Landmark recognition and navigation with AprilTags

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Abstract. Social robots such as MiRo have an important role to play in the future; they can be a very useful tool in care homes as they can engage with people of need at an emotional level and provide entertainment. This project explores the use of AprilTags in order for a MiRo robot to be able to map its surroundings and navigate to a given target room. To achieve this, we have implemented mapping, navigation and AprilTag detection techniques that takes inspiration from fiducial markers found in nature. The project has demonstrated the viability of robots such as MiRo at performing simple room mapping and navigation procedures in an environment such as a care home. The report concludes that the MiRo robot has successfully fulfilled the aims of this project, whilst detailing areas for future research.

Keywords: AprilTag · Navigation · Mapping · MiRo

1 Introduction

1.1 Background

The project considers the application of MiRo within the domain of robot assisted therapy [1]. With 35% of care home residents estimated to be severely lonely [2], the use of robots in care environments is becoming increasingly popular. However, care robots can be costly and complicated to install. The project aims to create a simple navigation system that allows MiRo to navigate between rooms. Further behaviours could then be implemented on top of the system to enable MiRo to better support and help care home residents. Such a system would increase the viability of robots in care homes and other such environments. A viable system has the potential to increase quality of life that residents of care homes have in the UK, something that is sometimes overlooked.

1.2 Recent Work in the Area

Numerous examples can be found of research into how robots can be used in place of animals in preventing loneliness and increasing the general mood of care home residents. One robot, Paro, has been developed with this aim. This robot in particular has been proven to have great potential to provide mental health care for older people [3] and even reduce stress levels of healthcare staff [4].

Another study found that robotic dogs can increase the general mood and decrease psychological symptoms such as depression in subjects, and that the use of robots as therapy animals is promising [5].

1.3 Possible Applications

The aim of this project is to build a foundation upon which robot behaviour can be built upon. Examples of this behaviour include:

- Interaction with care home residents, whereby a robot navigates to a resident in order to interact with them, based on a command by care home staff and/or residents.
- Delivery of items such as food/medicine to different rooms based on commands from care home staff.
- Resident companionship, imitative of a pet dog or cat, based upon the navigation and mapping set up by this project.

2 Methodology

2.1 Overview of the established methods in the area

Fiducial Markers A fiducial marker is an object that is used as a point of reference in an imaging system. The marker is placed within the field of view of the imaging system and has different applications depending on the system. For example, fiducial markers are used in Physics for measurement of other objects within the image, as shown in Figure 1.

Fiducial markers have also been used in robotics. One study found that using fiducial markers as artificial landmarks in SLAM is a viable alternative to using natural landmarks [7]. Artificial landmarks have been shown to produce better localisation repeatability, as they are highly distinguishable. Many indoor robot navigation systems employ the use of artificial landmarks for this reason. However, these systems can come with complex calibration and measurement processes, as well as the problem of changes in the indoor environment. The aforementioned study looks to solve these problems through the use of fiducial markers.

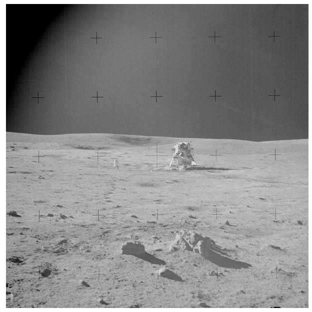

Fig. 1. An image from the Apollo 14 moon landing with crosshair reticles being used as fiducial markers.[6]

The use of fiducial markers in a navigation system is mimetic of how place cells work in mammalian navigation. Place cells are neurons within the hippocampus that fire when an animal is in a particular place that it recognises, and are an important part of how mammals navigate. Place cell firing patterns are believed to be based upon stimuli such as landmarks [8]. This is similar to how a robot could place itself in an environment using a fiducial marker.

AprilTags Research has been previously carried out into efficient and robust fiducial detection [9] of AprilTags. AprilTags require specialised algorithms to detect markers among other features in a natural scene. The paper describes a new AprilTag detection algorithm which improves upon the previous attempts, reducing the rate of false positives, increasing the detection rate of the tags, and reducing the amount of computing time needed for detection. These improvements make robust tag detection viable on computation-limited systems such as smartphones, and extends the usefulness of tag tracking in real-time applications.

2.2 Robot Behaviour

The behaviour of the robot is broken down into two parts, navigation and mapping. The robot maps a set of rooms when it is first introduced to them. Once the map is complete the robot is able to navigate from room to room based on commands given to it from the command line.

Mapping The mapping task requires all the AprilTags contained in each room to be known before hand; each room contains two AprilTags for each door that leads to a new room. This information is provided to the program as a dictionary - the key being the name of the room (e.g. ‘A’), and the value being a list of tags that will be found in that room.

The MiRo robot will start in a room and rotate around in place until it identifies an AprilTag. One AprilTag is placed on the left side of the door and another one on the right side in order for the robot to be able to calculate its way through the middle of the doorway. The robot will align itself with the doorway using the tags and navigate through it. Once the robot has entered the new room it will then identify the room by referring to the provided dictionary of rooms and AprilTags. This is repeated until all the provided AprilTags have been found.

As AprilTags are identified, a map in the form of a two-dimensional array is built. The array contains a number of arrays equal to twice the number of doorways in the building. This is because there is a different set of tags on either side of the door, so that the robot can distinguish between rooms. Each doorway list contains a start room, the two

AprilTags either side of the door, and the destination room. A doorway connecting room A to room B, using AprilTags 1 and 2 would be represented by a list: `['A', '01', '02', 'B']`. If the tags on the other side of the door, in room B, were tags 3 and 4, the doorway in reverse would be represented by a list: `['B', '03', '04', 'A']`.

Navigation Once the map is created, the robot behaviour defaults to waiting for a command. The command is simply the string identifier of a room to which the robot must navigate. Once the robot receives a command, it uses the map to work out which doorways it must go through in order to reach it's destination. Below is an example map:

```
['A', 01, 02, 'B']
['B', 03, 04, 'A']
['B', 05, 06, 'C']
['C', 07, 08, 'B']
```

If the robot is in room A and is given a command to move to room C, it must work out a path to room C. It finds all the doorways in the map for which the first element, or start room, is 'A'. In this example one is found: `['A', 01, 02, 'B']`. It then looks through all these doorways and sees if any of the fourth elements, or destination rooms, are equal to the command room - 'C'. If any of the doorways' fourth elements match the command room then the search is complete, and the robot has to pass the AprilTags in that doorway list in order to reach its destination. In this example, there is only one doorway, and it's destination room is 'B', so the search continues. The next step is to retrieve all doorways with a first element, or start room, of 'B', in this case one is found: `['B', 05, 06, 'C']`. Again, all of the doorways with a matching start room are checked to see if their fourth element matches the command room 'C'. In this case, the one doorway does have a destination of 'C' so the search is complete. The robot adds the AprilTags from each doorway used in finding the command room to a list. This list represents the path the robot must take, and for this example would be `[01,02,05,06]`.

3 Implementation

The previous methodology described the ideal design. However, when applying theory to a practical problem, the design often diverges and so this chapter will detail the actual implementation of our system on the MiRo platform.

3.1 Image rectifying

All retrieved images are flattened due to the radial distortion in the MiRo lens. This allows for more reliable AprilTag recognition and accurate distance calculations. This process was automatically completed at every step which the MiRo was using its camera senssors.

3.2 Mapping, Exploration and Navigation

Before commencing the mapping process, MiRo is given a predefined dictionary that contains the room names and the IDs of the AprilTags within in each room. Upon entering a new room, MiRo turns around on the spot until it has detected all AprilTags defined to be in that room. The ID of the first AprilTag identified in a new room is looked up in the predefined dictionary. The associated key is returned to indicate to MiRo the room it is in (current room). The values attached to the current room key indicate the tags in the room that MiRo needs to find before it can move through a doorway. MiRo continues to spin until it has found all tags defined to be in the current room. Once this is achieved, MiRo will begin to move through the doorway corresponding to the most recent AprilTag detected.

MiRo will then navigate through the doorway, centring itself by keeping both AprilTags which represent the doorway in each camera until it can no longer see the tags. Once these tags are no longer visible, there is a different class of AprilTag on the opposite wall visible through the doorway, MiRo now uses this to navigate completely into the room before repeating the process of detecting AprilTags and navigating through unexplored doorways until all rooms have been explored. This is checked by marking which rooms in the provided dictionary have been entered. When this process is complete, MiRo now waits for a command of which room to enter.

During this mapping process, an internal map is generated in the form of dictionaries. One dictionary details room adjacency, which room leads to which. While the other dictionary details which doorways lead to each room, such as the doorway represented by $[0, 1]$ leads to room B. When supplied a target room, using the internal map of which rooms are adjacent, MiRo finds a path to the target room. Through the use of these generated dictionaries, the path to the goal is calculated efficiently.

3.3 Flowchart of Implementation

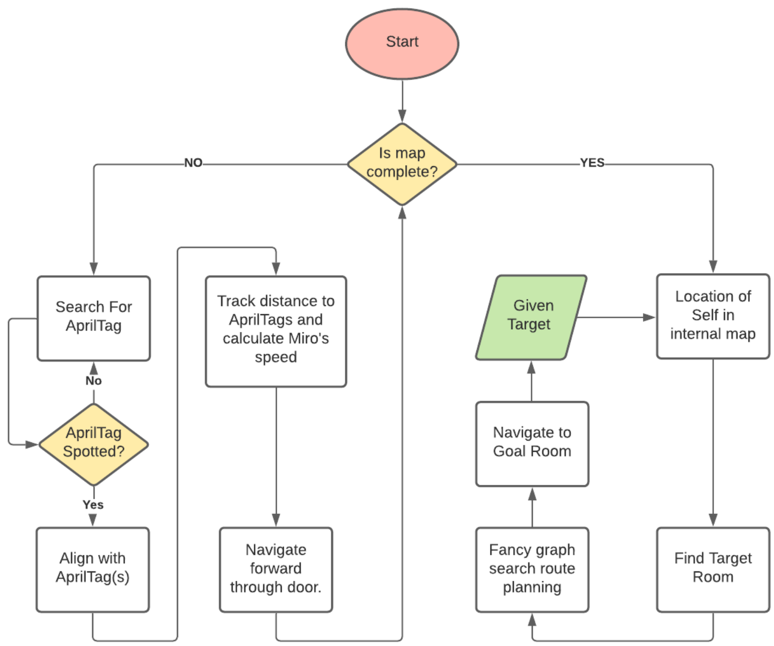

Fig. 2. The General System Design.

4 Results and Discussion

4.1 Achievements

A basic mapping and navigation system has been implemented in a simulated environment for this project. The robot is able to map out two rooms and navigate between the two on command. Commands are given via the terminal, as shown in Figure 3.

A shown in Figures 4 and 5, we have implemented the navigation and mapping system to allow the MiRo robot to scan a room for AprilTags by rotating on the spot whilst using its cameras to search for the tags, and then orientate itself between the two tags (one on either side of the doorway). We then control the motor wheels to guide MiRo forwards until the robot has passed through the doorway, and MiRo's next search for further AprilTags can begin.

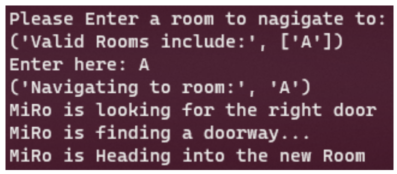

Fig. 3. Terminal input and output during navigation.

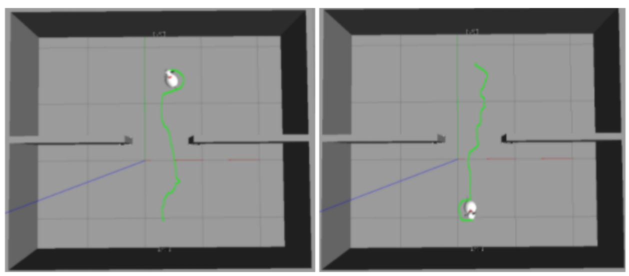

Fig. 4. Trajectory of navigation. Left: From room A to room B. Right: From room B to room A.

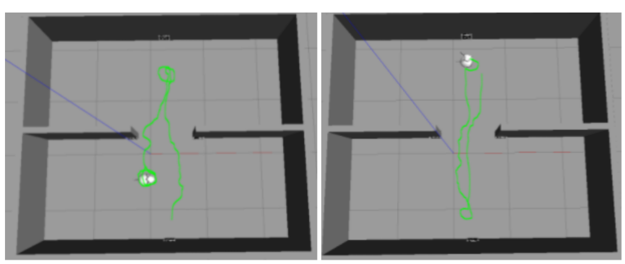

Fig. 5. Trajectory of mapping. Left: Begins mapping in room A. Right: Begins mapping in room B.

Mapping was tested by placing MiRo in the centre of room A and timing how long it took to map out the two rooms (A and B). Figure 5 shows the trajectory taken during one trial of the mapping process. Overall the trajectory remained quite consistent, with MiRo moving in a relatively straight line between rooms and rotating on the spot in between. The start position of MiRo remained constant through the trials, and the average time to map out the rooms was 171 seconds. The difference in results was 33 seconds, indicating the relative consistency of the trajectory taken by MiRo during mapping. The time seems slow given only two rooms are mapped and especially when you consider how many rooms there are in care homes. To reduce the time, the speed MiRo travels at could easily be increased via the code. With more processing power, MiRo could detect AprilTags at a faster rate and the speed of mapping could be increased further.

Table 1. A table of results showing the time taken to map the environment over 5 trials

Start Room	Time Taken (in seconds)
A	176
A	190
A	163
A	167
A	157

To test the navigation between rooms when given a command, MiRo was set to navigate between room A and B continuously. Since there are two rooms, the trajectory was more or less a straight line. The general trajectory of navigation between rooms, when MiRo starts approximately in the middle of the room is given in Figure 4. The trajectory taken is consistent, as is the same for mapping. It is recognised that the environment is simple, allowing for a consistent, stable trajectory. With obstacles or varying shaped rooms, the trajectory could vary more in real world conditions. Time taken to navigate between rooms remains consistent though, indicating reliable navigation in the two room simulated environment.

Table 2. A table of results showing the time taken to navigate to another room

Start Room	End Room	Time Taken (in seconds)
A	B	84
B	A	72
A	B	89
B	A	67
A	B	83
B	A	79
A	B	79
B	A	84
A	B	78
B	A	80

4.2 Limitations

In trialling the mapping process, some failures were witnessed. Shown in Figure 6, MiRo did not complete the mapping process on two occasions. The occasions occurred when MiRo began at a start position that was off centre to the door, highlighting a weakness in the moving through doorway function. Figure 7 indicates start positions within which MiRo has been consistently shown to achieve mapping reliably, not bumping into walls or confusing the current room for a new room. Perhaps Q-learning could be used to make the algorithm more robust to objects like walls, and obstacles.

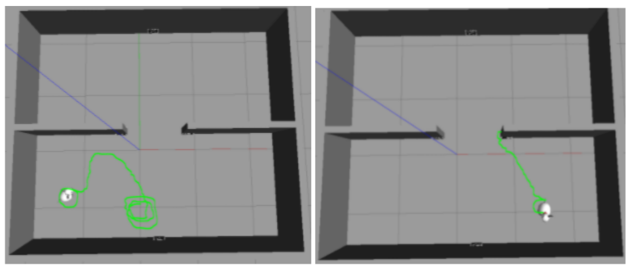

Fig. 6. Mapping failures. Left: Gets stuck in same room. Right: Collides with doorway and becomes stuck.

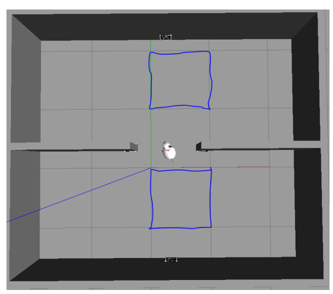

Fig. 7. Best starting positions for mapping and navigation.

4.3 Future Work

Certain assumptions had to be made in order to design the map. Firstly, the AprilTags had to be hard-coded beforehand. This is mainly due to the fact that no learning algorithm has been developed, and the robot needs to localise itself and be able to know when the whole environment has been completely mapped because the robot also has no method of determining when all areas have been covered otherwise.

Furthermore, another assumption is that the rooms have to be empty, so no obstacles can interfere with the exploration of the robot, since no obstacle avoidance algorithm is going to be employed. This is acceptable in the robot simulator and in the physical lab, however in a real world environment the MiRo robot would likely be expected to navigate around obstacles such as chairs and tables, to name a few.

A third potential area for improvement would be to improve the code so that MiRo could explore each room, as

opposed to just spinning on the spot. Currently, the room must be rectangular with all the AprilTags visible to the on-board cameras. However, in practice, rooms can be odd shapes, such as an ‘L’ shaped room. In this scenario, the robot could enter the room at one end of the ‘L’ and not be able to see the next AprilTag that was around the corner. Finally, our current solution only has the capability to navigate between two rooms. This is acceptable for a test environment, however care homes and other buildings in which this technology could be deployed usually have more rooms than that, meaning our current code would need further work to be able to handle the increased mapping complexity.
In terms of giving MiRo commands to navigate to rooms, it would be significantly preferable to do this via voice. The extension could be done using MiRos on board microphones to pick up sound, and would enable residents to instruct MiRo as of where to go using their voice.

4.4 Conclusions & Wider Context of our work

Our work demonstrated the absolute viability of using MiRo robots in a care home environment. We have proven its ability to navigate safely between rooms, which requires only very simple and inexpensive setup using AprilTags that can be simply attached to the walls around the doors. Commands can be issued to the robot, telling it in which room it is required. Creating a new system that can be used by staff and pensioners to direct the robot that is user-friendly would be a useful addition. The aesthetics of the robot make it a friendly and approachable device that pensioners inside a care home will hopefully warm to and will find some joy in interacting with MiRo.

5 Contribution of Authors

Josh: Structured and wrote sections of the report, including the abstract, parts of the methodology, results and discussion.

Frank: Wrote the introduction and methodology sections of the report. Also was involved in the project planning and design.

Stefanos: Worked on the implementation of mapping and navigation system. Also contributed to the project design.

William: Designed and built Gazebo worlds and models to develop in. Helped discuss design of navigation and mapping system. Contributed to report and project planning.

Mary: Implemented AprilTag detection and part of moving through doorway. Ran trials to test system. Contributed to introduction, implementation and results in report.

Everyone reviewed and approved the final version of the report.

6 Accessing the code

This project was developed collaboratory, the project was hosted on the teams GitHub repository accessible at this address: https://github.com/willrshaw/COM3528.

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