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Visual Sensing in Mobile Robots

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Submission date: December 2015
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Abstract

Preface

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

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Chapter 1

Introduction

This section is intended to provide an overview of the contents and context of this report. The first part of this section gives a brief introduction to the field of mobile autonomous robotics and computer vision, as well as the benefits and potential applications for this technology. The robot system and tools used in the project is presented in subsection ???. Lastly, each of the following sections will given short introductions.

1.1 Mobile Autonomous Robotics and Computer Vision

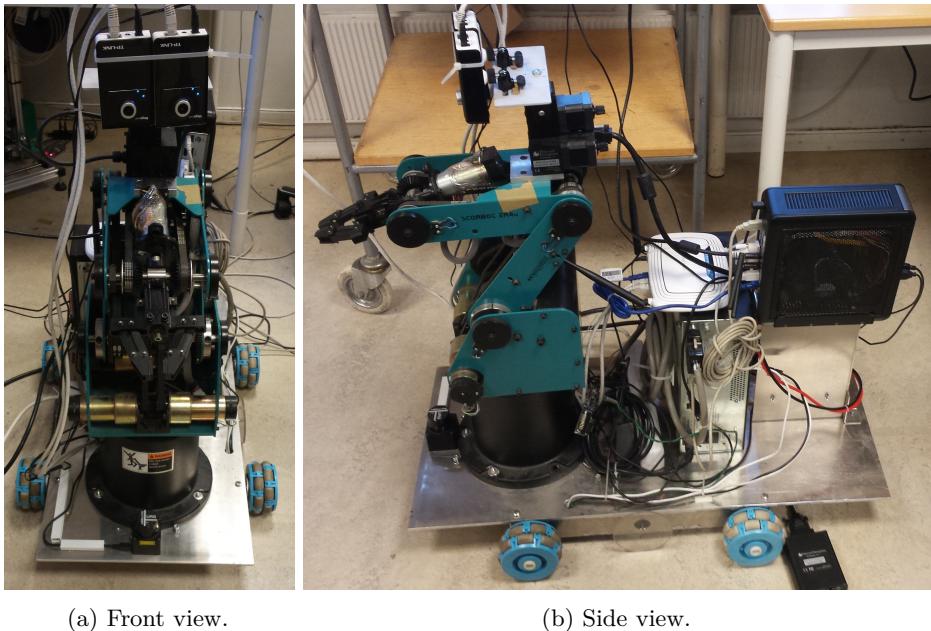
Put the task into a larger context. Bring in some points on the societal impact of autonomous robotics and the increased potential of mobile robotics.

The field of computer vision has seen an enormous growth over the last few decades - not only in scale, but in accessibility and capability as well. As a consequence of this recent growth, tapping into the field of computer vision is bound to reveal applications that are useful for a mobile autonomous maintenance robot. Recent discoveries within computer vision includes robust feature recognition and object detection, face detection and video processing. The latest great additions to the field are Big Data and Artificial Intelligence.

1.2 System Overview

The mobile robot being worked on in this project is shown in figure 1.1a. The manipulator arm has been used in previous projects on robotic maintenance, and it was placed on the mobile platform during the master thesis of (Aspunvik og siter). This section provides a short description of the hardware. If a more detailed description of the robot and it's equipment is required, consult the thesis of Aspunvik[cite].

2 1. INTRODUCTION



(a) Front view.

(b) Side view.

Figure 1.1: The robot used in the project.

1.2.1 Propulsion

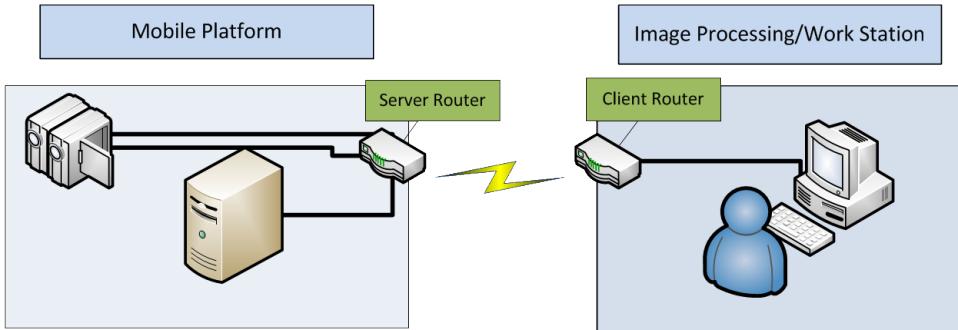
The steel chassis of the robot stands upon four omni-wheels. The wheel pairs are placed in parallel, making the vehicle uncontrollable along the lateral axis. Each wheel is powered by an electrical motor and motor driver. The motor drivers are controlled with pulse width modulation by an evaluation board from Atmel,(atmel kort).

1.2.2 Sensors

The robot was outfitted with several sensors over the course of previous projects. These are:

- Two odometer wheels with encoders. One on each side.
- Two infrared distance sensors.
- A LIDAR (Light Detection and Ranging).
- Two IP-cameras.

Only the cameras were used in this projects.



1.2.3 The Manipulator

1.3 Report Structure

How the report is structured, and a very brief description of the contents in each section.

Chapter Background Theory

2.1 Introduction to Computer Vision

2.1.1 Introduction

This chapter contains the background theory which is necessary to understand the implementations in chapter 4 and how they are intended to work.

2.1.2 How it's Done

nanana

2.1.3 OpenCV

OpenCV (Open Source Computer Vision Library) is an open source library with a vast number of advanced computer vision and machine learning algorithms. The library supports Windows, Linux, iOS and Android, and has interfaces to C, C++, Python, Java and MATLAB. All OpenCV applications in this project uses OpenCV 3.0.0 for Windows. OpenCV for Windows can be downloaded from sourceforge.net. This download contains source files, sample programs, sample data and a pre-built library for MSVC 2010 and 2013. The pre-build library can quickly be plugged into an IDE such as Qt Creator or Visual Studio 2013, thus giving the programmer access to all basic OpenCV features. A step-by-step guide for using both the pre-built and a custom-built library can be found in Appendix A.

2.2 Stereo Vision and Depth Perception

Stereo vision and depth perception is one of the core topics within this report. Here, the theory behind a method using two cameras is presented, while some additional methods are mentioned to provide context.

6 2. BACKGROUND THEORY

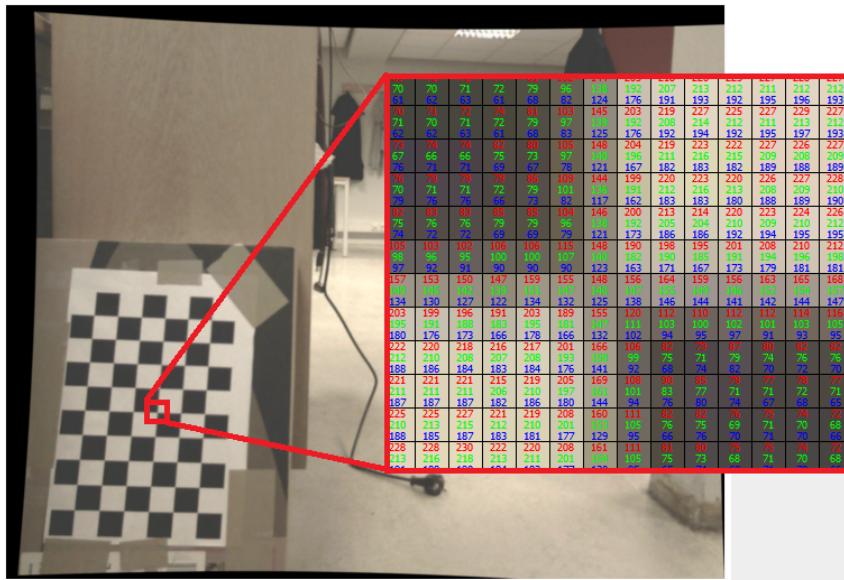


Figure 2.1: Elements in a cv::Mat representing an image. This is a 3-channel image with 8 bit RGB colors.

2.2.1 Various Methods

Methods for depth perception in computer vision can be separated into two main categories, i.e. active and passive. Active sensors will usually project a light pattern onto the scene to be perceived, before sensing how this pattern is displaced by the topology of the scene. The Kinect sensor and 3d-scanners using laser light are typical examples of active sensors. Passive depth perception makes use of many of the same cues we use to perceive depth. The most common passive sensors extract the depth information by observing a scene from at least two different positions.

Optical flow is another important method for depth perception. Optical flow may be either active or passive. The passive variant requires only one camera, but depends on motion and a stream of images to extract depth information. Observing how much some chosen features in a scene has moved in the image frame at $t = 1$ compared to the frame at $t = 0$ is the basis of depth sensing from optical flow. When the camera moves through a scene where all objects are stationary, objects that are far away will naturally have an optical flow field with a smaller magnitude than objects that are close.

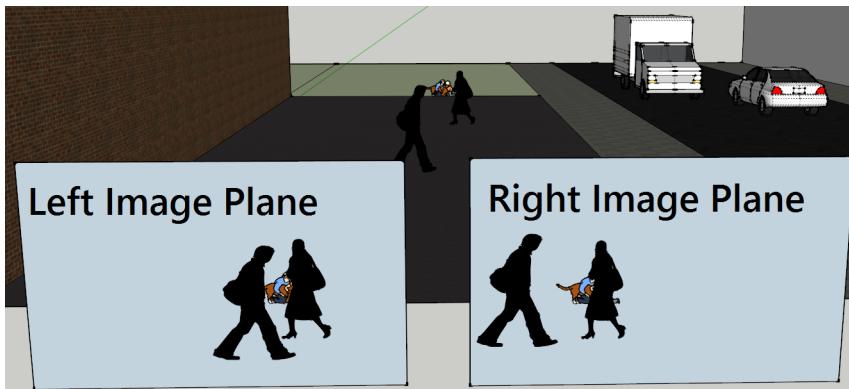


Figure 2.2: Left to right displacement on the image plane based on distance.

2.2.2 Stereoscopic Vision in General

In this project, passive stereoscopic vision is achieved by using two identical (in theory) cameras placed on the same plane. The gist of passive stereoscopic vision is based on the fact that objects close to the camera pair will have a large displacement from the left to the right camera compared to objects that are further away. This concept is illustrated in figure 2.2.

The Pinhole Camera Model Figure 2.3 illustrates the geometry of a pinhole camera. In a pinhole camera, a scene will be projected onto an image plane, often denoted π , through the camera projection point O which is located at the origin. The focal length f is the distance from the projection point O to the image plane π . In a true pinhole camera the image plane will be located behind the lens and the projection point O , and the scene projection will be rotated by 180° . A virtual image plane placed in front of O is intended to make the figure more straightforward.

Stereo Cameras Figure 2.4 shows an ideal stereo camera model. The model comprise two pinhole camera models where the virtual image planes are located on the same plane. The two image planes are separated by a horizontal translation B which is called the baseline. This implies that the projection point O_L in the left camera, relates to the projection point O_R

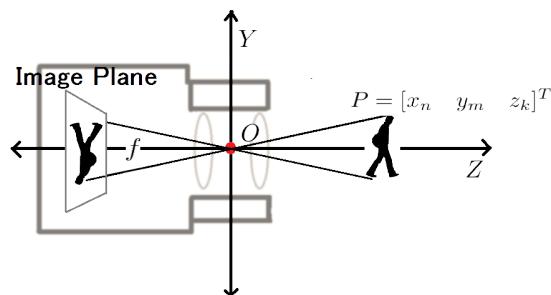


Figure 2.3: Geometry of a pinhole camera.

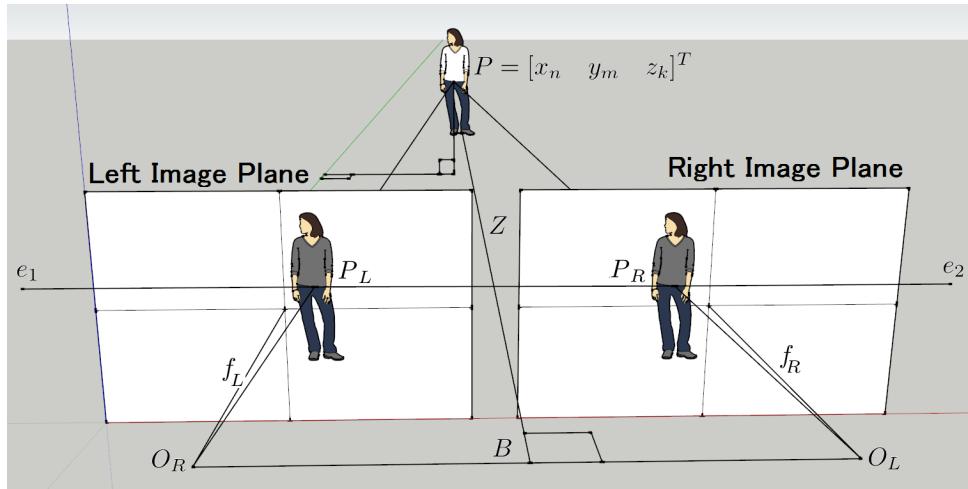


Figure 2.4: Geometry of stereo vision.

on the right camera through B : $O_R = O_L + B$. Each of the two image planes has a left handed pixel based coordinate system u, v , i.e. the origin is in the top left corner and the opposite pixel is in the bottom right corner.

Camera Distortion A downside of the otherwise cheap and useful pinhole camera is camera distortion. The distortion is usually severe enough to render the camera useless as a sensor if it is not calibrated. Calibration in OpenCV accounts for radial and tangential distortion by finding five distortion coefficients [3dC]:

$$Distortion_{coefficients} = (k_1 \ k_2 \ p_1 \ p_2 \ k_3)$$

where

$$p_i \quad \text{with} \quad i \in \{1, 2\}$$

are the radial distortion constants, and

$$k_i \quad \text{with} \quad i \in \{1, 2, 3\}$$

are the tangential distortion constants.

2.2.3 Stereoscopic Vision in OpenCV

The prebuilt version of OpenCV 3.0.0 comes with two stereo matching algorithms: Block Matching (BM) Block Matching (StereoBM) and Semi Global Block Matching (StereoSGBM). Additional algorithms are available if OpenCV is built with, e.g. CUDA.

StereoSGBM [Hir08] blablabalb BM.

Chapter 3 Example

Here is an example of how to use acronyms such as Norwegian University of Science and Technology (NTNU). The second time only NTNU is shown and if there were several you would write NTNUs. And here is an example¹ of citation [NN00].

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

This is the second paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

And after the second paragraph follows the third paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original

¹A footnote

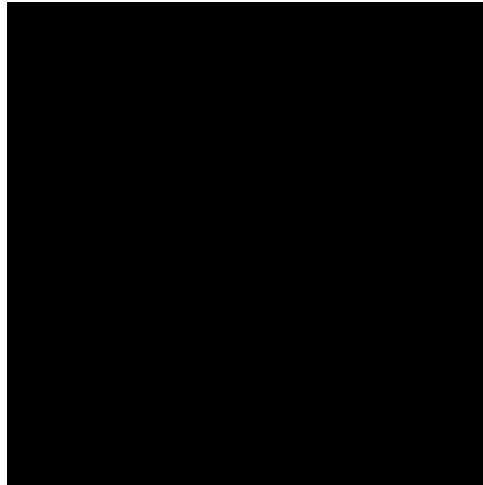


Figure 3.1: A figure

language. There is no need for special content, but the length of words should match the language.

3.1 First section

3.1.1 First subsection with some *Math* symbol

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

- item1
- item2
- ...

3.1.2 Mathematics

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. $\sin^2(\alpha) + \cos^2(\beta) = 1$. If you read this text, you will get no information $E = mc^2$. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not

Table 3.1: A table

a	b	c	d	e
f	g	h	i	j
k	l	m	n	o
p	q	r	s	t
u	v	w	x	y
z	æ	ø	å	

at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. $\sqrt[n]{a} \cdot \sqrt[n]{b} = \sqrt[n]{ab}$. This text should contain all letters of the alphabet and it should be written in of the original language. $\frac{\sqrt[n]{a}}{\sqrt[n]{b}} = \sqrt[n]{\frac{a}{b}}$. There is no need for special content, but the length of words should match the language. $a \sqrt[n]{b} = \sqrt[n]{a^n b}$.

B
 X_L
 X_R
 $P_R` P_L$
 $P = [x \ y \ z]^T$
 $P = [x_n \ y_m \ z_k]^T$
 e_1
 e_2
 O_R
 O_L
 $X = [x \ y \ z]^T$
 f
 Z
 Y

Proposition 3.1. *A proposition... (similar environments include: theorem, corollary, conjecture, lemma)*

Proof. And its proof. □

3.1.3 Source code example

You can refer to figures using the predefined command like Figure 3.1, to pages like page 12, to tables like Table 3.1, to chapters like Chapter 3 and to sections like Section 3.1 and you may define similar commands to refer to proposition, algorithms etc.

Algorithm 3.1 The Hello World! program in Java.

```
class HelloWorldApp {  
    public static void main(String[] args) {  
        //Display the string  
        System.out.println("Hello World!");  
    }  
}
```

Chapter 4

Implementation

4.1 Introduction

An obstruction detector and a vanishing point detector are the two attempted implementations presented in this report. The obstruction detector uses stereo vision to perceive depth and distance to possible objects in the path of the robot. The vanishing point detector attempts to find a single vanishing point by detecting lines in the environment before selecting a vanishing point based on line intersections.

4.2 Vanishing Point Detection

4.2.1 Overview

The goal of the vanishing point detector is to provide a setpoint for the robot to steer towards. In other words, steering towards a vanishing point is a good way to reach the end of a hallway or corridor. Choosing a method as a basis for a vanishing point detector was not easy. The selected method should be simple, suitable for in OpenCV and not go too far beyond the prior knowledge of the author. Another important factor was that spending too much time on this implementation would come at the expense of the obstruction detector. A detector method by D. Gerogiannis et. al. [GNL12] showed promise as it was based on line detection, which has good support in OpenCV. The method in [GNL12] appears to be suitable for structured environments with many straight lines, such as hallways, streets and corridors. The steps in the detection procedure are:

1. Detect edges in the image, e.g. by using Canny edge detection.
2. Detect line segments that may be used as vanishing lines based on the edges in step 1. Could be done with the Hough line transform.
3. Filter the detected lines. This is done by modelling new lines by using the major axis of ellipses with very high eccentricity. The ellipses are generated by

a split-and-merge algorithm. In short, it will merge similar line segments by assuming that their end points are collinear.

4. Find line intersection points based on the new filtered lines. Each point is stored and assigned a weight.
5. Find the vanishing point among the line intersections based on a voting scheme.

4.2.2 Line Detection

Line detection comprise step 1 and 2 from the list above. OpenCV comes with an implementation of the Canny edge detector ready for use. The detector returns a binary image of the detected edges. Edges are detected by convolving the input image with two kernels G_x and G_y . The convolutions will indicate change gradients in the x and y directions which in turn will give the direction of a potential edge. Finally, the detector rejects or accepts potential edges based on two gradient thresholds. Gradients below the lower threshold are rejected, edges above the upper threshold are accepted, and edges between the thresholds are only accepted if their neighbouring gradients are above the upper threshold[can].

```
cvtColor(cameraImg,grayImg,CV_RGB2GRAY);
blur( grayImg, blurredImg, Size(3,3) );
Canny(blurredImg, edgesImg, lowerThresh, upperThresh, 3);
gpu_edgesImg.upload(edgesImg);
lines = detectHoughLines(gpu_edgesImg);
```

4.2.3 Line Filtering

Line filtering is performed by splitting and merging ellipses until their major axis represents a set of approximations to collinear points. The points is the set of points that define the previously detected line segments.

4.2.4 Vanishing Point Detection

4.2.5 Vanishing Point Detector Application

Graphical User Interface A graphical user interface was created so that the parameters for the canny edge detector and Hough lines detector could be tuned on-line. All widgets shown in figure 4.1 have their functionality implemented. The user can turn on the camera feed, in this case from the web camera integrated into the laptop of the author, and switch line and edge detection on or off. Upper and lower edge detection thresholds, as well as line detection parameters can be set by using the sliders. The kernel size for the edge detector is set to 3 by 3, and can not

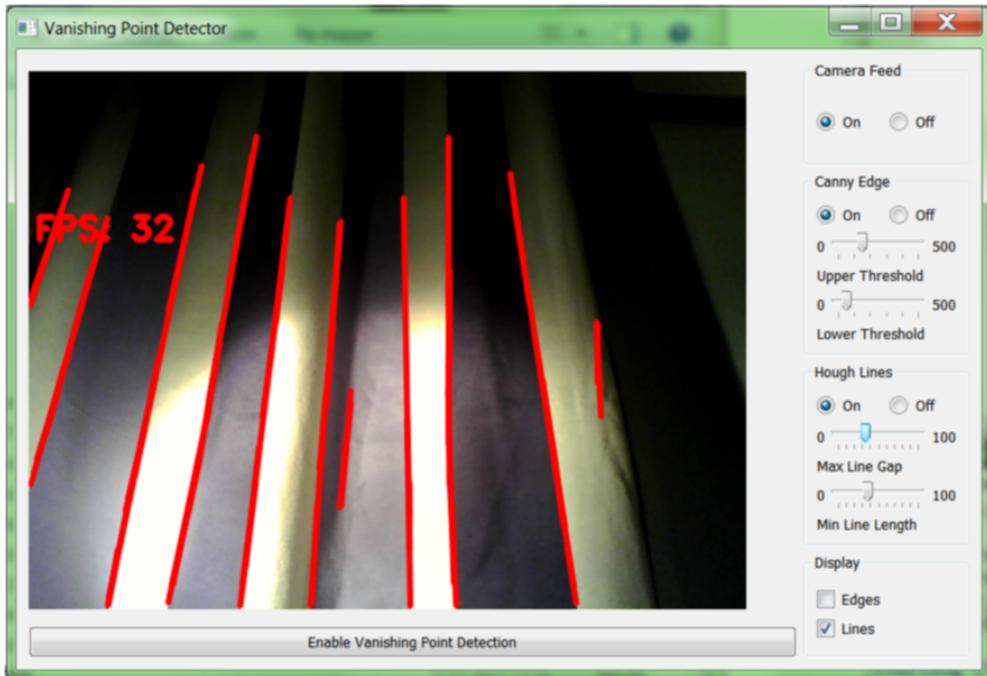


Figure 4.1: Graphical user interface for the vanishing point detector.

be changed by the user. When both edge detection and line detection is enabled, the user may turn on the vanishing point detector module. In this particular application, the ellipse line filter module not included.

4.2.6 Cause of Failure

4.3 Depth Perception and Obstruction Detection

4.3.1 Overview

4.3.2 The camera rig

The two IP cameras were moved together to form a stereo camera. This stereo camera was used in two positions. The first camera position is on the pan-tilt module on the robot arm, see figure ???. The second position is just over the LIDAR in front of the robot arm base, see figure ???. The workshop at ITK made a mounting bracket, so that the cameras could be placed over the LIDAR. In stereo vision, it is essential that the positions of the cameras relative to each other is constant. One problem encountered throughout the project was that the camera assembly, when placed either at the pan-tilt module and over the LIDAR, was not rigid enough. The

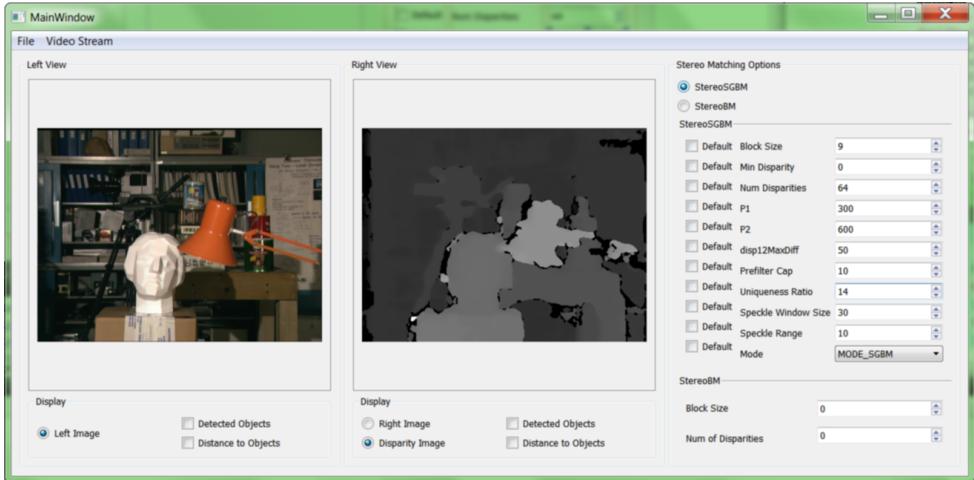


Figure 4.2: Graphical user interface for stereo matching. A disparity map is computed from the Tsukuba samples by using StereoSGBM.

severity of this problem was somewhat alleviated by wrapping a strap around both the cameras. This camera rig is ad hoc, i.e. suitable for the purpose of this project, and a better solution should be used for succeeding projects.

4.3.3 Graphical User Interface

Tuning the parameters for stereo matching in OpenCV is a wearisome task, especially without a good graphical user interface. Figure 4.2 shows the user interface which was used to observe how parameter tuning alters the disparity map quality. Not all functionalities were implemented.

4.3.4 Calibration

As mentioned in chapter 2, all cameras will have some distortion. If the distortion is too severe, as it often will be in the context of stereo vision, the camera must be calibrated. In addition, it was assumed that the image planes were located on the same plane, and that a projection pair, for example the projections X_L and X_R of an object X , form two equal epipolar lines, e_1 and e_2 , on the two image planes. In practice, these conditions are achieved through stereo calibration. The second purpose of the calibration procedure is to relate the sensor data to real world quantities, in order to measure the distance to detected objects. Code listings from Practical OpenCV by Samarth Brahmbhatt [Bra13] has been used as a basis for calibration in this project. Some parts of his code is almost unchanged, while other

parts of the listings are altered and expanded significantly. There are three steps in the calibration procedure:

1. Single camera calibration.
2. Stereo calibration.
3. Image rectification.

See figure ?? for an overview of the calibration procedure. All these steps require a familiar object with known dimensions to calibrate against. Among the three calibration patterns supported by OpenCV, this implementation utilized a black and white chessboard. The chessboard has 6 by 8 squares with sides $\approx 26\text{ mm}$ long.

Single Camera Calibration In this step, the cameras are calibrated separately. The purpose of this calibration procedure is to counter the constant radial and tangential distortion in a pinhole camera, and to relate the image pixels to real world quantities. The result of this procedure is the 3×3 camera matrix and the five distortion coefficients mentioned in the theory chapter. The results are stored in a .xml file:

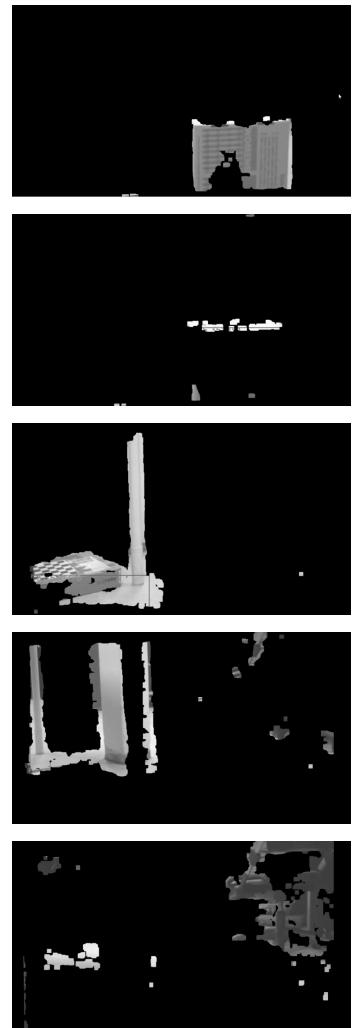
```
<?xml version="1.0"?>
<opencv_storage>
<cameraMatrix type_id="opencv-matrix">
    <rows>3</rows>
    <cols>3</cols>
    <dt>d</dt>
    <data>
        1.4478141049219482e+003 0. 6.6274484776761142e+002
        0. 1.4432743079138295e+003 4.7609546427843065e+002
        0. 0. 1.
    </data></cameraMatrix>
<distCoeffs type_id="opencv-matrix">
    <rows>1</rows>
    <cols>5</cols>
    <dt>d</dt>
    <data>
        -2.6128696949919589e-001 3.4600669963821584e-001
        -2.2331413545278616e-003 -2.5710895791919218e-003
        -3.7144316064113458e-001</data></distCoeffs>
</opencv_storage>
```




Figure 4.4: The result of StereoSGBM.

When all the image samples has been read into the program, the program will check if the chessboard can be detected. If the chessboard is present in the image, the position of the corners will be stored in

Stereo Calibration



Stereo Rectification

Figure 4.3: Some of the depth layers in figure 4.4 separated by color

4.3.5 Stereo Matching

4.3.6 Finding Obstructions

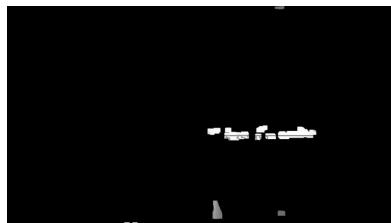
4.3.7 Distance Measurment

4.3.8 Problems

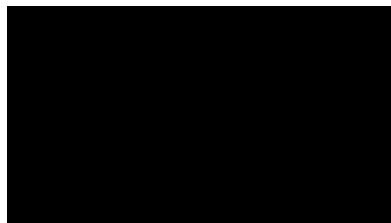
Encountered During Implementation



(a) $n = 10$ steps



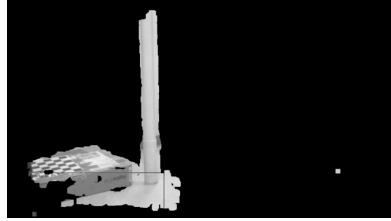
(b) $n = 25$ steps



(c) $n = 50$ steps



(d) $n = 50$ steps



(e) $n = 50$ steps

References

- [3dC] Camera calibration with opencv. http://docs.opencv.org/2.4/doc/tutorials/calib3d/camera_calibration/camera_calibration.html.
- [Bra13] Samarth Brahmabhatt. *Practical OpenCV*. Apress: Berkeley, CA, 2013.
- [can] Canny edge detection with opencv. http://docs.opencv.org/2.4/doc/tutorials/imgproc/imgtrans/canny_detector/canny_detector.html.
- [GNL12] Demetrios Gerogiannis, Christophoros Nikou, and Aristidis Likas. Fast and efficient vanishing point detection in indoor images. *Pattern Recognition (ICPR), 2012 21st International Conference on*, pages 3244 – 2347, nov 2012.
- [Hir08] Heiko Hirschmuller. Stereo processing by semiglobal matching and mutual information. *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, 30(2), 2008.
- [NN00] Firstname 1 Name1 and Firstname2 Name2. A dummy title. *A Fake Journal*, 1(1):000–000, June 2000.

Appendix A

Setting up a project with Qt and OpenCV

A.1 Setting up OpenCV

A.2 Setting up Qt Creator with OpenCV

A.3 Building OpenCV with CUDA and Qt from source