Mapping is an interesting and difficult problem in robotics. In order to create a map the position of the robot must be known. However, in order for the robot to determine its position it needs a map. This problem is referred to as simultaneous localization and mapping (SLAM). In this project a variant of SLAM is used, which is grid based FastSLAM. In this algorithm the position of the robot is estimated using a particle filter while the map is estimated using occupancy grids. The result of using this algorithm with the Xbox Kinect was 15 cm mapping accuracy over a 100 meter loop.
The Need for a Mapping Robot

A robot using SLAM creates accurate maps which can be used for a number of applications. Over the last decade, robotic applications of the SLAM algorithm have been the focus of many research projects. This area has been given so much attention because maps can be used in a variety of useful ways. Many of these applications involve robotic exploration in an environment inaccessible or hazardous to human beings such as, underwater caves or abandoned mines. A map that is generated by a robot using a SLAM algorithm can then be used by another robot for localization. The time saved by the lack of human involvement and the avoidance of human endangerment are beneficial assets a mapping robot can provide.

A much easier approach to the mapping problem is to assume that the position of the robot is directly observable and therefore all measurements of the map are taken at known locations. The problem with this assumption is that the robot’s motion and position are never directly observable; there is always a certain amount of error in the sensor measurements. The SLAM algorithm takes this error into account when estimating the map, leading to significantly more accurate results.

The Design Project Objectives and Requirements

**Design Objectives**

The goal of this project is for a robot to automatically generate a 3 dimensional color map using grid based FastSLAM. This is done using an Xbox Kinect on a mobile robot.

**Design Requirements**

The environment used to validate this design was the 2nd floor of Hurtig Hall at Northeastern University. The accuracy of the estimated 2 dimensional map should be within 10 cm of the actual building layout which was measured by hand. The 3D color data will be aligned to the 2D estimated map. The creation of the 3D color map is not constrained to the same 10 cm accuracy since it is not being estimated.
Design Concepts Considered

The main part of the project that was considered in the design process is which SLAM algorithm to use and how the map should be represented. From the beginning of Capstone this project was defined as a mobile robot using a SLAM algorithm with the Xbox Kinect to generate a 3D map. Therefore, the mobile robot platform and state estimation algorithms were the main focus in terms of design. The mobile robot platform went through five different iterations. All of the designs implemented differential drive motors with 1 or 2 casters. Also as the designs progressed the robot increased in height to ensure that the Xbox Kinect could see both the floor and the ceiling.

There were both local and global state estimation algorithms considered for this project. A Kalman filter was considered for estimating the angular rotation about the horizontal axes. An extended Kalman filter was considered for estimating linear and rotational velocity. There was also the decision of whether or not to estimate the 3rd dimension. By estimating the map in 3 dimensions then the 6 degrees of freedom of the robot need to be considered. Since this means significantly more processing the estimated map was chosen to be 2 dimensions.

There are many different SLAM algorithms that can be considered for indoor mapping. One of the largest distinctions is between feature based maps or grid based maps. Initially feature based mapping was considered because it often means it is less computationally expensive. However, one of the requirements of this project is for the map to be a human readable map which is more straightforward to construct as an occupancy grid map.

Recommended Design Concept

The final design uses an EKF to increase the accuracy of the apriori update of the particle filter. A standard particle filter is used for estimating the position of the robot while occupancy grids are used for estimating the map. Design Description

This project uses grid based FastSLAM with the Xbox Kinect to build a 3 dimensional color map of a flat indoor environment. This algorithm uses a standard particle filter to estimate the position of the robot and occupancy grids to estimate the map. Using a standard particle filter for estimating the position of the robot requires relatively good odometry. For this reason an extended Kalman filter is used for estimating the linear and rotational velocities of the robot from the gyro and encoder measurements. This approach leads to much more accurate particle position predictions. Because of this it is possible to
travel longer distances while maintaining a relatively accurate position prediction. The robot is able to drive autonomously through the environment using a path planning algorithm known as potential functions. Using this algorithm the robot is able to determine the best direction of travel based on the most recent measurement from the Kinect and is not dependent on the robot having a map. It does this by creating a virtual force field around obstacles it has measured with the Kinect. These virtual force fields then create a local velocity vector field which directs the robot.

**Experimental Investigations**

Using this algorithm it was possible to close the loop of a 100 meter path. Also after the robot finished the first lap around the building it was able to maintain 15 cm mapping accuracy.

**Key Advantages of Recommended Concept**

One of the main advantages of this design is that it is possible to rely more on the position prediction by using the EKF. Other particle filter SLAM algorithms will add additional steps such as scan matching to the position prediction in order to increase the robustness of the algorithm. Using an EKF for increasing the accuracy of the apriori update is also less computationally expensive compared to other approaches like scan matching for example.

Figure 2 shows a map of Hurtig Hall generated using raw odometry compared to the map generated using the FastSLAM algorithm. This clearly shows the advantages of using the FastSLAM algorithm over the simpler method which uses raw odometry.

**Financial Issues**

The total cost of the robot (excluding the CPU) was approximately $650. Many similar projects cost thousands of dollars mainly due to the expensive 2D laser scanners that are used. However, it is also possible to recreate this project using less expensive parts. The main focus of this project was on the state estimation algorithms; therefore many improvements can be made in the hardware used and the structural design of the robot.
Recommended Improvements

Direct drive motors should be used to increase dynamic model accuracy. Modify the FastSLAM algorithm so it can run online.

One of the main things that can be improved on this robot is switching to direct drive motors. The 20:1 gear ratio of the motors that were used caused a lot of inaccuracy in the dynamic model of the robot. By having direct drive motors a better dynamic model and therefore a more robust EKF estimate would be attainable. Increased accuracy in odometry is also attainable by combining the individual motor mounts into a single mount. The EKF should also be changed so that the gyro bias is also estimated. Scan matching should also be implemented to further improve the position prediction. Including this step shows a huge improvement in the algorithms effectiveness. Lastly, the current implementation runs the FastSLAM algorithm after the robot has completed collecting data. Running the FastSLAM algorithm on the robot as it is driving through the environment would allow the robot to make much more efficient path planning decisions.