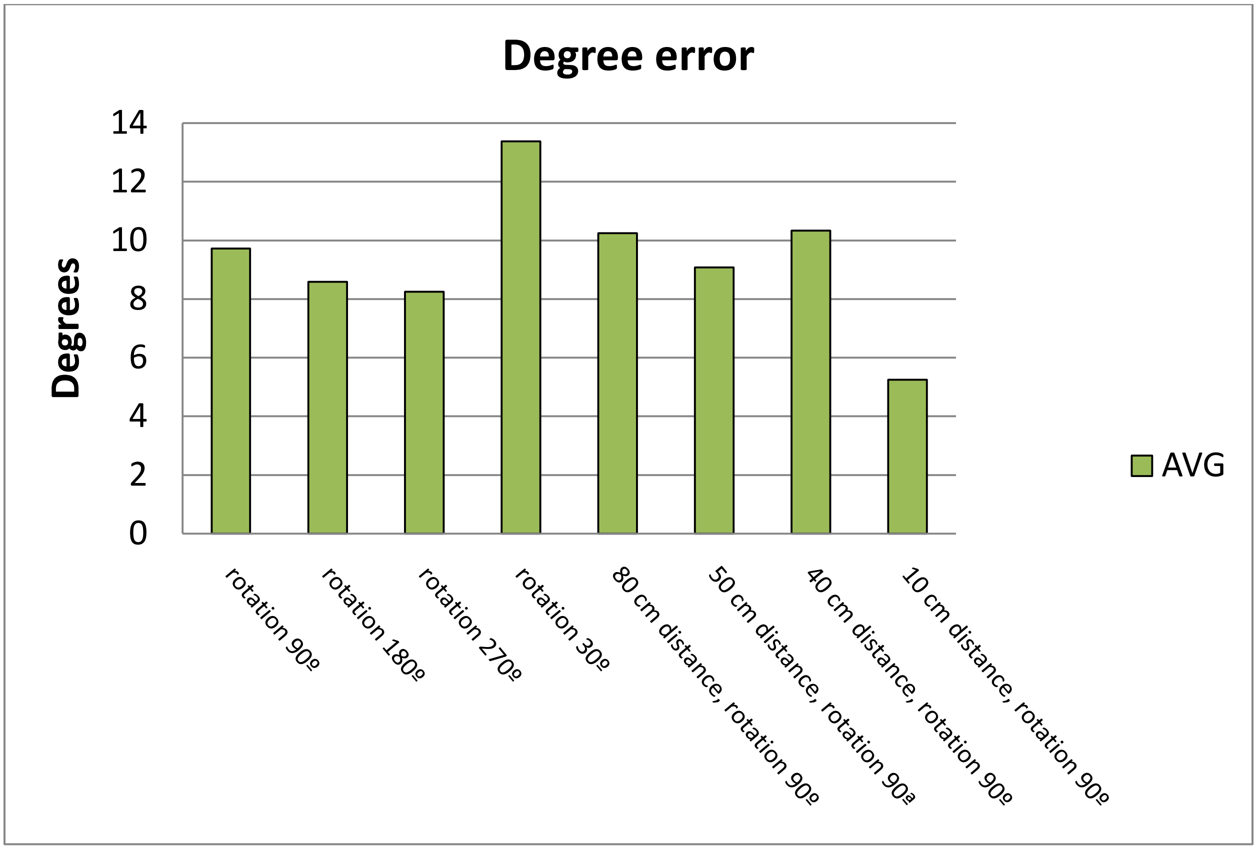


Figure 4.5.4.1 Degree error average

On average, users were able to successfully complete the test. Because the robot can only move in ten degree increments, most of the average results can be regarded as a sucess since they are under this threshold. A counterargument can be made that if a user was 8 degrees off, a single movement could lace them at only two degrees in the other direction. Though this is true, it is important to keep in mind that there is a difficulty for the user to physically see such a small inclination, and would usually default to keeping the robot in that position. Because of this, the results seem to be in the same realm of success as the distance tests.

Figure 4.5.4.2 Degree error standard deviation

The Deviation in the degrees must also be taken into consideration the previously mentioned robot limitation. Because the deviation is less than nine degrees in the worst case, this can be interpreted as being one rotational movement off at worst. This shows how close users were to each other and also reinforces the idea that users learning experience did not differ dramatically from each other.

4.5.5 Gender statistics

When looking at the statistics as we did in the previous sections, it seems users were overall effective. Because of this, we decided to analyze how the two different genders performed. It is important to mention that, on average, women claimed to have less experience with Tangible User Interfaces than men.

On average, men and women performed at a similar level when it came to actions taken. Since this parameter was not stressed, having similar results does show that the learning curve was similar. It is worth noteing that women tended to have higher deviation in the last test. This could probably be atributed to their lack of experience with TUIs. Still, the results are encouraging. These results are visible in figures 4.5.5.1 and 4.5.5.2

When it came to the time department, women had a tendency to take much longer than men and have much more scattered time ranges than men. This could be due to the fact that on later tests, women tended to have better results than men so it could indicate higher attention to detail or less confidence, which is consistent with their lack of experience. In both Distance and degree error, it was interresting to see how women were more precise in the combinational test and had less deviation. It seems that women had a tendency to strive for perfection in these tests while men strived for efficency.

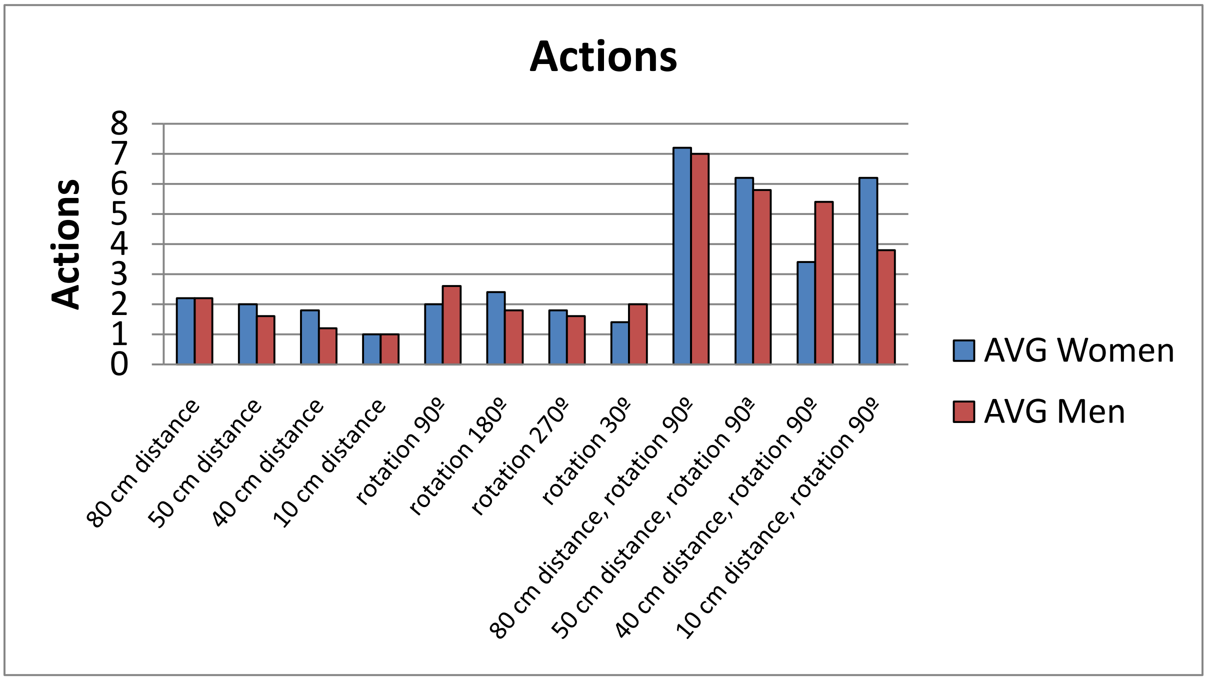


Figure 4.5.5.1 Average actions comparison between men and women

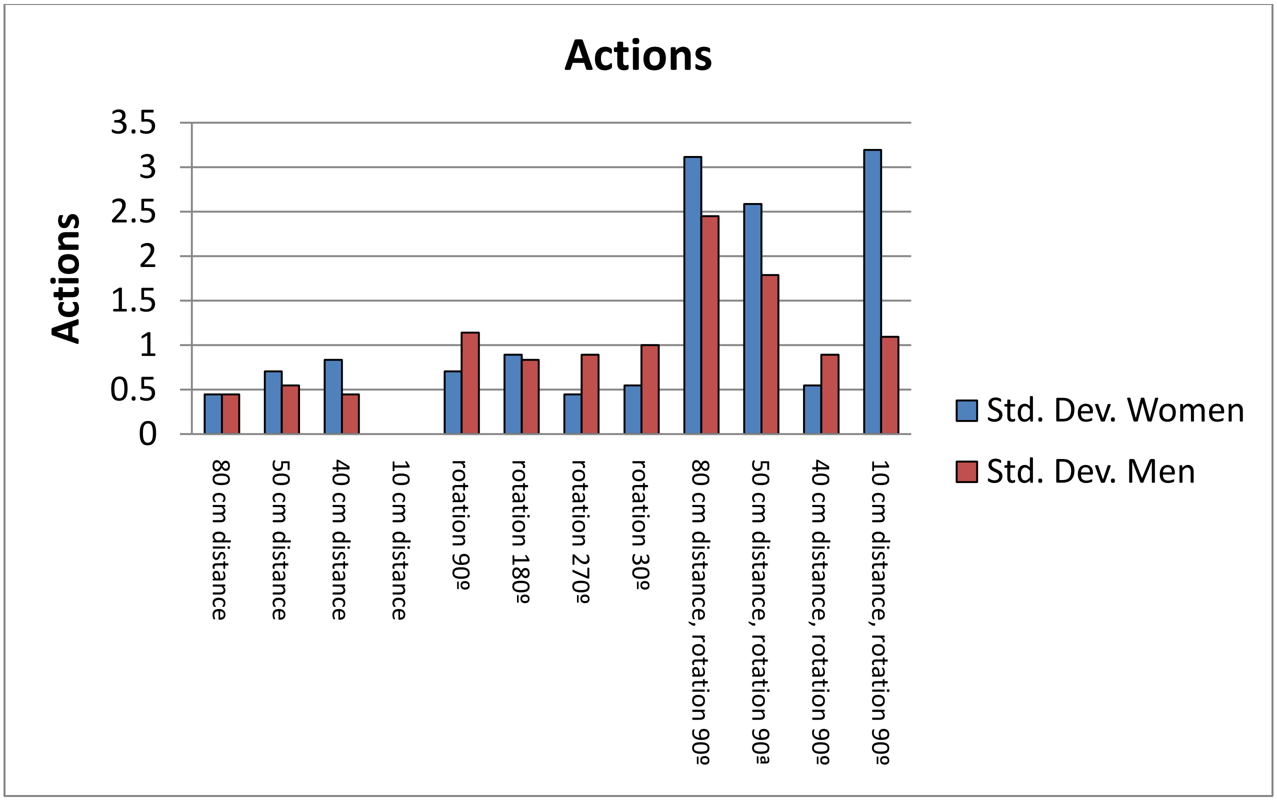


Figure 4.5.5.2 Standard deviation actions comparison between men and women

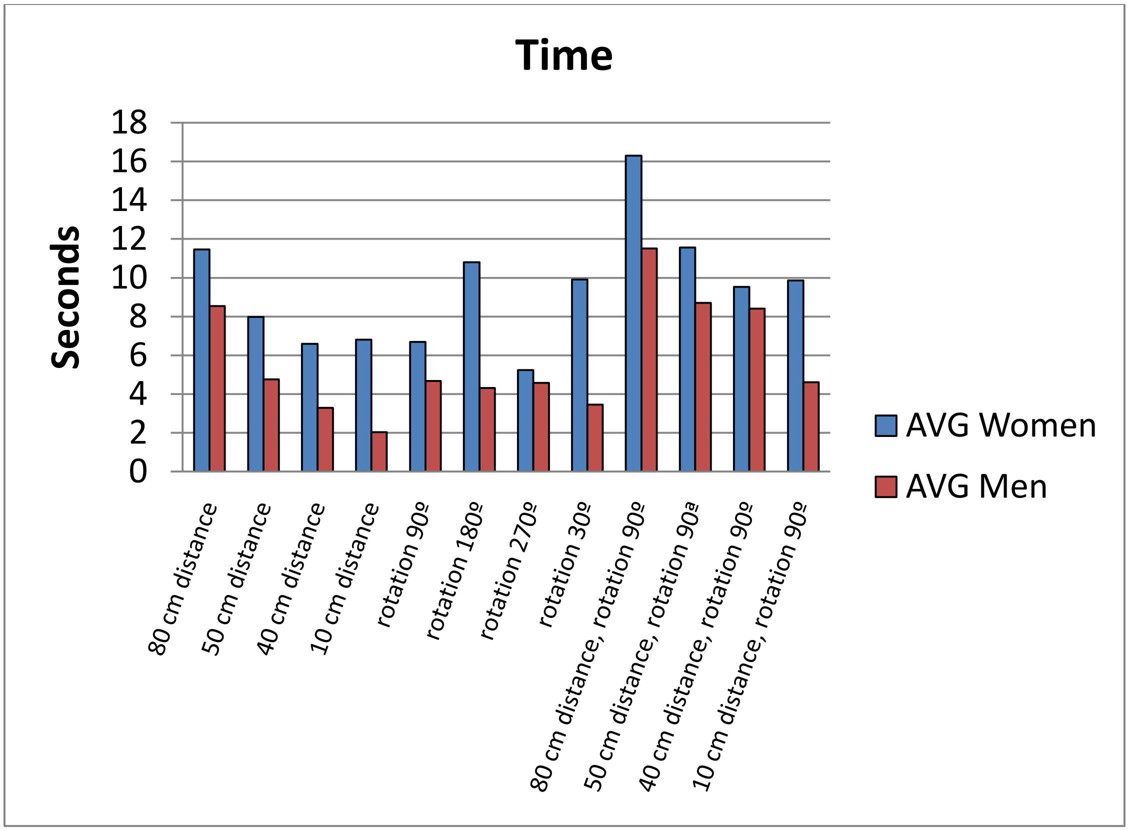


Figure 4.5.5.3 Average time comparison between men and women

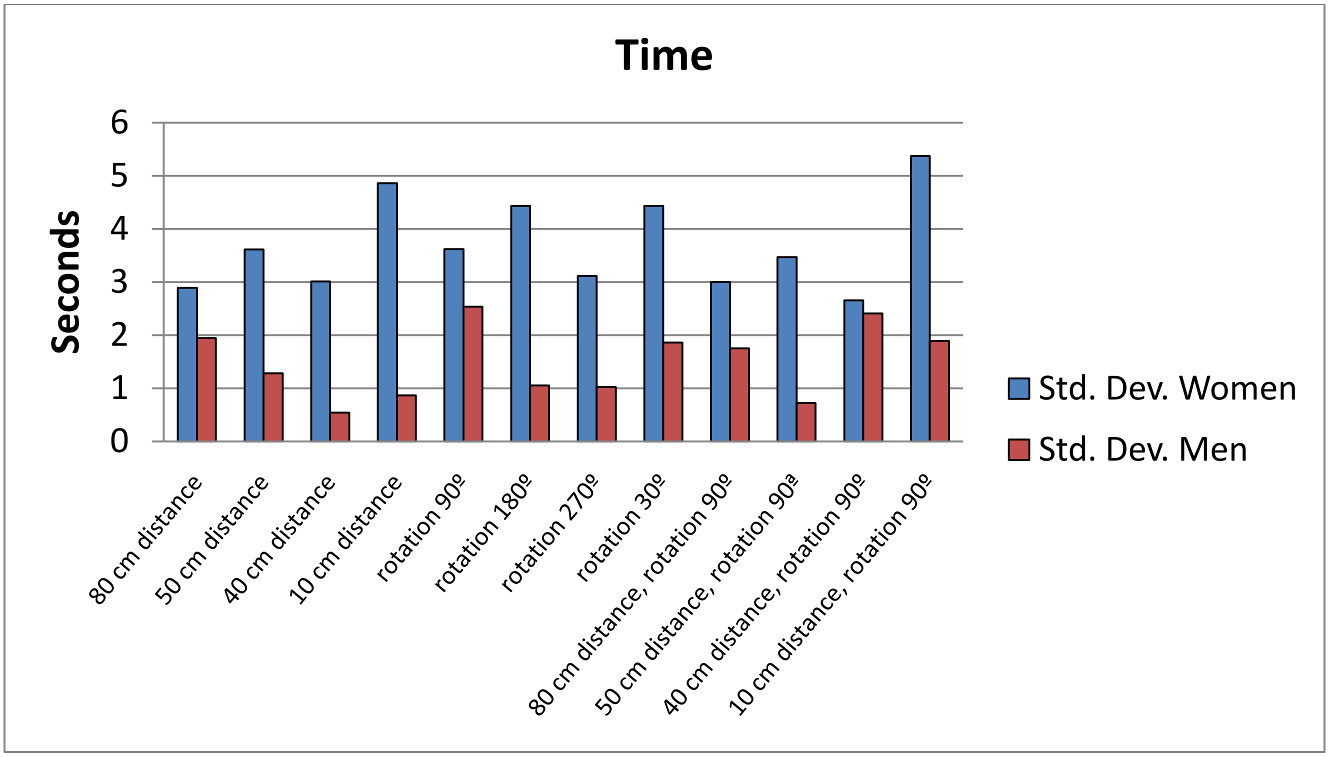


Figure 4.5.5.4 Standard deviation time comparison between men and women

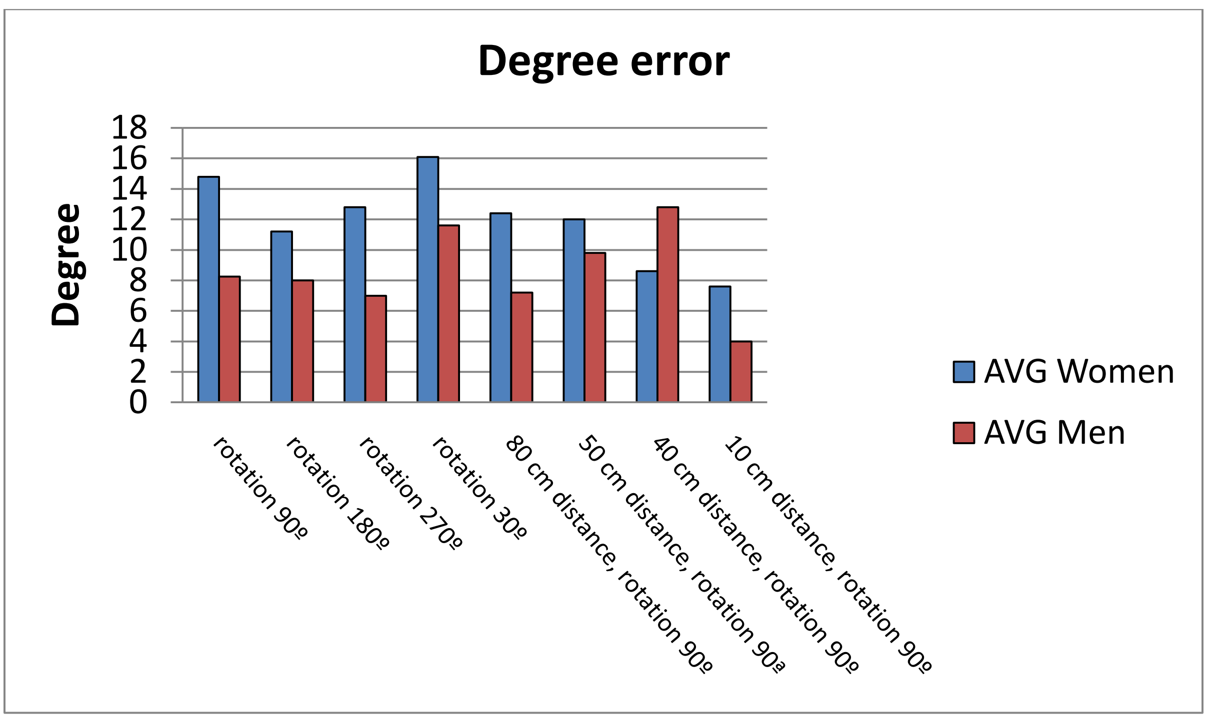


Figure 4.5.5.5 Average degree error comparison between men and women

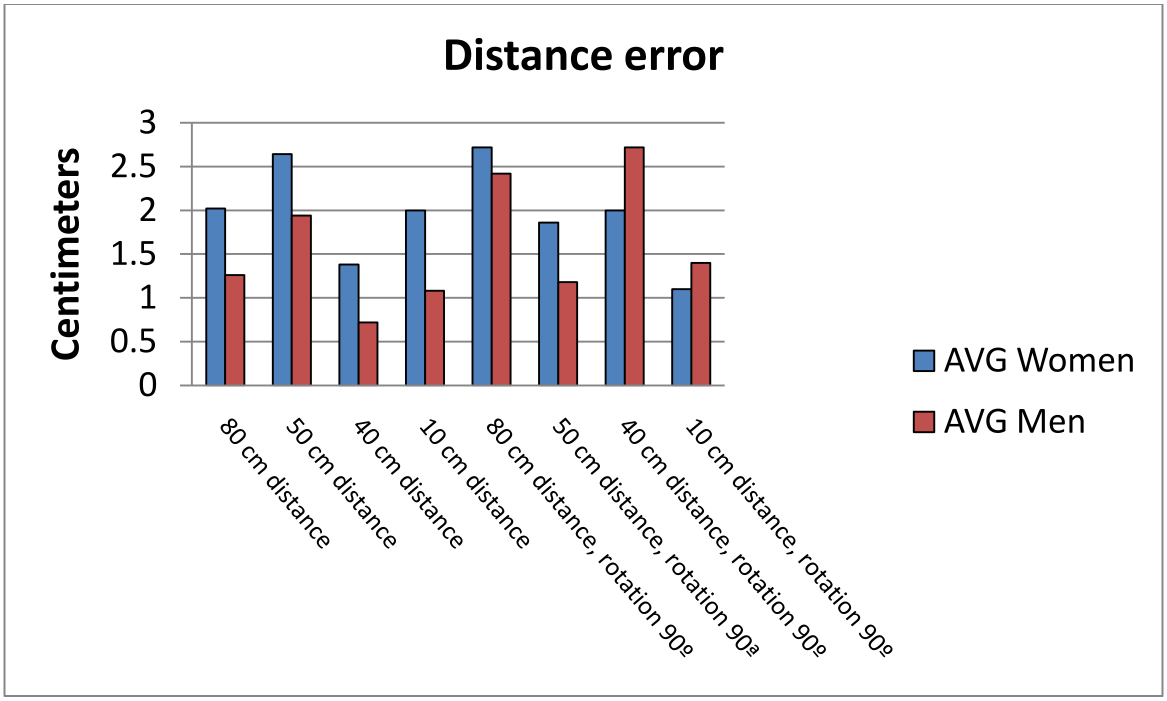


Figure 4.5.5.6 Average distance error comparison between men and women

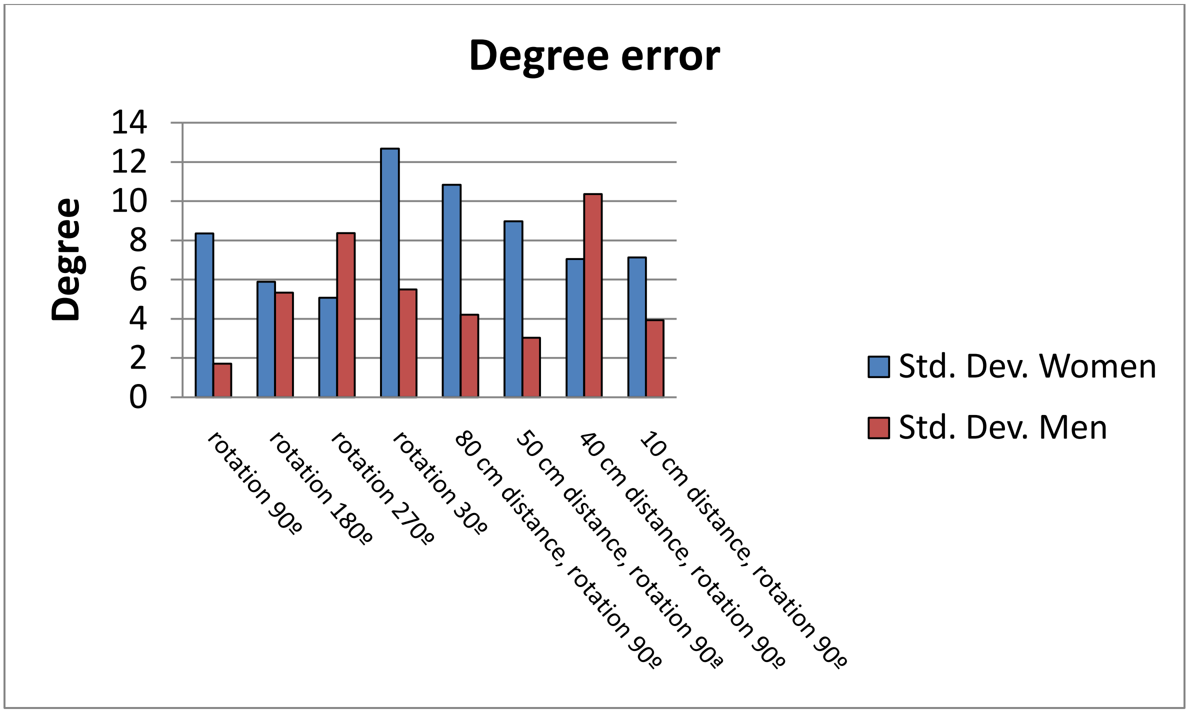


Figure 4.5.5.7 Standard deviation degree error comparison between men and women

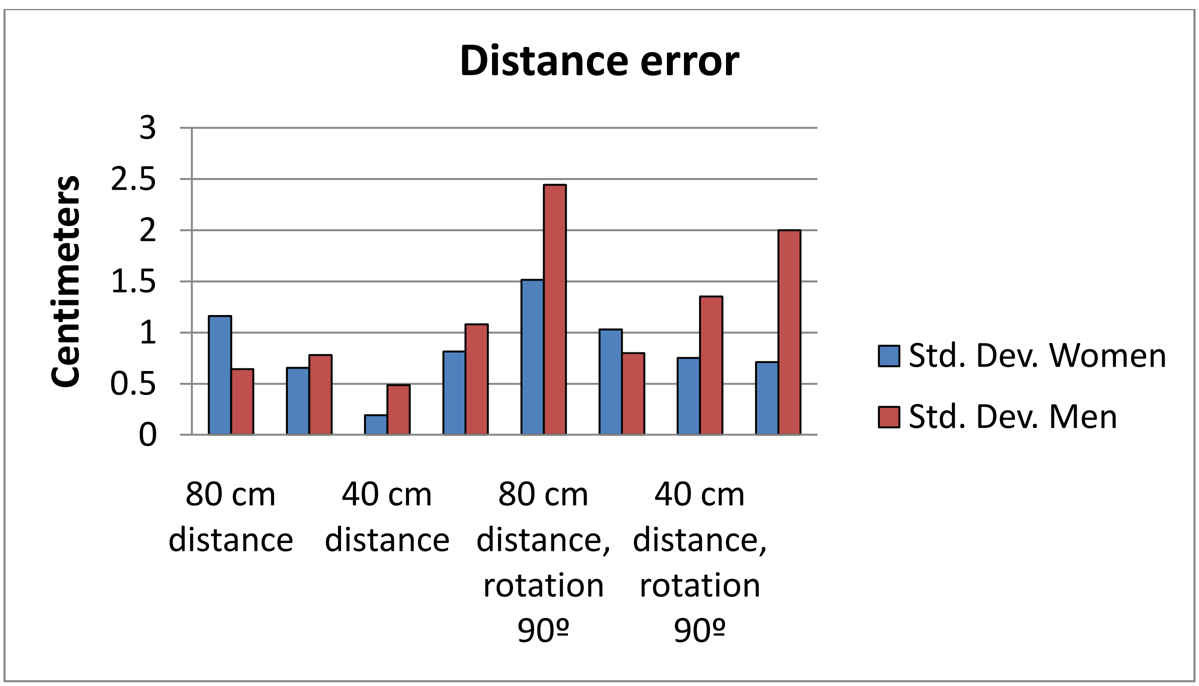


Figure 4.5.5.8 Standard deviation distance error comparison between men and women

4.5.6 User reviews.

The user reviews show on average how users found the system easy to use. The mental and physical demand was extremely low according to most users and required little effort with minimum frustration. The interesting statistic however is how, despite users overall good performance in the tests, the performance stat is less than 70% percent. This stat reflects users' satisfaction with their own performance, zero being completely unhappy and one hundred believing being perfect. It seems users believed they could do better, which shows a willingness to not only keep using the system but to improve, despite the fact the overall performance was very high.

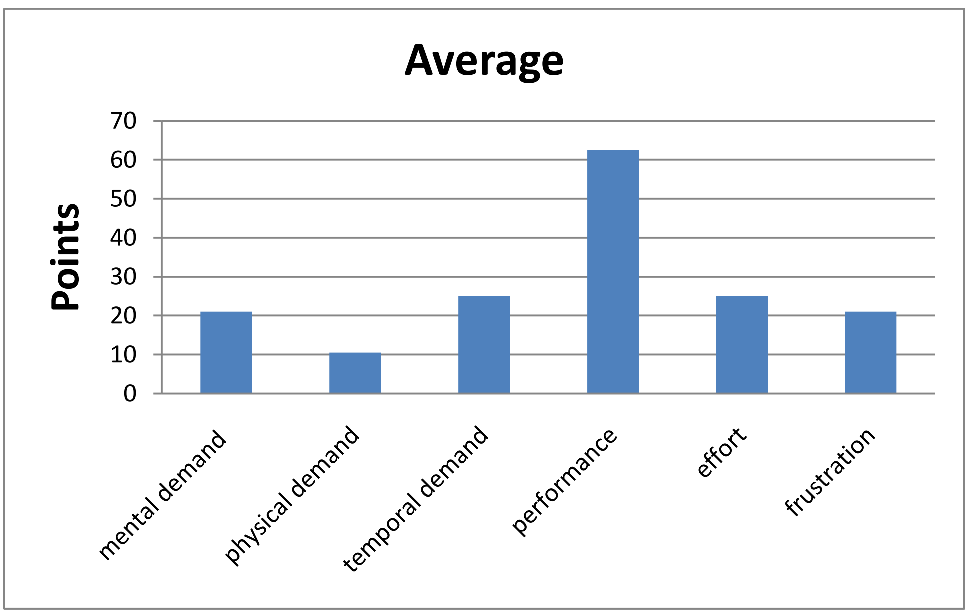


Figure 4.5.6.1 Average user review points

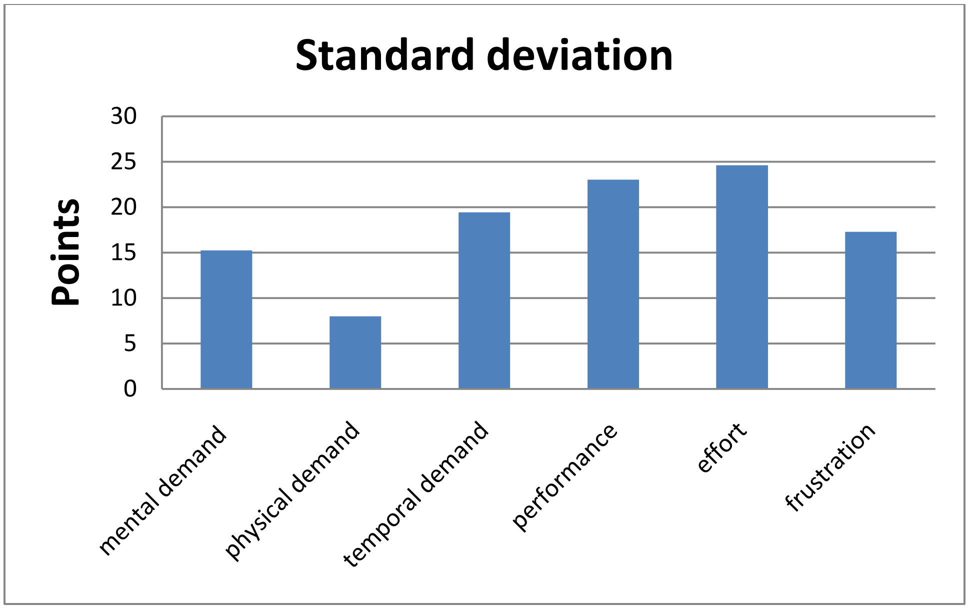


Figure 4.5.6.2 Standard deviation user review points

4.6- Discussion on intangibles

After the conclusion of each test, additional information was obtained from the participants by having hands off conversation with them. This showed that there were certain special circumstances in which the basic design could result more cumbersome than expected. One such example is in the case of lefties. Because of the manner in which the AppMATe is ideally held (similarly to a pencil), lefties sometimes had trouble as they would naturally grasp the AppMATe in a different manner, which would lead to either miscues or difficulties, such as when turning.

Another interesting situation was that some users, more specifically those with little to no routine interaction with videogames, had a tendency in overturning the AppMATe, which would cause it to turn in the opposite direction. This is due to the AppMATe using the initial angle as a reference. The AppMATe only requires users to slightly turn the object, and the same effect is always obtained. Some users however, in their excitement would continue turning (despite this having no effect on the robot) and would eventually break the line which divides turning left and turning right.

Users also complained that due to their positioning, they could not see how precise they had achieved the objective without standing, this is an interesting development that highlights the potential help the virtual aspect discussed in section 5 can bring.

4.7- Conclusions

The tests seem to indicate rather clearly how easy adapting to the system was to users of all spectrums. It also very encouraging that some of the statistics did not turn out better because of physical robot limitations and not because of the control scheme implemented.

It is also extremely indicative that users strived for perfection without complaining or giving up. They were very interested in having good performances and highly satisfied when seeing their own improvement. Low deviations across the board showed that there was little difference regarding usability among users.

5- New Game design groundwork with Unity 3D

5.1 Introduction

To add on the robot control scheme, we decided to also add in a new layer to game design using Unity 3D.

The reason we chose Unity 3D is because of Unity 5.0 which has optimized 2D development. Allowing for more resource management and easier development for 2D oriented applications. The Tangibot also included the design a group of games that used group of tiles, which could form large boards. With our proposal, we aim to add a virtual element to this process: allowing users to have not only a replica of said board, but to also use it in combination with the controls created for this project to have a synergy between what happens in the virtual world and what happens in the real world.

This new dimension also helps with game development, as it gives the versatility to include elements that before were less likely, remote play comes to mind. It also allows a degree of overseeing and perspective that the player would otherwise have to obtain by physically moving around the board. This new dimension of information adds more immersion into the game or whatever application our project is used for.

5.2 Technology overview

As previously mentioned, we used Unity 3D (specifically its 2D development model) to create an application that allows the user to generate a gridded board.

The program currently allows for the creation of a two by two grid, with the user defining the amount of columns and the amount of rows.

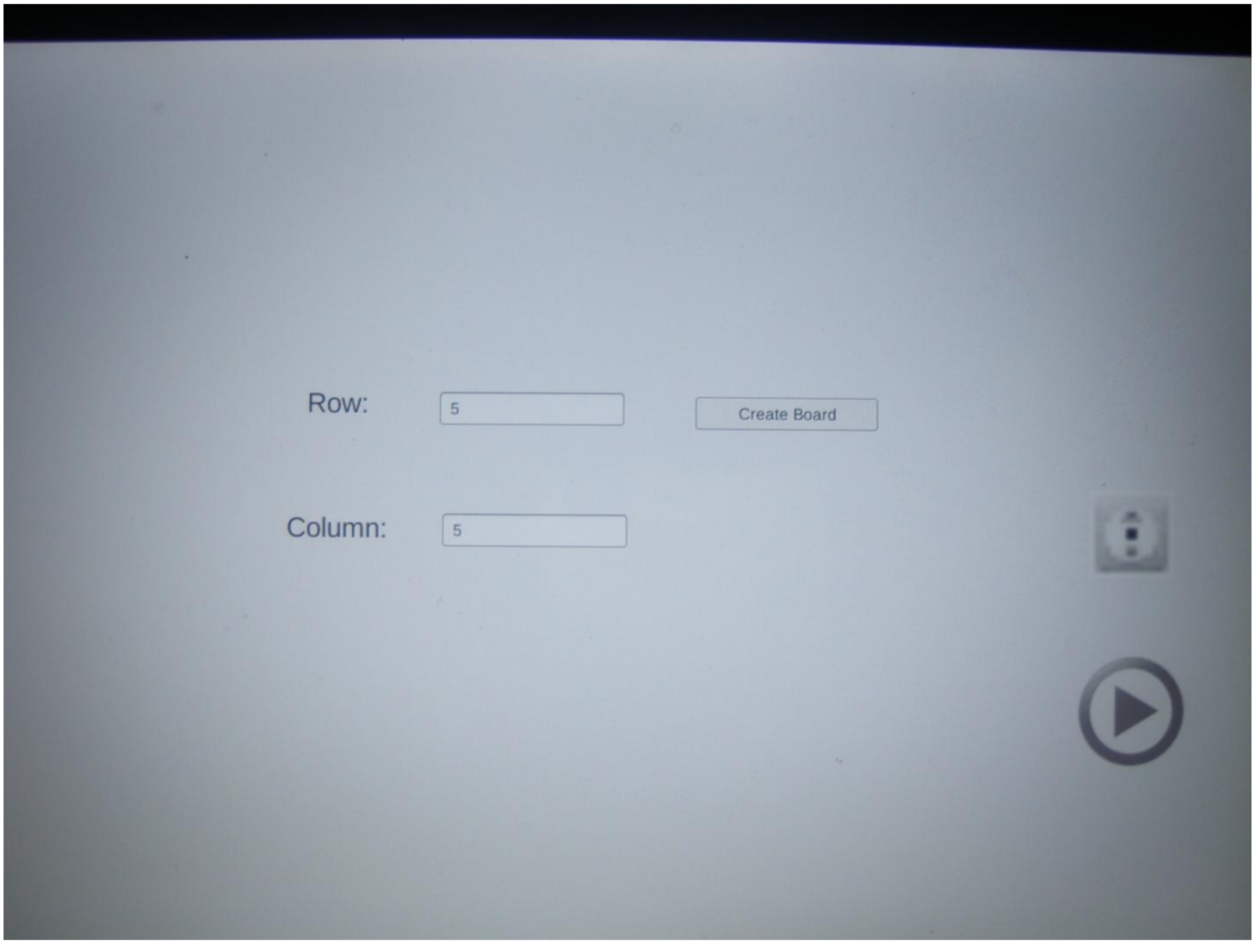


Figure 5.2.1 Gridded board generation UI

After the user decides this and clicks the “create board” button, the tiles are internally generated and placed in the appropriate positioning in a “deactivated” state. At this point, the there are two possible buttons the user can press but by default, they can toggle each tile with a simple touch.

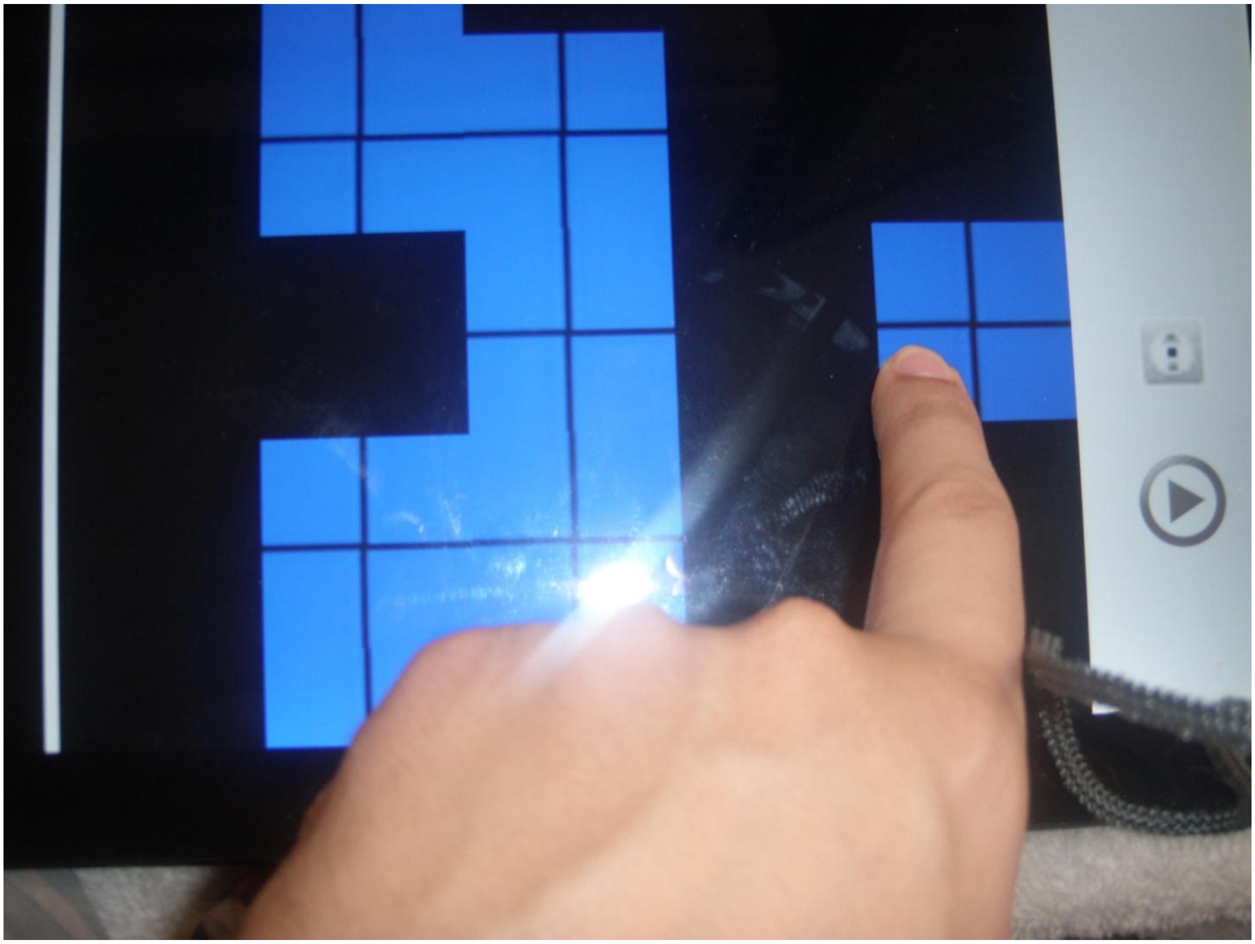


Figure 5.2.2 Gridded board tiles definition UI

The two buttons are the “scroll” and the “play” button.

The Scroll Button: This button removes the ability to toggle tiles and instead allows the user the ability to move the board.

The Play Button: Initiates the game. This now expects the user to use the AppMATe and only responds to three contacts or more.

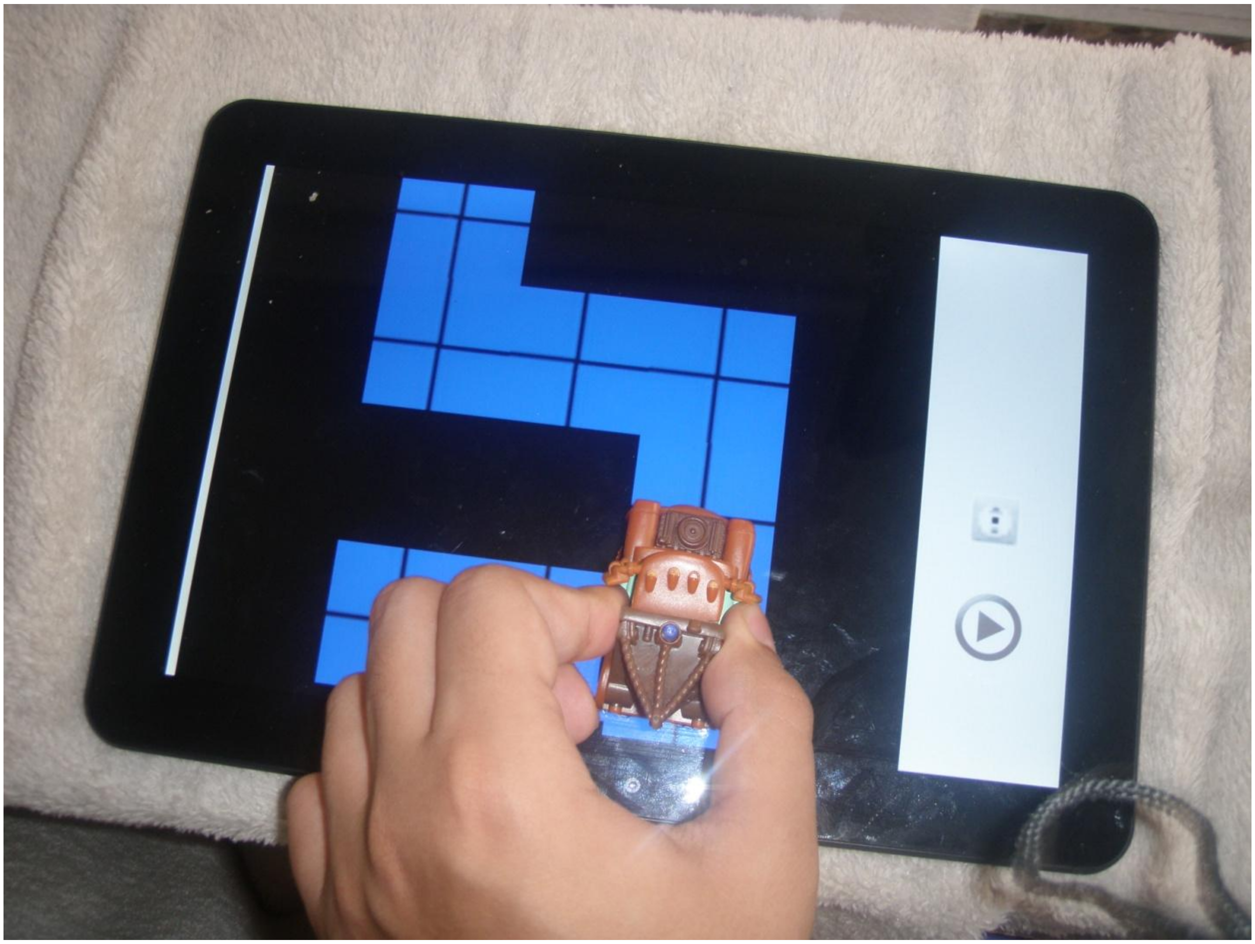


Figure 5.2.3 Application use example

5.3 Game design with unity

In the Tangibot project, game design was done with the express intent in designing a board in which the robot can play in. The express point of the unity application is to replicate this board in a virtual environment.

Figure 5.3 Real board

This allows the user the ability to better visualize the board, as they have both the physical board in front of them as well as an overhead view. This allows not only more accessibility but it opens up the door for more development options. It also gives the option of portability and multiple users participating.

6- Future Work

The application, although function, still requires some additional polish and work. The map auto scroll requires some adjusting to fully match the robots speed. Furthermore, the tests used in this project were done with an additional application developed in android studio.

The reason for this is that the connectivity via Bluetooth with the EV3 Robot is a complex process to adapt. We were able to achieve this connection in the end but a full migration to .Net will be required.

Another interesting point to touch on will be adapting the messaging system to better reflect the board situations in the Unity board. Contrary to the application used in the test, the messages will not depend exclusively on the user's motion, it will also depend on the obstacles that should be manifested in the virtual game as well as the physical; there should never be a situation in which the Robot con run into an obstacle, such as leaving the map. This will have to be worked in though the groundwork is already in place.

Another key point that needs to be addressed in future work is developing a safeguard system for the turning methods. As the intangibles section showed, some users would become over exited when turning the robot, this lead to them overturning the AppMATe, currently, there is no safeguard for this, and it should be implemented.

The ability to move in reverse is something the robot is capable of, however it has not been included in the robots statistic program nor is it available in the Unity virtual replication. This is something that should be worked into the project as it allows for more versatility, and in a thesis that is based off of adding versatility, this could be a great asset.

7- Conclusions

With the positive results from the usability test and the indirect demand for better visibility from users, it is clear to us that the possibility of using Tangible User Interfaces in this type of projects could be extremely beneficial.

When looking at the results, the main question, "Can users easily adapt to this control scheme?" seems to be answered. The users not only were able to successfully adapt with minimum training, but also were excited in continued use of the system.

There are also weaknesses shown in the experiments, specifically regarding general size of the robot. This interferes with visibility and is something multiple users complained about. This highlights the need for the Unity 3D compliment that we developed, which would alleviate this problem somewhat. Another issue we discovered is the need to implement the ability to move in reverse or limit the need to do so. Because of the test subjects comfort level with the control scheme, they became increasingly interested in performing well in the tasks, which lead to unexpected situation of having the robot and its physical limitations being the factor keeping users away from perfection.

Overall, with some added additional work, Tangible User Interfaces seems to be a great way to improve the user comfort, adding more intractability with a smaller learning curve.

8- Acknowledgments

This Project could not have been completed without the assistance of the ISSI Group of the Polytechnic University of Valencia, who not only gave me the space needed to conduct the tests but assisted in providing me assistance when required.

A special thanks needs to be given to the Director of the project, Dr. Francisco Javier Jaén Martínez, with whose suggestions and direct assistance made an incredibly positive impact.

I would also like to thank Paula Navarro for her assistance with the statistical graphs and analysis.

9- References

[1] Garcia-Sanjuan, F., Jaen, J., Catala, A. , Augmented Tangible Surfaces to Support Cognitive Games for Ageing People. 6th International Symposium on Ambient Intelligence (ISAmI), 2015.

[2]Suzuki, H. and Kato, H. Interaction-level support for collaborative learning: AlgoBlock—an open programming language. In Proc. CSCL'95, John L. Schnase and Edward L. Cunnius (Eds.). L. Erlbaum Associates Inc., Hillsdale, NJ, USA, pp. 349-355, 1995.

[3]Cockburn, A. and Bryant, A. Cleogo: Collaborative and Multi-Metaphor Programming for Kids. APCHI '98 Proceedings of the Third Asian Pacific Computer and Human Interaction, pp.189-194, 1998.

[4] Guo C., Sharlin E., Exploring Tangible User Interfaces in Human-Robot Interaction, University of Calgary, 2008.

[5] Scott, G., Leritz, L. and Mumford, M. The Effectiveness of Creativity Training: A Quantitative Review. Creativity Research Journal, 16(4), 361-388, 2004.

[6] AppMATe. http://www.appmatestoys.com/

[7] Ullmer, B. and Ishii, H. Emerging Frameworks for Tangible User Interfaces, In Human-Computer Interaction in the New Millenium, Ed. John M. Carroll, Addison-Wesley, pp.579-601, 2001.

[8] Sternberg, J.S. et al. Handbook of Creativity, Robert. J. Stenberg Ed., Cambridge University Press, 1999.

[9] Vincenzo Del Fatto, Gabriella Dodero, RosellaGennari, AlessandraMelonio, MarcoMontali, Simon Razniewski, Santina Torello,XiaofengWang,FlorianoZini, Gamified Children Universities: an Exploratory Study, Faculty of Computer Science, Free University of Bozen-Bolzano.

[10] Michael, D. and Chen, S. Serious Games: Games that Educate, Train, and Inform. Course Technology PTR, 2005.

[11]Suzuki, H. and Kato, H. Interaction-level support for collaborative learning: AlgoBlock—an open programming language. In Proc. CSCL'95, John L. Schnase and Edward L. Cunnius (Eds.). L. Erlbaum Associates Inc., Hillsdale, NJ, USA, pp. 349-355, 1995.