Stereo Image Calibration for Size Measurement

Final Year Project Viva

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Table of Content

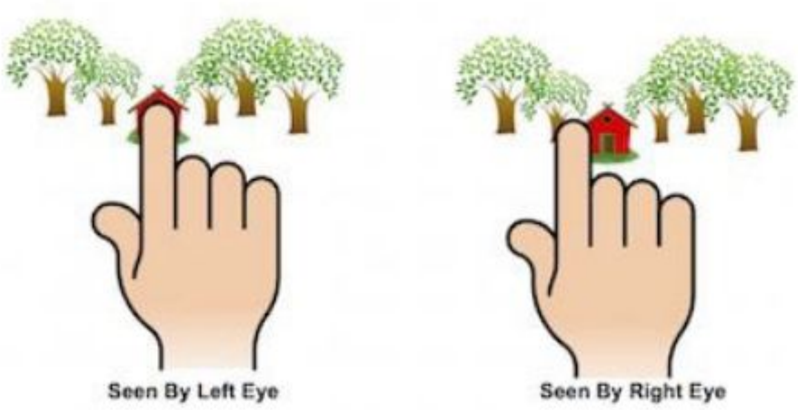
Introduction

What are stereo cameras?

- Cameras are tools that give computers sight.
- Stereo camera setups involves 2 cameras placed side by side.

How do they work?

- It mimics the human eyes for depth sensing.



- The disparity in the 2 point of views is what gives stereo images depth.

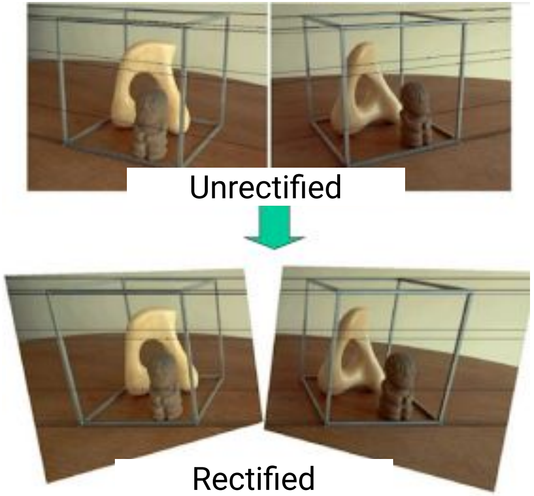
4 steps for stereo computer vision (1)

Step 1: Calibration:

- Removing distortions from cameras.

Step 2: Rectification:

- Aligning the 2 cameras.



Steps for stereo computer vision (2)

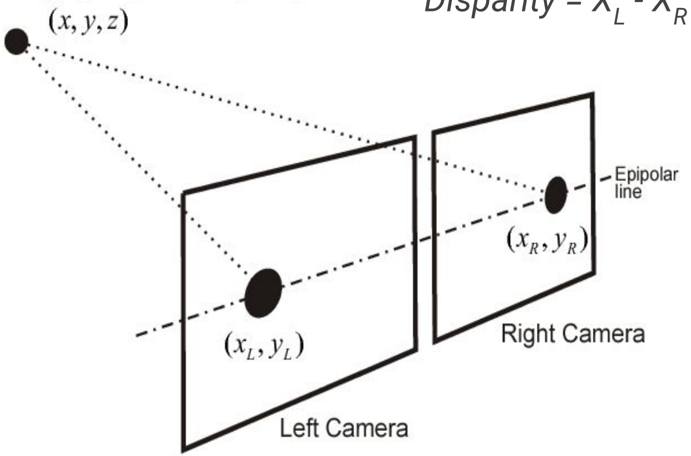
Step 3: Stereo Matching:

- Match same points in stereo image.

Step 4: Distance estimation:

- Estimate distance of object from disparity.

Disparity = X_L - X_R



Problem Statement

Camera Image Distortion

All cameras have some form of distortion due to imperfections.

Stereo Image Misalignment

Identical cameras are still subject to misalignment due to internal sensor.

Stereo Matching Accuracy

Accuracy of stereo matching is low without calibration and rectification.

Objectives

Objective

To estimate distance and size of object from stereo images

Approaches

Calibrate and rectify stereo camera for stereo vision.

Estimate the distance and size of an object from disparity and pixel size.

Scope of Work

Create a set of stereo camera with USB cameras.

Calibrate and rectify stereo camera with Image Processing Tools in Python.

Perform stereo matching and generate disparity map from stereo images.

Estimate size and distance of object from disparity.

Research Questions

Approach 1

To calibrate and rectify stereo camera for stereo vision.

Does Stereo Rectification improve the accuracy of Stereo Matching and Depth Map Generation?

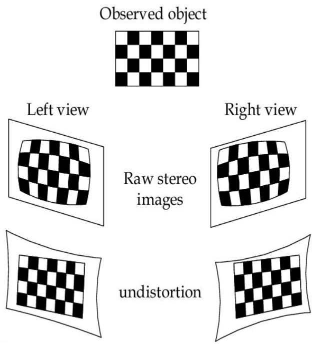
Approach 2

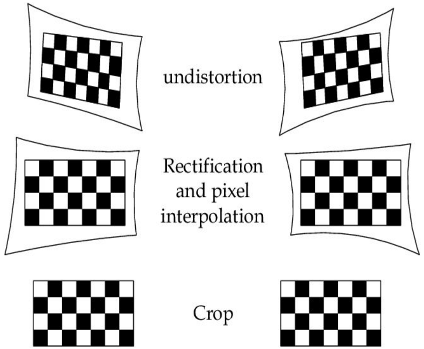
To estimate the distance of an object from from disparity.

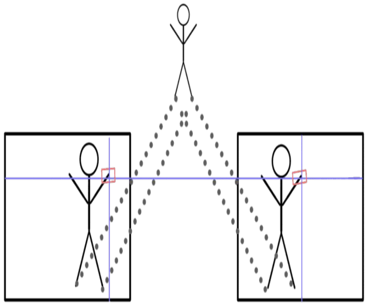
What is the relationship between the stereo matching disparity and distance of object?

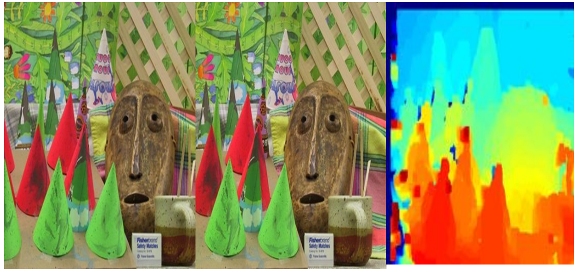
Literature Review (1)

1 Calibration
2 Rectification
3 Stereo Matching
4 Disparity Map Generation







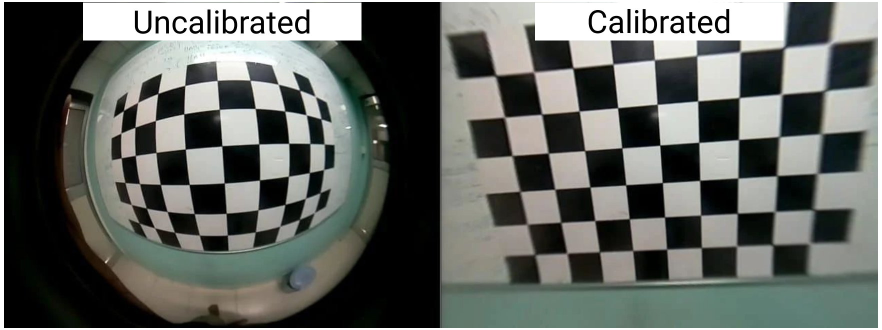


4 steps in a complete Stereo Camera setup for distance measurement.

Literature Review (2)

Step 1: Calibration

Calibration improves the consistency of images taken at different positions, angles, and environments by removing distortion.

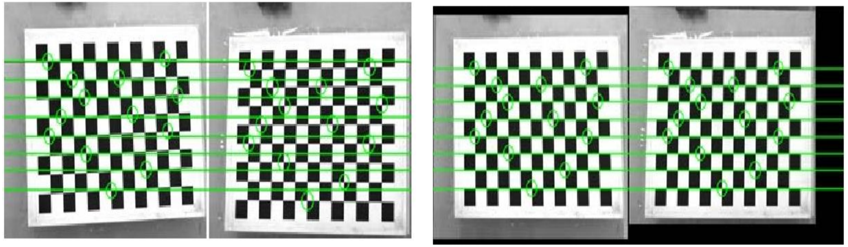


Common Calibration Algorithms:

- Zhang's Method - based on Direct Linear Transformation. [5]
- Tsai's Method - Slightly lower accuracy, lower computation time compared to Zhang's method. [5]
- **Bouguet's Method - Based on Zhang's method, used in Matlab and OpenCV library for camera calibration. [12]**

Literature Review (3)

Rectification improves the stereo matching process by distorting the image such that the same points in a scene lie on the same y coordinate in both stereo images.



a) Before rectification

b) After rectification

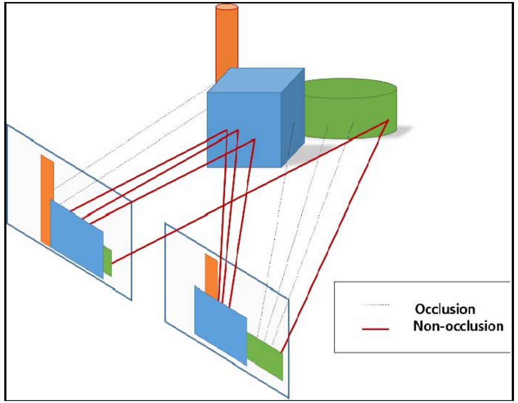
Step 2: Rectification

Common Rectification Algorithms:

- Longuet-Higgins' algorithm - based on singular value decomposition. [4]
- Hartley's algorithm - based on Longuet-Higgins' algorithm, commonly used by researchers to solve camera placement. [4]
- **Bouguet's Method - based on Hartley's Algorithm, used in Matlab and OpenCV Library for camera rectification. [12]**

Literature Review (4)

Stereo Matching finds points in a stereo image and its correspondent that lie on the same y coordinate to obtain disparity.



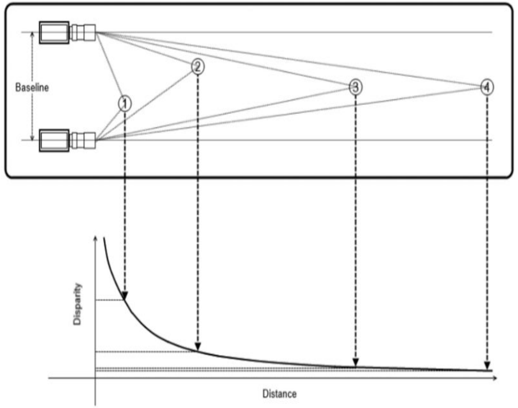
Step 3: Stereo Matching

Common Stereo Matching Algorithms:

- Local matching - scans small windows to calculate disparity. Faster but low accuracy. [7]
- Global Matching - scans entire image to get disparity. Slower but good accuracy. Unable to be run in real time. [7]
- **Semi-Global Matching - mix of both local and global. Can be used in real time, available in OpenCV Library.** [7]

Literature Review (5)

Depth Map Generation gives depth to images from the disparity map of the scene, where the depth of object is calculated from the disparity.



Relationship between disparity and distance

Step 4: Depth Map Generation

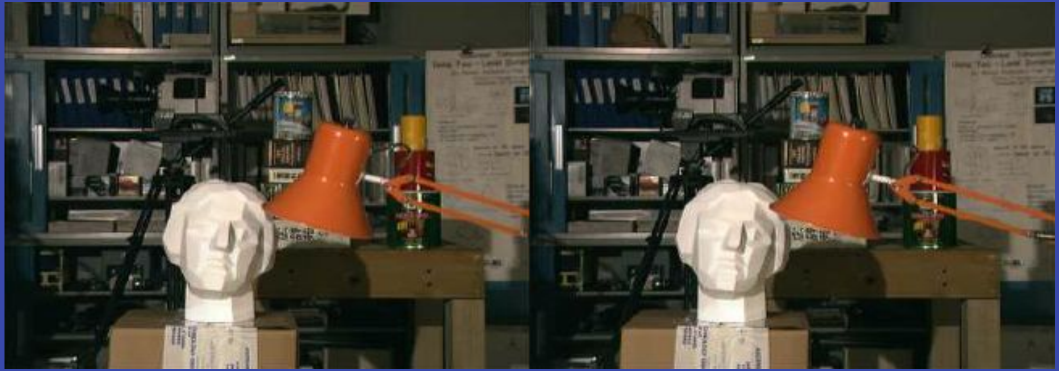
Common Depth Calculation Algorithms:

- **Principle of similar triangles - most commonly used. Requires on focal length of stereo camera and disparity. [2]**
- Mrovlje & Vrancic method - sometimes used in self-driving cars. Requires angle of the object from camera and disparity. [3]

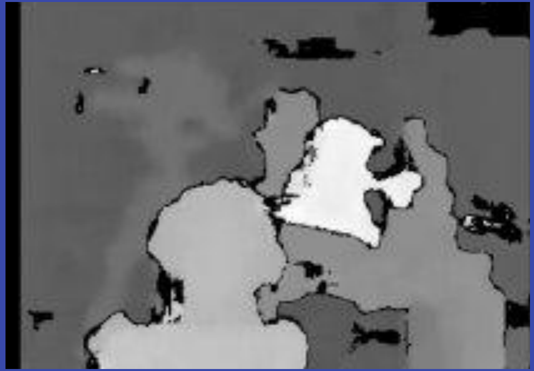
Literature Review (6)

Step 4: Depth Map Generation

Stereo Matching...

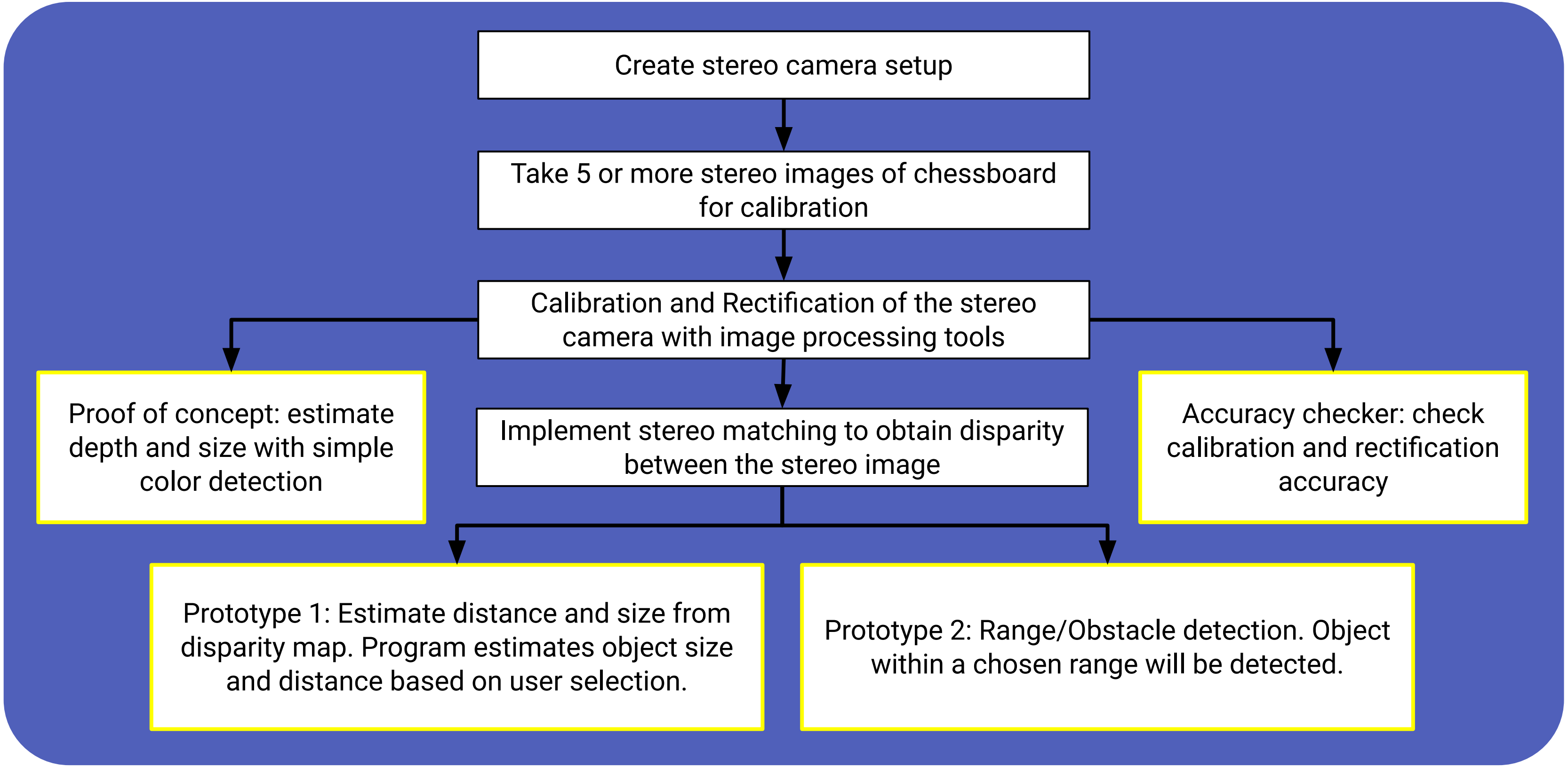


Depth map generated!



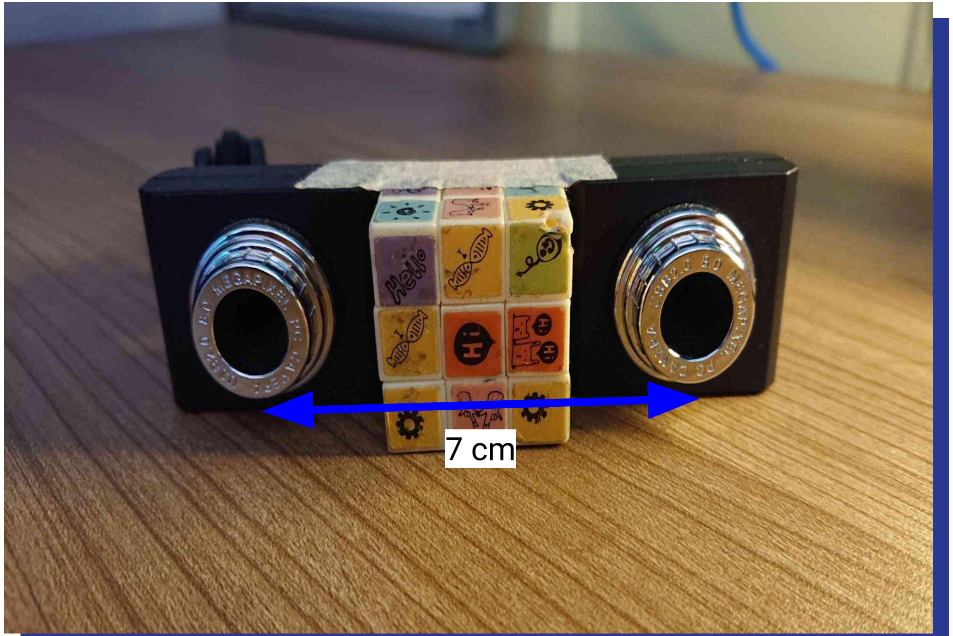
- Whiter = closer, darker = farther
- If the calibration is good and the stereo matching parameters are right, you should be able to see the shape of the objects

Project Methodology (1)



Project Methodology (2)

Stereo camera setup



Custom made stereo camera setup. Cameras 7 cm apart from each other. Made with:

- 2 USB Cameras
- Some tape
- A piece of wood
- A rubik's cube

Project Methodology (3)

Calibration pictures

`./images/stereoLeft/` `./images/stereoRight/`

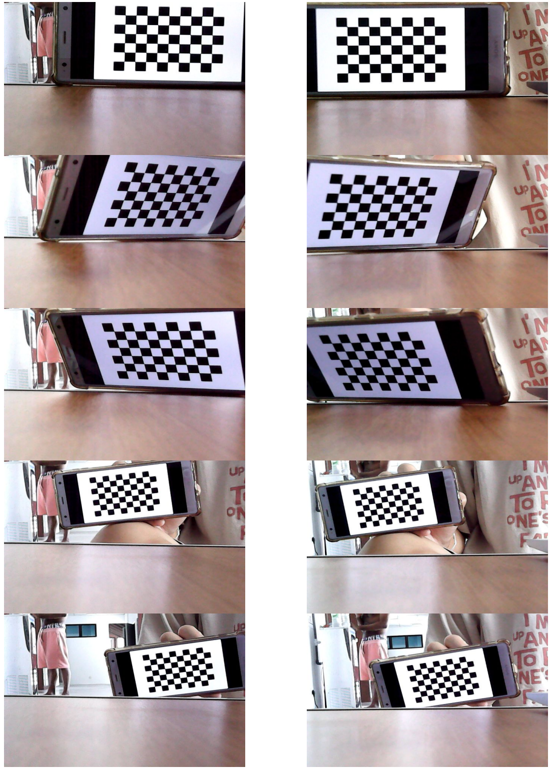
`img0.png`

`img1.png`

`img2.png`

`img3.png`

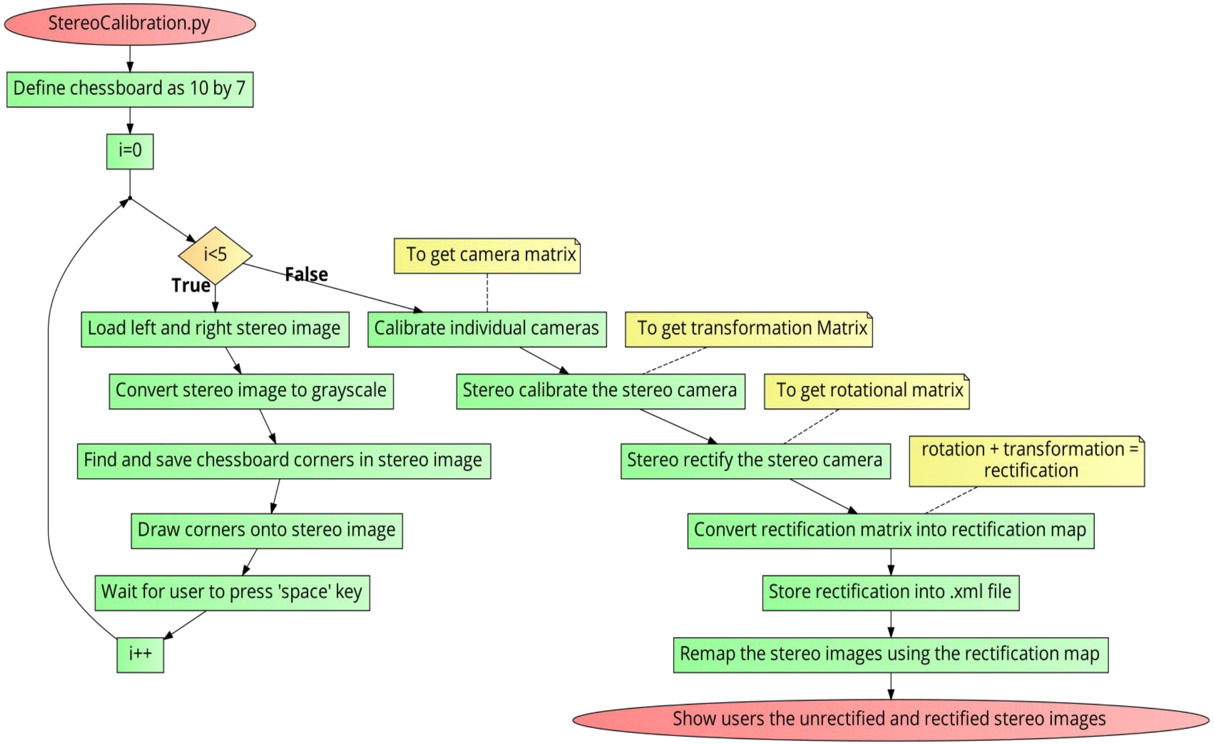
`img4.png`



Taking pictures needed for stereo calibration:
Take 5 (or more) stereo images of a 10x7 chessboard at different distances and angles.

Project Methodology (4)

Stereo calibration & rectification



Using Bouguet's method available in OpenCV.

1. Find chessboard in stereo images.
2. Compute stereo calibration and rectification matrix.
3. Save stereo rectification map.

Project Methodology (5)

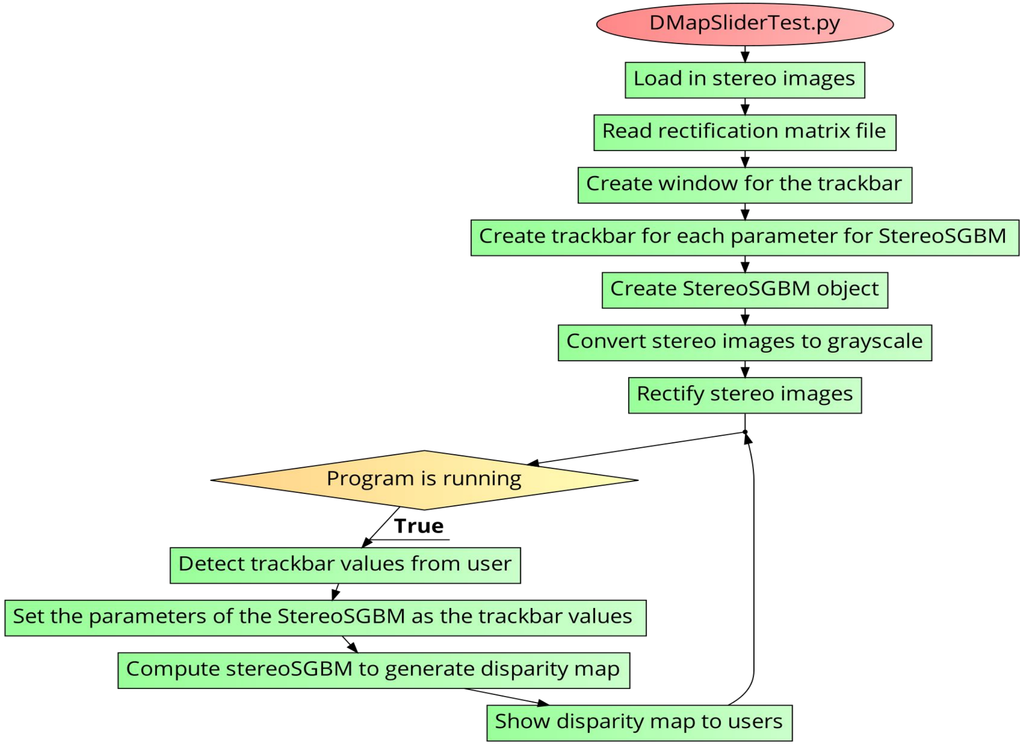
Stereo calibration & rectification

Example stereo image output before calibration.

Example stereo image output after calibration.

Project Methodology (6)

Stereo matching and disparity map generation

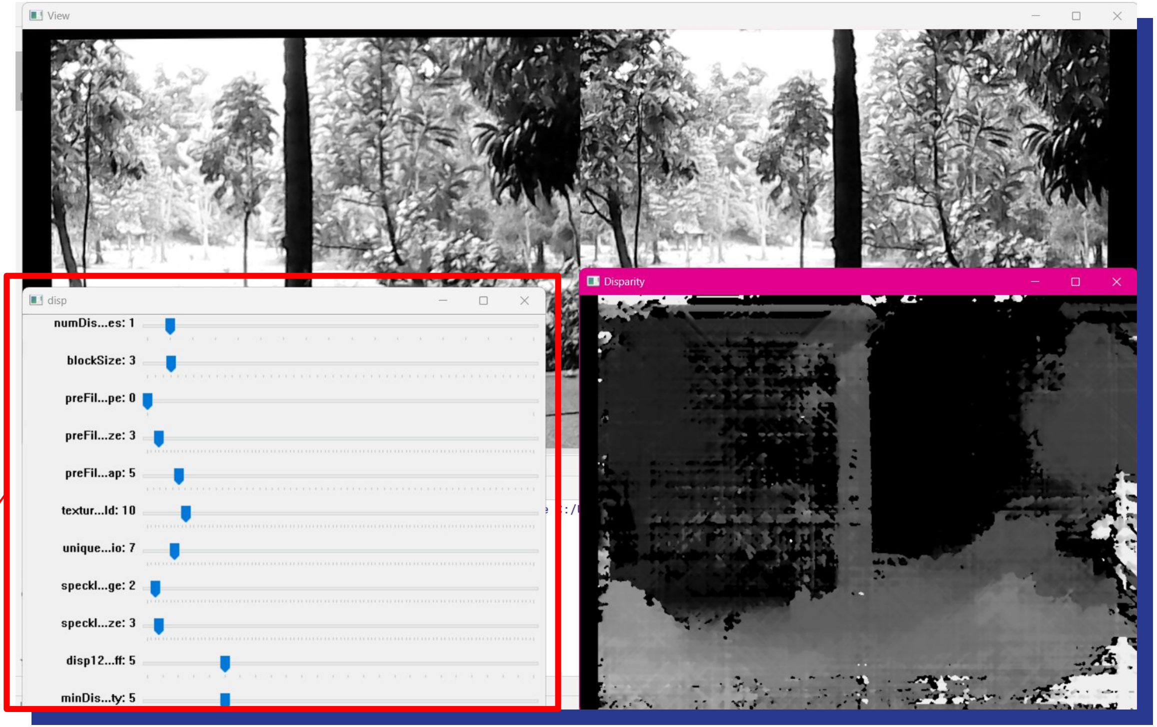


Using semi global block matching. A UI tool was created to obtain best SGBM parameters for this project's implementation.

1. Create stereoSGBM object.
2. Detect user trackbar values.
3. Compute stereo matching & disparity map.

Project Methodology (7)

Stereo matching and disparity map generation



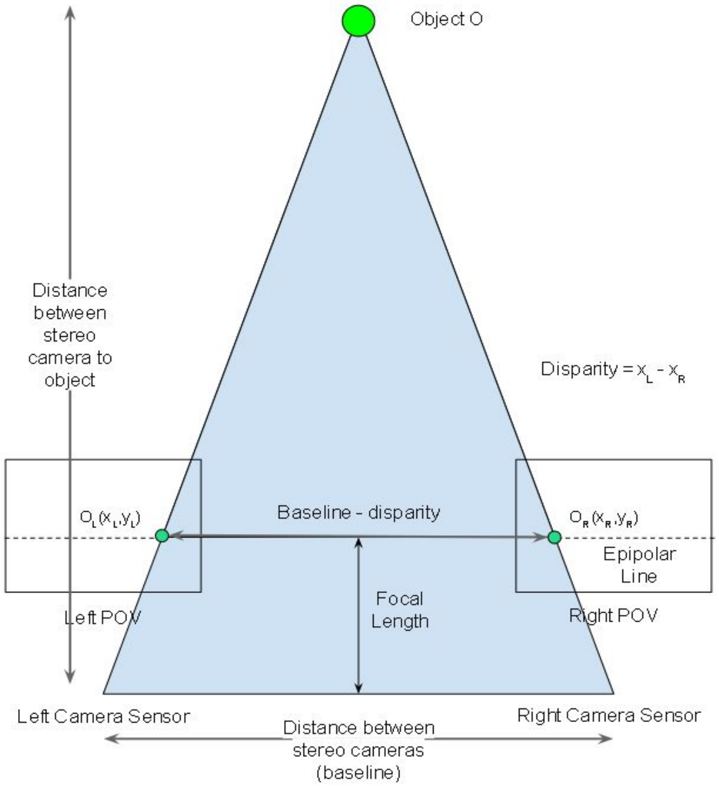
User adjusts Stereo SGBM parameters

Users manually adjust the values until a satisfactory disparity map is generated.

There is no one parameter value that will work for every scenario.

Project Methodology (8)

Distance measurement

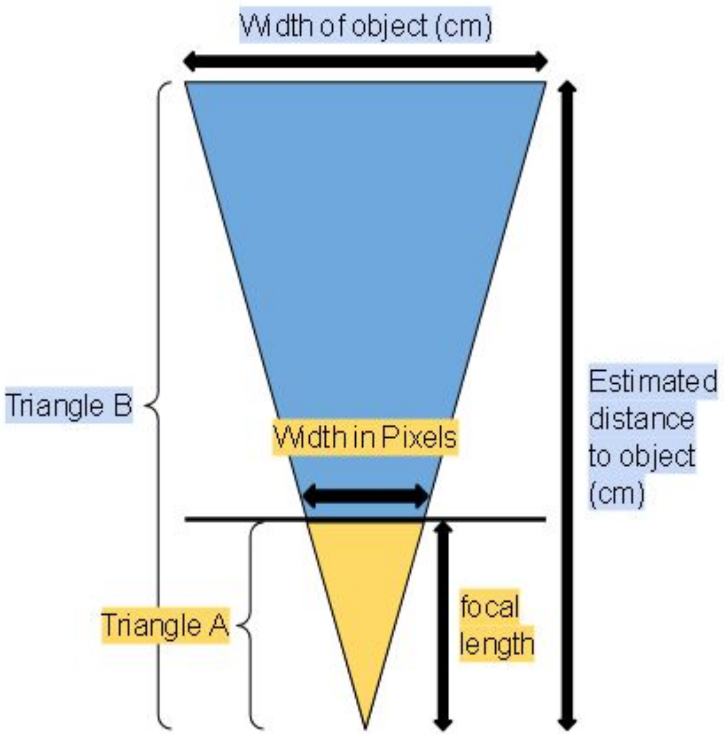


Using the principle of similar triangles, distance can be estimated from the focal length, disparity and baseline.

*Distance from camera to object in m = baseline * focal length / Disparity in pixels [2]*

Project Methodology (9)

Size measurement



Using the principle of similar triangles, size can be estimated from the focal length, estimated distance and pixel width of the object.

*Width in m = Estimated distance in m * Width in pixels / Focal Length [8]*

Project Methodology (10)

Prototypes

Calibration Accuracy Checker

Checks accuracy of stereo calibration and rectification using chessboard detection.

Proof of Concept

To test the relationship between disparity and distance of object using simple color detection.

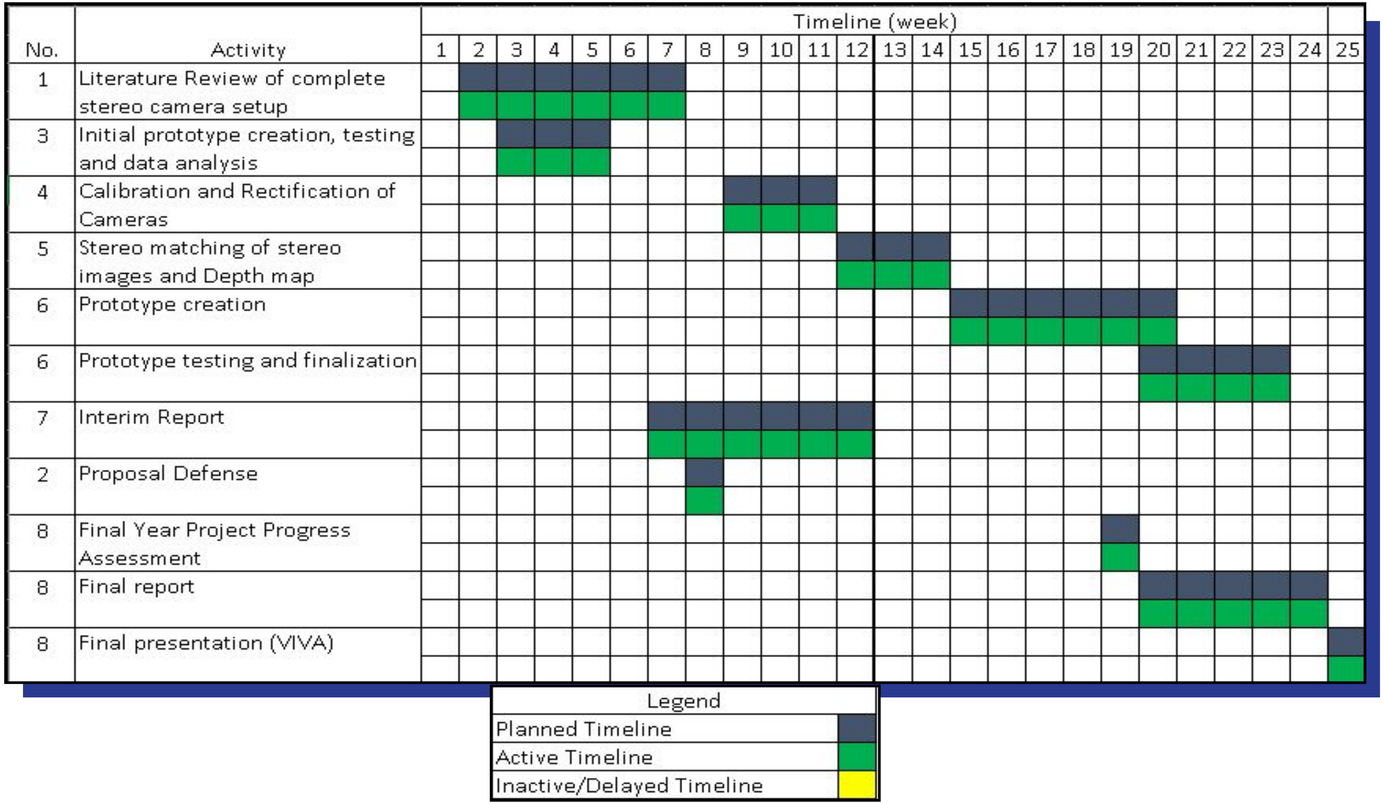
Distance & Size Measuring

Use the disparity map generated to detect the size and distance of objects based on user selection.

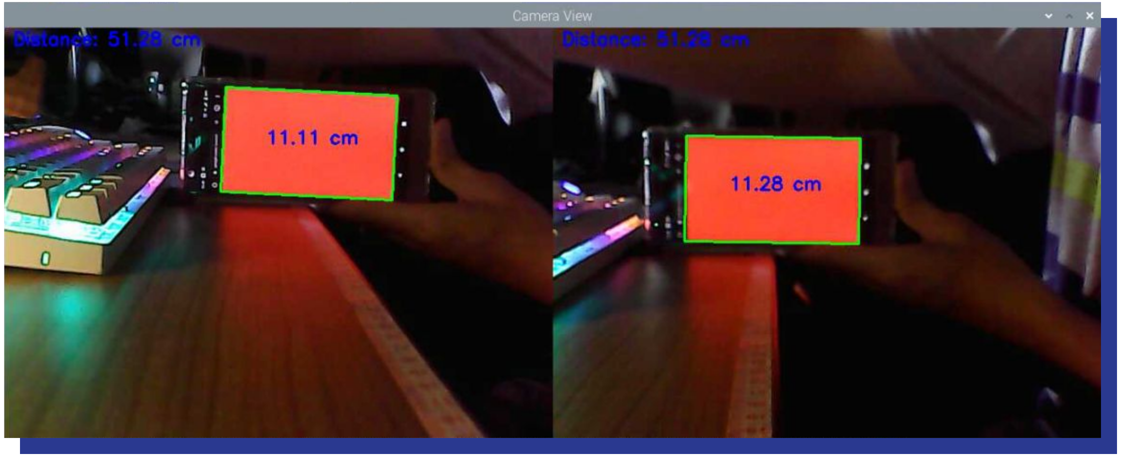
Obstacle Detector

Example use case scenario of stereo camera distance detection capabilities - obstacle/range detection.

Project Timeline & Milestones



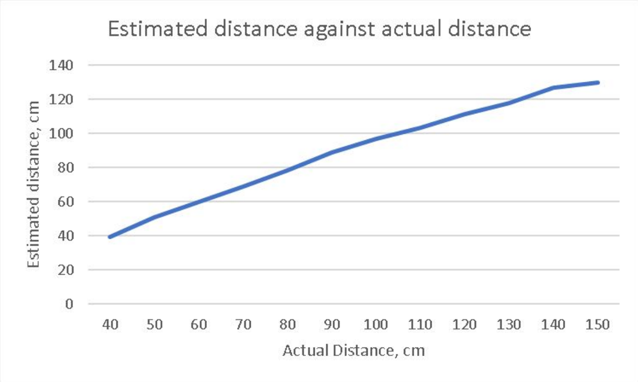
Preliminary Results (1)

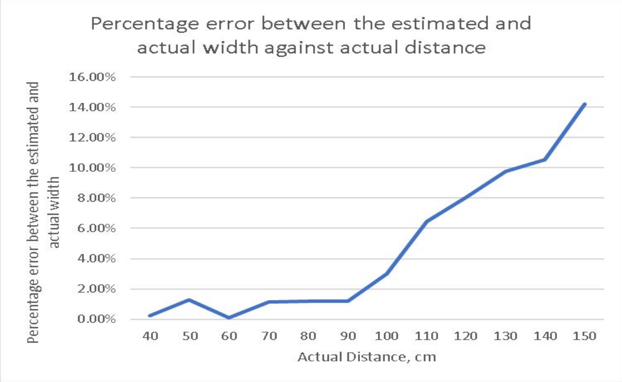


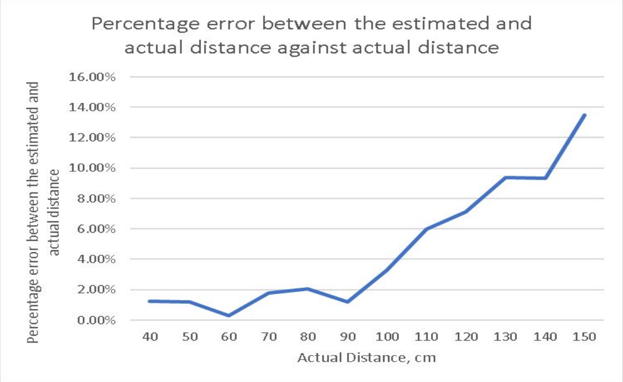
During the preliminary phases of the project, a prototype was created to test the relationship between disparity and estimated distance using a constant point to match.

The prototype uses simple color detection to obtain disparity. Stereo calibration and rectification was not done.

Preliminary Results (2)







*Average of 1000 results

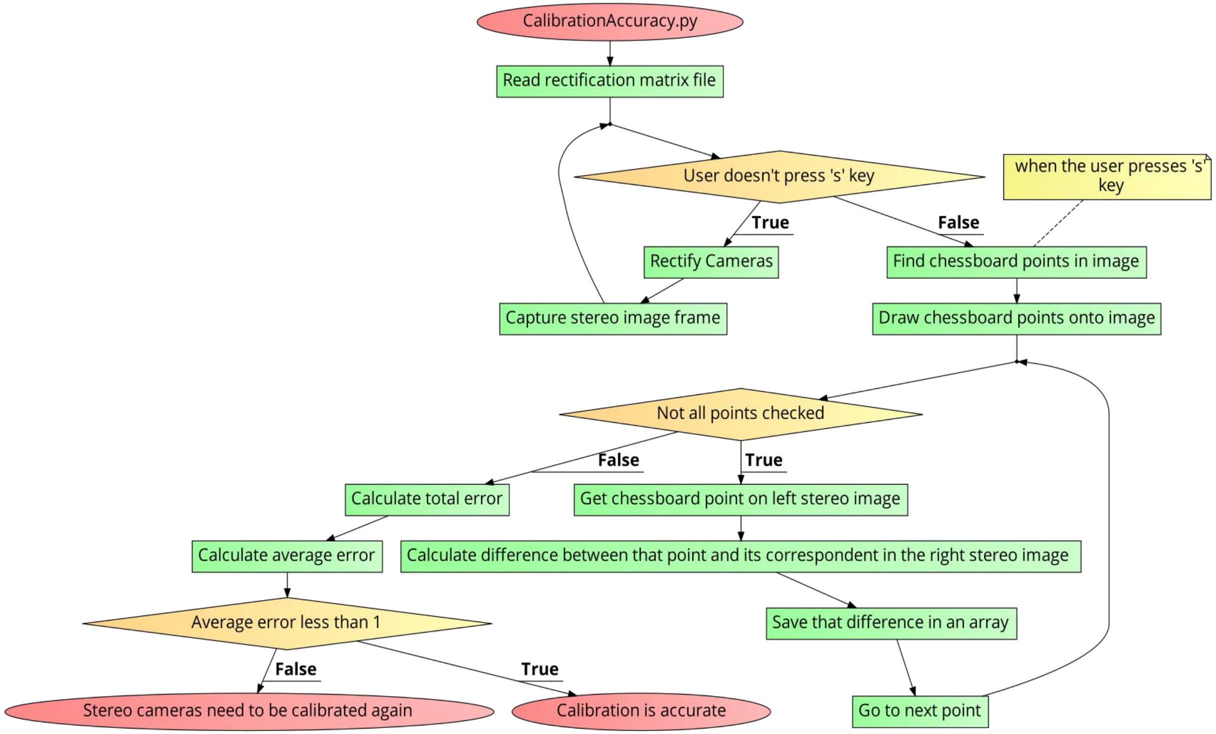
Estimated distance increases proportionally with actual distance.

Estimated distance and size of red object starts to deviate from their actual values when the red object is placed at just 90 cm away from the camera.
Conclusion: Without calibration, the usable range of the stereo vision is very small at 90 cm.

Results & Discussion (1)

Calibration Accuracy Checker

Check the accuracy of calibration done on the stereo camera



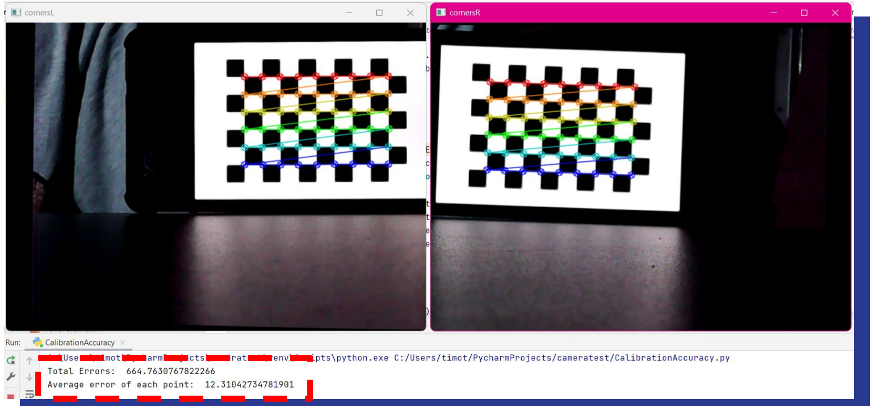
Checks the total error in chessboard points y coordinates after rectification.

1. Take stereo rectified image of chessboard.
2. Check y difference for each chessboard point in left and right stereo image.
3. Compute average difference.

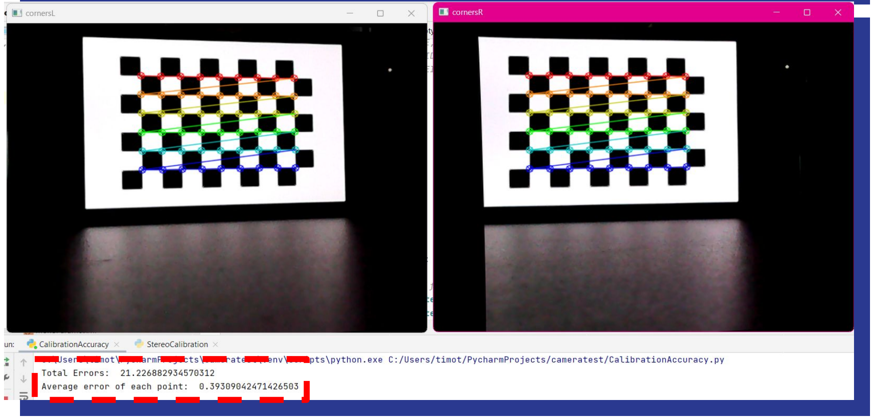
Results & Discussion (2)

Calibration Accuracy Checker

Check the accuracy of calibration done on the stereo camera



Example output: Average error between the y coordinate of each point is 12 pixels, hence the calibration is unacceptable.

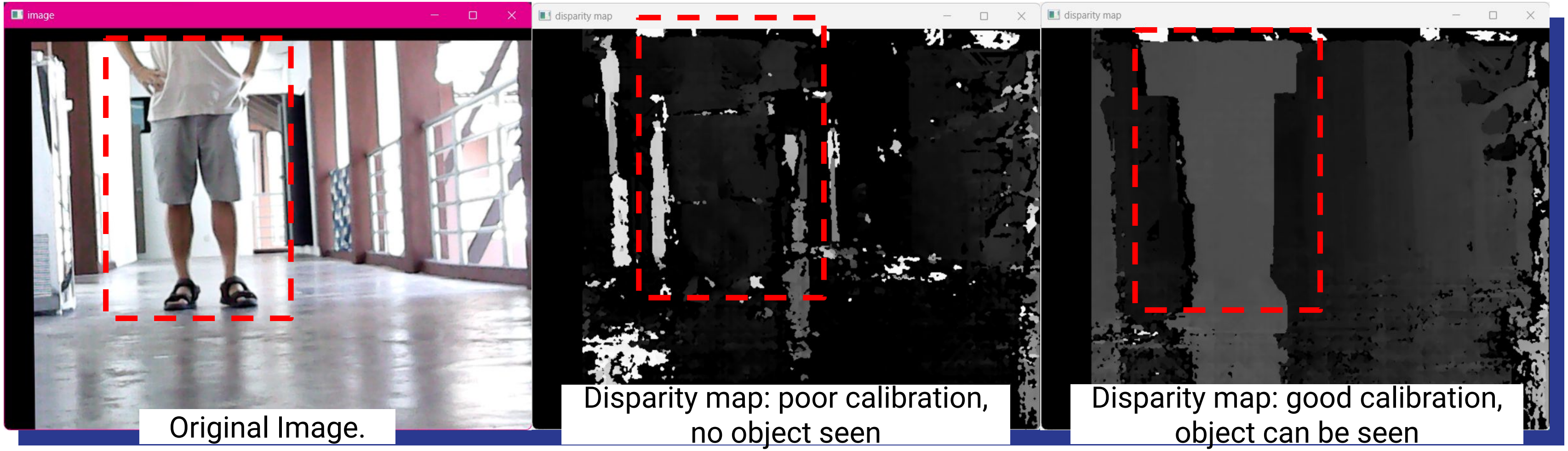


Example output: Average error between the y coordinate of each point is 0.4 pixels, hence the calibration is acceptable.

Results & Discussion (3)

Calibration Accuracy Checker

Check the accuracy of calibration done on the stereo camera



Original Image.

Disparity map: poor calibration, no object seen

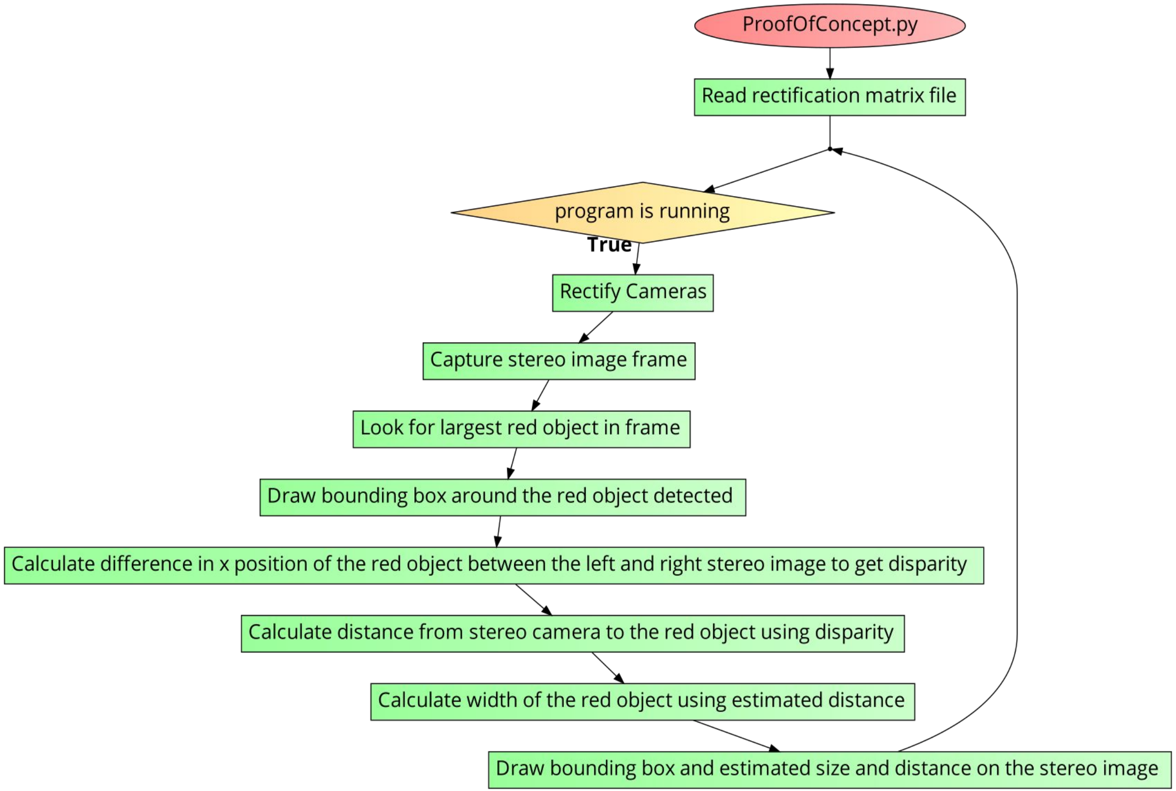
Disparity map: good calibration, object can be seen

Example improvement of disparity map generation. The shape of the object is more visible when calibration is done correctly.

Results & Discussion (4)

Proof of Concept

Relationship between disparity and estimated distance



Preliminary results with addition of stereo calibration

1. Rectify stereo cameras.
2. Look for largest red area in image.
3. Calculate difference in x coordinate between the red area in the left and right image.
4. Compute distance and size of the red area.

Results & Discussion (5)

Proof of Concept

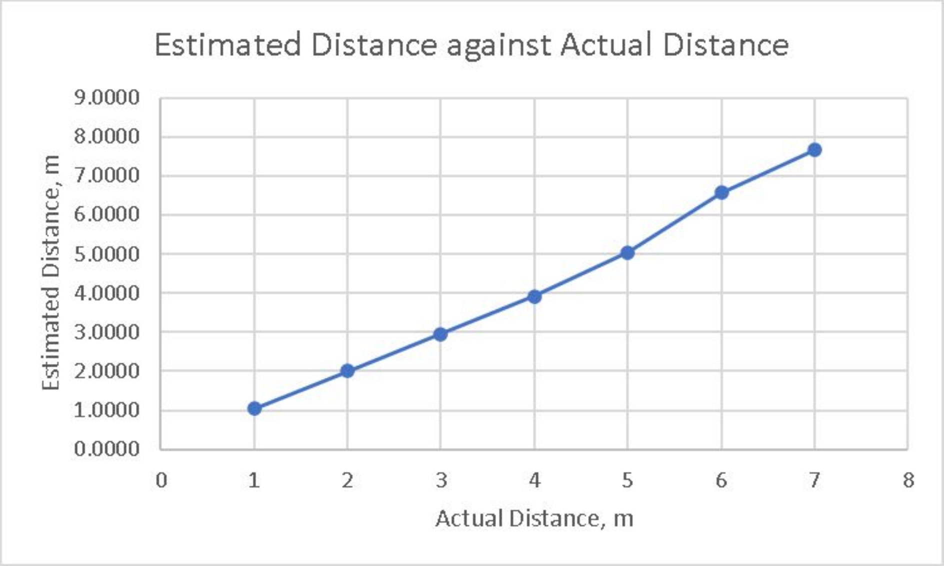
Relationship between disparity and estimated distance

Example output of program.
Red color is set as the constant object detected to simulate a perfect stereo matching scenario.
Distance and width estimated are shown.

Results & Discussion (6)

Proof of Concept

Relationship between disparity and estimated distance



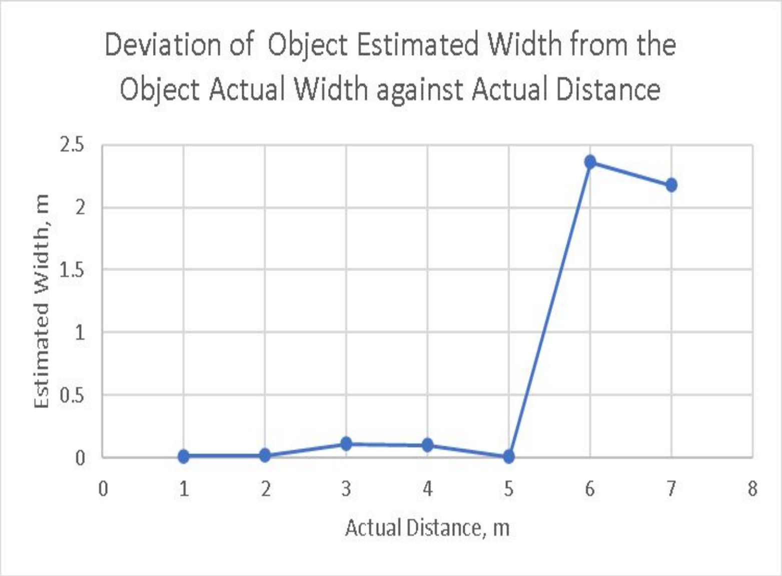
*Average of 500 results

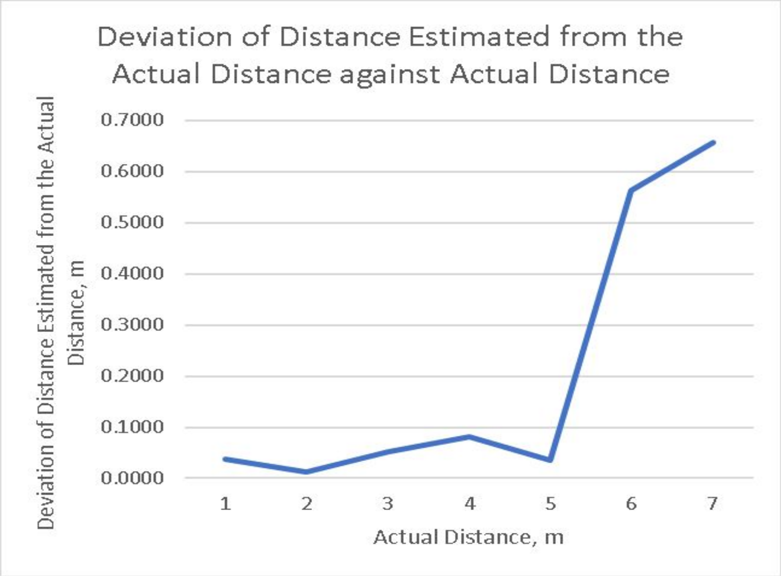
Estimated distance increases proportionally with actual distance.

Results & Discussion (7)

Proof of Concept

Relationship between disparity and estimated distance



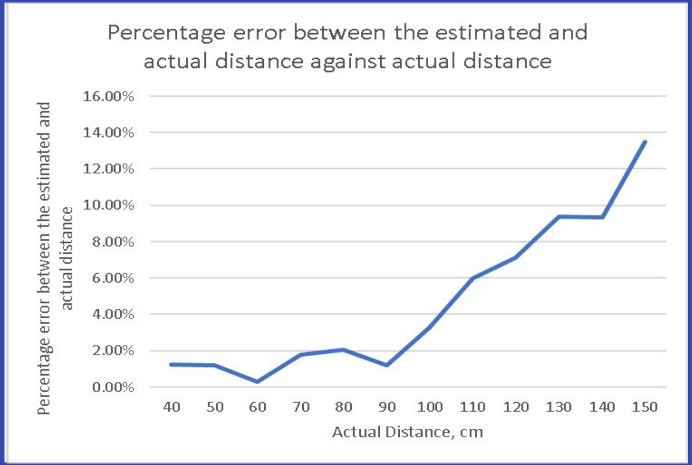


The usable range of the stereo distance estimation is until 5 meters, beyond 5 meters the distance and size estimation starts to deviate too much from their actual values.

Results & Discussion (8)

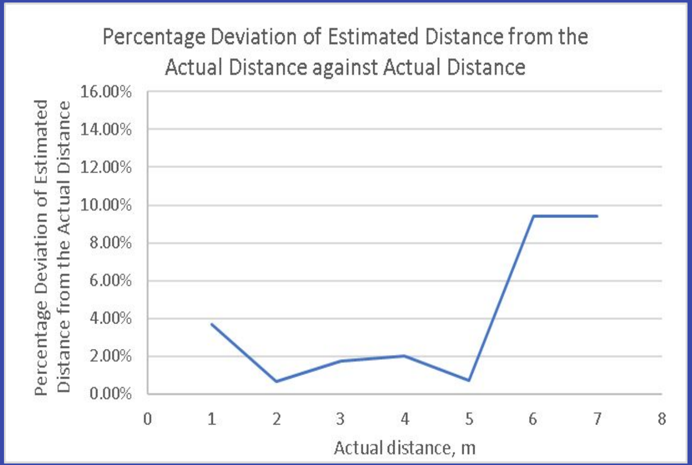
Proof of Concept v. Preliminary results

Before calibration (preliminary results)



Usable range: 0.9 meters

After calibration (proof of concept)



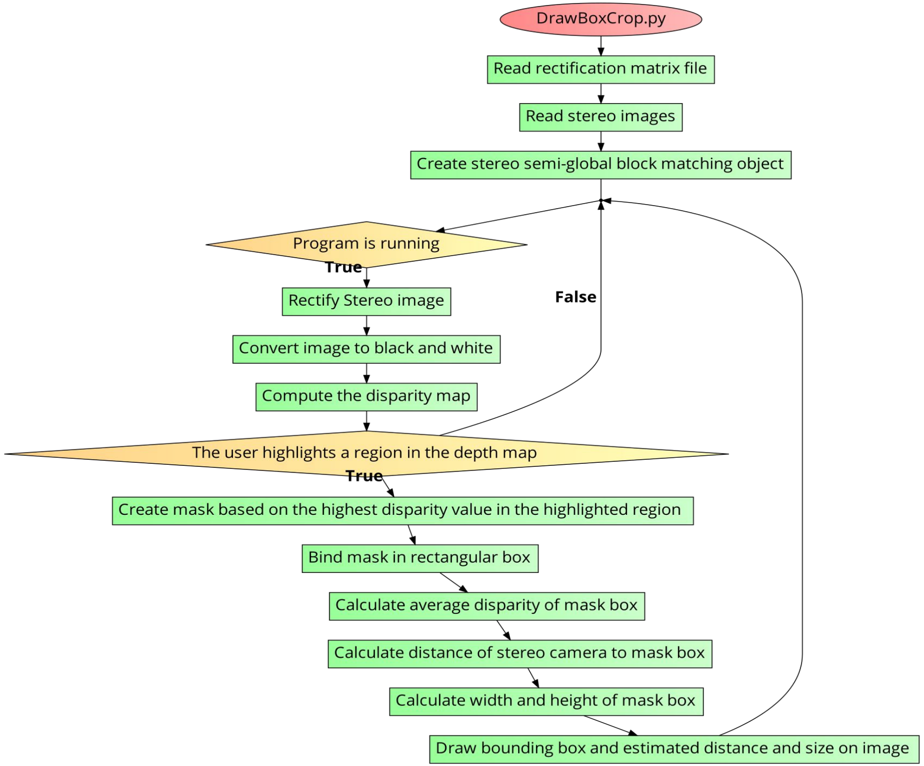
Usable range: 5 meters

After stereo calibration, the usable range of the same stereo vision system increases from 0.9m to 5m. It is safe to say that stereo calibration is vital to stereo distance estimation.

Results & Discussion (9)

Prototype 1

Obtain distance and size based on disparity map



Users are allowed to select a region and the program will compute the size and distance of the region.

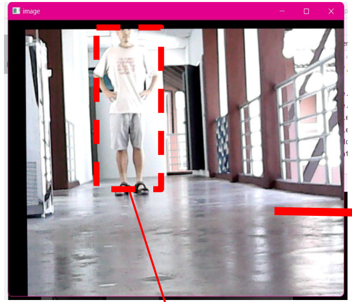
1. Compute stereo matching and disparity map.
2. User selects a region.
3. Compute distance and size of selected region from disparity and size of region.

Results & Discussion (10)

Prototype 1

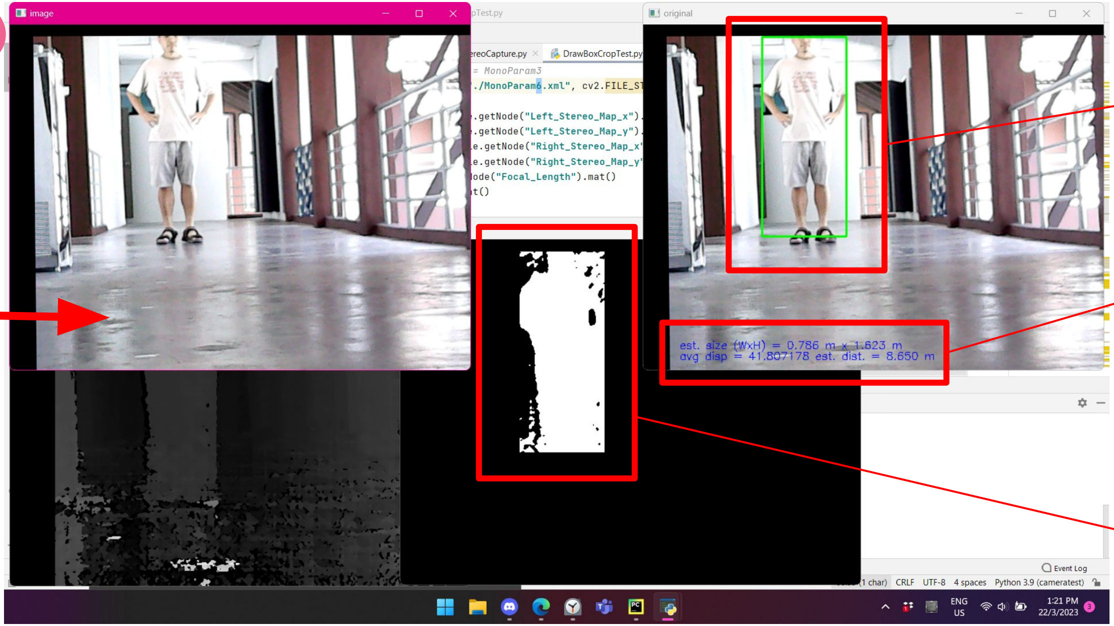
Obtain distance and size based on disparity map

1



User selects a region using the cursor.

2



User selected region is shown.

The region's estimated size and distance is calculated.

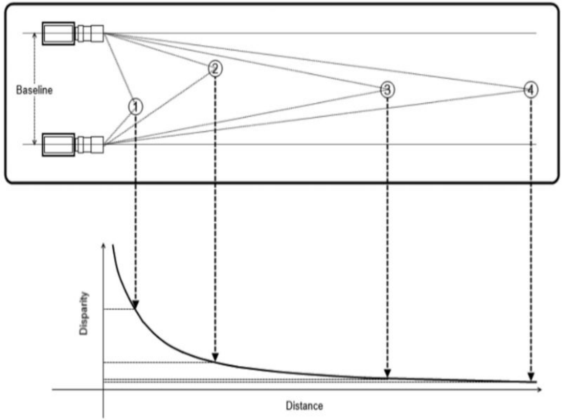
User selected region's depth map region is shown.

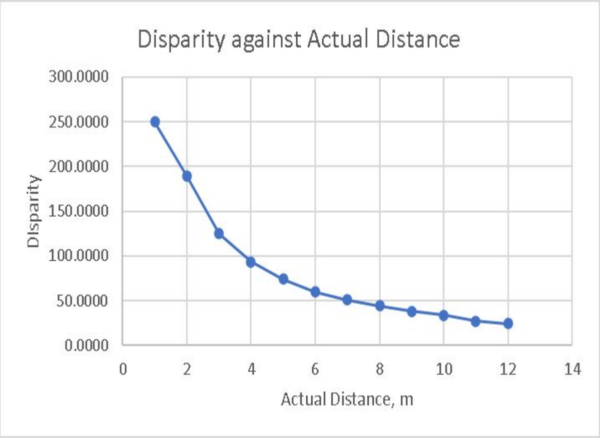
- Due to lack of object detection, user has to highlight object manually, and the shape of the object is roughly estimated

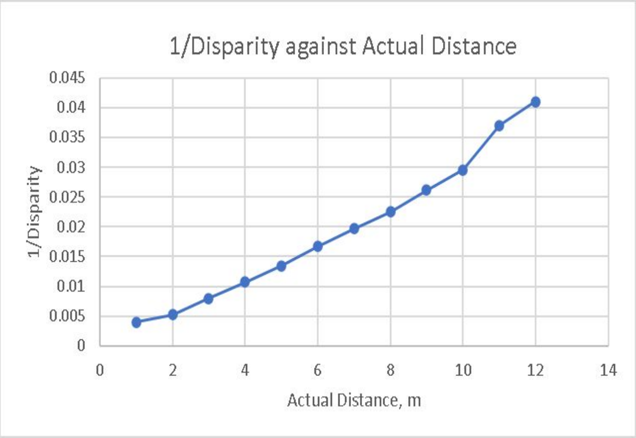
Results & Discussion (11)

Prototype 1

Obtain distance and size based on disparity map





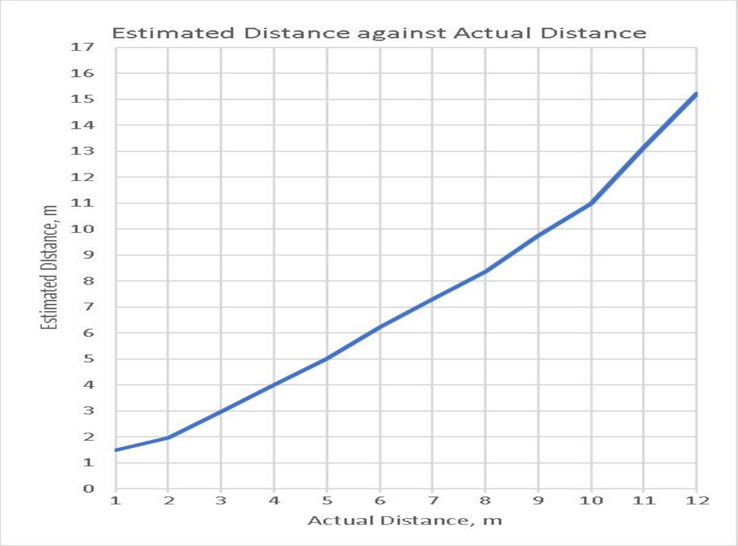


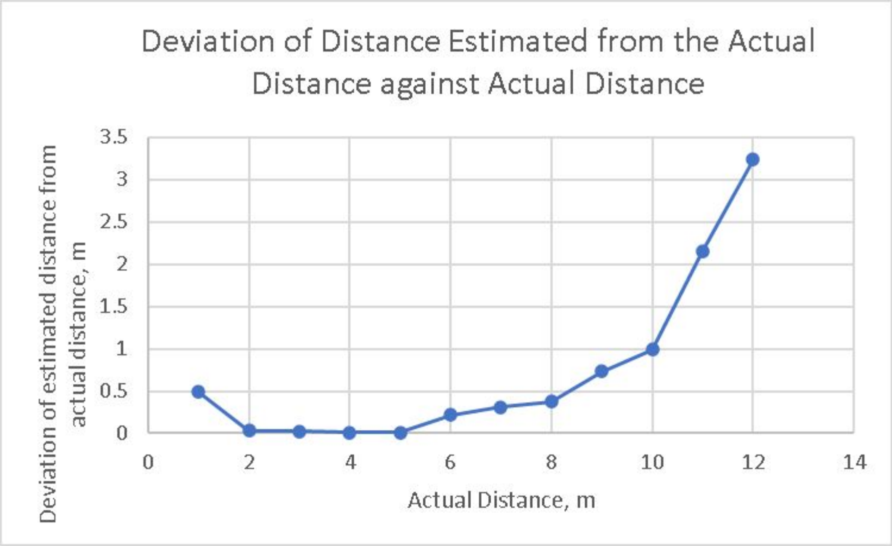
Disparity is inversely proportional to the actual distance between object and the stereo camera. Similar trend as relationship established in Literature review.

Results & Discussion (12)

Prototype 1

Obtain distance and size based on disparity map

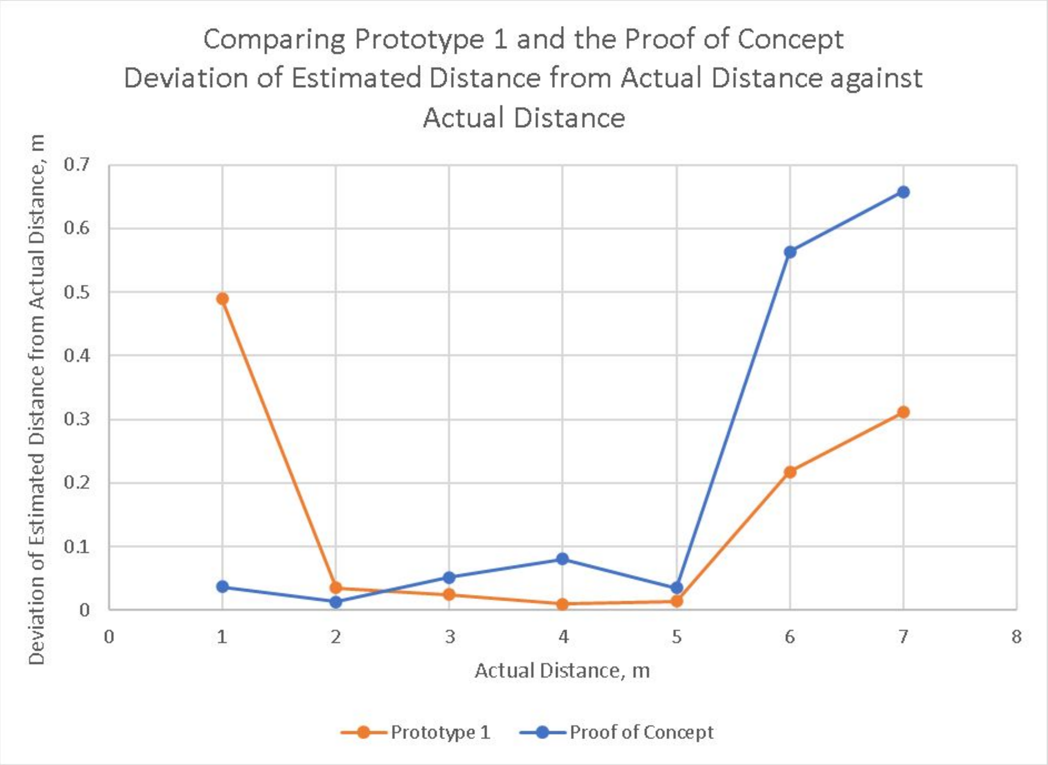




The usable range of the stereo distance estimation is 2 to 5 meters. Below 2 meter and beyond 5 meters, the distance and size estimation starts to deviate too much from their actual values.

Results & Discussion (13)

Prototype 1 v Proof of Concept



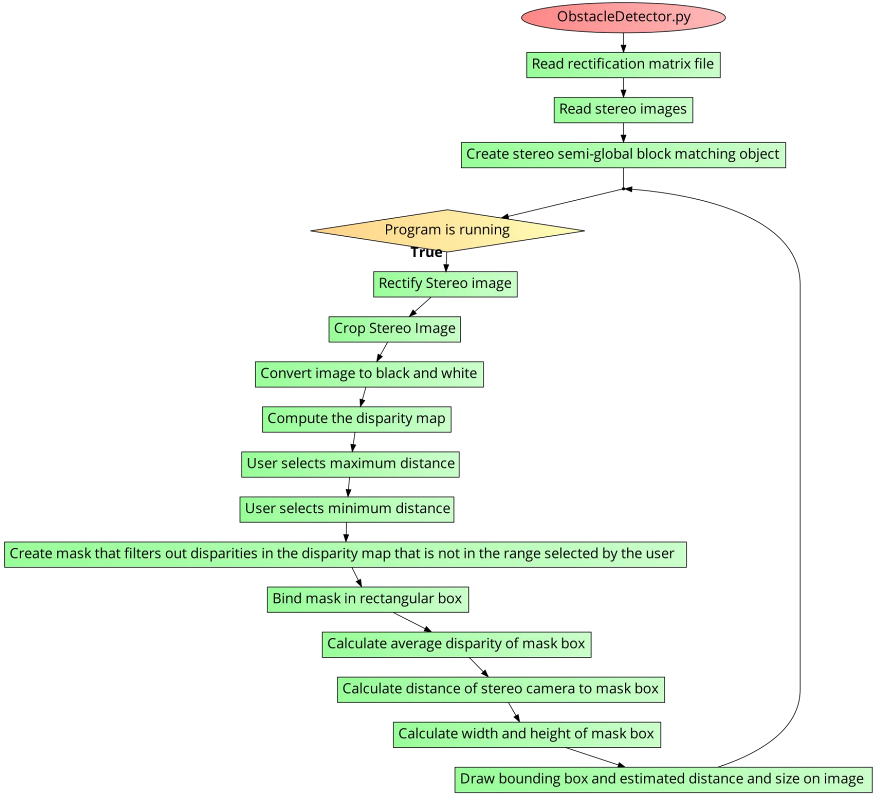
Proof of Concept: uses simple color detection to get disparity. Prototype 1: uses stereo matching to get disparity.

When overlaid on top of each other, Prototype 1 and the Proof of Concept shows a similar trend - the maximum usable range of the stereo camera is 5 meters.

Possible way to increase the range: increase the distance between cameras. [11]

Results & Discussion (14)

Prototype 2
Range/Obstacle Detection



A possible application of stereo distance estimation is obstacle detection.
Simple obstacle detection program:

1. User specifies a maximum and minimum. distance range for the detection algorithm
2. Compute and filter disparity map to only show objects within the specified range (0 to 10 meters).
3. Compute distance and size of the detected region.

Results & Discussion (15)

Prototype 2
Range/Obstacle Detection

White = within range. Black = outside range.

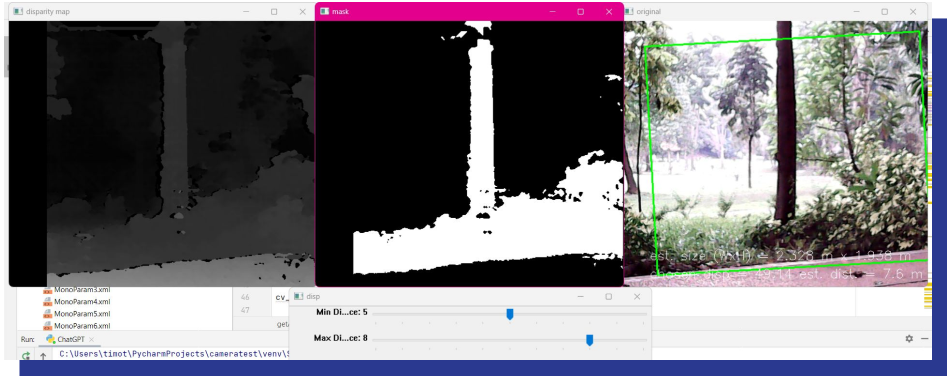
User specifies range

Region within specified range is shown, estimated distance and size shown at the bottom

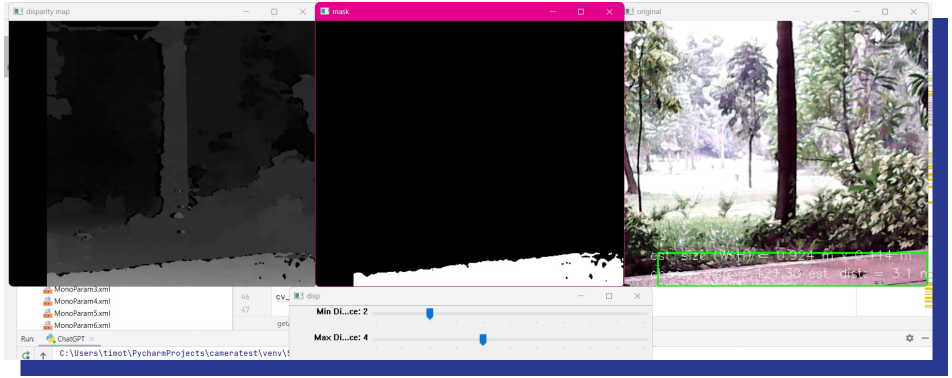
Example output when the detection range is set from 0m (min) to 10m (max).
Footage is captured live.
User can fix detection range in code to fully automate program.

Results & Discussion (16)

Prototype 2
Range/Obstacle Detection



Example output when the detection range is set from 5m (min) to 8m (max). Bushes and trees are detected in that range.



Example output when the detection range is set from 2m (min) to 4m (max). The edge of the sidewalk is detected in that range.

Conclusion (1)

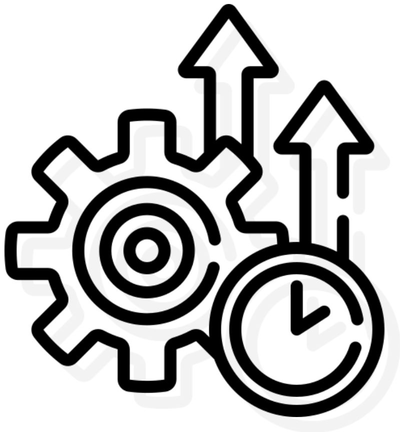
Stereo distance estimation has improved results after calibration and rectification - Preliminary results usable up to 90cm, after calibration usable up to 5 meters.

There is a limited range the distance estimation works best in (2-5 meters) in this setup. Factors that could affect this range:

- Camera quality.
- Distance between stereo cameras.

Conclusion (2)

Future Improvements



Disparity map affected when both cameras have different settings i.e. exposure, brightness. Improvement expected with fixed settings for both.

Study the relationship between distance between stereo cameras and range of accurate distance estimation. [11]

Improve disparity map generation i.e. Machine Learning.

Add object detection/ segmentation for better size measurement.

Conclusion (3)

Stereo vision is a viable method for distance and size estimation with limited range based on implementation.

Applications include:

- Size measurement of object as seen in Prototype 1 and the proof of concept.
- Obstacle detection in robotics as seen in Prototype 2.

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