Logistical Robotic Assistance in Medical Facilities Using youBot Platform and Simulated Environments

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Abstract—The use of robotic solutions in hospitals seems to be the next step in the modernization of medical facilities. Using mobile robots allows for logistical solutions to basic tasks, this paper covers a potential next step to current solutions.

Key Words—Robots, KUKA youBot, V-Rep, Medical Robots, Logistical Robots, Proximity and Colour Sensors, Autonomous Mobile Robot, Automated Guided Vehicles, Cognex In-Sight, Computer Vision, Simulation, Robot Systems.

1 INTRODUCTION

1.1 The Problem

The problem of the report will be sorting delivery of various medical supplies in a small medical facility; chosen because it highlights a case where robots are being used and developed today, implemented in similar scenarios, to solve real-world problems cheaply and efficiently. Also, the solution can be implemented into various other scenarios making this a beneficial solution to strive for.

The various differently coloured blocks represent boxes of medication and supplies, each with a different destination in the facility. The robot is used to replace a human; providing a more efficient and reliable solution, as well as freeing up members of staff to do more important tasks. It has to work with the sensory input and work in the existing environment, not designed for robots to operate within.

Figure 1 [5] - showing the problem scenario

The above image demonstrates the scenario tackled in this report. This paper proposes a step forward from this and also from current robot solutions both theorised and implemented in various medical settings. The delivery distribution is one of the main activities in operations management within hospitals [8] which is why this scenario is always important to innovate within.

1.2 Literature Review

The literature review will be conducted to investigate and explore what is currently available in terms of solutions applied in the environment and research done into the field, which will aid the development and design of this solution. "The ability of one mobile robot to service several locations and perform a greatly expanded range of tasks offers a great appeal for specialized applications" [15] Beginning the research by looking at existing solutions for similar scenarios, moving onto the proposed solution to develop a rounded review into the problems proposed by the scenario.

1.2.1 Current Solutions

Hospitals are currently employing mobile robots for various tasks in the logistical problems that arise when running a medical facility. There are various developments in robotic applications being pursued in similar scenarios to solve these challenges. Most solutions implement an Autonomous Mobile Robot (AMR) solution, which acts almost like a taxi taking supplies around the facility using path planning algorithms but requires human interaction (see figure 2) to stock the robot and tell it where to go.

Figure 2 [7]

Figure 3[5]

Figure 3 highlights how the AMRs work in the environment and this implementation should be examined to create an effective solution. AMRs such as this one allows the automated delivery of items within the facility, alongside secure and accurate tracking of items. Thus, allowing staff to focus on jobs during peak times, increasing productivity and patient satisfaction [5]

Solutions such as the Phollower 100 allow safe delivery of medical materials in hospital quarantine zones [3] and are proving robots are increasingly important in the current climate. Automated Guided Vehicles (AGV) are very similar to AMRs except with a few differences, mainly with the way they navigate around their environment. AGVs are the older model of the two and have been around for over half a century [1] and provide effective solutions to logistical problems, however, the more modern ARMs use intelligent system algorithms to map their environment to evaluate a myriad of routes around obstacles [18] which, while costing more, future proof the system.

Systems like the TUG autonomous robot uses an ARM framework to move materials and clinical supplies. Maintaining the staff's focus on patients' care and improves the overall efficiency of logistics [16].

Figure 5 [16]

The above image shows the TUG system using intelligent systems, found in ARMs, to navigate around the obstacle in the corridor. Traditional AGVs would not be able to perform such an operation. It is crucial to consider this when designing a solution, as hospitals are a busy environment and the scenario depicted above is extremely likely.

1.2.2 Proposed Solution

The problem of the scenario outlines would benefit from the use of a mobile robot as it is already implemented as a logistical delivery solution. The mobility of mobile robots, such as the KUKA youBot, provides a more flexible solution and does not require renovation that a traditional AGV system and the manipulation that the KUKA platform provides is a proposed next step from the current solutions.

Implementing a mobile solution with the addition of a robotic manipulation arm allows for the complete removal of human interaction. This will increase productivity further than traditional solutions as there is now no need for interaction.

Figure 5 [13] - showing the KUKA youBot robot

Although the KUKA youBot may be small it demonstrates what is possible with mobile robot applications. It is also crucial to develop these solutions, as a decline in employees in the sector could be solved with robotic aid [12]. With that being said, the below table and picture demonstrate how the youBot could be effective.

Department	Drugs package required	Department	Drugs package required
1	1	11	1
2	1	12	2
3	2	13	1
4	1	14	1
5	1	15	2
6	2	16	2
7	2	17	1
8	2	18	1
9	3	19	1
10	3	20	1

Figure 6[15] - department demand

The table shows how each department, in this case study from San Paolo Hospital [15], required at max 3 packages. This would allow the youBot's platform to hold, with ease as shown below, multiple departments drug supply or supply the departments with higher demand in one trip. Which although when compared to TUG systems delivering carts of supplies [16], is a step further from that as it has the manipulation features associated with the arm.

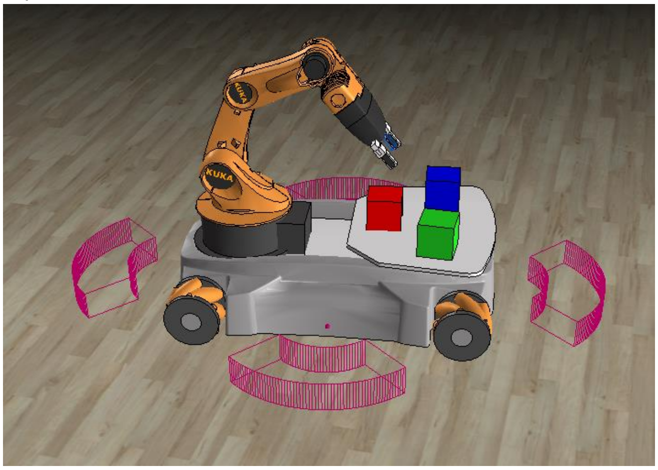


Figure 7 - showing youBot with 3 packages on

Evaluating the current solutions compared to the proposed one indicates a significant gap in the development market. Demonstrating a requirement in research where autonomous robotic solutions complete all of the tasks without any human interaction, in a safe manner. Which is not only efficient but accepted by patients and staff alike, as both demographics are likely to challenge the change [12]

Looking at how ARMs navigate using fuzzy logic algorithms, it can be gathered how to efficiently navigate a solution based on the flowchart below (figure 8).

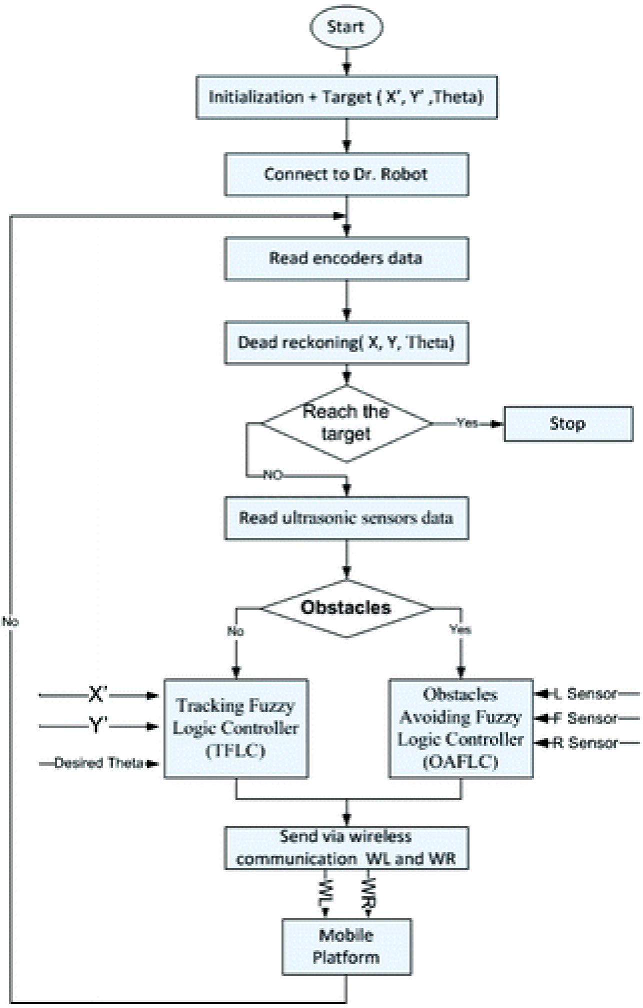


Figure 8[9] – showing the logic of movement

The above flowchart can be used to implement a less intricate solution using path planning and obstacle avoidance using proximity sensors. Although the above flowchart is a complex solution, evaluating how it works allows for the development of a simpler solution on the youBot platform.

For the robot to solve the problems proposed in the scenario it must be able to use sensory input to differentiate tasks, using computer vision systems this would be possible. This is a highly complex solution to implement and would not be required for this scenario as we are merely proposing the ideas, however, it would be recommended that if implemented that this option would be explored.

KUKA implement COGNEX cameras [7] with their robotic solutions, this will be simulated in the scenario to achieve a realistic outcome in the scenario. Using depth and colour sensing will show off what is possible and allow for an efficient solution to be created.

Figure 9[19] Showing KUKA arm and Cognex Sensor

2 Approach

2.1 Scenario

To efficiently develop a solution simulation and adequate testing must be done before any further developments are made. Using V-Rep and Cognex In-sight, robotics simulation software, we can accurately construct a scenario much like the one where the robot will be applied. This will also allow testing for the robot before placing it into a real-world environment.

The combination of these two pieces of software were chosen because of the integrity of the software in creating solutions which can be scaled up to real-world problems. "Simulation is a useful scientific tool that can complement more traditional experimental approaches" [2]

2.2 Software and Hardware

With regards to the software, V-Rep will be used as it provides the scalable simulation alongside the KUKA youBot model already available for use. The software includes so many useful features to simulate effectively; such as scripting and scene editing with a vast model browser, including basic sensors. [14]

Within Cognex In-sight you can accurately train and emulate the hardware which would be used in the real-world situation, allowing for testing to be done to see if the proposed solution would be viable. This adds to the V-Rep demonstrations to create a well-rounded solution to the scenario. The basic vision sensors used in V-Rep will be used in place of a Cognex camera, but the In-Sight software will emulate this. [7] RGB Colour sensors will be used to ascertain the end location of the package in the hospital. (*see 2.4/2.5*) and will be simulated in V-Rep as vision sensors and In-Sight as a Cognex camera.

Proximity sensors will be used on all 4 sides of the robot to avoid collision with obstacles inside the simulated scenario. These sensors will control the movement of the robot and will use real-time location to adjust the movement of the robot when an obstacle is detected. (*see 2.5.1*)

The KUKA youBot Manipulation arm is part of the youBot platform and provides extra features from a standard ARM of AGV. This provides a suitable next step to the current solutions. The below figure shows the dimensions of the youBot arm and demonstrates what is possible with degrees of freedom and movement.

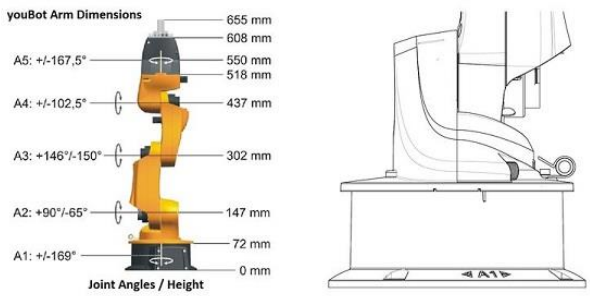


Figure 10 [13] - showing the dimensions of youBot manipulator

Simulation software will be used to create efficient testing of the implementation of the proposed system, and using the two different software will allow for more accurate testing and also the implementation of the proposed hardware/software combination will be simpler, saving costs and increasing confidence in the solution. Simulation is now a powerful tool supporting the design, planning, analysis, and decisions in different areas of research and development [20].

2.3 Environment and Objects

The objects being used simulate drug packages and medical supplies, and come in 3 colours, this signifies the package label and will determine where the package ends up. This is supplemented with various obstacles, such as walls and a dummy human which realises the scenario. This roughly mimics the problem environment to test the expected operation. Although the youBot places the object on the floor in the demo, this could be altered to place them anywhere in the proposed application of the solution.

The conveyor belt which houses the 6 test boxes will move the boxes until one reaches the pick-up zone, this allows for the youBot to pick it up efficiently. The youBot robot is a realistic model of the real-world version, providing a stepping stone to the real-life implementation

2.4 Object Categorisation – Cognex In-Sight

Cognex In-Sight software will demonstrate, in a more detailed way, how the vision of the system is working. But will also be demonstrated in V-Rep to provide a cohesive simulation which can be used to evaluate the effectiveness of the solution.

A greyscale camera can be used but provides more errors so the solution will be using an RGB sensor to gain colour information. The below images show how RGB colours are represented in greyscale, this demonstrates the chance for error in not using the more expensive RGB camera solution.

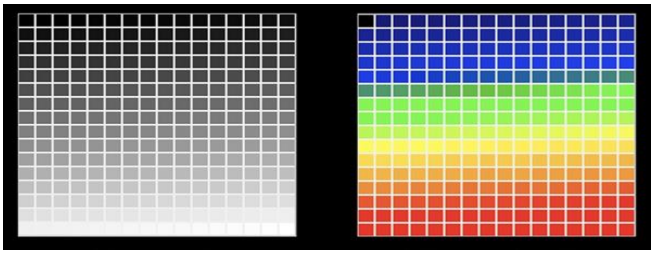


Figure 11 [11] - the difference between RGB and greyscale

Figure 13 is taken from the In-Sight software and shows how the software recognises the colour from the function extractColour Training, which trains the system to differentiate colours in the vision area.

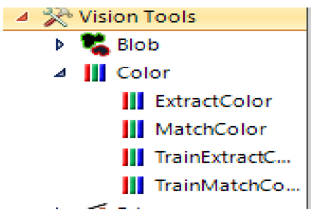
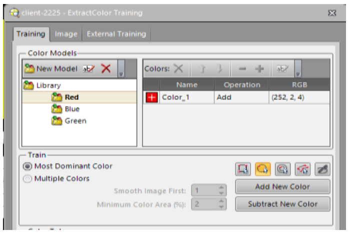


Figure 12 - shows where to gather the training functions from

The existing functions in In-Sight allow for rapid deployment of scenarios in training vision software. This develops a good simulation for the implementation of solutions to scenarios.



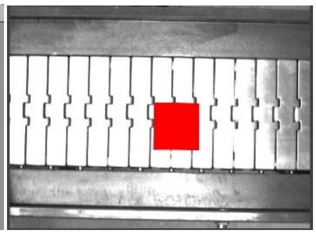
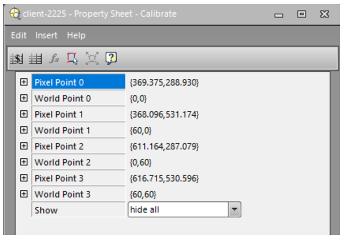


Figure 13 - training *Figure 14- conveyor and box*

Figure 14 shows the conveyor belt and supply box as the simulation runs the box changes location and the software recognises this (demonstrated in attached videos). The software is then calibrated to detect boxes of colour and size of the ones simulated in the V-Rep scene so that they can both be integrated into a real-world solution.



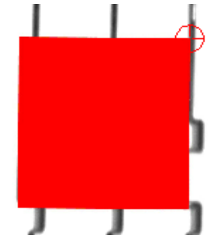


Figure 15 - calibration *Figure 16 - calibration*

The two above figures demonstrate just how to calibrate the sensor. This allows the user to make sure the camera can accurately recognise the medical supply boxes when running and will ensure accuracy in simulation. The figure below then shows the output of the camera simulation, showing colour and coordinates in the top left 'custom view'.

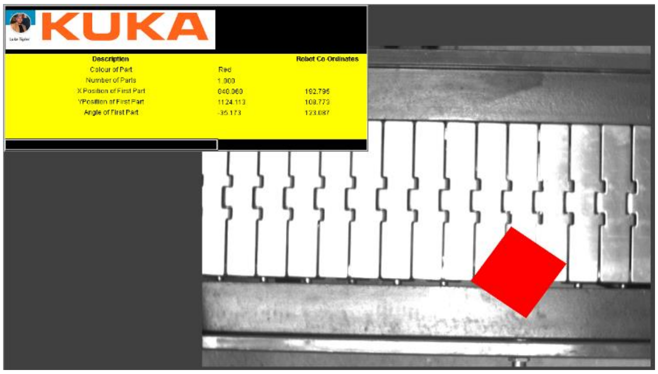


Figure 17 - showing the output of the simulation, with colour and position data of the box on the conveyor

2.5 Object Categorisation – V-Rep

The below section of code, taken from the youBot script, shows how the youBot handles the vision sensor information to manipulate its movement based on sensory information. It handles the vision sensor and takes the colour information as an output of 0-1 values for the RGB output. If statements are used to decide if the colour value, [1] depicts red values, if greater than 0.5 then it is decided to be that colour, but it is checked that the other values are under 0.1 which allows for small scales of error.

```
dropToColour=function()
    sim.handleVisionSensor(camera)
    colour = sim.getVisionSensorImage(camera,0,0,2,2,0) -- 2,2 defines the central pixel for colour recognition
    if (colour[1]>0.5) and (colour[2]<0.1) and (colour[3]<0.1) then --red box
        dropToPlace(place1,0,dropHeight1,pickup2,false,'red')
```

Figure 18 - shows V-Rep colour differentiation code

The V-Rep simulation uses the vision sensor model provided with the software. This basic RGB camera is set up to detect what colour the central pixel is, and then the youBot reads this and manipulates its movement to complete the scenario.

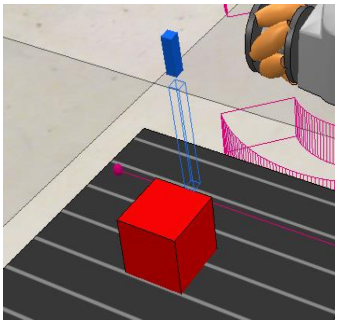


Figure 19 - showing the vision sensor set up on the convevor

The vision sensor is set up at the end of the conveyor and allows the youBot to know the colour of the box which is used to identify the end location. The sensor stores this data in the box data on the youBot platform, to ensure multiple packages can be carried, as discussed in the literature review this is an important factor for success in the scenario.

Although this would be sufficient on its own to simulate the proposed solution, the addition of the In-Sight simulation allows for a more comprehensive proposal.

Storing the values from the vision sensor into an array will allow for the navigation system not to visit anywhere it doesn't need to go, or visit anywhere twice.

2.5 Navigation

Although a fuzzy-logic system which would be able to navigate effectively around the environment, the proposed system employs a path following robot which navigates to intermediate points set out on the scene's floor, these are defined as intermediate points, which the 'youBot_referenceTarget' will navigate to until it reaches the point and moves onto the next one.

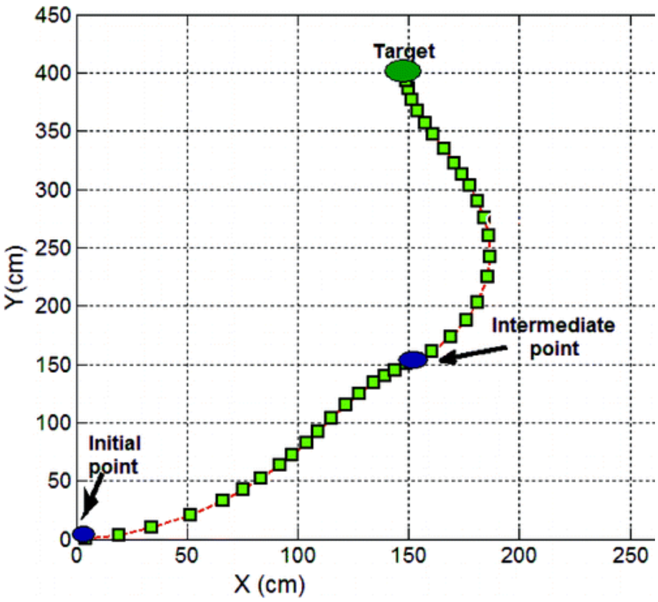


Figure 20[9] – showing the step-by-step path planning

As shown in the literature review, AGV's are successfully implemented solutions and are effective for the scenario selected, as long as they can avoid collisions then the system will be effective in the desired location.

The system will take values from the vision sensor, stored in an array, and will use this to decide which set or sets of nodes it needs to visit. The below pseudocode shows this.

```
colourArray = []

if colourArray[1]or[2]or[3] = red
        then go drop coresdponding at location
if colourArray[1]or[2]or[3] = blue
        then go drop coresdponding at location
if colourArray[1]or[2]or[3] = green
        then go drop coresdponding at location
```

Figure 21 - pseudocode showing how the array would work

The path planning in V-Rep follows the paths drawn in the figure below, this demonstrates the small-scale application and could be scaled up to include more nodes to navigate between, but for demonstration purposes, this is a suitable way to show off what is possible.

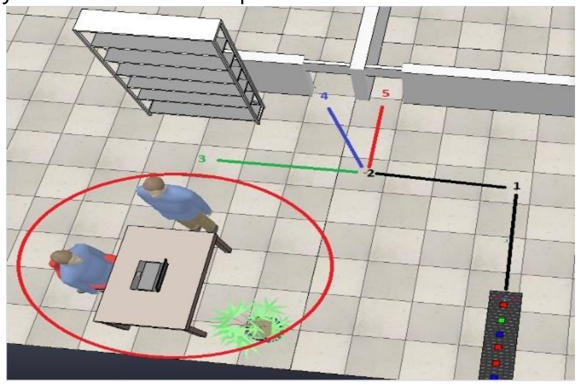


Figure 22 - path nodes are shown for the V-Rep simulation

Paths 3,4,5 will only be visited if it is required, improving efficiency and speed of the solution. The algorithm will then take the robot back to node 2 and decide if it needs to visit any other nodes or return to the conveyor.

2.5.1 Collision Avoidance

The youBot has proximity sensors on all 4 sides of the robot base, shown below, this allows for real-time detection of collisions; allowing the youBot to actively scan the environment and stop movement if obstacles are detected.

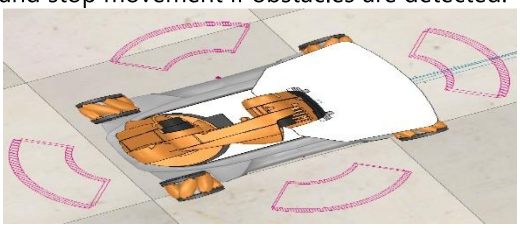


Figure 23 - proximity sensor configuration

The below section of code, taken from the 'robot control' section of the youBot code, shows how the collision avoidance algorithm works. The proximity sensors are located on each side of the youBot and are named accordingly.

```
if (fobs_distance > 0) or (bobs_distance > 0) or (lobs_distance > 0) or (robs_distance > 0) then
    sim.setJointTargetVelocity(wheelJoints[1],0) -- will set all wheels to 0 if an obstacle is in the way.
    sim.setJointTargetVelocity(wheelJoints[2],0) -- this happens if any obstacle is detected
    sim.setJointTargetVelocity(wheelJoints[3],0)
    sim.setJointTargetVelocity(wheelJoints[4],0)
end
```

Figure 24 - obstacle avoidance code

This algorithm allows the youBot to intelligently plan its path and not collide with objects as they appear around it, making it safe to work in the hospital environment.

2.6 Object Collection and Manipulation

The youBot uses the manipulation arm built in to collect and move the objects around the scene. Boxes representing medical supplies are stacked onto the youBot platform with a maximum of 3 at one time, this is to allow the arm to effectively collect them from the platform.

Figure 25[10] - youBot arm and gripper

The youBot collects from the conveyor by targeting the dummy which is in the location of the stop sensor and box. This allows the system to run through as many boxes of supplies until it is stopped. Using a proximity sensor on the end of the conveyor allows for the youBot to decide whether to collect another box and stops the belt for collection.

As hospital departments are a fixed location, the use of drop points is suitable as they do not move. The robot can build a map and navigate this with x, y, z coordinates, alongside the collision detection algorithm.

The kinematics used in the youBot differs depending on what function is being performed. Forward kinematics is used to translate given the location of the joints, whereas inverse kinematics are used to calculate the joint angles required to reach the endpoint. In practice this means, IK is used when you need to calculate where to set the joints to ascertain a required point, and FK is the reverse of this.

3 Results

3.1 Testing

Effectiveness of solution was tested by changing the colours of the blocks and running the simulations multiple times, both in V-Rep and in In-Sight. This testing provided an accurate analysis of the efficiency and reliability of the solutions. The following tests were carried out to assess the competency of the proposed solution. Navigation testing to make sure the robot can follow the path. Colour differentiation tests on both sets of software to ensure reliability. Collision avoidance testing to ensure no collisions would occur once implemented.

3.2 V-Rep Testing

Navigation tests were carried out to test out the algorithms used to plan robot movement. The robot was told to follow the path along each node and was recorded at each point to check it was following them as it should be. Coloured planes were placed on the scene floor for a recognisable correct test result.

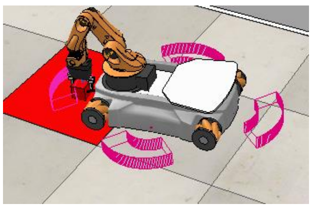


Figure 26 - red test

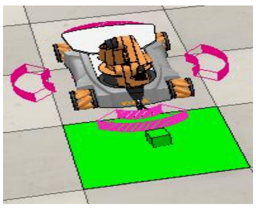


Figure 27 - green test

Collision avoidance was tested by having the robot perform the tasks it set out to do and moving various obstacles around it inside the collision detection zones. The following images show how each sensor is accurate and how the youBot stops once an obstacle is detected and then returns to movement when the obstacle is moved away.

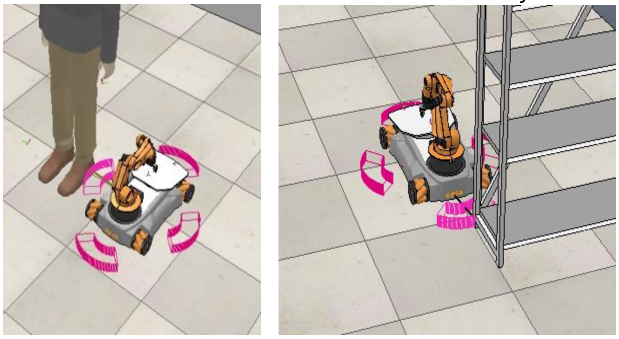


Figure 28 and 29 - showing obstacles being detected

Every sensor was tested and demonstrated which shows how the avoidance system works and how the robot intelligently plans its path with these algorithms.

Colour detection was tested by sending multiple boxes through the sensor. In addition to the tests described below in the In-Sight software, V-Rep colour recognition testing was done by implementing a floating view displaying the camera's image. This allowed checking what the sensor was seeing. Combining this with navigation tests done previously allowed for the clear demonstration of the accurate tests achieved.

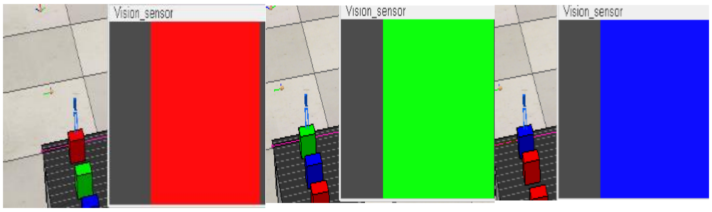
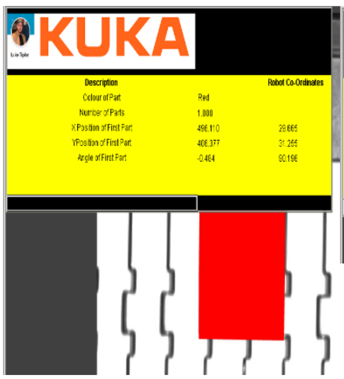


Figure 30, 31 and 32 - vision sensor floating views displaying accurate colours for the blocks.

3.3 In-Sight Testing

In-Sight testing was done by providing the software with different coloured images and testing whether it accurately detects them. This proves that the calibration was done correctly and that the system performs as expected, as the system shows the correct position and colours of the blocks on the conveyor.



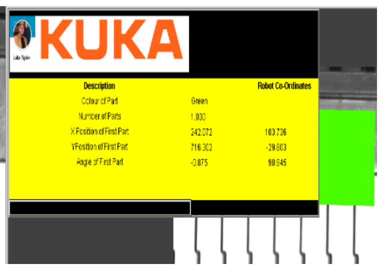
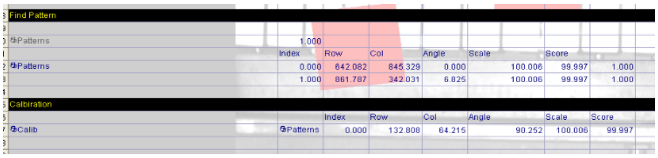


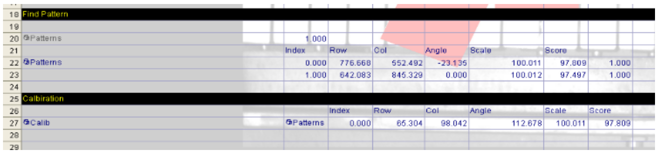
Figure 33 and 34 - showing red and green tests

The In-Sight testing shows the real-world application of the vision sensor into the scenario. Allowing for direct insight into how effective the proposed solution would be once implemented. The results show how accurate the cameras are. The below image also shows the accuracy which the software states it is running at, further proving how effective the use of this camera would be, and how the tests are conclusively accurate. With 99.997% accuracy on 14 out of 15 of the tests. With 1 test showing 97.807% and 97.497%. This demonstrates an accuracy of at least 97% on all tests. Conclusively proving it to be a viable solution with very a small error of < 3%.



Find Pattern							
Patterns	1.000						
	Index	Row	Col	Angle	Scale	Score	
Patterns	0.000	642.082	845.329	0.000	100.006	99.997	1.000
	1.000	861.787	342.031	6.825	100.006	99.997	1.000
Calibration							
		Index	Row	Col	Angle	Scale	Score
Calib	Patterns	0.000	132.808	64.215	90.252	100.006	99.997

Figure 32 - showing ~99% accuracy tests



18	Find Pattern							
19								
20	Patterns	1.000						
21		Index	Row	Col	Angle	Scale	Score	
22	Patterns	0.000	776.668	552.492	-23.135	100.011	97.809	1.000
23		1.000	642.083	845.329	0.000	100.012	97.497	1.000
24								
25	Calibration							
26			Index	Row	Col	Angle	Scale	Score
27	Calib	Patterns	0.000	65.304	98.042	112.678	100.011	97.809
28								
29								

Figure 33 - showing the erroneous tests at ~97%

3.4 Analysis

The system performs just as expected with both of the simulations showing off the accuracy of the algorithms set up. The comprehensive tests allow the system to be demonstrated accurately which is used to evaluate how well the proposed scenario meets the requirements set out.

The system meets the requirements set out for each of the testing points. The experimental test results highlight how the system meets all the points set out for the aim of the project. Each of the results shown allows insight for the completion of set points. Intensive testing of each standard made sure the solution was viable.

4 Discussion and Conclusion

4.1 Performance

The solution performed well, as discussed in section 3, and all sections completed the tasks set out in testing. This made sure that the solution was viable and complete.

Errors did occur (*see 4.2*) and were mainly due to the manipulation of moving objects. This was a challenge and the youBot would often misplace the gripper target and be unable to manipulate the box. This can be handled by giving the youBot the quaternion of the handles, as this had not been considered before.

Whilst vision software manufacturers claim sub-pixel accuracy of location algorithms, this is rarely repeatable in real-world conditions. However, this is only the simulation so testing of the real-world implementation would have to be considered before application.

4.2 Issues

Some small issues arose during the development of the solution. 2 main ones have been highlighted below and are described as followed:

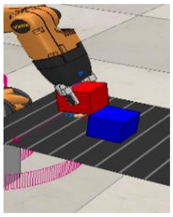


Figure 34

Occasionally the boxes on the conveyor would collide when being picked up. This was solved in the simulation by separating them by 0.2m. In the real world, this could be solved by adding a brace to the conveyor which would align all of the boxes of supplies.

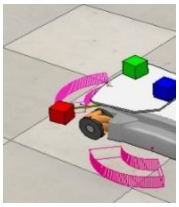


Figure 35

During manipulation of the boxes after they were placed onto the platform, sometimes the manipulator arm would knock the box off the platform. This was fixed by adjusting the pick-up location of the box and making sure the orientation and speed of the arm were appropriate.

4.3 Improvements

The system could be improved in future work by developing the robotic platform chosen. As the youBot is purely for education, the proposal would have to develop a new robot which combines the usefulness of the youBot with a transport robot, like the TUG [16] robot, to create a solution viable for the environment.

To further develop the system, the youBot should be configured to not select the boxes by their object handles, but instead a location dummy. However, due to the movement of the platform, it is difficult to localise the boxes as they move across the platform during the simulation.

The Cognex camera system proposed would be a viable solution however if there was to be a change to the robotic base of the solution, then compatibility would have to be considered.

4.4 Conclusion

This report aimed to explore potential additions to the currently implemented robotic logistical solutions in medical environments. The use of simulation to emphasise the points covered allowed for a comprehensive discussion on how the proposed solution is effective and could be potentially developed in future work.

The literature review explored current solutions and the techniques they employed to achieve a more robust proposed solution. The research of applied ARMs and AGVs gave insight into how a solution should function and what standards a solution would have to come to. This also highlighted the drawbacks of current solutions, allowing comparison of results to observe efficiency and competency.

The project was approached by delving into the insight provided by the literature review and drawing upon techniques already chosen by current solutions. the practicality of using the currently implemented solutions and building on the strengths previously identified. The approach highlights, in-depth, how each factor was manipulated to create the solution. The software chosen to simulate the scenario allows for the accurate demonstration of potential implementation before real-world application, highlighting both strengths and drawbacks. Using V-Rep and In-Sight gives a well-rounded review into the capabilities of the solution and direct comparison to solutions currently implemented.

To meet the project requirements, the project was delivered in such a way to show off how effective the end product is. Sensory feedback is a key output of the solution so was a key deliverable of the project. Using vision sensors, real-time sensory feedback was implemented to adjust robotic manipulation. Sensory implementation was completed with the use of proximity sensors. These sensors were used to detect the position of an object for the youBot to avoid collision and then applied alongside intelligent algorithms to effectively plan the route around the scene.
Results of the creation of the solution came back as expected, proving a robust solution to the problem scenario. The accurate testing on In-Sight displayed how precise the implemented system would be, and as the delivery of medical supplies can always be redelivered on the small 0.003% average error.

Issues arose in the development in the solution and these must be highlighted, alongside how they were solved, so that once implemented in the real world they can be efficiently solved if they appeared during real-world iterations. As the solution is only simulated, it is not possible to sufficiently test the solution, however, the guide provided in this paper allows the stepping stone for future developments and implementation.

In conclusion, the report was in-depth enough so that further development would be feasible and realistic in implementing the solution. Each of the sections covered allowed for the creation of a robust logistical robotic solution, which would challenge the prevalence of the current solutions and provide a new potential direction for the problem scenario.

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