Depth based room mapping using Kinect

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Contents

Chapter 1

Abstract

In this project, an indoor path planning algorithm is proposed for autonomously detecting and exiting a door. Complex situation in indoor environment may lead to serious problem with analysis of data to process corners and edges of doors. For this reason, a Microsoft Kinect sensor is used. Kinect can give depth information of an image. This depth information from Kinect is processed to detect edges and corners of a door and using serial communication, the robot is made to exit the room. Experiments on different indoor scenarios have been performed to verify the efficiency of algorithm.

Chapter 2

Objective of the work

The aim of this project is to use depth sensing to create a depth map of a room using Kinect sensor. The robot is used for movement and Kinect to create a depth map of the room. The final goal is to exit the room from the only single door depending on the depth map created.

Sr.No	**Tasks**	**Deadline**
1.)	Learning Fire Bird V programming, Kinect API	5 days
2.)	Develop code for Fire Bird V movement	3 days
3.)	Creation of Depth Map for the room using Kinect	5 days
4.)	Decision making about exiting the room based on depth map	12 days
5.)	Testing/Documentation (Usage Manual, Documented Code)	5 days

Chapter 3

Completion

Robot exits the door through the door present in the room in most of cases. All tasks have been completed. The following work has been done in each task.

3.1 Task 1- Learning Firebird V and Kinect API

- Installed the following libraries:
  - **freenect**: This library contains necessary modules for installing Kinect Application Programming Interface (API). It provides sample programs which can be used to test the functionality of Kinect.
  - **python wrapper for freenect**: This library is used for reading data from Kinect in python.
  - **opencv**: This library provides various modules which are used for processing an image. The data retrieved from Kinect has a lot of noise. This image can be converted into a grayscale image and modules of opencv are applied to remove noise.
  - **numpy**: numpy provides an easier way to use arrays in python.
  - **matplotlib**: In our project, matplotlib is used to create a Gaussian distribution curve and calculate probabilities.

- Learned various Kinect modules to perform the following operations:
  - Retrieve a depth map from Kinect. (3.3)
  - Control the motor of the Kinect.
  - Retrive image from the RGB camera of Kinect.
  - Control the LED's present on the device

3.2 Task 2 - Develop a code for Firebird V movement

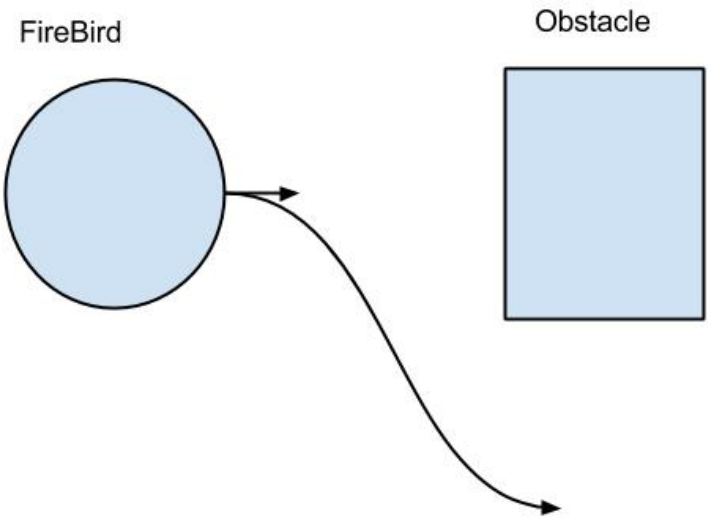
The robot will move forward till it can deduce that it is at a sufficient distance from a wall. This will be decided by taking the mean of the pixels in a particular space. After this, the robot will move along the wall and detect doors in the given space. It will map all the objects that look like a door by analyzing the stream. One can never be sure whether a rectangular object detected is a door or not. Hence, every such object will be associated with a probability. If this probability is above a threshold value, then the robot will decide that the obstacle detected is a door and will exit through it. If not, then it will scan the rest of the arena. Two types of movements have been defined for robot traversal.

1. Regular movement:

This algorithm is used when the robot is trying to detect a door. In this algorithm, the image is divided into 8 frames. Suppose the frames are numbered consecutively from left to right. If a obstacle appears in the first frame, the robot takes a soft right turn. If the obstacle appears in the last frame, the robot takes a soft left turn. if the obstacle is in 2nd frame, the robot will take a harder right turn than the previous case. Similarly, if the obstacle is in 7th frame, the robot takes a harder left turn. Similarly, when the obstacle is in 3rd or 6th frame, the robot takes an even harder left or right turn . When the obstacle is detected in 4th or 5th frame, the robot takes a perfect hard turn. There may exist two cases:

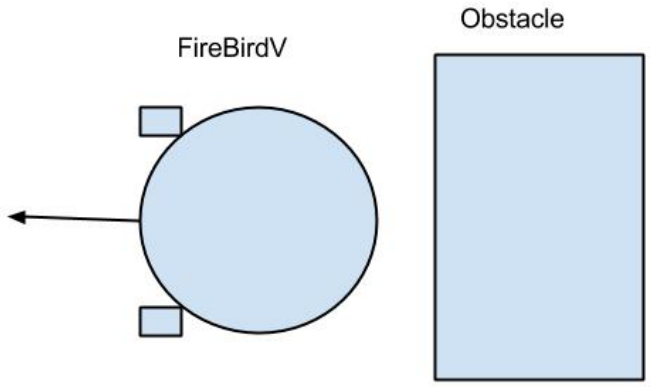
Case 1: Obstacle which lies beyond 40cm:

In this case, the obstacle lies within Kinect's detection range. Hence, the movement of the robot looks as shown below:



Case 2: Obstacle which lies between 0 - 40cm:

In this case, the obstacle does not lie within the Kinect's detection range. The obstacle is detected using number of unknown pixels in Kinect feed. The movement of the robot would look as shown:



2. Doorway Movement: This algorithm is used when a door is detected. After a door is detected, the image is divided into three vertical frames (left, middle and right frame). If there is sufficient space in the middle frame, then the robot moves forward. Else, depth in right and left areas are compared to decide whether a left turn should be taken or a right turn.

3.3 Task 3 - Creation of a depth map of room using Kinect

Under this task, a depth map of the environment was obtained from Kinect. A depth map is an image which contains information about depth in every pixel. So, when such a raw feed is converted into a grayscale image, the objects that are closer to the Kinect appears darker than the objects away from Kinect. Example:

The original image:

Depth Map:

The depth map of the environment can be retrieved from Kinect in python using the following code snippet:

```
depth = freenect.sync_get_depth(format=freenect.DEPTH_11BIT)
```

After retrieving the depth map, bilateral filter is applied on the image obtained. Bilateral filter is used so that edges are not affected. After applying bilateral filter, the image now becomes :

After further research, It was realized that it is beneficial to use a different format for the feed which returns depth of each pixel in mm. This feed can be retrieved using:

```
depth = freenect.sync_get_depth(format=freenect.DEPTH_MM)
```

The depth feed is a numpy array and contains values ranging from 0 to 8000mm: the value '0' represents unknown distance. Unknown distance may be obtained due to any reflective surface like mirrors or glasses. These values can be fit into the range 0-255 by converting it into grayscale image, ignoring few lower bits, and optionally fitting the values in 0-255 range if required. All the pixels which have value above 255 are assigned value equal to 255. This is known as clipping. Results of ignoring different number of lower bits are shown below:

Image after ignoring lower 4 bits:

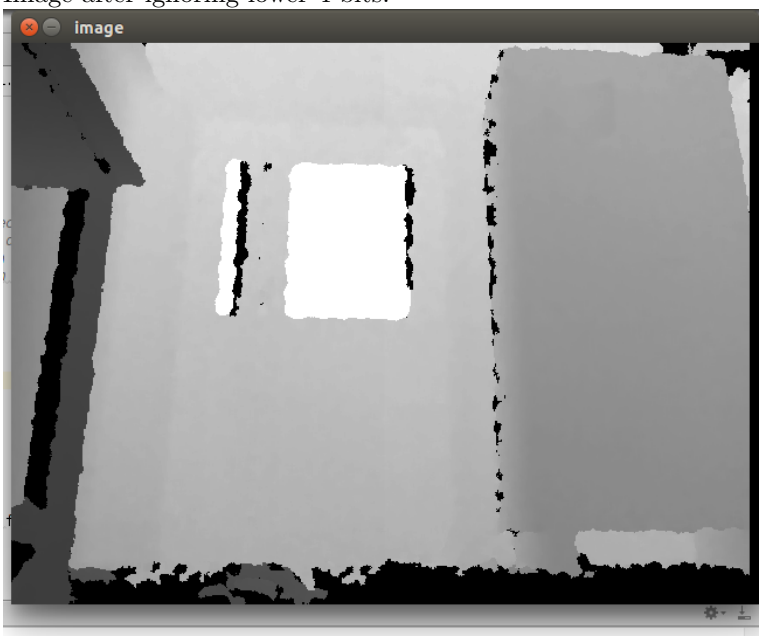


Image after ignoring lower 5 bits:

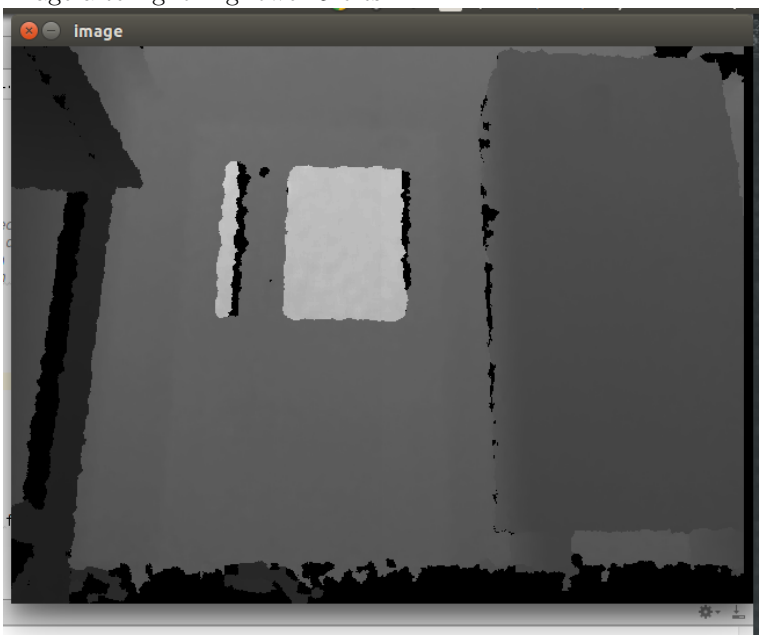


Image after ignoring lower 3 bits and clipping

This feed is filtered using the following method: This algorithm is similar to the algorithm used for median blur. A kernel element is taken and the mean of the depth array in the kernel element is calculated. The pixels where depth cannot be calculated contains zero value. Such noise pixels are replaced with the mean value calculated before using simple masking techniques. The result of this filter on an image is shown below:

Noisy image:

After applying filter:

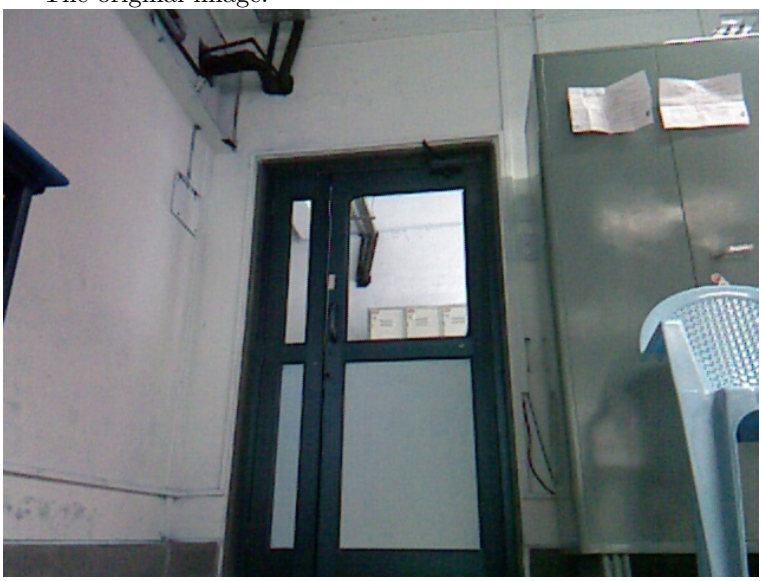
3.4 Task - 4: Decison making about exiting the room based on depth map

In this project, 4 tests are used to determine whether an obstacle having left and right edges is a door or not.

Test 1: Depth analysis to determine edges

First, the image feed is retrieved from Kinect and noise is removed using steps mentioned in previous task. After this, A copy of this image is made and every row element is shifted by one column. The difference between both the arrays is calculated and stored in another variable. Every element of this array is multiplied by 255. Hence, we have a resultant image which contains the edges of obstacles. These edges can be retrieved by thresholding and taking contours of the resultatnt image. Note: Right or left edge depends on which array is subtracted from which array. Subtracting the final array from the initial array will give all the left vertical edges of obstacles. All contours in this resultant image are calculated. Every contour having area less than a threshold value are ignored.

The original image:



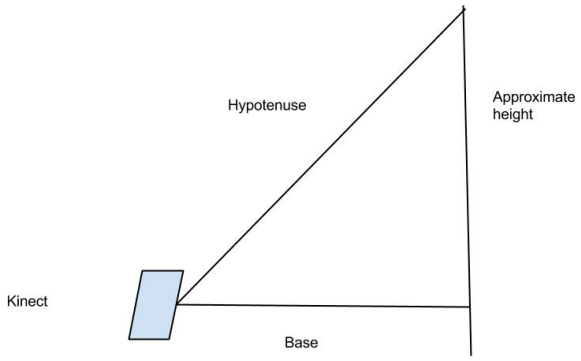
After filtering objects with respect to height, the resultant image is obtained:

The co-ordinates for contours of bigger obstacles are processed again. If a left edge (outgoing) appears before a right edge (incoming edge), then the object can be considered as a door. If a right edge appears before the left edge, then the obstacle is something other than a door, probably a cupboard.

Test 2: Height analysis:

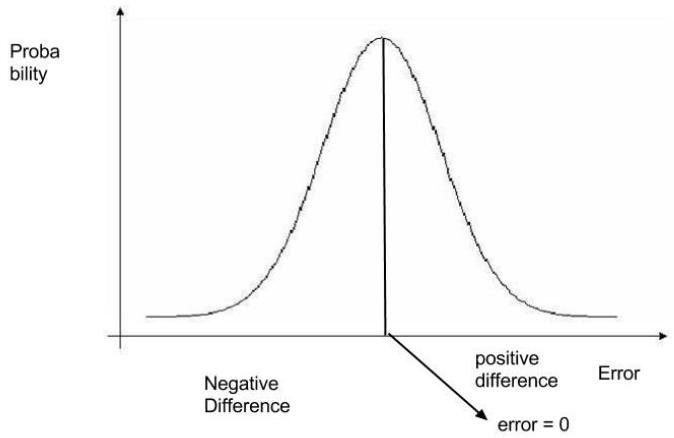
The height of obstacles are calculated using trigonometric operation.

First, the edges of the obstacle are segregated using methods from previous test. A bounded rectangle is formed around this contour. Now, the depth of the topmost point and the nearest point are noted. These values must be the base and hypotenuse of a triangle as shown:



This height is compared with the assumed standard height of a door. The assumed standard height of a door was take as 2000mm. The difference between calculated height and actual height gives the error in height. Using this error in height, a probability value can be estimated which will reflect how much a particular obstacle passes this test. The probability is calculated using a Gaussian Distribution curve.

Gaussian distribution is a very common continuous probability distribution. The normal distribution is sometimes informally called the bell curve. A bell curve appears as shown:



The probability density of the normal distribution is:

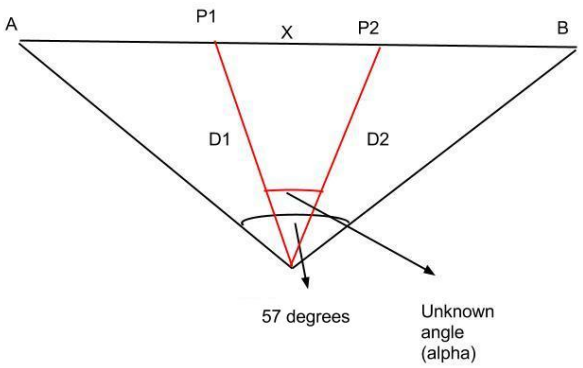
$$f(x|\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(\frac{(x-\mu)^2}{2\sigma^2}} \tag{3.1}$$

Here, μ is the mean or expectation of the distribution (and also its median and mode) The parameter σ is its standard deviation with its variance then σ^2. A random variable with a Gaussian distribution is said to be normally distributed and is called a normal deviate.

In the tests performed in this project, the probability depends on the value 'x - μ'. 'x' is the value obtained by depth calculations. This difference determines the probability whether the obstacle in front of camera is a door or not. When the difference is 0, maximum probability i.e. 1 is obtained. Distribution curve behaves in a similar way for both negative and positive difference. Initially, for a certain value, the rate of change or the rate of fall of probability is low. As the difference increases, the rate of change increases exponentially. For the purpose of detection of doors, where a deviation from ideal value is always expected, this curve is instrumental.

3: Width analysis:

This test is similar to the previous test. The width of the door is calculated as shown:



The field of view of Kinect covers an angle of 57 degrees. The total pixel count in horizontal direction is 640. Suppose we need the width x. We first calculate the ratio at which the pixels are divide. This will be equal to:

$$P1(x) - \frac{P2(x)}{640} \tag{3.2}$$

Now, the angle alpha will also divide the total angle in equivalent proportions. Hence,

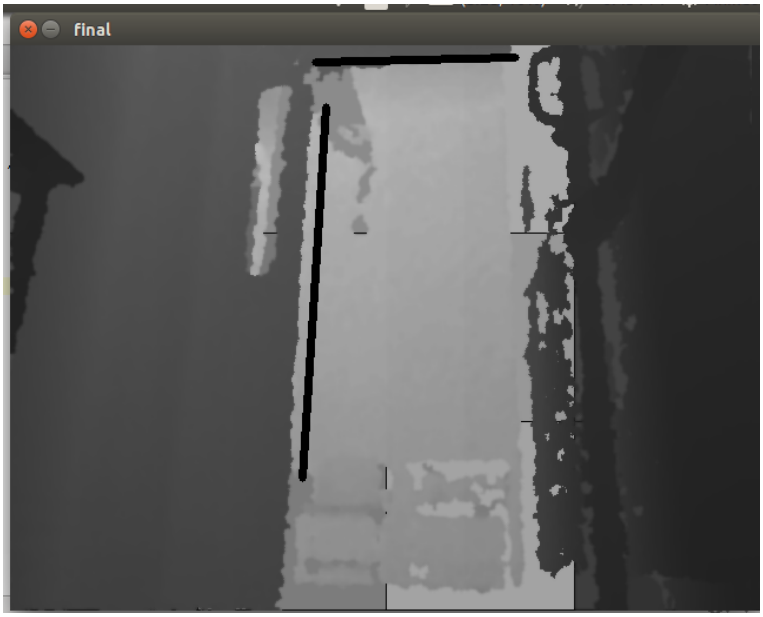
$$\alpha = P1(x) - \frac{P2(x)}{640} * 57 \tag{3.3}$$

Now, once we know the sides of a triangle and angle between them, the distance x can be calculated by using cosine rule:

$$X = D1^2 + D2^2 - 2 * D1 * D2 * \cos\alpha \tag{3.4}$$

4: Horizontal edge test:

This test can only be applied when a horizontal edge(or the upper edge) of the door is detected. In this test, the depth map numpy array is shifted to a value equal to five times the maximum width of frame viz 640 pixels. This will cause every element to shift by multiple columns. Hence, the difference of original array from this array will give areas where there's a difference in depth. Segregating these areas, contours can be identified where an horizontal edge lies. These edges can again be separated based on whether the edge is an outgoing (negative difference) or a incoming (positive difference) edge. In this test, a horizontal edge is identified which lies between two vertical edges. The centroid of this horizontal edge is calculated. This must approximately lie at the centre of the centroid of edges. The difference between these two values is the required error. Probability is calculated based on Gaussian Distribution function.



3.5 Weighing of probabilities:

This project contains four tests. The first test only detects presence of a door like object. A probability value cannot be obtained from the first test. The remaining three tests return a probability value.

Through experiments, it was found that if the robot is close to the door, a horizontal edge may not be detected. For this reason, the weight of the fourth test is lower than the weight of second and third test. Also, by experiments, it was observed that the calculations of height are more accurate than the width calculation. For this reason, the weight of second test is slightly greater than that of third test.

Weights given to different tests:

Height analysis test: 50 %

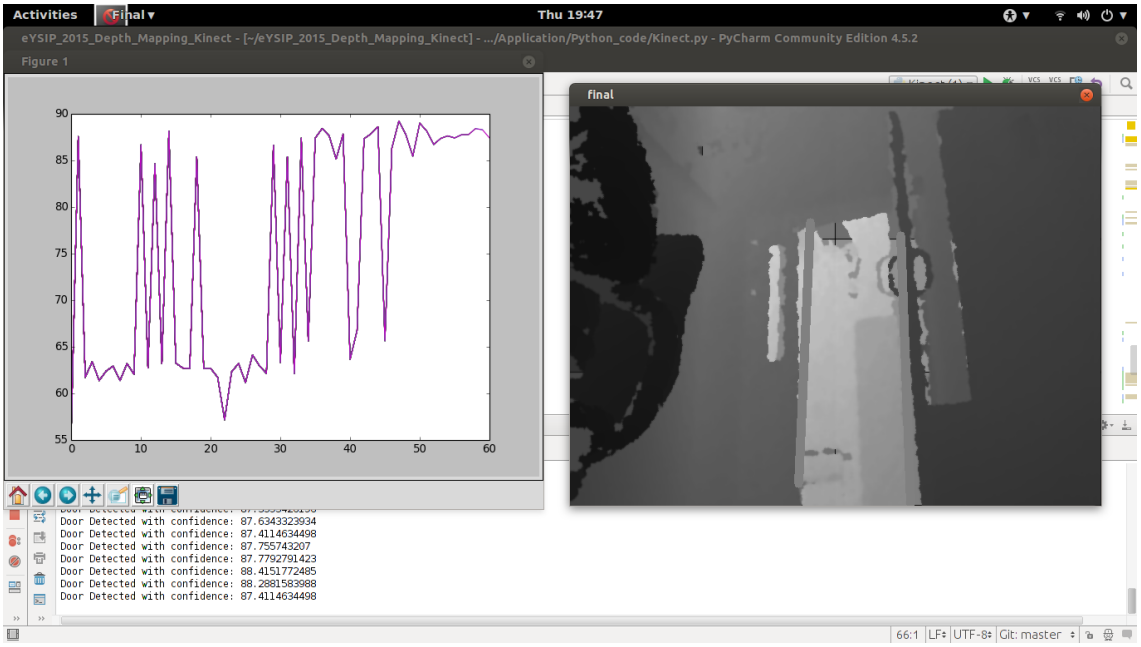
Width analysis test: 40 %

Horizontal edge analysis test: 10 %

3.6 Determination of Confidence value:

In real world, it can never be ascertained that the obstacle present in front of the robot is a door or not. For this reason, every such obstacle which is detected as a door is associated with a confidence value. This confidence value is a result of weighted sum of the proabilities from the tests. It is used as the basis for determining whether the robot should exit the door or not. If a detected door has a confidence value above 60 percent, then it is considered as a door and robot exits through the door.

The following image shows the variation in confidence value when the robot is kept in front of a door:



Chapter 4

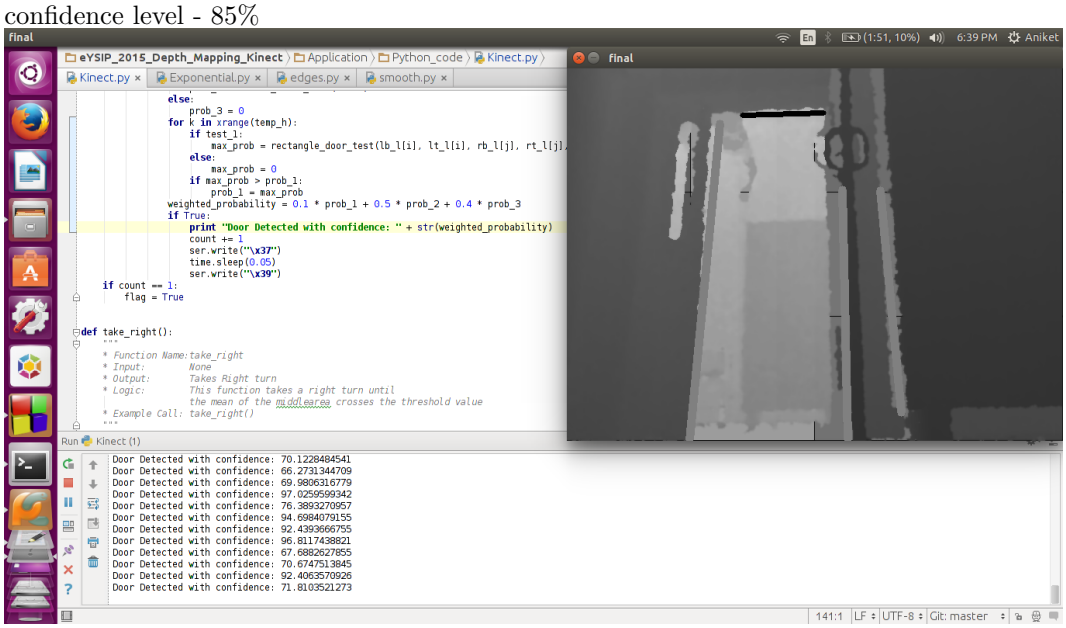
Result and Discussion:

The end product consists of a Kinect mounted on Firebird V. This setup is capable of detecting and exiting doors in almost all the cases. The Firebird V robot with Kinect has been tested on various environments. Few of the environments along with the confidence levels are shown in the following images:

- SIC304.

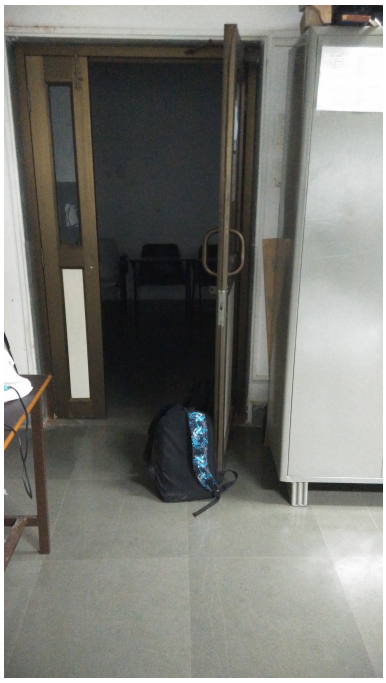
  Original image:

confidence level - 85%

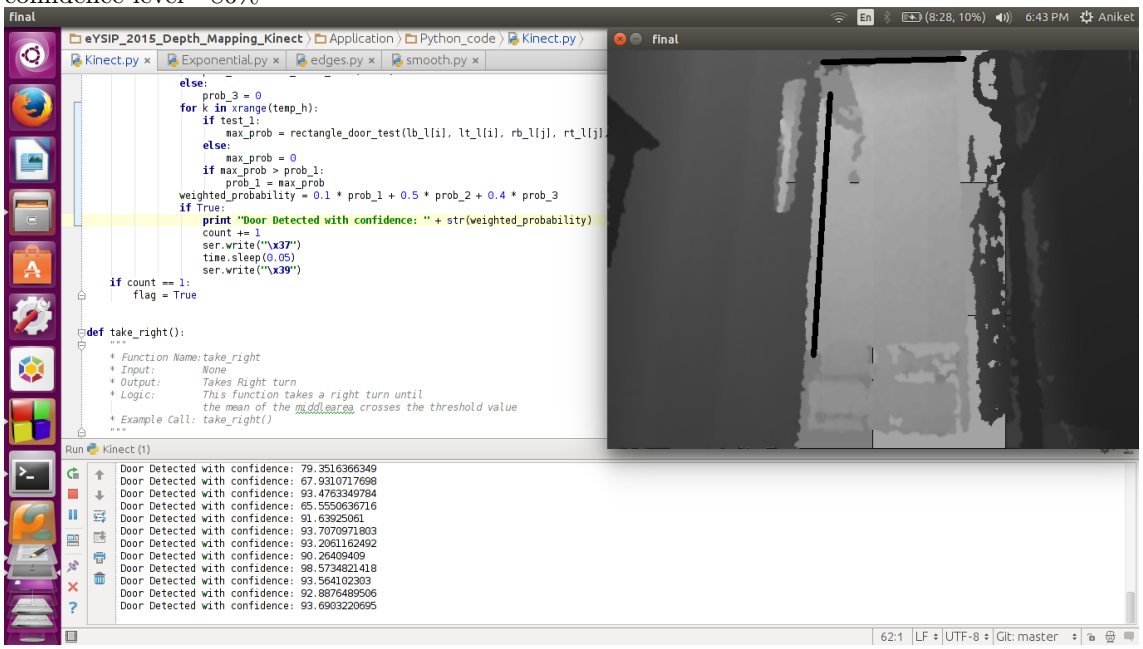


- SIC204.

  Original image:



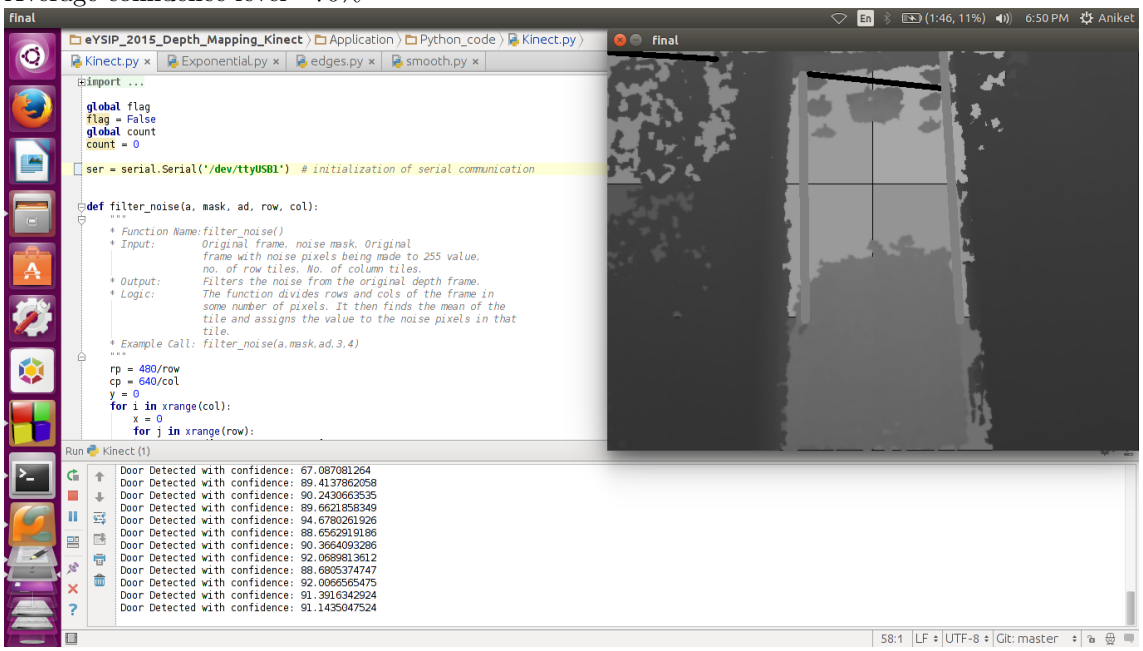
confidence level - 86%



- Elevator door.

  Original image:

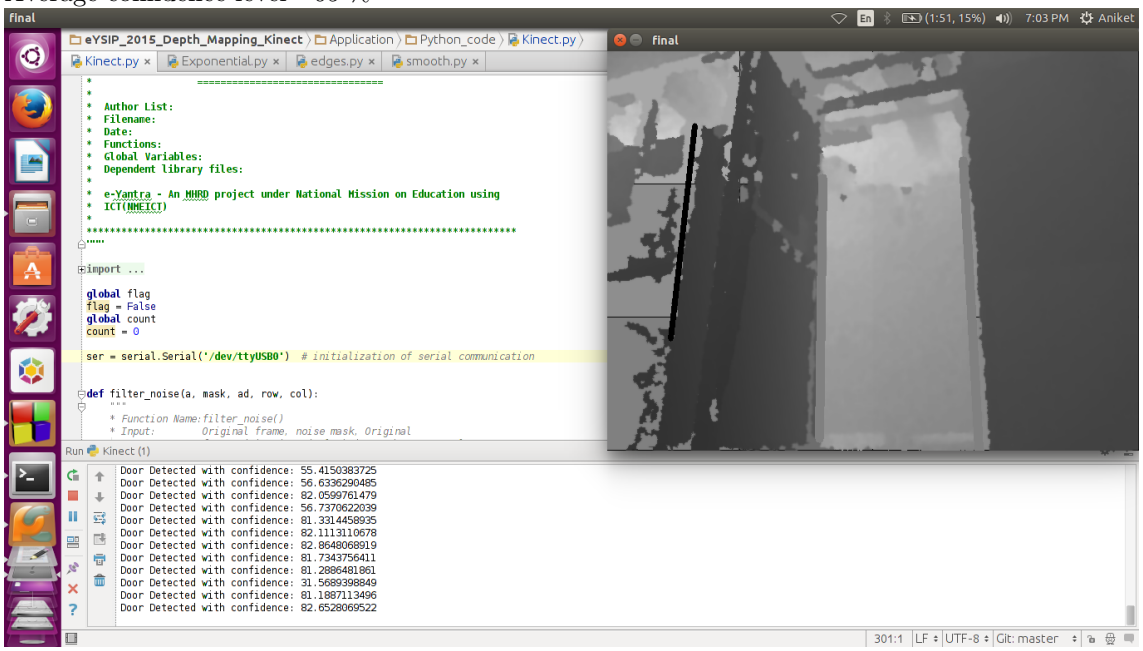
Average confidence level - 70%



- ERTS labs.

  Original image:

Average confidence level - 65 %



Chapter 5

Issues

1. Loose connection of wires: Sometimes, the program stopped due to loose connection of serial cable. This was fixed by using XBEE communication instead of serial cable.

2. The method used for calculation of width is not accurate. Sometimes, it may give values very different from the actual value.

Chapter 6

Future Work

1. **Floor planning**: Currently, floor planning has not been considered. It is assumed that the surface on which the robot moves is flat. This might not always be the case. Floor planning can be done in order to detect surfaces over which robot cannot move. This will also add as a feature of door. A door must start from ground. Hence, another test can be developed which will utilize this feature.

2. **Using different robots**: The whole system can be ported to Firebird VI which will be able to handle heavier objects more efficiently.

Chapter 7

References

1. $http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber = 6926245$
2. $http://docs.opencv.org/3.0 - beta/doc/py\_tutorials/py_tutorials.html$
3. http://openkinect.org/wiki/Documentation
4. $http://ieeexplore.ieee.org/stamp/stamp.jsp?tp = \&arnumber = 6573398\&tag = 1$
5. $http://campar.in.tum.de/pub/hinterstoisser2011linemod/hinterstoisser2011linemod.pdf$
6. $http://www - home.htwg - konstanz.de/\ bittel/Publikationen/icaart_doordetection_2010.pdf$
7. $http://research.ijcaonline.org/volume86/number8/pxc3893182.pdf$
8. $http://www.intel.com/content/dam/www/public/us/en/documents/guides/bkm-installing-ubunto-os-on-de2i-150-board-guide.pdf$
9. $https://github.com/amiller/libfreenect-goodies$