University of Victoria

# Design and Application of Autonomous Mobile Robot

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## Introduction

- An autonomous mobile robot (AMR) describes a mobile platform that can complete a series of actions automatically through the use of mechatronic design and programmable logic.
- AMR is designed with multiple abilities in mind - most importantly navigation, object avoidance, object recognition, and mapping.
- AMR is currently able to be remotely operated, track and follow a line on the ground, generate an accurate 2D map of an environment, and navigate a known map while avoiding objects.
- This set of applications can be extended and modified with goals in mind such as: intra-hospital transportation of goods, mapping unknown areas, warehousing etc.

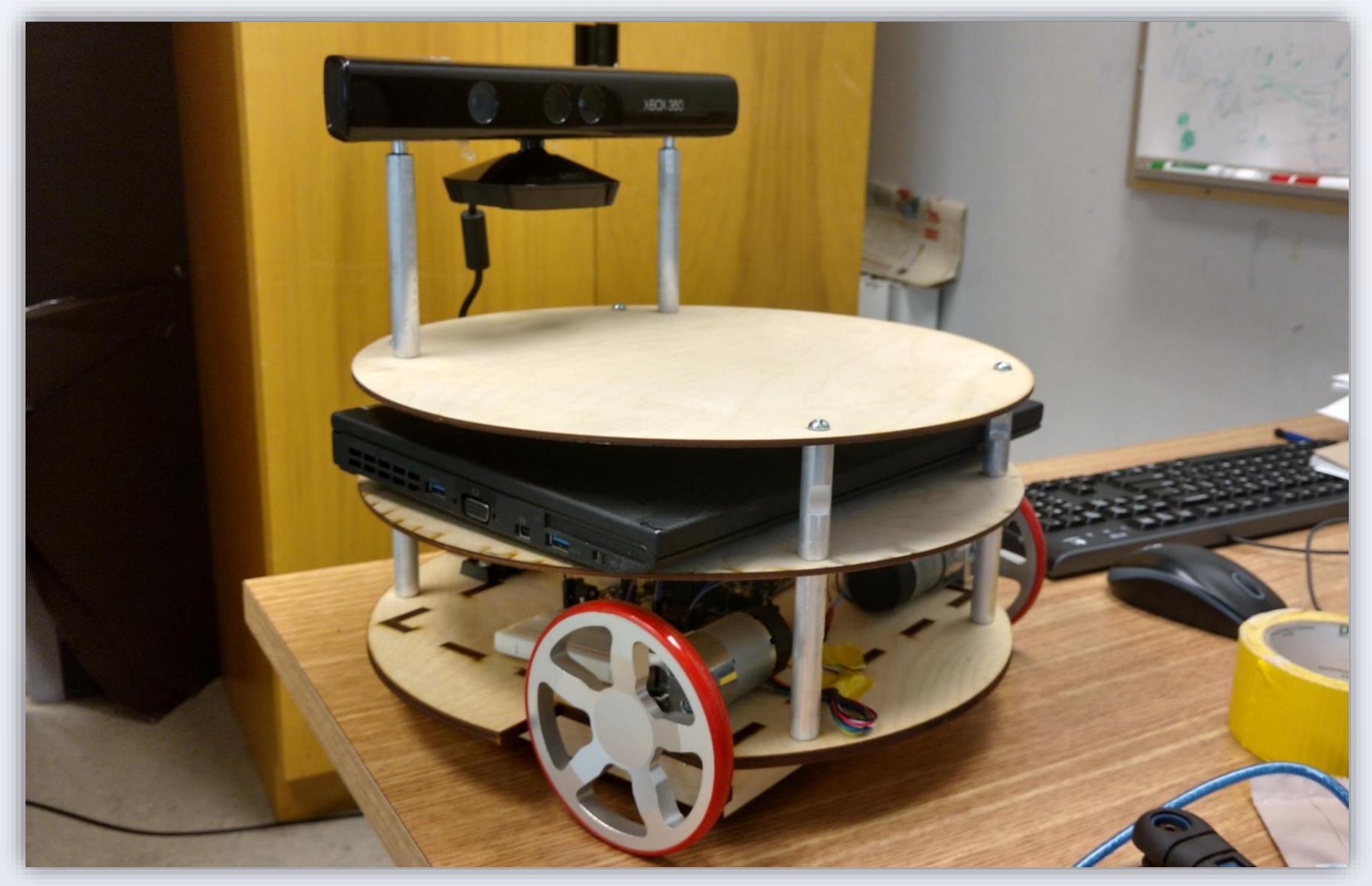
Fig 1. Autonomous Mobile Robot

## Design

### Design Goals

- The following design requirements (Table 1) were chosen in order to ensure that the mobile robot will be physically robust and comfortably able to complete anything that is required of it.

Table 1. Basic Design Goals

| | |
|---|---|
| Maximum Acceleration | $0.5 m/s^2$ |
| Maximum Velocity | 0.8m/s |
| Maximum Payload (including suspended weight) | 15kg |
| Maximum Run Time | 2 hours |

### Mechanical Drive Design

- AMR utilizes what is known as a differential drive control scheme (Fig 2.). This design offers simple motion control, and the use of only two motors which limits cost.
- The disadvantage to differential drive robots are that they cannot translate perpendicular to the direction they are pointed which means path plans must be longer.

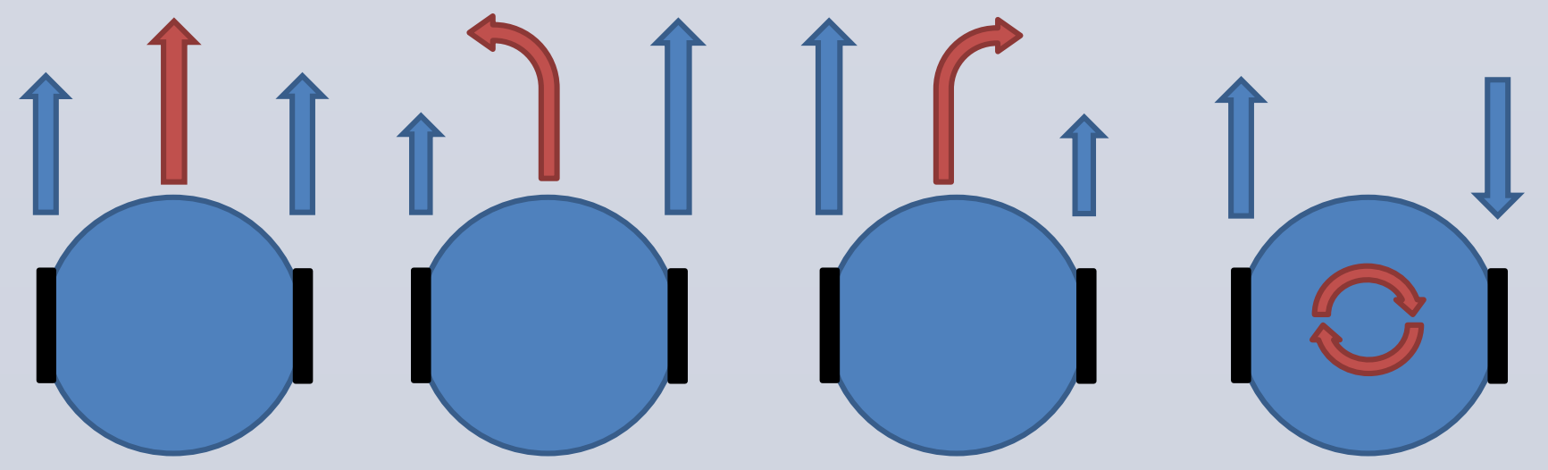
Fig 2. Differential Drive Control Scheme

### Structural Design

- In order to have predictable smooth motion it is important to have rigidly mounted wheels.
- The wheels are attached to the body of AMR through a motor bracket, which is mounted on the base of the AMR (made from plywood).
- Both the motor bracket and plywood frame of AMR must be analysed to determine how much they will bend or displace under the maximum payload required.

### Motor Brackets

- Finite element analysis (FEA) is a useful tool for predicting how a material of a certain shape will react to a certain type of loading.
- The motor brackets can be simulated using FEA in order to determine if the motor bracket will perform under the maximum load of 15kg.
- The following graphics (Fig. 3 & 4) display deformation in the material in millimeters.

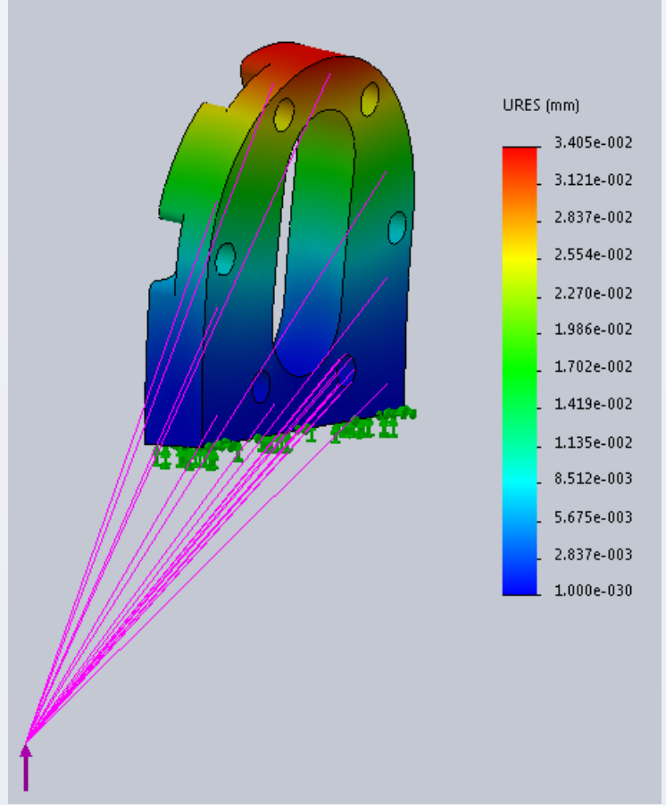
Fig 3. Machined Aluminum Bracket

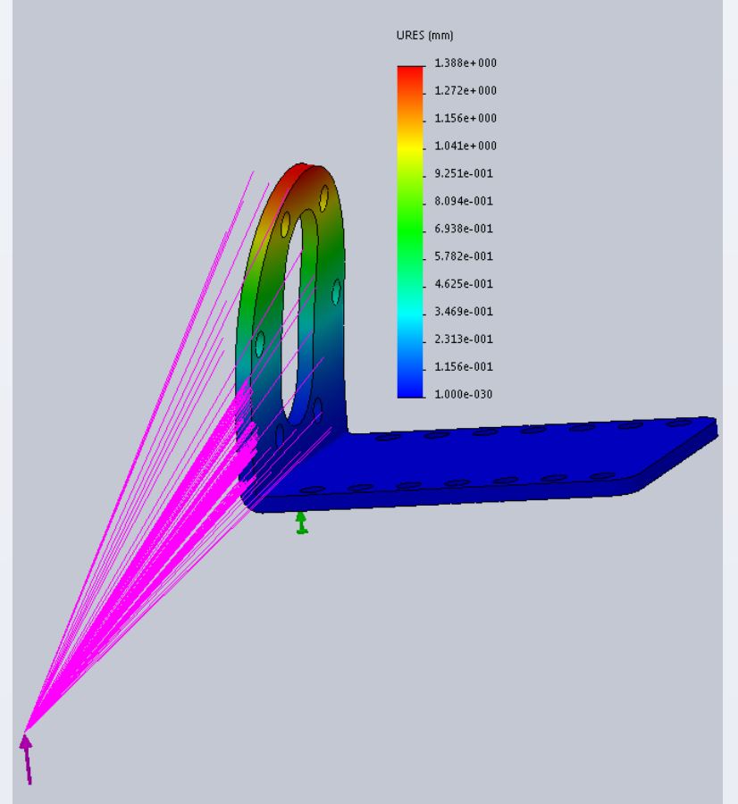
Fig 4. Stamped Aluminum Bracket

### AMR Base Plate

- Inexpensive materials were a priority, ¼ in thick plywood base is cost effective, but must be reinforced in order to ensure rigidity.
- The graphics below demonstrate the effect of different shapes for reinforcing the base plate.
- Figure 7 shows the increased rigidity of the box shape, compared to that of the others.

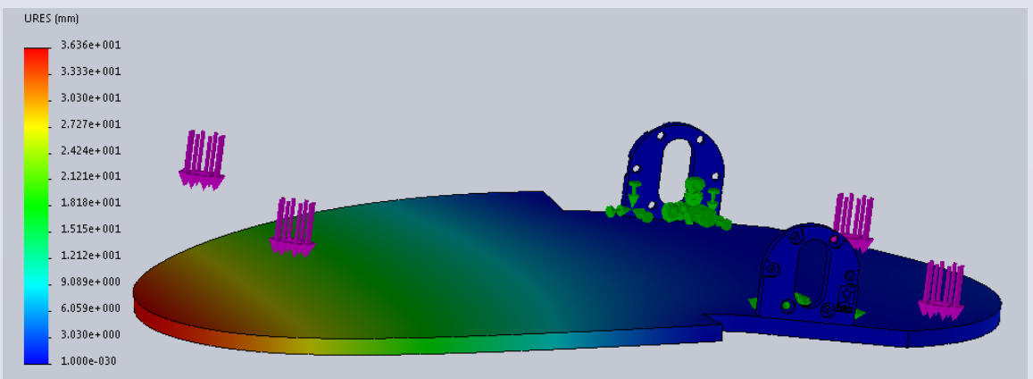
Fig 5. 1/4in plywood base with no support

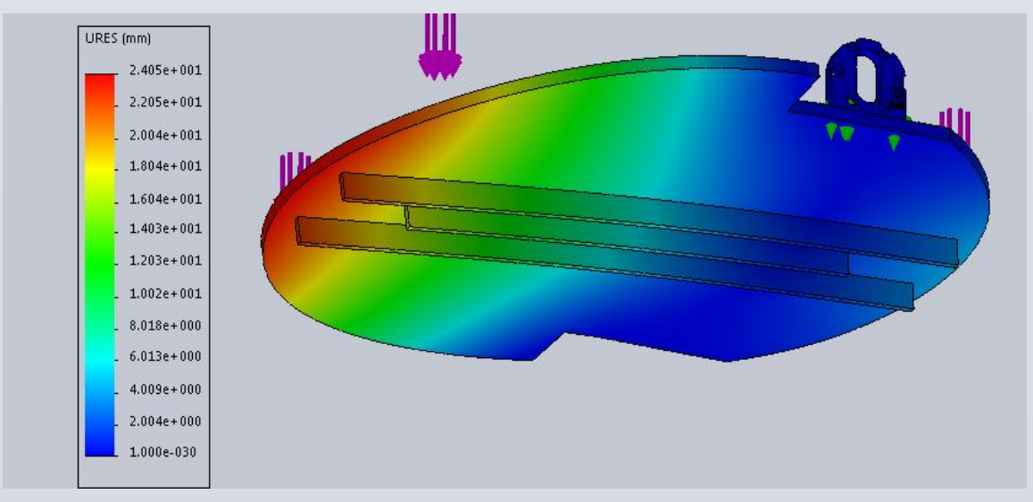
Fig 6. 1/4in plywood base with three splines for support

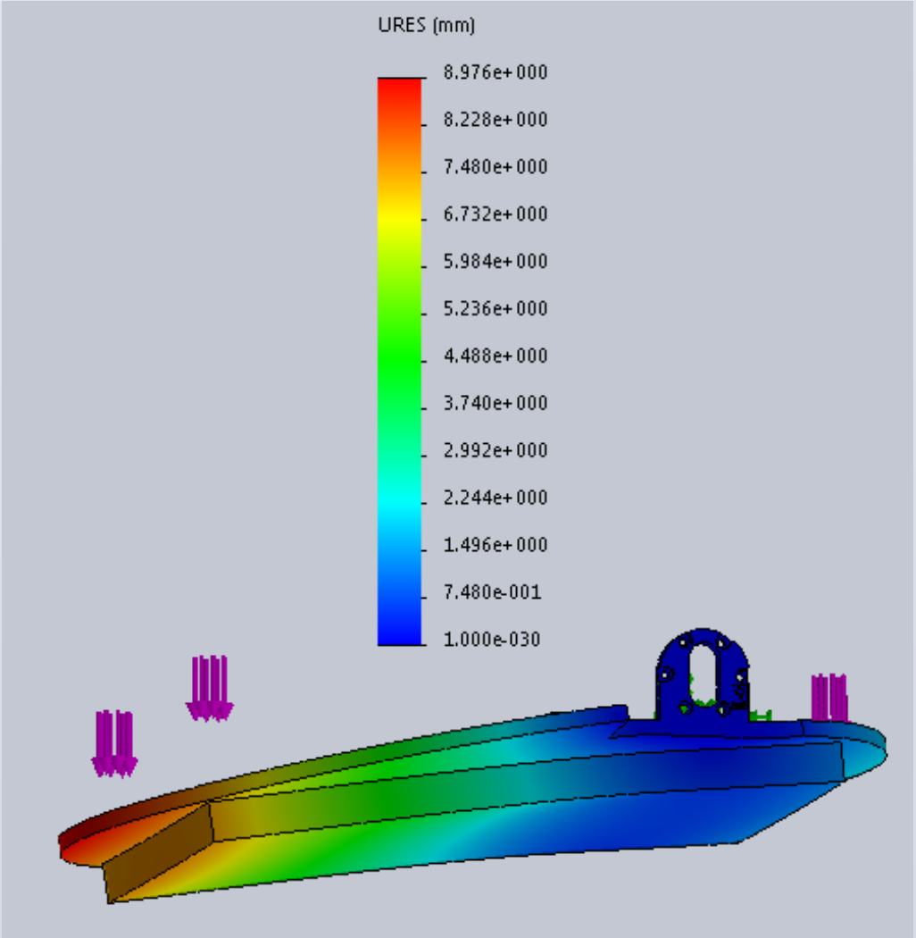
Fig 7. 1/4in plywood base with box for support

### Electrical Design

**Actuator Specifications**

- AMR relies on multiple sensors for environmental input and actuators for movement.
- The actuators must be able to drive a mass of maximum payload at the maximum required acceleration, and at the maximum speed.
- DC geared motors were selected due to an appropriate RPM-to-torque relationship for the given application.

**Sensors to Provide Odometry**

- Odometry answers the question "where have I been?", displaying an accurate path of AMR's movement history.
- AMR uses three different sensors (depth camera, quadrature encoders, and an IMU) to provide odometry data.
- An IMU (Fig. 8) tells AMR what direction it is pointing using an accelerometer, a gyroscope, and an electronic compass.
- All three sensors must be filtered and then combined together to calculate accurate orientation in a process known as Kalman filtering and sensor fusion.

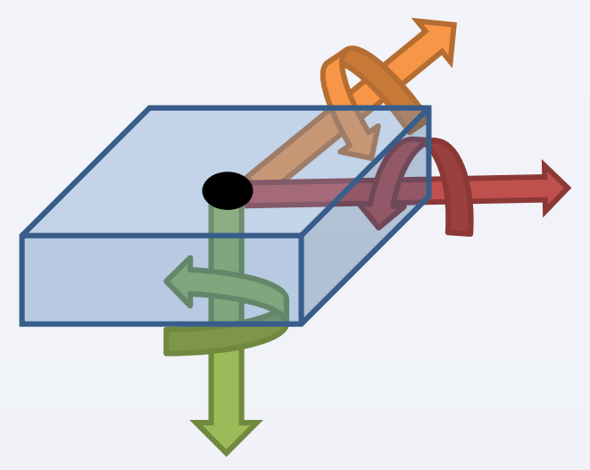
Fig 8. IMU to Measure Yaw, Pitch, and Roll

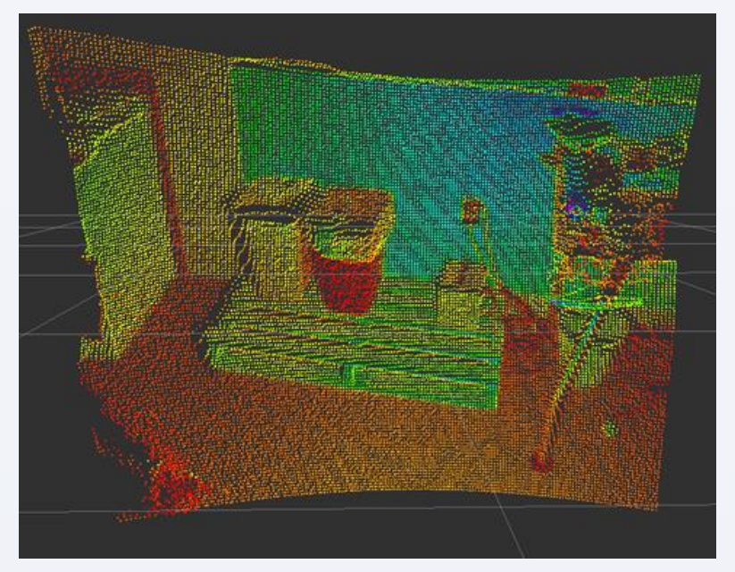
Fig 9. Depth Sensor Point Cloud [1]

- The depth camera is an RGB-D sensor capable of measuring the distance from its lens to any object in its vision using infrared stereo vision. It can produce a point cloud image of its surroundings (Fig. 9).
- The depth camera supplies AMR with vision, allowing it to map unknown areas (Fig. 10) and then recognize places it has already been.
- Quadrature encoders measure wheel rotation, and from that wheel speed. AMR uses this information to understand how far it has travelled, and how fast it is moving.

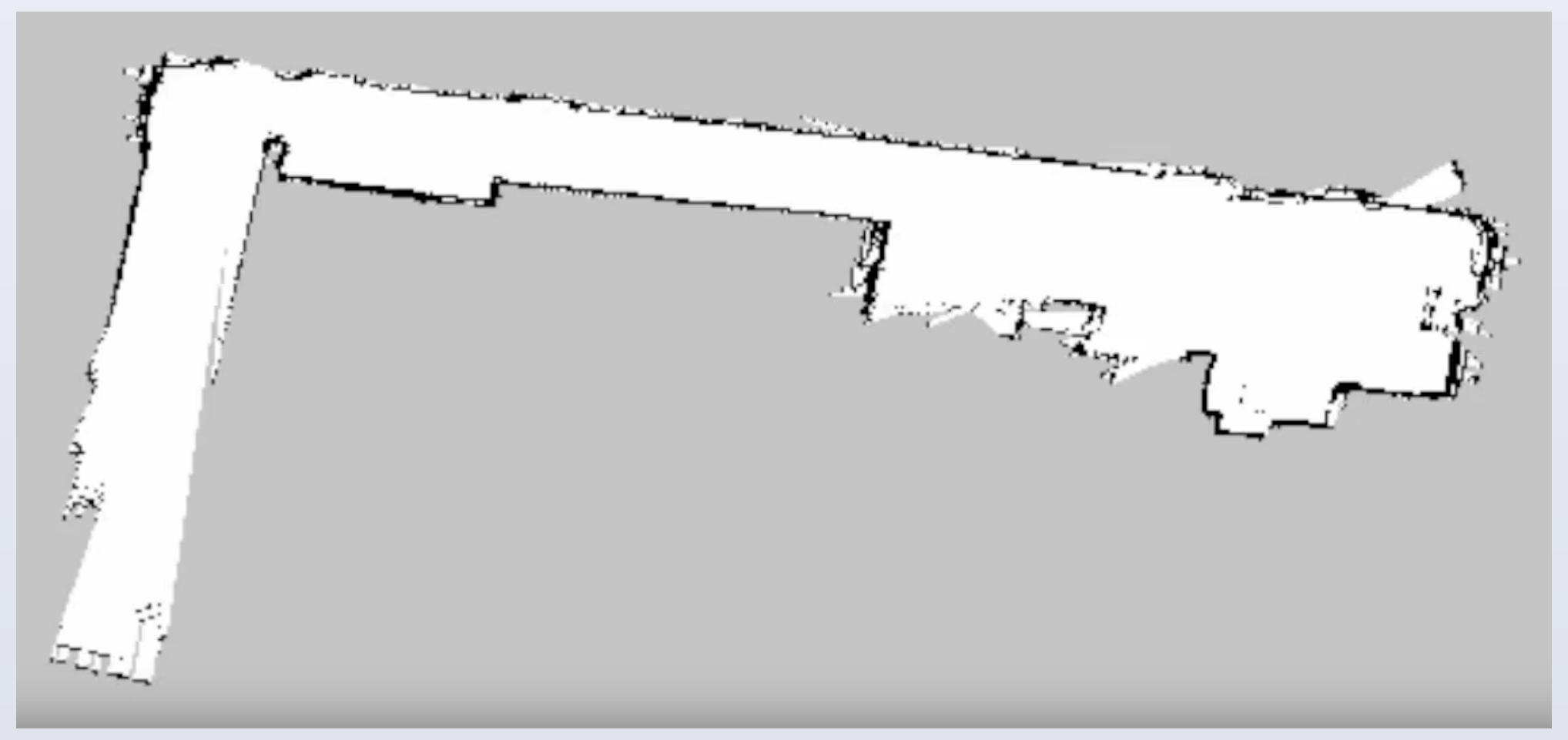
Fig 10. Map of Engineering Office Wing Basement from AMR

## Results

### Line Following Using Computer Vision

- AMR is able to use the RGB-D sensor and the OpenCV C++ library to perform visual analysis on its environment.
- The camera is able to identify the line on the ground and extract the orientation of the line (Fig. 12).
- This offers the ability for AMR to move faster when the line is straight and has little change in direction, and slow down appropriately for an upcoming corner.
- A PID (proportional integral derivative) controller is running in order to keep AMR centred about the line.
- The input to the control system is the location of the centre of the line.
- The difference between this location and the central axis of the robot determines how much the robot will turn in order to rectify this difference.


Fig 11. AMR Performing Line Following

Fig 12. Camera View of Fig.11 Shows Recognition of the line and its orientation using OpenCV

### SLAM, Navigation, and Object Avoidance

- Simultaneous localization and mapping, known as SLAM, is a powerful tool for AMR allowing it to use the RGB-D depth information to develop a map of its surroundings.
- Using an algorithm called Adaptive Monte Carlo Localization (AMCL) AMR can locate itself within a map based on what it is currently seeing and how that compares with its known map.
- Without AMCL to correct the robot's location it would suffer from 'drift', which is a slowly increasing error in position caused by measurement error from the IMU and quad encoders.
- Once a map has been created using SLAM (Fig. 10 & 13), AMR is able to autonomously navigate the known space while avoiding any obstacles
- AMR creates a path plan in order to travel from one place to another, this path plan takes known obstacles from the saved map into consideration in its initial plan.
- The path plan is updated to allow AMR to maneuver around newly discovered obstacles in the robots view. In figure 13 and 14 AMR is able to move around two buckets using this technique.

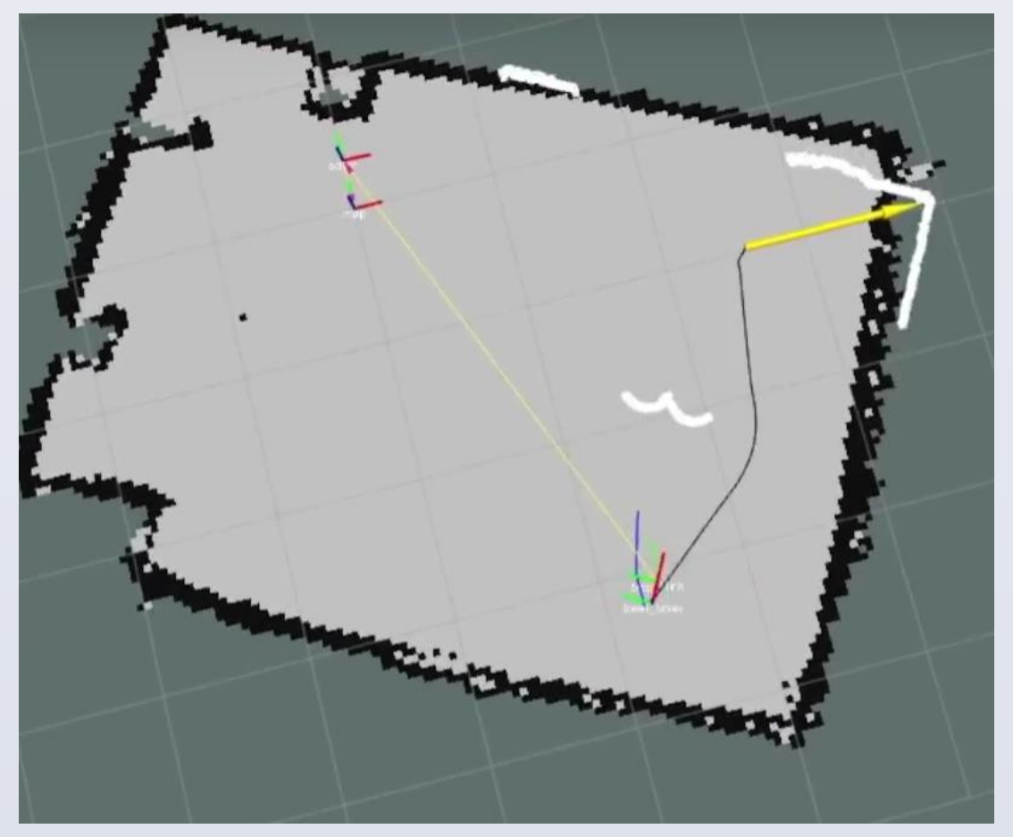
Fig 13. Rviz View of AMR Creating a Path Plan Around Two Buckets

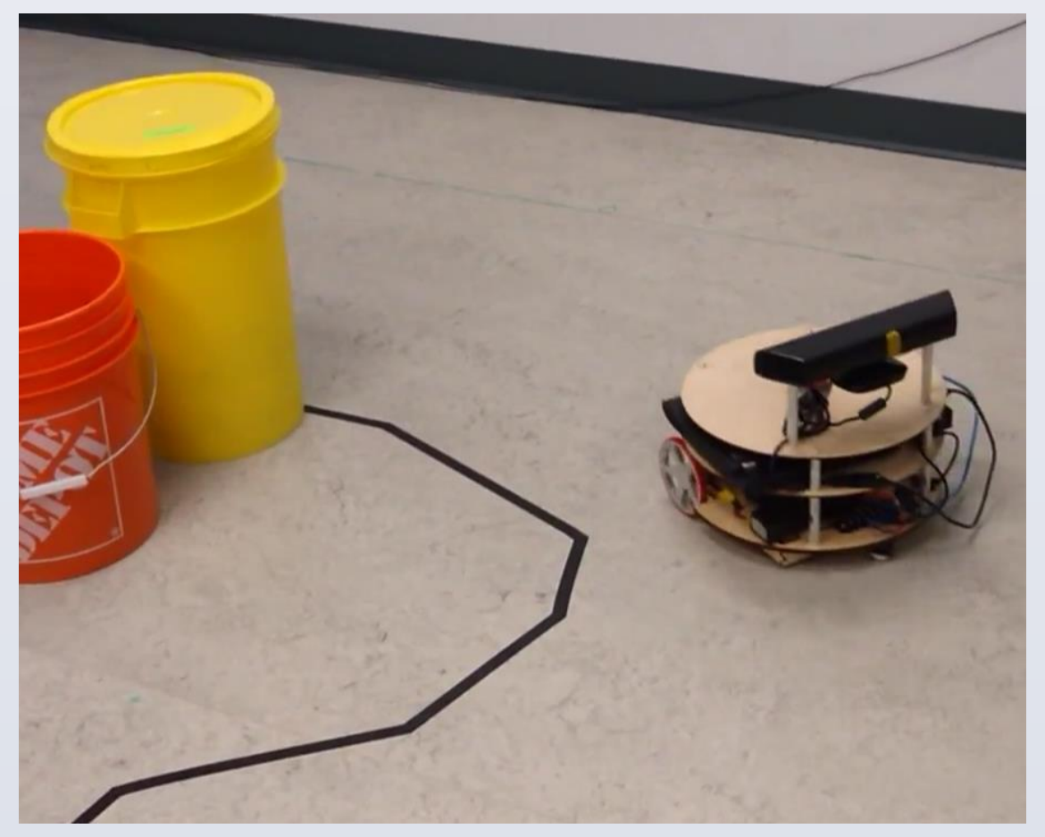
Fig 14. AMR Navigating Around Obstacles

## Conclusions

- AMR met all described design goals making it suitable for more physically demanding tasks.
- Using a camera and the OpenCV library AMR was able to successfully follow a line, and recognize the orientation of the line with respect to its central axis.
- AMR can create an accurate and navigable two-dimensional map using its depth sensor. It can autonomously navigate the known space while reacting to newly discovered obstructions.

## Future Work

- With a manipulator mounted on AMR, it would have the ability to interact with its environment – applications could be easily extended towards a warehousing environment where objects need to be sorted.

## Acknowledgements

Acknowledgement and thanks goes to my supervisor, Dr. Yang Shi, for his support and guidance throughout this project.

## References

**[1] Foote, T. (2015, July 14). ROS Driver for the IFM Efector O3D303. Retrieved from http://www.ros.org/news/robots/sensors/**