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Abstract

The rapid progression in developing and improving "human aware navigating autonomous robots" has pushed the field of robotics but it has left gaps, one such gap is the comfort of a human follower of a robot guide. The motivation of this project was to design a method of guiding a human while keeping the human comfortable while she/he follows. This was done by looking at other robot guide methods and research to design and make 3 methods for guiding a human. These methods were made and tested in simulator before being put onto Linda, a robot from the STRANDS, to be tested with human participants, in a hands off approach manner" to find the most comfortable method to the participants. The outcomes from the testing showed that the user was more comfortable following a robot that gave them verbal feedback on the robots action, a robot that checks to see if the participant is still following when stopping and moving and a robot that reacts to their presence.

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1 List of tables and figures

2 Introduction

The aim of this report is to discuss both the different techniques and methods used for managing the project and the designing & developing of the artefact.

This reports structure firstly discusses the aims and objectives of this project, then the background research was discussed which helped with the different methods and techniques used for the project management, the software development, tools and research. After that the report focuses on the designing, developing and testing of the artefact. The report continues on to the artefact's evaluation which leads onto the conclusion were the report talks about if the project was successful or not. The final part of this report is about the project as a whole, what was bad/good and what would be changed if this project was to be attempted again.

2.1 Motivation

In the last few years there has been a constant drive to develop and improve the current way human aware navigating autonomous robots work and while this has pushed the field of robotics it has left a few gaps in some of the different aspects of human aware navigating autonomous robots. One of these gaps is a robot guiding a human and this could become a problem as robots will become more prevalent in our daily lives *"Robots are gradually entering into our daily life as part of logistical support in factories, for cleaning in supermarkets, and as part of professional service in offices and hospitals."(Pacchierotti et al., 2006)*. A robot guiding a human has many applications, such as guiding tourists around landmarks, guiding passengers to their correct plane terminal and guiding people in care homes, to name but a few applications of a robot guide.

There have already been some robot guides mostly found in places like museums such as the 3 Mobot robots (Nourbakhsh et al., 2003) or for a more recent museum example the robot Rackham (Clodic et al., 2006) and there has been some development to get robot guides in other places, such as an office "*A system for visitor guidance in an office environment has been designed*" *(Pacchierotti et al., 2006)*.

So the motivation behind this project is to see if improvements can be made on some of the previous projects and research of human robot guides and improve on some of the their shortcomings, for example "Cice" the museum robot guide (Macaluso et al., 2005) can detect people and is able to tell if an exhibit/place is full and will skip it and come back to it later, but if the followers of the robot, are the people that are at the exhibit, then the robot will not know if that is them and will presume that the followers are still following, so a solution would be to get the robot to keep track of its followers and then be able to respond if they move on ahead or stop following. While there is research about a robot directly interacting with humans, there is not much around the comfort of the human while following the robot, this is also part of the motivation to see if a method can be made so that a human will feel comfortable while following a robot. There are other problems with the current research such as there are not a lot of robots that are able to guide and accommodate different people with different disabilities and other such issues. Though there has been research in the last few years that has attempted to address this problem, such as Feng designing a way for robot to help guide a blind person "*we present a design for how robots can guide blind people to an indoor destination in an effective and socially-acceptable way."(Feng et al., 2015)*

3 Aims and objectives

The project's aim to have Linda the STRAND project robot, being able to guide a person around a predefined route using different methods to determine the most comfortable and efficient designed methods.

To accomplish this aim, at least 3 methods were designed & developed in the ROS simulator, with the first being a baseline method and each method afterwards being a more complex version of the first. Once proven to work in the simulator they were then integrated into the robot Linda. To find out which of the methods meets the aim, a user group study was conducted, where each participant done a test with each method and while they did the test data was recorded from the robot e.g. how long it took them to complete a test. After the tests each participant was asked some questions about how they felt with the robot guide, this gave qualitative data to evaluate which of the methods the users found the most comfortable and also indicates what needs to be improved.

Objectives:

- Design guide methods - This is where the methods that will guide a person around a specified route are designed, at least 3 methods will be designed to be used to compare against each other.
- Integration of guide methods- the methods will be built in the ROS simulator, starting with a baseline method, then make them more complex as each one is developed.
- Test in the simulator - the developed methods will be tested in the simulator to make sure they do as designed in that environment.
- Integrate with robot - the methods will be intergraded to work on Linda the robot.
- Test Linda with integrated methods –short tests will be run to make sure each method works on the robot as they do in the simulation.
- Live test - once intergraded and testing have been done next will be to test the methods with live human participants, these tests will give me the qualitative and quantitative data that will be needed.
- Evaluate - the user feedback and the two data sets will be evaluated to find out which method was the most comfortable for the user to follow.

Requirement:

- Must complete the route according to the method being used.
- Robot must not be a hindrance to other walkers - must not get in the way of other walkers or obstruct them i.e. cutting across the path through people to get to the next point.

4 Background

Human aware navigating autonomous robots and the improvement of them have held the interest of people for years, this is not only because there are so many applications a human aware robot can do such as guiding people to places, interacting with humans to help them and following robots, but also improving human-aware robot will make them more accepted, be safer and be more efficient in both domestic and public environments. In Kruse 2013 survey they believe the interest in the human-aware robots is only growing as the years go on "*The growing number of publications on the topic indicates the growing interest*" (Kruse et al., 2013) from the paper "*Human-Aware Robot Navigation: A Survey*"

This project uses a Human aware robot that can guide a person around a controlled indoor environment following a predefined route. There have been several autonomous guide robots in the last 15 years that follow different strategies & methods, most of the time these types of robots have be deployed in museums or other indoors environments where a person may need to be guided somewhere. Below are robots that were deployed in museums, these robots have been grouped into a few broad strategy groups:

Waypoint strategy – the bases of this strategy is to have the robot moving from one point to the next point until there are none left. When used in a museum this strategy has the robot go from one exhibit to another, while making sure not to crash into any people or any of the exhibits, at each exhibit it waits and will normally display or play audio clips with information about the exhibit before moving onto the next exhibit, where it will repeat the process until it has finished its tour. The Rhino (Burgard et al., 1999) from the paper "*Experiences with an interactive museum tour-guide robot*", Robox (Siegwart et al., 2003)from paper "*Design, implementation and exploitation of a new fully autonomous tour guide robot.*" and all 3 of the Mobot (Nourbakhsh et al., 2003)form paper "*The Mobot museum robot installations: A five year experiment.*" robots use this strategy with some variations e.g. Robox will also ask the people it is guiding some questions and wait for a response. The 3 methods are based of this strategy, with the first method being a baseline that does as described here and proceeding methods being more complex.

User input strategy – in the museum setting this strategy works by having the user input the places/ exhibits they want to see and then the robot will plan a path to go to the users choices, it will then mostly follow the waypoint strategy i.e. go to a place and play an audio clip and move to the next, the only difference is if it detects that there are lots of people at one of the desired exhibits, it will plan a new route to skip the full one and come back later when it is less full. One of the robots that follows this strategy is the robot Cice (Macaluso et al., 2005)from paper

"*Experiences with CiceRobot, a museum guide cognitive robot.*". Having the user able to input a desired route or choice of location to travel, to give the user more freedom of choice which potentially can make them more comfortable, this could even be extended to allowing the user to input certain variables e.g. robot speed. This could have been a method 4 implementation but this was ultimately not done for reasons that are discussed later in this report, so instead this could be done for future improvements.

Find user strategy – this strategy has the robot go find a user to guide, it works by first finding a person and if that person doesn't have a guide approach them and wait. If the person greets the robot then the robot will greet the person and then ask if they want a guide, if the person does not say anything then the robot will ask them if they want to be guided by robot. The person can then either accept the offer, reject or ignore the offer, if the user either rejects the offer or ignores the robot then the robot will leave to repeat the process but if the person agrees to the offer then the robot will guide the user from then on. One of the robots that did this strategy is the robot Rackham (Clodic et al., 2006) from paper "*Rackham: Aninteractive robot-guides".* This again shows potential for future improvements and extensions to this project, but one major aspect that was taken from this strategy and was developed as part of method 2 and 3 was that there needed to be an end state/give up state, as with Rackham gives up on interacting with the human when ignored.

Of course there are other human aware navigating autonomous robots that don't fit these strategies, such as the Robot Xavier(Simmons et al., 2000) from the paper "*Lessons learned from Xavier*" or The Nurse-bot Pearl (Montemerlo et al., 2002) from the paper "*Experiences with a mobile robotic guide for the elderly*". In Pearls case this robot does many aspects of these strategies, like guiding the elderly from place to place and having user input data. While these robots do not directly relate to guiding strategies they do show how the different aspects of the strategies can be used elsewhere and not just as a museum tour guide. Another museum robot guide is Jinny (Kim et al., 2004) from the paper "*The autonomous tour-guide robot Jinny*". This robot is designed not only to guide visitors but to entertain them as well by playing a game with them and dancing to music "*The Jinny plays a simple game with visitors, and dances to the music*" (Kim et al., 2004).

These examples above all have a person/ people following the robot but none mention if the robot checks that the people are still behind and some will skip an exhibit if it has a lot of people there and come back later, *"there are some visitors so that the robot is not able to reach it, CiceRobot will continue the visit and it will reschedule the skipped window*."(Macaluso et al., 2005) but what happens if the people that are there are the people that was following the robot but got there faster than the robot? This shows there some aspects of the guiding robot that have not being explored and so method 2 and 3 where developed with that in mind and now both keep tabs on the follower, with method 3 watching for most of the time.

Comfort of the human is another important part of the robot guide, if the human that is following the robot feels discomfort or unsafe the person will not enjoy the guide and may end up leaving. There has been some research into finding out how comfortable humans are with robots, such as koay's "*Empirical Results from Using a Comfort Level Device in Human-Robot Interaction Studies*" paper where they talk about the experiment they conducted where the participants interact with a robot and used a handheld device to state their comfort/discomfort "*We built a handheld comfort level monitoring device that would allow subjects to indicate their internal comfort level during the experiment*"(Koay et al., 2006).

In Kerstin Dautenhahn's paper" *What is a Robot Companion – Friend, Assistant or Butler?*" they talk about the trials they ran to find out how people feel about a future robotic companion, the paper goes through different aspects that would be relevant to making guiding methods more comfortable for the followers, such as the speed of an approaching robot "*When asked about what speed a considerate robot should approach, the majority (56%) responded neither fast nor slow‡. 22% would want the robot to move at a very slow or slow speed.*"(Dautenhahn et al., 2005) and in the same paper they mentioned in there study a high percentage wanted the robot to come closer to them *"Regarding how close the robot should come to them, 63% said that it should come close to them. Only 4% wanted the robot to come very close to them"* (Dautenhahn et al., 2005). This influenced the design of the questionnaire in that it does try to find out where the participants are comfortable with the robots movement speed and during the tests the robot did track the participants distance from the robot to see what was comfortable for them.

5 Methodology

5.1 Project Management

When doing a project of this size it is important to keep track of time and resources, failing to do so can cause delays and inaccuracies with the results. This part of the report discusses how this project was managed and what aspects of the project needed more management.

The project was split into two parts the development of the methods and the documentation of the project. Each was then again split into more manageable parts such as documentation into background research, evaluation etc..., with these smaller parts it was easier to estimate the amount of time and resources that each part will need to be complete.

This project had a few demanding aspects that required more thought on about how much time and resources they each required. Below these aspects are discussed and explained.

The background research required a lot of time to get the information from creditable and academic sources and then to make that information useable, if this part is rushed or not done correctly it could then undermine the project, the design methods and reason for doing the project; for those reasons this part has was given a lot time to ensure that it is done correctly.

Designing the methods did take some time but it mainly required meetings with the supervisor to see the designs and agree to what is going to be made, this back and forth did take a while and like with the background, this part also needed to be done correctly to ensure the proceeding parts don’t suffer from this part being rushed or mismanaged.

Integrating the methods & testing on robot aspect, the main problem was the limited amount of time that the robot was available, so to make the most of that time each method needed to work in the simulator before integrating the methods onto the robot, this was to remove as many bugs as possible. Which did give more time for testing and fixing new bugs and problems that did come from integration.

The User study was one of the harder aspects of the project to manage as there was limited amount of time that the robot was available and the participants also had a limited amount time to do the tests before the next participant arrived. An extension to this is the amount time gathering data did mean more time sorting that data which was another aspect that needed to be managed. So while a lot of time could not be given directly to the user study the other aspects where given more time and resources to make sure the limited time was used efficiently.

A Gantt chart was made to help manage (see appendix 10) the time and resources for the different aspects listed above as well the different milestones but unfortunately the project was not able to stick to the different time frames set in the Gantt chart, the reasons for this are discussed in the reflection section of this report. A risk assessment was also made for this project (see appendix 11) listing some of the risks to the project but most of the risks didn’t happen and the 1 that did will be discussed in the reflection section of this report

5.2 Software Development

The development of the software in this project was done using an iterative software development approach (ISDA), the main reasons for using this approach is because the ISDA lets me break down this large project into smaller parts and since each preceding method after the first will be a better iterative of the first it made sense to use the ISDA.

Following the ISDA steps, the requirements of the first method were obtained from background research. From there the design for it was made and then implemented in the simulator where it was tested, then it was evaluated to see if it does as the requirements states. When it did not meet the requirements it then went back to being developed in the simulator and the process was then repeated until it did as the requirements stated.

Once the first method met the requirements, the next method is based on the first and its improvements obtained from the background research and the same process of design implementation and testing was repeated from the prior method onto this 1. Once method 2 meets the requirement, method 3 was developed in the same way as method 2.

So as you can see the ISDA was the correct choice but it was not the only choice of software development approach; there is the waterfall model but that was discounted due to its restrictive and rigid structure i.e. having to complete the whole cycle before changes can be considered. RAID could have been used but is generally used for small projects.

5.3 Toolsets and Machine Environments

Git was used for the version control of the project and as the general back up since a repository was made for my project, this also allows for my supervisors to view the work that has been going on with the project. Subversion (SVN) could have been used instead, as it is also a version control system that allows pulling subtrees from a repo instead of cloning the whole repo and its backing up is simpler, but git is generally faster and easier to go back to other versions in case something goes wrong.

This project uses the robot Linda as the guide, this is because Linda has a lot of the functionality and components that was needed to be able to guide a person through a route. For instance Linda has good people detection already, this will be used to keep tabs on the person following to make sure they are still behind and are keeping up.

Linda is of average human height and is able to rotate 360 degrees, move forward and backwards. Linda also have a camera on top her frame that is used for seeing, below that encased in a plastic sphere is her head, this head can rotate 180 degrees to the left and right, the head has eyes that can blink. The head is mainly for people to have a focus point on Linda, this is also used in the project to indicate where Linda is looking. Linda also has a laser range finder in the base used to detect legs, below that Linda has a rubber bumper if this bumper is pressed Linda will stop moving, this is for the safety of people around Linda and so Linda does not damage herself while moving. Lastly Linda has two more direct ways of communicating with people, there is a touch screen panel protruding from Linda's back this can be used for interacting with Linda; Linda also has speaking capabilities which was used in the project to tell the follower what Linda is doing. An image of Linda is shown in (Fig 2)

Figure 1 Robot Linda (2015)

Linda uses a motion planner to move around in an indoor environment, it works by Linda first making a grid around its location with each cell being a possible place Linda can move to, then it runs a simulation on where it can move and evaluates the results, Linda will do this several times with each result giving a score and the simulation with the highest score is the cell where Linda will move to. With this motion planner Linda is able to move around the environment while avoiding objects and people.

To detect people Linda use a two sensors, one is a upper body detector that uses RBG-D data from a Kinect and the other is a leg detector that uses data from a range finder laser and the AdaBoost algorithm to build a classifier that is used to detect legs. For more detail about the upper body detector read "*Real-Time RGB-D based People Detection and Tracking for Mobile Robots and Head-Worn Cameras*"(Jafari et al., 2014) and "*Close-Range Human Detection for Head-Mounted Cameras*"(Mitzel and Leibe, 2012) papers, both of these go into more detail. To know more about the leg detector read "*Using Boosted Features for the Detection of People in 2D Range Data*" (Arras et al., 2007) paper

Linda tracks people by applying Kalman filter to the data sets from the upper body and leg detector, this gives Linda a good estimator for tracking the human. Linda use two models: the state model and the observer model this tries to predict the person that the robot is tracking, this tracking system can also track more than one person. More detail on how the tracker works can be read from "*Multisensor-Based Human Detection and Tracking for Mobile Service Robots*" (Bellotto and Hu, 2009)

The Robot Operating System (ROS) framework was used to make the different methods that the robot use to guide people, ROS was chosen over other robot frameworks as it is the currently one of the more widely used robotic middleware. Middleware is an abstract layer between operating system layer and the application layer, middleware manages lots of components/processes and allows for multiple components/processes to interactive with each other, Elkady states "I*t is designed to manage the heterogeneity of the hardware, improve software application quality, simplify software design*" (Elkady and Sobh, 2012). Also the robot Linda and the simulator that was used for testing the methods are both built using ROS, so this means for the methods to be integrated into the robot Linda the methods had to be made using ROS. ROS also comes with lots of libraries that help the development and has a large helpful community that did help the project when problems occurred with ROS. There are of course other robotic frameworks that could be used but that would require integrating a lot of in-house functions, that are unique to the strands project e.g. human detection and then getting it to work on the robot as well, this would all have taken too much time for this project.

Python is the language that the program is coded in, this is because ROS only has two languages integrated with it, C++ and Python, thought integrating a different language into ROS is possible, it would have taken too much time. Python was chosen over C++ because while C++ is a powerful language which lets you have lots of control over most aspects, it is also a lot more complex. Whereas Python is a simpler language which has garbage collection and is a quicker language to develop in, given the time frame of this project the faster the methods can be developed and tested meant more time for user testing.

Testing the methods on the robot and doing the human participation tests was all done in upper part of the robotics lab, this place is the only environment that the robot could be tested in due to the robot not being allowed to leave the premises and the lower part of the lab would have had a lot of people moving around. The upper part of the lab was large enough to have the robot still be an effective guide while not being too large for the participants to get lost or feel uncomfortable within the environment. The testing environment is comprised of 2 rooms, one large room with lots of open spaces from the door to the back of the room but has a few tables/seats by the walls, the other room is more like an open plan office, with a row of computers splitting the room mostly in half. The robots route has 7 waypoints including a starting waypoint, the robot moves to the starting waypoint just outside of the large room, then the robot will guide the participant into and around that room, then it will leave the room to come into the other room where it will guide the participant around the row of computers to reach the other side of the room where it ends the guide.

5.4 Research Methods

The aim of the project was to find out which of the designed methods is the most comfortable to the user and the most efficient e.g. the quickest method to get the user to the end of the route. To find this out live testing was conducted with human participants.

A qualitative user study was used as this allows the participants to experience the robot guiding them and from that we can find out how comfortable they are with a robot guide. The participants tested each method once by having the robot guide them on a pre-defined route, after each test the participants were asked to do a questionnaire on how they felt and were they comfortable during that guide (see appendix item 1). When the participants had done all tests, they were given another questionnaire which was about their overall comfort with the tests and also give some optional open ended questions to see if they have any comments about their experience with the robot guide (see appendix item 2 & 3). Both questionnaires where used to get a qualitative data set, the data set was used to compare the results against the other participant's results in the evaluation section of this report to find the most comfortable method.

Both questionnaires are a Likert scale questionnaire as suggested by the Kruse2013survey paper "*Human participants experiencing the robot rate the performance of the robot on scales, such as a Likert scale*" (Kruse et al., 2013) and was mention In Kanda & Ishiguro book "Human-Robot Interaction in Social Robotics" that they use a questionnaire that uses a Likert scale 1-7 "*We obtained participants' subjective impressions with a questionnaire. Following questions were included on l-to-7 point Likert scales*" (Kanda and Ishiguro, 2012 p.136). There was other methods that could have been used to find the users comfort in human-robot interactions, but questionnaires are the most common or so say Koay "*Two main strategies are commonly used for evaluating human-robot interaction from a human subjects' perspective 1) questionnaires … and 2) video analysis of interactions*" (Koay et al., 2006).

To make sure the participants know what they are getting into and so they know there rights regarding their participation in the tests, a consent form was given to each one to read and sign if they still wished to participate (see appendix item 5). A demographic questionnaire was also given to all the participants for them to fill out before they started any of the tests (see appendix item 4), this was used to find out more about the participants, things like their experience with robots and with technology in general.

The tests went like this, the participant was only told to wait at the starting point and then follow the robot as instructed by the robot. The participant would wait in the smaller of the 2 rooms for the robot to approach them, the robot would approach them greet them and then ask them to follow from behind. From there the robot would move to the next waypoint and the robots behaviour from then onwards would depend on the method being used at the time, although each method does go the same route. The robot would lead the participant to the entrance of the large open spaced room for its next waypoint, then to the middle of the room, then the back of the room and rotate around, back to the middle facing towards the exit, to the entrance of the other room and then finally the robot would lead the participant around the row of computers in the other room and to the back of said room, where the robot ends the guide differently depending on the method.

while the participants were doing their tests the robot recorded some quantitative data, such as how long it took the robot to complete a guide with each method, how often the robot lost sight of the human during the guide, what the distance the human was spotted at and how long it took for the human to be spotted, this data was used to compare the methods against each other and was evaluated in the evaluation section of this report to find the most efficient method.

Graphs and tables are the main ways of representing both quantitative and qualitative data sets, graphs to show some of the larger data e.g. average guide times and tables to show smaller data e.g. the occupation of the participants.

6 Design

Method 1 - Baseline

As stated in the background section of this paper the most common type of method for a robot to guide people is to have the robot go to predefined waypoints and wait for a set amount of time before moving onto the next waypoint, this would continue until the robot has reached the end. Method 1 will be doing the same and it will act as a baseline for the other methods.

Method 1 works by having the robot move to a starting waypoint, this is where the human will be at. At the starting waypoint the robot asks the user to follow behind it, it will wait for a fixed amount of seconds for them to do so and then the robot loads then next waypoint then proceeds to move to it. These waypoints are kept in a text file to make them easy to change and add to. Once the robot has reach the next waypoint, it wait for fixed amount of time to make sure the human has caught up and then loads the next waypoint and moves to it. This continues until the robot has finished the route. Once the guide route has been completed the robot thanks the human for following and then moves back to the charging station. Having the robot wait for a fixed amount of time, does of course affect the completion time and this is taken into account at the evaluation.

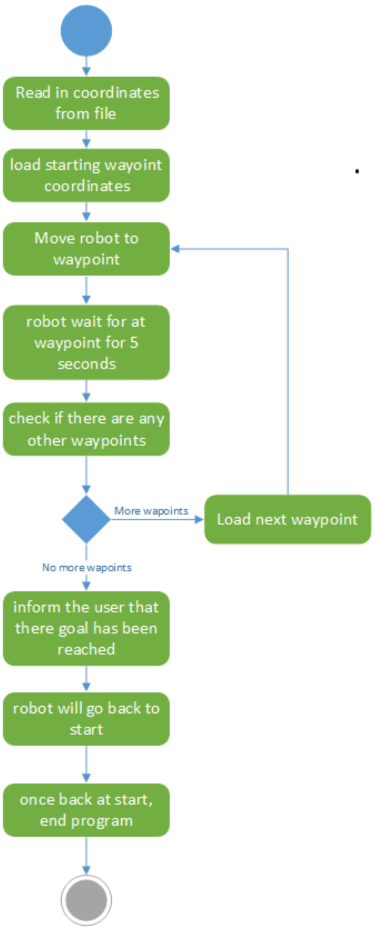

Figure 2 Baseline Activity Diagram

Method 2

Method 2 is similar to the method 1 as it also reads from a text file to get coordinates but unlike the first method this method does have the robot look for a human before moving on to the next waypoint.

It works like this, the robot moves to the starting waypoint, once it is at the start the robot will then tell the human to follow from behind and then proceed to move to the next waypoint. Upon arriving at the waypoint the robot rotates its top camera to face behind itself and then the robot will wait for a fixed amount of time for a human to appear. Once the robot has seen the human the robot stops waiting and then moves on to the next waypoint, this does continue until it has no more waypoints going forward. If at any of the waypoints after the starting one, no human appears within the fixed amount of time, the robot than goes back to a prior waypoint and again waits for the same amount time for a human to appear. If a human appears again the robot will go to next waypoint but if again no human appears in the amount of time then the robot will repeat the process until there is no prior waypoints to go back to. Once there are no more waypoints going forward or no more prior waypoints, the robot ends the guide then the robot goes back to the charging station.

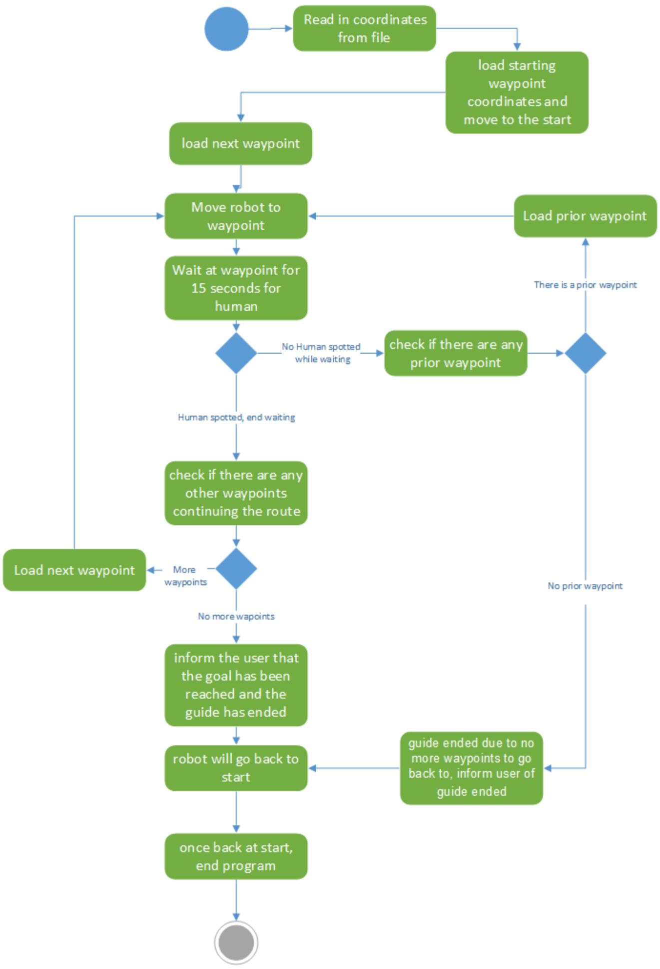

Figure 3 Second method Activity Diagram

<u>Method 3</u>

This method 3 shares a lot of the same functionally as method 2, it moves to the starting waypoint, waits for a fixed amount of time for a human at the waypoints, goes back to a prior waypoint if no human spotted and it ends the guide if there are either no more waypoints or no prior waypoints to go too.

What method 3 does do differently, is that it keeps looking at the human following it, if the robot cannot see the human following for a few seconds then the robot stops in its current location and waits for a fixed amount of time for the human to appear, If the human appears within that amount of time then the robot resumes moving to the waypoint but if no human appears, it then goes back to a prior waypoint if there is no prior waypoint then the robot ends the guide.

When the robot is moving back to a prior waypoint, the robot does not look for the human behind itself as it does when moving to a forward waypoint, this is done because the robot assumes the human is at the prior waypoint. Like in the other methods this method also gives audio feedback on what the robot is doing or what it wants the human to do.

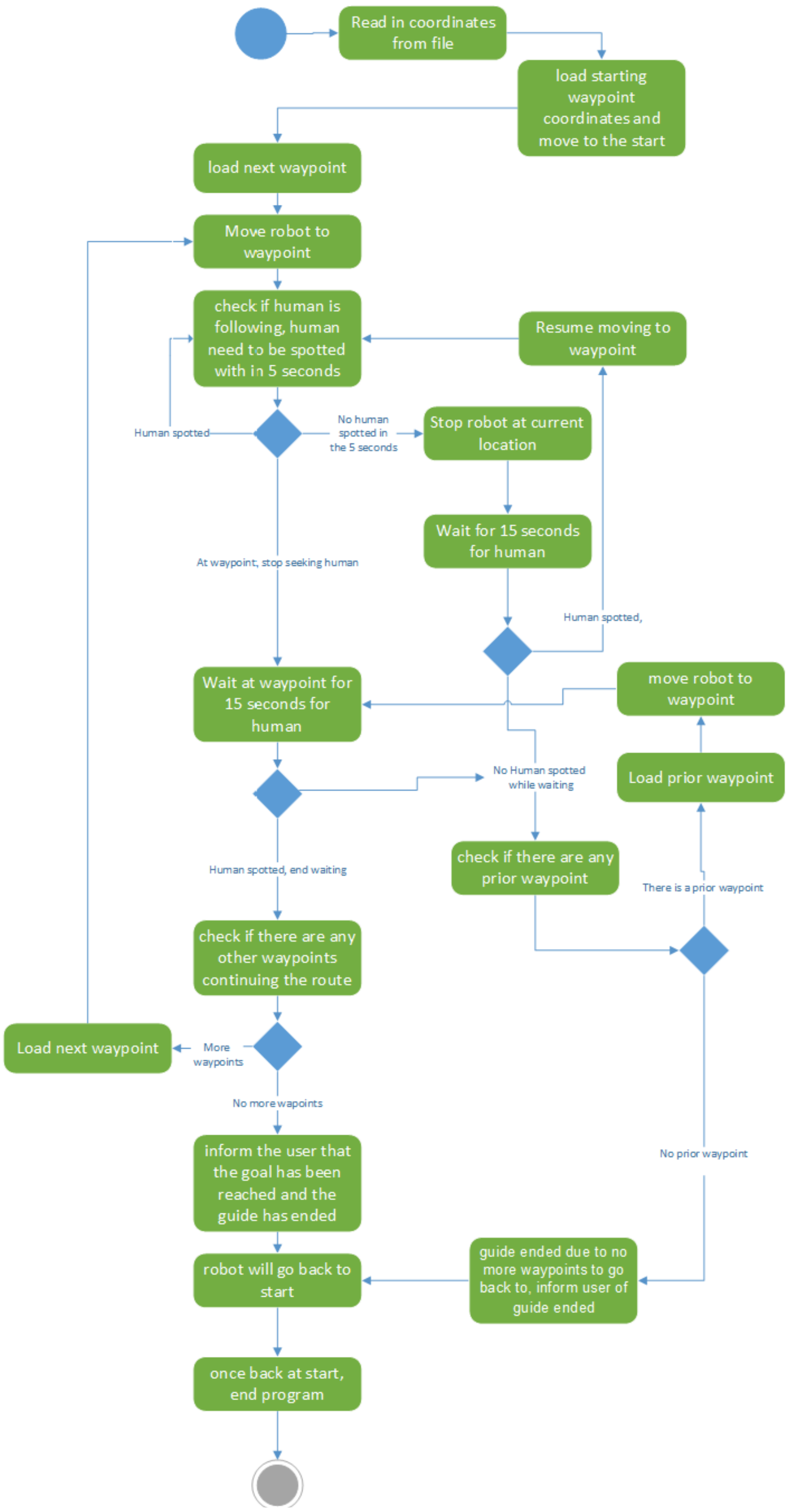

Figure 4 third method Activity Diagram

7 Development

This section of the report discusses how the different components make the guiding possible. Work and how they are used.

Moving the robot

One of the important aspects of a guide robot is its ability to move and navigate around its environment. Linda makes use of a map to move and navigate, this map is a grid with each cell corresponded to a coordinate, with these coordinates you can tell Linda where you want her to move to. First though Linda needs to know approximately where she is on this map i.e. localization. With knowing where Linda is going to and from Linda can now plan how to get there, this is done by using the global planner and costmap which works out the best route to take. With the route decided Linda will start moving on the route to set coordinates. While Linda is moving the set coordinates uses a local planner and costmap to avoid objects that global planner and costmap can't account for such as a chair not on the route, the local planner and costmap are used to work out a way around it so they can carry on moving to the set coordinates.

Thankfully this is all handled by the robot and all the methods have to do is supply the waypoint coordinates for the robot to go to, then the methods check if the robot is there, then the robot will act in the behaviour of the methods, then move to the next waypoint.

Seeing a human

Method 2 & 3 makes use of the robots camera to be able to spot a human within a certain distance. Both methods use the STRANDS project's already made human detection which has been discussed under the tools section of this report. The human detection returns 2D coordinates of where the human was detected in relation to the robot, with those 2D coordinates the Euclidean distance is worked out to tell how far the human is away from the robot. Method 2 and 3 use this to tell if a human is within a specific range, the range can't be too big or it will spot people that are not the follower and it can't be too small or the person will have to be up close to the robot and this could affect the comfort of the human.

Speaking

All 3 methods make use of Linda's speaking capabilities, this was done to give verbal feedback on what Linda was doing and what she wanted the participant to do. All 3 methods have Linda greet the participant and ask the participant to follow from behind, inform the participant that the robot is going to a waypoint, when they have arrived at the waypoint and when the guide has finished. Method 2 and 3 also have other phrases such as telling the follower that robot will now look for them, when the robot has seen the person and if the robot is going back to a prior waypoint. Linda's voice capabilities were used instead of the touch screen because it is easier for the participant to hear what Linda's intentions are than it is for them to read while the robot is moving, this also removes the need for the participant to stand close to Linda, meaning following the robot is potentially more comfortable for the participant.

Head Turing

Both method 2 and 3 make use of Linda's head turning capabilities, the robot rotates its head when the robot is looking for the participant at waypoints. This was added to show the participant where Linda was looking, once Linda spots the participant she then rotates her head to face forward again to show the participant she is about to set off. This also added a more human like behaviour element to those 2 methods as this is similar to what a human guide would do, a human guide will turn to see if you are still following and then turn back to face forward and carry on the guiding. This was all in an effort to make the human more comfortable following the robot.

Collected data

So that the most efficient method could be determined, the robot recorded quantitative data while the participant did the tests. Method 1 just recorded how long it took for the participant to complete the test. Method 2 records the same data as method 1 but it also recorded how often the robot spotted the participant, the range the participant was spotted at, how long it took the robot to spot the human and how often the robot failed to see the participant so goes back to a prior waypoint. Method 3 records the same data as method 2 but also records how often the robot has to stop to look for the human while moving to the waypoint.

8 Testing

Testing was split into 3 parts, first part was testing the functionality and the reliability of each method in the simulator as well making sure it does as the described in the design section of the report. The simulator was used as the initial testing environment because if something was not working or if something went wrong then it would easier to stop and it would not affect the actual robot, this was also a quicker way of testing and then fixing issues that were found.

Part 2 was testing the same types of tests as in part1 but on the real robot this time instead of in the simulator, even if the tests passed in the simulator they were not assured to pass on the real robot as the real robots responds differently due to having to deal with things like noise. Tests on the real robot also gave me the opportunity to tweak the methods to work better in a real environment things such as wait times.

Part 3 involved having human participants to test the 3 methods, the test were to find out how comfortable they are following the methods and to determine which of the methods are the most comfortable, the tests were also used to gather other statistical data such as how long it took the robot to complete the guide, how long the robot was waiting for humans, what was the distance the human was standing behind the robot and what distances was the humans following the by.

Part 1 & 2 results are shown in a table below, the table say what was tested, how many times, what was the expected/correct outcome, what actually happened, what was the error and what fixed it. Part 3 results is the main focus of the evaluation part of this report so will not be discussed further in this part of the report.

8.1 Tests in the Simulator

<u>Functions that all 3 methods use</u>

What was being tested	What was expected	What happened	What was the error	What was the fix
Load Speaking text file	Loads a .txt file that stored all what Linda is meant to say into a list, output to console that it's done.	Does as expected	n/a	n/a
Load cords text file	Loads a .txt file that stored all the coordinate that Linda will travel to into a list, output to console that it's done.	Does as expected but caused error "moving to waypoint" test 1	While it loaded the file, it was stored as a string. That why error moving to waypoint test 1	Change numpy arrays that store values as floats.
Pick random line to speak	Each speaking action will pick a random line	Does as expected	n/a	n/a

at specific actions	to say from a range pending on the action, will output the line no. to console			
Linda speaking	Linda is meant to speak one line at a time on all the methods	Does as expected	n/a	n/a
Stopping the program	Upon terminating ROS the python scrip is meant to end	Would end some of the time, other time it would try and finish an action before quitting	All the methods could/did get stuck in while loops	Didn't fix till was testing on robot.
1.Moving to waypoint	Should arrive at waypoint facing the correct way	Would throw an error	Was storing coordinate as a string, needs to be a float	Changed it to store as a float instead of string
2.Moving to waypoint	Should arrive at waypoint facing the correct way	Arrived at waypoint but would face in the wrong direction	Was not publishing both orientation coordinates	Rewrote the function to publish both
3.Moving to waypoint	Should arrive at waypoint facing the correct way	Does as expected	n/a	n/a
No more forward waypoint to load	When the robot has no more waypoint to travel to, the robot will then end the guide and return to charging station	Does as expected	n/a	n/a

<u>Baseline method</u>

What was being tested	What was expected	What happened	What was the error	What was the fix
Robot waiting at waypoints	Robot waits at waypoints for 5 seconds before moving on	Does as expected	n/a	n/a
1.When guide finished- go back to charging station	When the robot has completed the guide the robot is meant to go back to the charging station and end the program	The robot would go back to the station but would not stop the program and would keep saying "going back"	I didn't have the program update its state once a move goal was made to send it to station	Fixed when testing on the robot

<u>Method 2</u>

What was being tested	What was expected	What happened	What was the error	What was the fix
Seeing the human in range	Inform the human of been seen when the human is in range between 0.5 and 3.5 meters from robot	Does as expected	n/a	n/a
Robot looks for human at waypoint	The robot will wait and look for a human when the robot makes it to a waypoint.	Does as expected	n/a	n/a
Human at waypoint	Once the human is seen the robot will then go to the next waypoint	Does as expected	n/a	n/a
No human at waypoint	If no human is seen while waiting at waypoint the robot will got back to a prior waypoint	Does as expected	n/a	n/a
No prior way point to go back to	If there are no prior waypoint then end guide and go to charging station	Does as expected	n/a	n/a

<u>Method 3</u>

What was being tested	What was expected	What happened	What was the error	What was the fix
Seeing the human in range	Inform the human of been seen when the human is in range between 0.5 and 3.5 meters from robot	Does as expected	n/a	n/a
Look for human then moving	The robot is meant to look for the human while moving to waypoints	Does as expected	n/a	n/a
While moving, no human seen	If while the robot is moving to a waypoint, the robot cannot see a human for 5 sec, robot will stop at current place	Does as expected	n/a	n/a
Human appears after stop	If a human appears after stopping, then robot will then	Does as expected	n/a	n/a

	continue to current waypoint			
Still no human after stopping	After stopping the robot will wait for 15 second, if still no human appears, robot will go back to a prior waypoint.	Does as expected	n/a	n/a
Robot looks for human at waypoint	The robot will wait and look for a human when the robot makes it to a waypoint.	Does as expected	n/a	n/a
No human at waypoint	If no human is seen while waiting at waypoint the robot will got back to a prior waypoint	Does as expected	n/a	n/a
No prior way point to go back to	If there are no prior waypoint then end guide and go to charging station	Does as expected	n/a	n/a

8.2 Tests on robot in real environment

<u>Functions that all 3 methods use</u>

What was being tested	What was expected	What happened	What was the error	What was the fix
Load Speaking text file	Loads .txt file that store all what Linda is meant to say, output to console that it's done.	Does as expected	n/a	n/a
Load cords text file	Loads .txt file that store all the coordinate that Linda will travel toy, output to console that it's done.	Does as expected	n/a	n/a
Pick random line to speak at specific actions	Each speaking action will pick a random line to say from a range pending on the action, will output the line no. to console	Does as expected	n/a	n/a
1.Linda speaking, on every method	Linda is meant to speak one line at a time on all the methods	Linda on each of the methods would speak over itself, so what	Linda's speaking actionlib was out-of-date	Update Linda's speaking Actionlib to

		was being said was all jumbled		newest version
2.Linda speaking, on every method	Linda is meant to speak one line at a time on all the methods	Does as expected	n/a	n/a
1.Stopping the program, on all three methods	Upon terminating ROS the python scrip is meant to end	Would end some of the time, other time it would try and finish an action before quitting	All the methods could/did get stuck in while loops	Added a Ros termination to the while loops
2.Stopping the program, on all three methods	Upon terminating ROS the python scrip is meant to end	Does as expected	n/a	n/a
1.Moving to waypoint	Should arrive at waypoint facing the correct way	Arrived near waypoint and would face in the wrong direction	Ros navigation threshold was changed	Changed it back to 3.0
2.Moving to waypoint	Should arrive at waypoint facing the correct way	Does as expected	n/a	n/a
No more forward waypoint to load	When the robot has no more waypoint to travel to, the robot will then end the guide and return to charging station	Does as expected	n/a	n/a

Baseline – method 1

What was being tested	What was expected	What happened	What was the error	What was the fix
Robot waiting at waypoints	Robot waits at waypoints for 5 seconds before moving on	Does as expected	n/a	n/a
1.When guide finished- go back to charging station	When the robot has completed the guide the robot is meant to go back to the charging station and end the program	The robot would go back to the station but would not stop the program and would keep saying “going back”	I didn’t have the program update its state once a move goal was made to send it to station	Had the program get the state once the robot move to station was done
2.When guide finished- go back to charging station	When the robot has completed the guide the robot is meant to go back to the charging station and end the program	Does as expected	n/a	n/a

Method 2

What was being tested	What was expected	What happened	What was the error	What was the fix
1.Seeing the human in range	Inform the human of been seen when the human is in range between 0.5 and 3.5 meters from robot	Would not recognize that a human is in range	Robots human detection was using the maps coordinates, so range calculation where incorrect	Changed it, so the human detection was using the robot coordinates system.
2.Seeing the human in range	Inform the human of been seen when the human is in range between 0.5 and 3.5 meters from robot	Does as expected	n/a	n/a
Robot looks for human at waypoint	The robot will wait and look for a human when the robot makes it to a waypoint.	Does as expected	n/a	n/a
Human at waypoint	Once the human is seen the robot will then go to the next waypoint	Does as expected	n/a	n/a
No human at waypoint	If no human is seen while waiting at waypoint the robot will got back to a prior waypoint	Does as expected	n/a	n/a
No prior way point to go back to	If there are no prior waypoint then end guide and go to charging station	Does as expected	n/a	n/a

Method 3

What was being tested	What was expected	What happened	What was the error	What was the fix
1.Seeing the human in range	Inform the human of been seen when the human is in range between 0.5 and 3.5 meters from robot	Would not recognize that a human is in range	Robot was not using the correct map, so range calculation where incorrect	The map was change to the one I was basing ranges off.

2.Seeing the human in range	Inform the human of been seen when the human is in range between 0.5 and 3.5 meters from robot	Does as expected	n/a	n/a
Look for human then moving	The robot is meant to look for the human while moving to waypoints	Does as expected	n/a	n/a
While moving, no human seen	If while the robot is moving to a waypoint, the robot cannot see a human for 5 sec, robot will stop at current place	Does as expected	n/a	n/a
Human appears after stop	If a human appears after stopping, then robot will then continue to current waypoint	Does as expected	n/a	n/a
Still no human after stopping	After stopping the robot will wait for 15 second, if still no human appears, robot will go back to a prior waypoint.	Does as expected	n/a	n/a
Robot looks for human at waypoint	The robot will wait and look for a human when the robot makes it to a waypoint.	Does as expected	n/a	n/a
Human at waypoint	Once the human is seen the robot will then go to the next waypoint	Does as expected	n/a	n/a
No human at waypoint	If no human is seen while waiting at waypoint the robot will got back to a prior waypoint	Does as expected	n/a	n/a
No prior way point to go back to	If there are no prior waypoint then end guide and go to charging station	Does as expected	n/a	n/a

9 Evaluation

This part of the report discuss the results from the live human participation tests. This is done in 2 parts, part 1 just shows the results from the different questionnaires and the data the robot collected, part 2 will be the discussion of these results.

9.1 Results

9.1.1 The participants

These are the responses to the demographic questionnaire. The age range of the participants where between “less than” 20 and 30 as shown in (table 1).

Age range	No.
less than 20	2
20-25	10
26-30	1

Table 1 Age ranges count

When asked about their occupation, all but 1 stated they are a student. Shown in (table2)

Occupation	No.
Researcher	1
student	12

Table 2 Occupation count

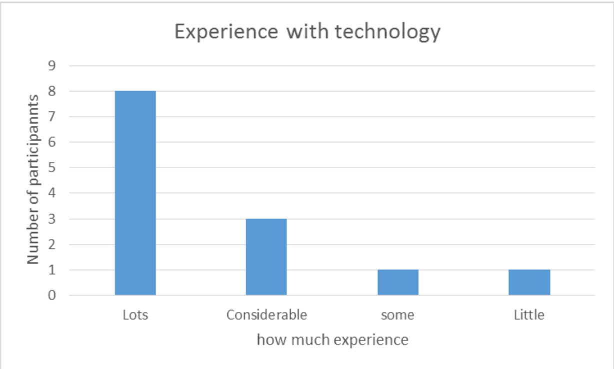

Figure 5 Experience with technology

(Fig 5) shows that a lot of the participants said they are good with technology, with the majority stating they have lots experience.

The demographic questionnaire also asked them about there currently amount of experience with the robots, (Fig 6) shows how they responded.

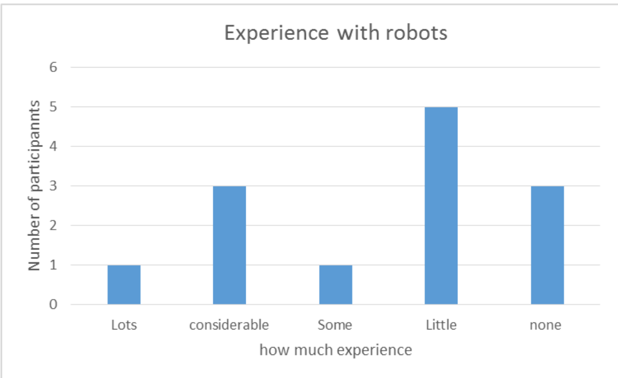

Figure 6 Experience with robots

9.1.2 Quantitative data

Below is the data that was taken from the robot while the participants did their different tests.

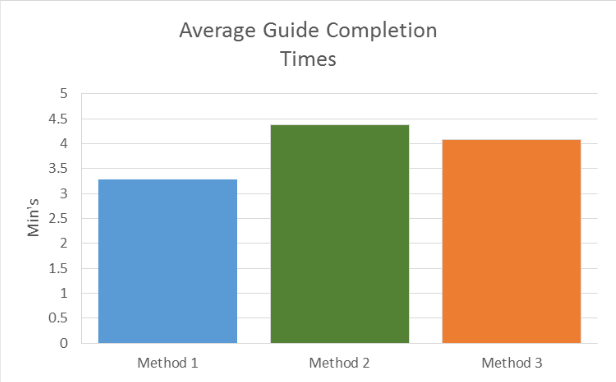

Figure 7 graph of average guide completion times

While the participants were doing there tests the robot recorded how long each participant took to complete it, (Fig 7) shows the averages time it took each method to complete the guide.

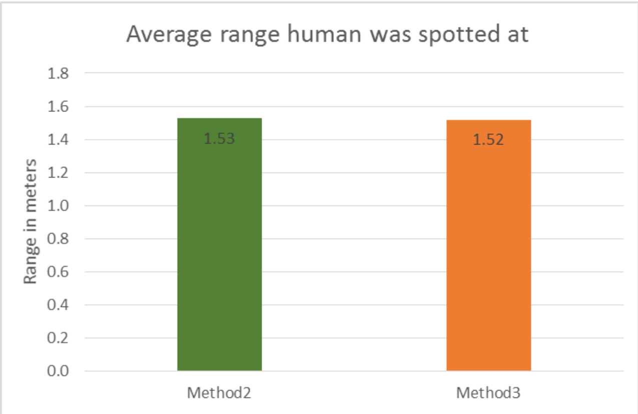

Figure 8 Average range human was spotted

Method 2 and 3 both look for the human every time the robot spots the human it records the distance the human was spotted at, (fig 8) show the average distance the human was spotted at with each method.

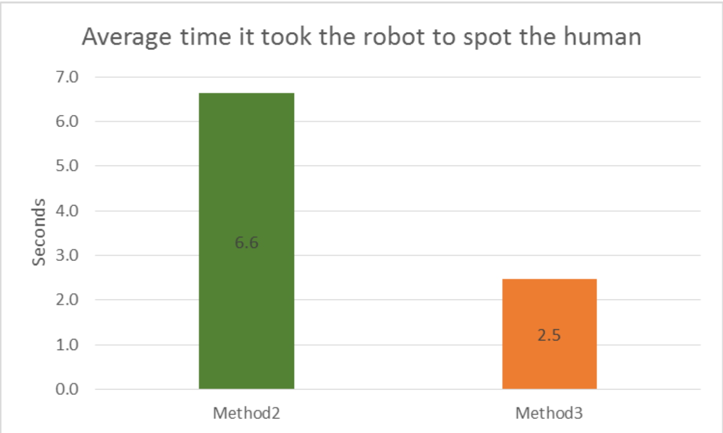

Figure 9 Average time human was spotted

The time it had taken the robot to see the human was also recorded, (fig 9) shows the average time for both methods, with method 2 taking a lot longer than method 3 but method 2 does have to rotate the camera to see the human.

9.1.3 Categorical quantitative data.

The qualitative data from the questionnaires was counted/averaged in their categories thus it is now categorical quantitative data.

After each test the participants were asked to do a questionnaire about their experience with the test, below is the results from all 3 methods.

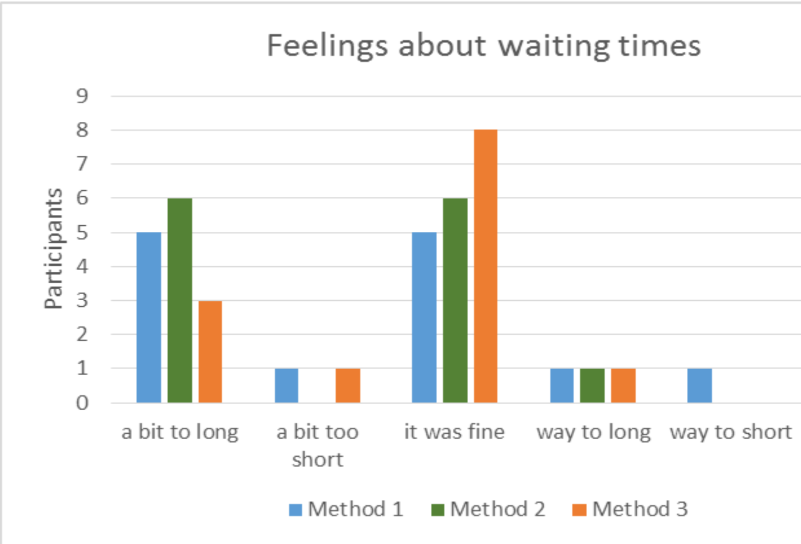

Figure 10 waiting times graph

(Fig 10) shows the results from "Did you feel the waiting time at each waypoint was too long/short?" question.

The chart shows that there was an even split in the participant in whether it was too long or it was fine with method 1 and method 2, method 3 being the only method showing a clear majority of 61% saying it was fine.

For the question "Was the robot moving too fast/slow during this guide" (fig 11) shows their answers. 69% of the participants felt it was fine in method 1 but 69% felt it was a bit slow for method 2.

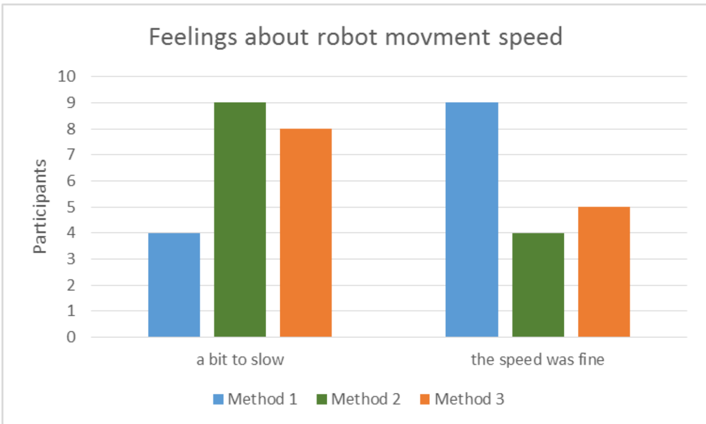

Figure 11 Robots movement speed graph

"Do you feel that the robot was reacting to your presence?" answers are shown in (Fig 12). Method 1 61% of the participants felt that the robot was not reacting to their presence though 15% of them did think it reacted to them often. Method 2 had the most diverse answers, with 38% of the participants mostly feeling that the robot reacted to them, 30% felt little reaction and 23% feeling it only sometimes. Method 3 majority of 38% felt it is was "a little".

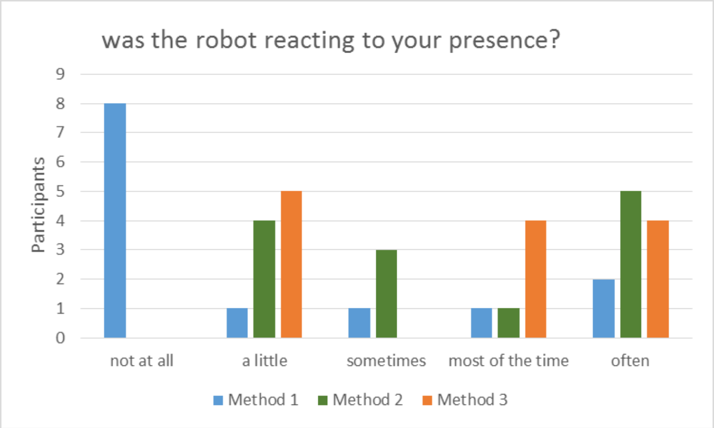

Figure 12 Robot reacting graph

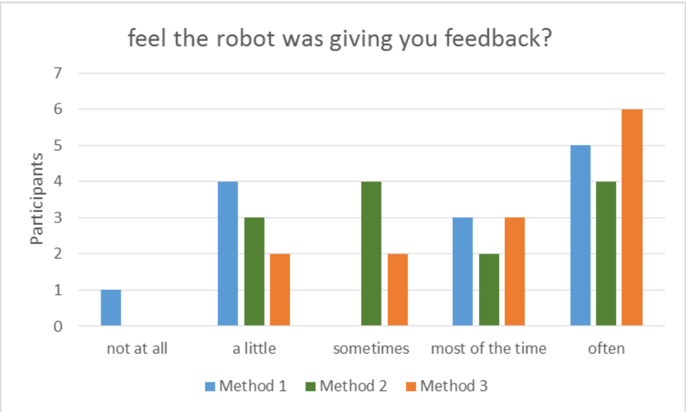

Figure 13 Robot feedback

"Did you feel the robot was giving you feedback on its actions?" questions results are shown in (Fig 13), the graph shows that the majority for methods 1 (38%) & method 3(46%) was "often". method 2 has a split majority of 30% to both "sometimes" and "often"

9.1.4 Comfort Questions

This part of the results shows the answers of the comfort questions asked in the questionnaire. Each Likert chart question answer had a score (very uncomfortable -2, slightly uncomfortable-1, I was fine+1, slightly comfortable+2 very comfortable+3), each graph shows the result from these scores worked out and the average for each method.

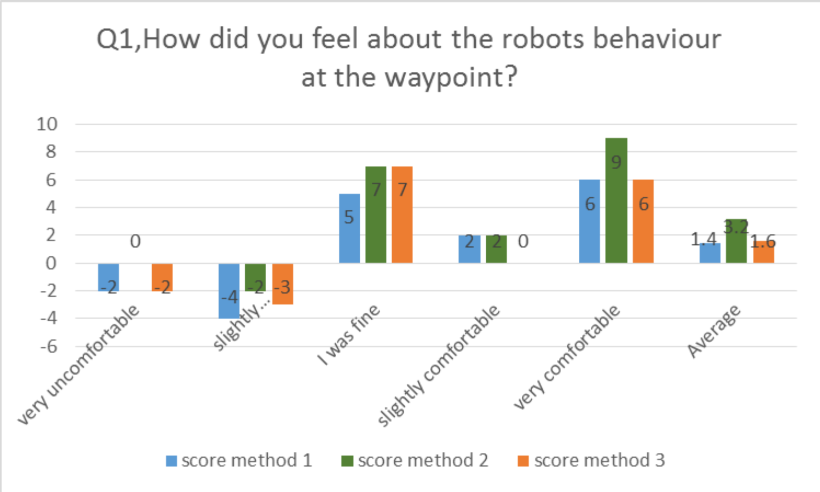

Figure 14 comfort with robot behaviour at waypoints

"How did you feel about the robots behaviour at the waypoint?" answers are shown in (Fig 14). From the average you can see the participants were more comfortable with methods 2 robot's behaviour at the waypoint. With a difference of 1.6, method 3 is the second most comfortable. Method 1 was the least comfortable at waypoints with a difference 1.8 from method 2.

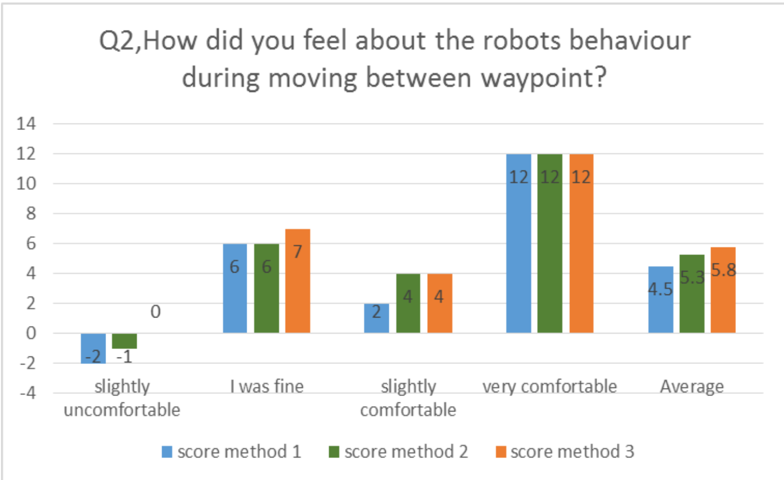

Figure 15 comfort with robot moving behaviour

"How did you feel about the robots behaviour during moving between waypoint?" question's results are shown in (Fig 15). The participants were the most comfortable with methods 3 robots behaviour while moving though method 2 is a close second with a difference of 0.5. Method 1 was the least comfortable to follow with average of 4.5, with a difference of 1.2 from method 3.

"How did you feel about following the robot using this method?" answers are shown in (Fig 16). Going by the average method 2 is the most comfortable method for the participants to follow with method 1 being a close second with a difference of 0.3 and method 3 being the least comfortable method to follow with an average of 3.0 a difference of 1.3 from method 2.

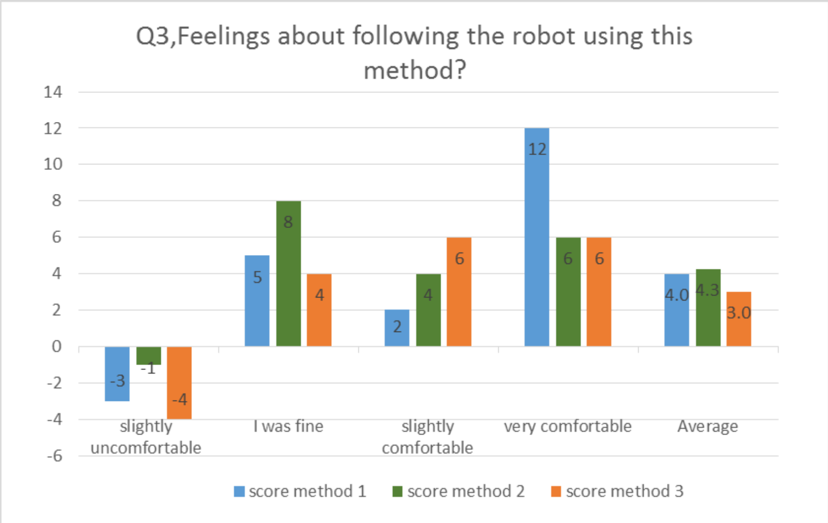

Figure 16 Comfort a following a method

9.1.5 General 1 time questionnaire results

Below are the results from the questionnaire that the participants were given after all the tests were done.

"How comfortable were you before the test" answers (Fig 17) shows the majority (61%) of the participants said they were very comfortable before the test, (23%) said they were slightly comfortable with no one saying they were uncomfortable.

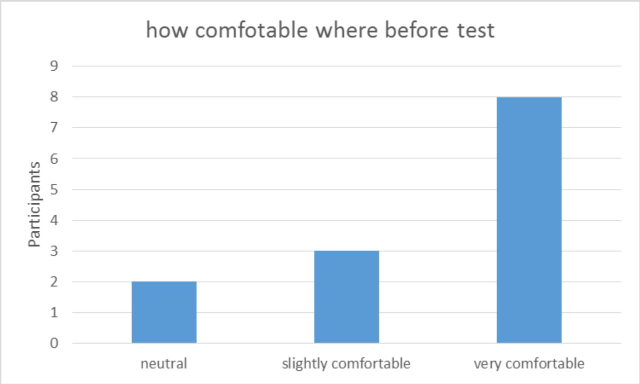

Figure 17 comfort before test

"Were you comfortable in the place you were doing the tests" (Fig 18) show the results, the majority (69%) of the participant said they were very comfortable in the environment, (23%) answered with neutral.

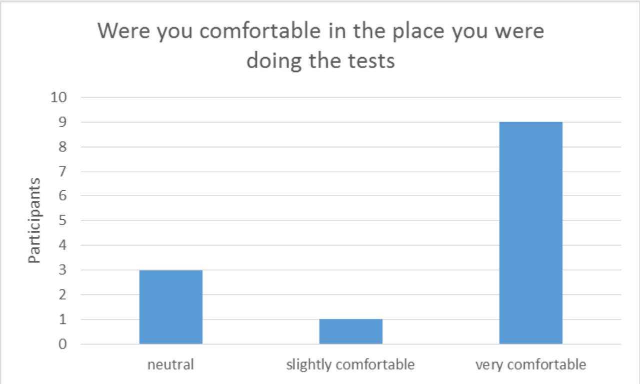

Figure 18 comfort in place of test

"Were you comfortable/uncomfortable when the robot talks to you" result shown in (Fig 19). The majority (61%) answered with very comfortable with the robot speaking. Both slightly comfortable and uncomfortable had (15%) of the participants pick those answers.

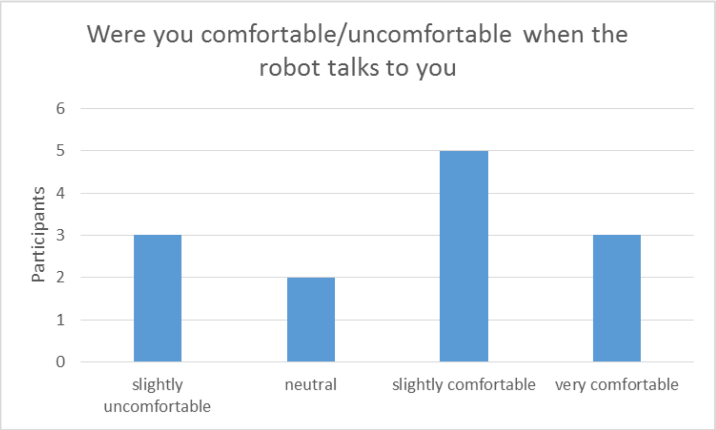

Figure 19 Comfort after tests

9.2 Discussion

The order the participants took the tests was randomly different for each other, this was to stop the results from being bias to a single method as well as to stop other participants, if there was any waiting, from seeing and then doing the same thing in the same order as this could have potentially affected their answers to the questionnaire. To limit potential bias to the other participants and so the participants themselves do not have to wait ages for their turn, we had participants come in groups or 2's and 3's and have the waiting participants wait in a different part of the labs.

9.2.1 Participants

13 participants took part in the live human participation tests. But unfortunately there was not much diversity in gender, with having 92% of participants being male, this could potentially bias the results.

The participants had different ranges in the age, with 7% of the participants in the "26-30" range and with the majority 76% of the participants between the ages 20-25 leaving the rest to be under the age of 20. This was to be expected as 92% of the participants said they are students. Being young students could also explain why 23% of them saying they have considerable amounts experience and with the majority 61% of them claim to have lots of experience with technology.

When asked about their experience with the robot the results was quite varied, while the majority 38% of the participants said they had little and 23% saying they had no experience, 23% claimed they have considerable amounts of experience.

Those with more experience with robots and to a lesser extent those with lots of experience with technology could be more comfortable with the guide than those without, this of course may affect the qualitative results slightly but thankfully the majority only have little or less experience with robots.

9.2.2 Quantitative data

When comparing the average time that it took the methods to completed the guide, it was found that method 1 was quicker, with a difference of 1.2 compared to method 2 and 0.9 compared to method 3 but that was expected as method 1 is not reliant on the participant to move the robot onwards. What was surprising was that it was not much quicker than the other methods. This little different is due to method 1 having the robot wait a fixed amount of time at each waypoint.

Method 2 and 3 both look for the human, method 2 on average found them at a range of 1.53 whereas method 3 on average at the range of 1.52, this was not surprising that the ranges are quite similar, because when observing the participants following behind the robot initially they stand quite close to the robot and as the tests go on they do not move that far away from the robot. This could be because the robot asks the participants to stand behind itself. At the distance of 1.5m (4 feet 11inchs) the robot is just outside the participant's "not close" personal space and is in "close" social space according to E.T halls (Hall et al., 1968 p.93), this means the participants happy to be close to the robot, the same closeness that you would have to talk with another human.

Though what was surprising was the difference in how long it took the robot to spot the human, with a difference of 4.1 seconds method 3 was a lot faster at spotting the participant, but this was due to method 3 having the camera always facing behind itself whereas method 2 has to rotate the camera.

In terms of efficiency, Method 1 was the fastest method with an average time of 3.4 minutes, method 3 was second fastest with a time of 4.1. This of course means method 2 was the slowest with a time of 4.4 though not by much. Method 3 was a lot faster at spotting the participant with an average time 2.5 seconds whereas method 2 took on average 6.6 seconds to spot the human, method 1 does not try to look for the human. So the most efficient method would be method 3 as it is fastest method to spot a participant and second fastest to complete the guide.

9.2.3 Categorical quantitative data

The results from "Did you feel the waiting time at each waypoint was too long/short?" question's answers was more diverse then was expected, as both method 1 & 2 are mainly split on them finding the waiting "a bit too long" and being fine with the waiting time, whereas 61% of them were fine with method 3's waiting time. This could be due to the robot spotting the participant a lot faster in method 3 as shown in (Fig 9), meaning that the robot would move to the next waypoint faster. The reason why the participants might feel method 1 is slow could be due to what order they had taken the tests in, for instance if method 1 was there first test then the route would be new to them and the 5 second waiting will seem less but if it is their second or third test for them, then they already know the route and waypoints thus making the waiting seem longer. This question was ask to find the out if improvements where needed in the robots waiting.

For the question "Was the robot moving too fast/slow during this guide" shows there answers again are surprising due to the robots movement speed never changed between the methods but the majority of participants for method 2 & 3 felt the robot was moving slow, but 69% of the participants felt it was fine in method 1. The participants might of felt method 3 was slower due to the robot would stop moving if it could not see the participant for 5 seconds leading it to seem a bit slower if it has to stop to look for you. This question was asked to see if the participant would prefer the robot to move faster or slower in future iterations.

“Do you feel that the robot was reacting to your presence?” results were mostly as expected. Method 1 61% of the participant correctly felt that the robot was not reacting to their presence though 15% of them did think it reacted to them often. Method 2 had the most diverse answers, with 38% of the participant mostly feeling that the robot reacted to them, 30% felt little reaction and 23% feeling it only sometimes, this diversity could be due to more participants had some problems with method 2 recognising that they were human at time. Method 3’s majority of 38% felt the robot reacted little to them while 30% felt it was reacting “often”, with the rest feeling it was “most of the time”. This question was asked to see of the participants could tell if the robots ability to react to them was changing between the methods.

“Did you feel the robot was giving you feedback on its actions?” answers show that the majority for both methods 1 & 3 felt that the robot was giving feedback “often” but it seems again method 2 is diverse in the range of its answers as there not much between them, 30% to both “often” and “sometimes” and 23% to “little”. Method 1 also has 30% of its participants say there was little feedback.

9.2.4 Open questions responses

This part of the report will discuss some of the common comments the participant made from the open ended questions, for the full list of their responses please see (appendix item 9).

“Did you notice any difference between the guide behaviours?” responses shows that all the participants saw a change in the robot when doing the different tests, most commented on the head and camera rotation and some commented on the change in the robots reaction and wait times “*there seemed to be a difference in the waiting times and how it reacted to me at waypoint*” (participant 9). A few of the comments did stand out like participant 5 says the robotic voice was “scary” and participant 10 not liking the robot moving the robots eye (robots head) and camera finding it a bit “disconcerting”, while this may have affected their comfort the majority never mention any problems with these elements from their comments, though it would be something to look into more in future iteration

“Was there anything you liked/dislike about the different guide behaviours?” responses show the participants liked the robot looking for them and making sure they are still following, but participant 2 didn’t like the robot saying it was checking to see if they were there. Participant 6 unlike no.5, liked the robots “*human-like voice*”. One problem a few of the participants said they didn't like the robot looking at them for any length of time and participant 10 again mentioned not liking the eyes "*uncomfortable as the eyes were a little disconcerting*"

"Do you have any further comment on any of the guides?" response showed that a few participants wanted the robot to move faster, this is also shown in (fig 10), and that the waiting times, mainly in method 1, are too long.

9.2.5 General 1 time questionnaire discussion

How comfortable where you before the test" was ask of the participants to find out if they were comfortable before the test or at least not uncomfortable, this was asked because if they started the tests feeling uncomfortable than that would affect the results but thankfully none of the participants were uncomfortable.

"Were you comfortable in the place you were doing the tests" was asked for a similar reasons as the previous question. If they are uncomfortable with the place then, it would affect the results from them but no one was uncomfortable in the test environment, in fact most where very comfortable.

"Were you comfortable/uncomfortable when the robot talks to you?" was ask to see if the robots voice was the reason for any discomfort to the participants. While most where comfortable with the robots voice "*liked the human – like voice*" (participant 6), it did make some of the participant uncomfortable "*voice was scary*" (participant 5) and since that is how the robot gives its feedback this could explain the diverse results in (Fig 13).

All 13 participants answered "How did you feel about the route the robot took you on?" by saying the route was fine to them, meant that it didn't affect their comfort when following that route.

9.2.6 Determining the comfortable method

This part of the report discusses the comfort questions results.

"Q1, How did you feel about the robots behaviour at the waypoint?" question results show that on average method 2 was the most comfortable for the participants at waypoints, this could be due to Linda looking for them, as few of the participants mentioned that they liked that aspect of the method in the open questions section. Method 1 was the least comfortable method at waypoints, the waiting times could be factor here as show in (fig11) along with the robot not being reactive to the participant (fig12) could mean the participants felt awkward while waiting for the robot to respond or do something at waypoints, whereas method 2 & 3 were moving the head and camera at waypoints.

"Q2, How did you feel about the robots behaviour during moving between waypoint?" averages show that there was not that much between method 2 & 3 with only having 0.5 difference between but it's still difference so that means on average participants were comfortable with method 3 while moving to waypoint. This might be due to the participants feeling that method 3 gave more feedback (fig 13) so it informed them better that is was moving to another waypoint.

"Q3, How did you feel about following the robot using this method?" results show method 2 being the most comfortable method to follow with method 1 being a close second with a different of 0.3 from method 2. Method 3 was the least comfortable method to follow with an average score 3.0 which was surprising considering how well it scored in the other graphs but looking at some of the users comments such as participant 7"*3rd was the best while it worked, but failed the most*" some of the users felt that method 3 was not working as they thought it should have or at least not all the time.

These 3 questions by themselves do not give a clear answer on which method is the most comfortable to the user but (Fig 20) shows the averages from each questions and averages them.

Looking at the averages you can see that method 2 on average scored the best out of the 3 questions with an average of 4.2 meaning the method 2 is the most comfortable method to the participants.

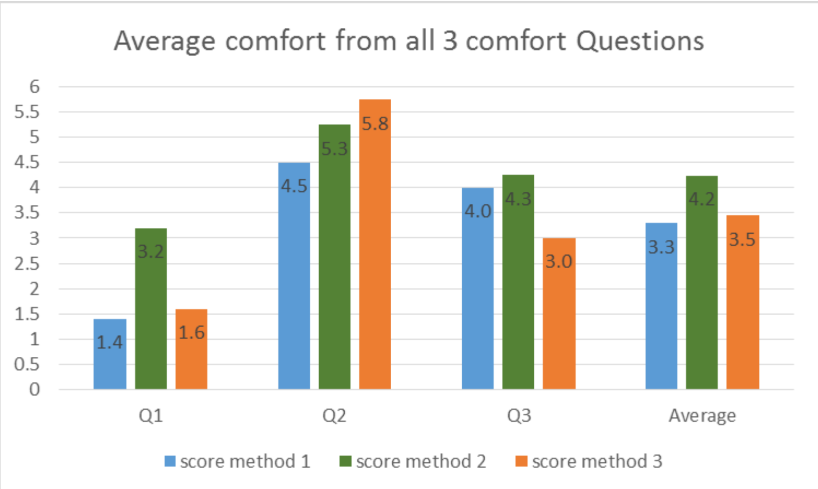

Figure 20 Average comfort from all 3 comfort Questions

There are other things to back this up: it scored the best comfort at the two basic parts of a tour guide robot, following & stopping at waypoints, method 2 was felt to give the participant the most feedback (Fig13). Though participants did feel that method 2 was the slowest of the methods, but the participants comments from the open questions show that is was liked by them. The participants like that this method turned both the camera and it head like a human would when looking behind themselves to look at the follower like participant 3 mentions "*preferred the robot looking at me as I get to the destination as it more human like*" and participant 11 "*I preferred when the guide looked at me directly with its face*"

Method 3 is the second most comfortable method to the participants, with a difference of 0.2 it just beat method 1. This could be due to method 3 felt to the participants to have the best waiting time (fig 11) meaning the overall experience was more fluid less waiting around, whereas method 1 at each waypoint the participant had to wait for 5 seconds. Part of method 1 being the least comfortable is probably due to the fact it didn’t react to participants and they noticed it (fig 12), also as mentioned in the open question section, the participants liked that fact the robot looks for them as long as the robot doesn’t stare at them which is what both methods 2 and 3 do.

So the most comfortable method to the participant is method 2.

10 Conclusion

The aim of the project was to find which of the designed methods is the most comfortable and efficient and this aim has been met with method 2 being the most comfortable to the participants and method 3 is the most efficient as it spots humans faster and completes the guide quicker.

Though this does mean there is no one method that is both the most efficient and most comfortable but since method 3 is the most efficient method and a close second for the most comfortable, it is then the most comfortable and efficient method of out of the 3 designed methods.

So for the participants the most comfortable and efficient method is a method that speaks to the user and gives feedback, keeps watch for the participant while moving, reacts to the user and at waypoints will stop to make sure the user is still following.

10.1 Future work

With this program there is a few things that could be improved upon, such as having the robot being able to actually know what human is following them instead as just it looking for any human following, but at the time of designing and developing the methods Linda did not have such capabilities and it would be beyond the scope of this project to develop such capabilities so this is something that could be done in the future.

Other things that can be change or improved upon in future iterations are the number of methods used, instead of only have 3 methods, 4-5 methods would give more areas to test in, for instance have a method that has the user pick a route. The project could be expanded upon by having groups of people instead of a single participant at a time and see how that compares to the results of one at a time.

Since a lot of the participants mention the speed of the robot one of the future changes could be to have the robot's speed changed pending on the person following, this could either be done by the participant selecting a speed at the start or done via a new method that its speed would be dependent on how close the user was, so if the user is getting closer, the robot would speed up a bit but if the participant was getting further away than the robot would slow down.

The testing environment could be changed, so that the participants have larger area to be guided around, this would change how close the waypoints are to each other and how many there would be, which according to the results of testing, was one of their concerns.

11 Reflective Analysis

The project as a whole worked, but there were a lot of problems that cropped up that were not planned for and there were issues that were planned for but ended up larger than anticipated which hindered the project. One of these issues was time management, the time available for the project was planned out using the different tools mentioned in the project management section but mainly it was with a Gantt chart, but the time allocated for developing the first method was vastly underestimated thus pushing back the other proceeding items. Though developing the 2nd and 3rd method was a lot quicker than the first. More time for testing was needed, this would have allowed for more participants which would have greatly improved the diversity in age, gender and experience with technology and robots, which of course would have made the results more conclusive. Looking back at the live testing, there were too many waypoints on the route, this in made the route for the participants become a bit tedious especially considering the participant had to go along that route 3 times.

A lot the risks that had a “contingency plan” in my risk assessment (appendix item 11) never occurred and the few that did occur didn’t have the impact on the project as I thought it would. Both the simulator and the labs where updated to a new version of ROS, but since I was working off my laptop and I was nearing the end of developing and testing the methods there was little point me updating my working version of the simulator so it was not a problem for my project. Another risk that was expected to have a large impact on the project was the robot Linda becoming inoperable and unavailable but my supervisors were quick to inform me of when the robot was inoperable and when it would be operable and available again, so my plans for when I needed the robot where not affected by these risks. The only problem that did affect my project was the number of participants that showed up for the live testing, compared to the number that said they would show was quite different but this was out of my control and the effect was mitigated by going out an asking random people if they would like to participate in tests.

While I think the methods where designed and implemented well there are some common aspects that the participants didn’t like, such as the robot waiting times, this was mainly for method 1 as it used a fixed waiting time, I should have done some more testing to get a better fixed time for the participant live tests. Method 2 and 3 both send the robot back to a prior waypoint if there was no human spotted, in the real world the robot is unlikely to find the human this way due to the fact the human would have wondered off. This was added to speed up the human participation testing, as if the robot could not see the participant during the test the robot would just go back a waypoint instead of having to reset the robot and start the test again.

The project does have some good elements as well, such as the background research, which made designing the different methods easier and it made writing the questionnaires easier due to knowing what comfort areas to ask about. Using the simulator to test the methods made the testing on the actual robot a lot quicker, as there was mainly only bugs from the methods being integrated onto the robot. The live human participants test went well using a hands off approach and leaving the participants in the hands of the guiding method gave interesting results to work with but again more participants would have been better. The method the robot took for guiding the participant worked well as it had the participants move through and stop in different areas, some with better lighting and some with more space, this gave me result from slightly different environments.

If this same project was to be done again, the major thing that would be different is how the different aspects would be planned out. The time management would need to be improved greatly, this would be done by reviewing the weekly progress against the plan, if aspects where starting to slip it would be more noticeable and then steps could be taken to fix it or if that is not possible then the rest of the plan could be altered to accommodate the change. More participants would be recruited for the live testing to get a greater range of people which would give more weight to the end results. one change that would be made is the amount of tests given to the participants in one go, for instance have the participant do two of my tests then have the other conductor take them and do their tests, once they are done they will continue with my tests; this would break up the repetition of going over the same route and to the same waypoints.

More methods could be developed to get a broader range of following types, e.g. have a method that would go to each waypoint but would not stop at any of them but the last one, as long as a human was following behind; this would give the user the experience of following a robot that takes them from A to B which would also be a good method to compare against. The last thing that would be done differently would be to have to live tests, the first to get feedback on what works and what didn’t work with the method from 1 group of participants and then another live test to get the comfort data from a different group of participant. I would also do statistical testing on the results, this would give me hard statistical evidence that the participants where more comfortable with method 2 over the other methods.

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13 Appendix

13.1 Item 1 – Repeat questionnaire

Below is the Likert scale questionnaire the each participant in the testing was asked to do after each test:

Participant's name_______

Robot behaviour

Did you feel the waiting time at each waypoint was too long/short?				
Way to short	A bit too short	It was fine	A bit too long	Way to long
Was the robot moving too fast/slow during this guide				
Way to fast	A bit too fast	The speed was fine	A bit too slow	Way to slow
Do you feel that the robot was reacting to your presence?				
Not at all	A little	sometime	Often	Most of the time
How did you feel about the robots behaviour at the waypoint?				
I was very uncomfortable	I was slightly Uncomfortable	I was fine	I was slightly comfortable	I was very comfortable
How did you feel about the robots behaviour during moving between waypoint				
I was very uncomfortable	I was slightly Uncomfortable	I was fine	I was slightly comfortable	I was very comfortable
Did you feel the robot was giving you feedback on its actions				
Not at all	A little	sometime	Often	Most of the time
How did you feel about following the robot using this method?				
I was very uncomfortable	I was slightly Uncomfortable	I was fine	I slightly comfortable	I was very comfortable

13.2 Item 2 – Once questionnaire

Below is the Likert scale questionnaire that the participants where asked to after doing all the tests:

Participant's name________

General Questions about your interaction with the robot and how you feel/felt

How comfortable/uncomfortable were you before starting the tests?				
Very uncomfortable	Slightly uncomfortable	Neutral	Slightly comfortable	Very comfortable
Were you comfortable in the place you were doing the tests				
Very uncomfortable	Slightly uncomfortable	Neutral	Slightly comfortable	Very comfortable
Were you comfortable/uncomfortable when the robot talks to you?				
Very uncomfortable	Slightly uncomfortable	Neutral	Slightly comfortable	Very comfortable
How did you feel about the route the robot took you on?				
Was too short	Was a bit short	It was fine	It was a bit long	Was too long
Did you feel there was to many/little waypoint on the route?				
Need lots more	Need a few more	There was enough	There was a few to many	There was too many
After doing the tests how comfortable/uncomfortable are you now?				
Very uncomfortable	Slightly uncomfortable	Neutral	Slightly comfortable	Very comfortable

13.3 Item 3 – optional open ended questions

Below are the optional questions give to the user after all the tests and other questionnaires were done:

Participant's name_____

Some open-ended questions

Did you notice any difference between the guide behaviours?
Was there anything you liked/dislike about the different guide behaviours?
Do you have any further comment on any of the guides?
Do you have any further comment on the tests as a whole?

13.4 Item 4 – Demographic questionnaire

Below is the demographic questionnaire that each participant was asked to do before do participating in any of the tests:

Participant name ___________

Below are Demographic and experience questions

<table>
<tr><td colspan="8">What gender are you?</td></tr>
<tr><td>Male</td><td colspan="2">Female</td><td colspan="4">Other</td><td>Rather not say</td></tr>
<tr><td></td><td colspan="2"></td><td colspan="4"></td><td></td></tr>
<tr><td colspan="8">What age are you?</td></tr>
<tr><td>Less than 20</td><td>20-25</td><td>26-30</td><td colspan="2">31-35</td><td colspan="2">Greater than 35</td><td>Rather not say</td></tr>
<tr><td></td><td></td><td></td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="8">What is your profession?</td></tr>
<tr><td>Student</td><td colspan="2">Teacher</td><td colspan="3">Researcher</td><td>Other</td><td>Unemployed</td></tr>
<tr><td></td><td colspan="2"></td><td colspan="3"></td><td></td><td></td></tr>
<tr><td colspan="8">How much experience do you have with robots & robotics?</td></tr>
<tr><td>None</td><td colspan="2">Little</td><td>Some</td><td colspan="3">Considerable</td><td>Lots</td></tr>
<tr><td></td><td colspan="2"></td><td></td><td colspan="3"></td><td></td></tr>
<tr><td colspan="8">How much experience do you have with computers and technology in general?</td></tr>
<tr><td>None</td><td colspan="2">Little</td><td>Some</td><td colspan="3">Considerable</td><td>Lots</td></tr>
<tr><td></td><td colspan="2"></td><td></td><td colspan="3"></td><td></td></tr>
</table>

13.5 Item 5 – Consent form

Below is the consent form each participants read and signed before doing any of the tests:

Consent form for the Follow Me Project.

Date: ___________

Participants Name: ______________

I consent to participating in Sandy May, Sinjun Strydom and Piotr Psuty respected projects and I acknowledge the following:

- I understand that if I feel uncomfortable during the tests I can stop at any time
- I understand that I can leave at any time during any of the tests and the data that was collected up to that point will be deleted and not used.
- I understand that I can withdraw from the test even after my completion of the test as long as I inform the conductor of the test of my withdrawal within 2 weeks of my participation.
- I've been verbally told about the tests, their purpose and what I am expected to do in them.
- I am happy for Sandy, Sinjun and Piotr to use the data that is collected from my participation in the tests to be used in there project evaluation.
- I understand that personal data collected from my participation will be anonymized
- I understand that if I wish, I can ask about the data collected from my participation after the tests and that if I want to then see that data I would be allowed to.
- I understand that the data collected from my participation will be deleted after a year, so if I want to request this data from the conductor it would have to be within that timeframe
- I understand that I can ask questions before and after each test but not during
- I understand that I will be recorded while I do the tests but I understand that the recordings will only be used for the project evaluation and will be destroyed once the project has been completed

With me signing this consent form I agree that I have read, understood and agree to the above points.

Participant Signature: ………………………………………………

Sandys May signature: …………………………………………..

Sinjun Strydom signature: …………………………………………..

Piotr Psuty signature: …………………………………………..

13.6 Item 6 – Method 1 code

Below is a GitHub link to method 1 code:

https://github.com/LCAS/follow_me/blob/master/src/base_move/script/robot_base1voice.py

13.7 Item 7 – Method 2 code

Below is a GitHub link to method 2 code:

https://github.com/LCAS/follow_me/blob/master/src/second_method/script/robot_2ndvoice.py

13.8 Item 8 – Method 3 code

Below is a GitHub link to method 3 code:

https://github.com/LCAS/follow_me/blob/master/src/third_method/scripts/robot_3mvoice.py

13.9 Item 9 – open questions responses

Did you notice any difference between the guide behaviours?

P1 – some notice that I was following other didn't, some had head movement

P2 - seems to be difference in the amount of interaction with the robot

P3 – some look at me before the destination, some while moving others did not

P4 – they all followed the same path but the eyes and camera changed

P5 -1st used the Kinect to check if I was still following, was a bit unresponsive -voice was scary.

2nd only paused, wasn't certain if it was checking for me or now

3rd saw her eyes + Kinect turn to check

P6 – 1st – no person detection, no camera movement, no head movement. 2nd person detection, 180 deg camera movement, 90deg head Turing, 3rd person detection, 180 head and camera movement

P7 – changes in delay, feedback and sensor apparatus; 3rd was the best while it worked, but failed the most

P8 – one of them had the head rotating 180 deg which is better

P9 – there seemed to be a difference in the waiting times and how it reacted to me at waypoint

p10 – guide 1 didn't require a human presence or no noticeable thing that told you that Linda knew you were there. Guide 2 moved the eyes with the camera – it was a little disconcerting. Guide 3 had the camera trained on you, it felt more personal

p11 – the 2 & 3 follow procedure asked if I was still there while the 1st seemed to not check at all. The 3rd test seemed to be quicker and the head did not turn completely

p12 – n/a

p13 – n/a

<u>Was there anything you liked/dislike about the different guide behaviours?</u>

P1 – like that it made sure I was following

P2 – it was uncomfortable when the robots said was checking if you are still following

P3 – preferred the robot looking at me as I get to the destination as it more human like

P4 – like that is being able to detect me but it delayed general movement by quite a bit

P5 – 3rd test was preferable – not too long or too short

1st didn't recognise me at one point

P6 – liked the human – like voice, disliked the turn just before detection of person

P7 – n/a

P8 – n/a

P9 – I didn't like waiting to long to move on. When the robot focus was fixed on me for a length a time it made me feel a little uncomfortable

p10 – I preferred guide 3 as it felt the most "human". Guide 2 made me felt more uncomfortable as the eyes were a little disconcerting

p11 – I liked the robot checking was I there for the 1st time but grew tiresome near the end

p12 – n/a

p13 – n/a

<u>Do you have any further comment on any of the guides?</u>

P1 – n/a

P2 – could do with the robot being faster

P3 – the robot should be aware of my presence during transport

P4 – n/a

P5 – pause time could be shorter and the speed increased

P6 – n/a

P7 –n/a

P8 – n/a

P9 – I find the ability of the robot to guide via following fascinating

p10 – I felt the stops in the guide 1 were to long seeing as linda wasn’t looking for you

p11 – I preferred when the guide looked at me directly with its face

p12 – n/a

p13 – n/a

<u>Do you have any further comment on the tests as a whole?</u>

P1 – would have preferred a unified speech at the waypoints

P2 – n/a

P3 – n/a

P4 – n/a

P5 – n/a

P6 – n/a

P7 –n/a

P8 – n/a

P9 – n/a

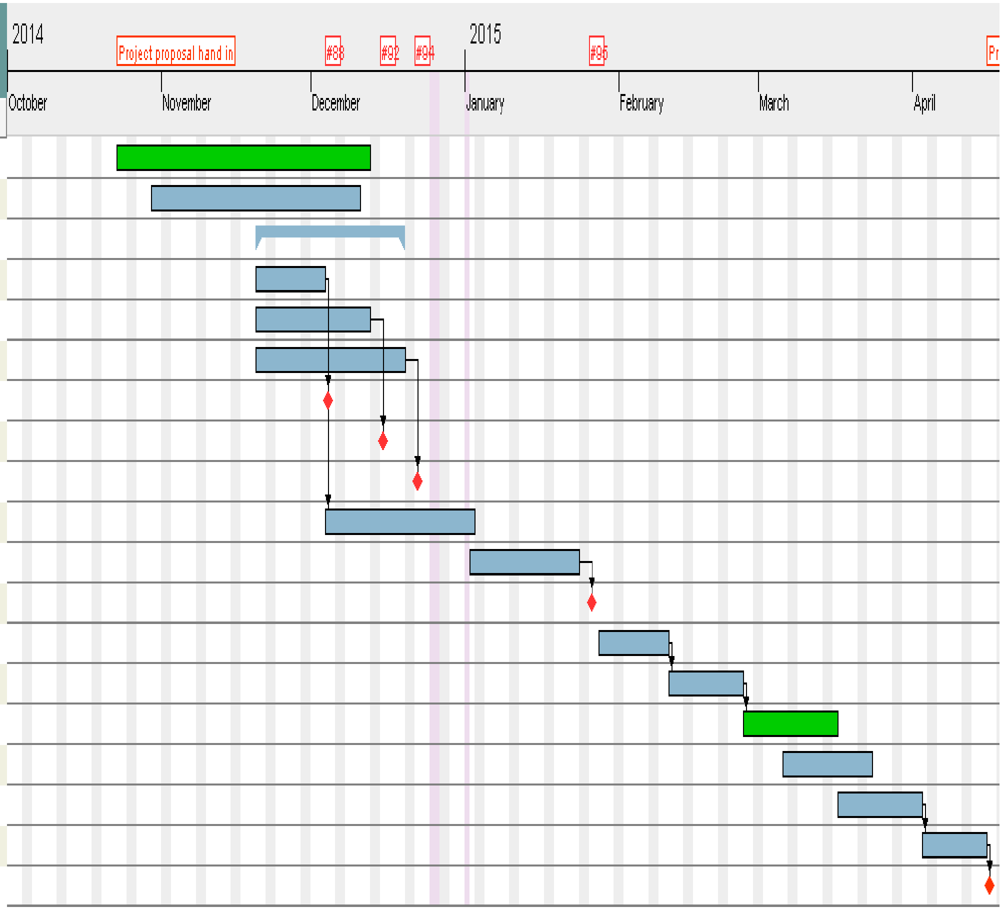
p10 –n/a

p11 – I enjoyed the test and liked how it was handled in a hands off approach p12 – n/a

p13 – n/a

13.10 Item 10 – Gantt chart

Name	Begin date	End date
Lit review	23/10/14	12/12/14
Design Methods	30/10/14	10/12/14
Develop Methods in ROS simulator	20/11/14	19/12/14
Method 1 in ROS simulator	20/11/14	03/12/14
Method 2 in ROS simulator	20/11/14	12/12/14
Method 3 in ROS simulator	20/11/14	19/12/14
Will have a working first baseline method in the simlulator	04/12/14	04/12/14
Will have second method working in the simulator	15/12/14	15/12/14
Have a working 3 method in the simlulator	22/12/14	22/12/14
Test Methods in simulator	04/12/14	02/01/15
Integate methods into Linda Robot	02/01/15	23/01/15
Will would have completed the intergation of the methods into linda	26/01/15	26/01/15
Test Linda with integrated methods	28/01/15	10/02/15
User study to test methods	11/02/15	25/02/15
Evaluation	26/02/15	16/03/15
Write conclusion	06/03/15	23/03/15
Reflective Analysis	17/03/15	02/04/15
Proof read	03/04/15	15/04/15
Project Hand in	16/04/15	16/04/15



13.11 Item 11 – Risk Assessment and Contingency Plans

Risk	Severity	Probability	Contingency
Robot Linda becomes inoperable	High	High	There several other type of robots available that could be used In the same way.
Robot Linda is unavailable for use	Low	medium	Booking use of the robot early with the help of the supervisor will ensure that I would have access to the robot
ROS Simulation cannot run on my laptop	Medium	medium	would have to use Labs computer or bring my pc from home to work on project
run out of time to finish the project	High	low	This should be avoidable by using tool like Gantt chart and other time keeping tool to manage my work load and time
Unable to get a range of different demographic people to test my methods	Medium	medium	Will have to settle for what people I can get to test the robot
Lose access to 365/ one drive	Medium	low	I have the documents backed up to google drive and have a copy on the computer. I will also be using Github to store work and for its version control
Changes to simulator break software	High	medium	A backup of the working Ubuntu OS with the working simulator will be kept- so can restore backup
Changes to ROS break program	High	medium	A backup of the working Ubuntu OS with the working simulator will be kept- so can restore backup
Computer labs change ROS version	Low	medium	I would continue to use my laptop or I would have to update my work to work on the new version