

Depth perception module for Acme Robotics

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Chapter 1

README

Depth perception module for Acme Robotics

Overview

The depth perception module aims to combine computer vision concepts with image processing techniques to estimate the distance of the human from the camera. We use the Histogram of Gradients (HOG) feature extractor as a human face feature detector and apply pioneering image processing techniques based on pin hole camera concept to provide accurate depth results.

We use the HOG (Histograms of Gradients) algorithm for human face detection. We use open source DLib for face detection. DLib inherently implements HOG with the best optimized hyperparameters for faster processing speeds on a CPU (benchmarks results show best - 'processing speed' vs accuracy ratio for dlib, even better than the SSD object detection by Google which is currently benchmarked as the best 'processing speed' detection algorithm and widely used). Dlib also have the best accuracy in terms of side view face detection. Dlib is Open Source (license) and widely used across industries.

We use OpenCV (v3.0) for supporting our computer vision and image processing tasks. OpenCV allows faster implementations and rapid prototyping and is open source (license).

We propose image processing techniques to estimate the distance of the human from the camera. We extrapolate the pin hole camera concept and apply it to real world scenarios. As explained in the diagram below, the distance of the human from the camera is a function of the camera focus and pixel width of the human face. The camera focus is calculated using a reference image with the human at a known depth from the camera.

Main features of the product

- Distance perception for 'multiple humans' concurrently from the Robots frame of reference
- Fast processing speed
- Cost effective solution - needs installation of only a camera in the Robot
- High accuracy
- Developed in C++(>11) with continuous integration
- Developed by a team of two in an Agile iterative process
- Standalone software product which includes all the dependencies.

Results

As illustrated in the demonstration result above, our product gives Humans location from the camera frame accurately along the X,Y and Z axis, where the X and Y coordinates specify the Humans position in the 2 Dimension and the Z axis specifies the human position in terms of the depth(distance from the camera) in the 3rd Dimension.

Result format = (x_coordinate <in pixels>="",<in pixels>="",<in pixels>="") The above result is appended on the lower right corner of the human face-bounding rectangle.

Accuracy: 100% (tested on 3 test images and got correct distances of the human faces for all the three test cases. Deviations of +-10 centimeters observed and ignored).

Processing speed: average 38 milliseconds (tested on images on I5 CPU with 8GB RAM. The results may vary with different system configurations and with increase in the number of faces in the frame).

Known Limitations and Assumptions for the product :

1. The depth estimation of the human from the robot's frame of reference works within a range of 0.25 meters to 10 meters.
2. The depth estimation model expects satisfactory lighting conditions.
3. The depth estimation model expects the human face to be facing the robot camera and within its field of view.
4. The depth estimation model presented here is tuned for Acme Robot camera specifications. Hyperparameters need to be re-calibrated before being deployed to another class of robots.
5. We assume that the average width of adult human face does not vary much. Calculation differences due to minor width differences (delta) are mitigated by P (pixel width values) which also increases proportionally with delta.

System Overview

Agile Development Process followed

AIP Details link

https://docs.google.com/spreadsheets/d/1t8c64cWS98ADABuzGFxU81cme3-aIhM_4wCTikXWeNU/edit?usp=sharing

Meeting Notes (Minutes of Meetings)

<https://docs.google.com/document/d/1sAKEH1b5n9JzFRYK6OL4Pm4foj7QHOMjy63lytvxo4Y/edit?usp=sharing>

Demo steps-Includes steps to run solitary unit test cases

```
For running our solution:
git clone https://github.com/shivamakhauri04/midterm_project.git
cd midterm_project
mkdir build
cd build
cmake ..
Enter system password for verification
make -j<number of cores> (Example- make -j12)
Run tests: ./test/cpp-test
Run program: ./app/shell-app
```


Known Issues and bugs

The open- source library used- Opencv and dlib have not been completely written in C++ 11 and greater. Hence cmake generates warnings.

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Contributors

-Shivam Akhauri (Driver) -Former Artificial Intelligence Engineer at Ether Labs. -Former Machine learning Engineer and Project Lead at Tata Elxsi. -Skilled in AI/ML with applications in Computer vision, NLP and Robotics.

-Toyas Dhake (Navigator) -Robotics engineer, University of Maryland College Park. -Skilled in embedded system with applications involving Arduino, Raspberry Pi and Jetson Boards.

Chapter 2

Class Index

2.1 Class List

Here are the classes, structs, unions and interfaces with brief descriptions:

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Face	11

Chapter 3

File Index

3.1 File List

Here is a list of all files with brief descriptions:

app/distance.cpp	
This is a class for depth perception module based on image from single camera	15
app/face.cpp	
This is a class to store properties of face	16
app/main.cpp	16
include/distance.hpp	
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Chapter 4

Class Documentation

4.1 CalculateDistance Class Reference

```
#include <distance.hpp>
```

Public Member Functions

- double [calculateFocalLength](#) ()
Function to calculate focal length of camera from a reference iamge.
- [CalculateDistance](#) ()
Constructor to set the width of human face and find focal length from reference image. @params _width Width of head @params _focalLength Focal length of camera.
- std::vector< [Face](#) > [getDistance](#) (cv::Mat image, dlib::frontal_face_detector detector)
This is the function which computes the distance of each human from the camera @params image Image captured by camera, dlib face detector object.
- double [calDist](#) (double width, double [focalLength](#))
This function contains the formula for distance calculation @params width of the detected face, focalLength of the camera.

Public Attributes

- double [focalLength](#)
- double [realTimeDistance](#) = 0

4.1.1 Constructor & Destructor Documentation

4.1.1.1 CalculateDistance()

```
CalculateDistance::CalculateDistance ( )
```

Constructor to set the width of human face and find focal length from reference image. @params _width Width of head @params _focalLength Focal length of camera.

4.1.2 Member Function Documentation

4.1.2.1 calculateFocalLength()

```
double CalculateDistance::calculateFocalLength ( )
```

Function to calculate focal length of camera from a reference iamge.

Returns

Focal length of camera calculated

4.1.2.2 calDist()

```
double CalculateDistance::calDist (
    double width,
    double focalLength )
```

This function contains the formula for distance calculation @params width of the detected face, focalLength of the camera.

Returns

double value of the calculated distance

4.1.2.3 getDistance()

```
std::vector< Face > CalculateDistance::getDistance (
    cv::Mat image,
    dlib::frontal_face_detector detector )
```

This is the function which computes the distance of each human from the camera @params image Image captured by camera, dlib face detector object.

Returns

vector of Distances for each face in the frame

4.1.3 Member Data Documentation

4.1.3.1 focalLength

```
double CalculateDistance::focalLength
```

4.1.3.2 realTimeDistance

```
double CalculateDistance::realTimeDistance = 0
```

The documentation for this class was generated from the following files:

- [include/distance.hpp](#)
- [app/distance.cpp](#)

4.2 Face Class Reference

```
#include <face.hpp>
```

Public Member Functions

- [Face](#) (double _x, double _y, double _w, double _h, double _distance)
Constructor to set x, y, width, height and distance of face. @params _x x coordinates of face @params _y y coordinates of face @params _w Width of face @params _h Height of face @params _distance Distance of face from camera.
- void [setX](#) (double _x)
This is the function to set x coordinates of face. @params _x x coordinates of face.
- double [getX](#) ()
This is the function to get x coordinates of face.
- void [setY](#) (double _y)
This is the function to set y coordinates of face. @params _y y coordinates of face.
- double [getY](#) ()
This is the function to get y coordinates of face.
- void [setH](#) (double _h)
This is the function to set height of face. @params _h Height of face.
- double [getH](#) ()
This is the function to get height of face.
- void [setW](#) (double _w)
This is the function to set width of face. @params _w Width of face.
- double [getW](#) ()
This is the function to get width of face.
- void [setDistance](#) (double _distance)
This is the function to set distance of face from camera. @params _distance Distance of face from camera.
- double [getDistance](#) ()
This is the function to get distance of face from camera.

4.2.1 Constructor & Destructor Documentation

4.2.1.1 Face()

```
Face::Face (
    double _x,
    double _y,
    double _w,
    double _h,
    double _distance )
```

Constructor to set x, y, width, height and distance of face. @params _x x coordinates of face @params _y y coordinates of face @params _w Width of face @params _h Height of face @params _distance Distance of face from camera.

4.2.2 Member Function Documentation

4.2.2.1 getDistance()

```
double Face::getDistance ( )
```

This is the function to get distance of face from camera.

Returns

Current distance of face from camera

4.2.2.2 getH()

```
double Face::getH ( )
```

This is the function to get height of face.

Returns

Current value of height of face

4.2.2.3 getW()

```
double Face::getW ( )
```

This is the function to get width of face.

Returns

Current value of width of face

4.2.2.4 getX()

```
double Face::getX ( )
```

This is the function to get x coordinates of face.

Returns

Current value of x

4.2.2.5 getY()

```
double Face::getY ( )
```

This is the function to get y coordinates of face.

Returns

Current value of y

4.2.2.6 setDistance()

```
void Face::setDistance (
    double _distance )
```

This is the function to set distance of face from camera. @params _distance Distance of face from camera.

4.2.2.7 setH()

```
void Face::setH (
    double _h )
```

This is the function to set height of face. @params _h Height of face.

4.2.2.8 setW()

```
void Face::setW (
    double _w )
```

This is the function to set width of face. @params _w Width of face.

4.2.2.9 setX()

```
void Face::setX (
    double _x )
```

This is the function to set x coordinates of face. @params _x x coordinates of face.

4.2.2.10 setY()

```
void Face::setY (
    double _y )
```

This is the function to set y coordinates of face. @params _y y coordinates of face.

The documentation for this class was generated from the following files:

- [include/face.hpp](#)
- [app/face.cpp](#)

Chapter 5

File Documentation

5.1 app/distance.cpp File Reference

This is a class for depth perception module based on image from single camera.

```
#include <dlib/opencv.h>
#include <dlib/image_processing/frontal_face_detector.h>
#include <dlib/image_processing/render_face_detections.h>
#include <dlib/image_processing.h>
#include <dlib/gui_widgets.h>
#include <dlib/image_io.h>
#include <iostream>
#include <distance.hpp>
#include <face.hpp>
#include <opencv2/highgui/highgui.hpp>
```

5.1.1 Detailed Description

This is a class for depth perception module based on image from single camera.

Author

Shivam Akhauri (Driver), Toyas Dhake (Navigator)

Date

19 October 2019

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5.2 app/face.cpp File Reference

This is a class to store properties of face.

```
#include <face.hpp>
```

5.2.1 Detailed Description

This is a class to store properties of face.

Author

Shivam Akhauri (Navigator), Toyas Dhake (Navigator)

Date

20 October 2019

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5.3 app/main.cpp File Reference

```
#include <dlib/opencv.h>
#include <dlib/gui_widgets.h>
#include <dlib/image_processing/frontal_face_detector.h>
#include <iostream>
#include <distance.hpp>
#include <face.hpp>
#include <opencv2/highgui/highgui.hpp>
```

Functions

- int [main](#) ()

5.3.1 Function Documentation

5.3.1.1 main()

```
int main ( )
```

5.4 test/main.cpp File Reference

```
#include <gtest/gtest.h>
```

Functions

- int [main](#) (int argc, char **argv)

5.4.1 Function Documentation

5.4.1.1 main()

```
int main (  
    int argc,  
    char ** argv )
```

5.5 include/distance.hpp File Reference

This is a class for depth perception module based on image from single camera.

```
#include <dlib/image_processing/frontal_face_detector.h>  
#include <vector>  
#include <opencv2/opencv.hpp>  
#include <face.hpp>
```

Classes

- class [CalculateDistance](#)

5.5.1 Detailed Description

This is a class for depth perception module based on image from single camera.

Author

Toyas Dhake (Driver), Shivam Akhauri (Navigator)

Date

11 October 2019

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5.6 include/face.hpp File Reference

This is a class to store properties of faces.

Classes

- class [Face](#)

5.6.1 Detailed Description

This is a class to store properties of faces.

Author

Toyas Dhake (Driver), Shivam Akhauri (Navigator)

Date

11 October 2019

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5.7.1 Function Documentation

5.7.1.1 files()

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5.8 README.md File Reference

5.9 test/test.cpp File Reference

```
#include <gtest/gtest.h>
#include <dlib/opencv.h>
#include <dlib/image_processing/frontal_face_detector.h>
#include <dlib/image_processing/render_face_detections.h>
#include <dlib/image_processing.h>
#include <dlib/gui_widgets.h>
#include <dlib/image_io.h>
#include <chrono>
#include <opencv2/highgui/highgui.hpp>
#include <distance.hpp>
#include <face.hpp>
```

Functions

- **TEST** ([Face](#), setterTestForLeftCoordinates)
Test for face left coordinates.
- **TEST** ([Face](#), setterTestForRightCoordinates)
Test for face right coordinates.
- **TEST** ([Face](#), setterTestForTopCoordinates)
Test for face top coordinates.
- **TEST** ([Face](#), setterTestForBottomCoordinates)
Test for face bottom coordinates.
- **TEST** ([Face](#), setterTestForFaceDistance)
Test for face Distance.
- **TEST** (calculateDistance, TestForCalDist)
Test for calDist function The focal length is set as per camera specs if width and known width are passed as 1, the return should be 1.
- **TEST** (calculateDistance, TestForFocalLength)
Test for calculate focal length. focal length of the camera from camera specifications. This should match with the return value from calculateFocalLength.

- **TEST** (calculateDistance, productAccuracyTest_1)
Test for ACCURACY with test image 1 Took a test image with known distance of person from camera ran getDistance function (solitary testing)
- **TEST** (calculateDistance, productAccuracyTest_2)
Test for ACCURACY with test image 2 Took a test image with known distance of person from camera ran getDistance function (solitary testing)
- **TEST** (calculateDistance, productAccuracyTest_3)
Test for ACCURACY with test image 3 Took a test image with known distance of person from camera ran getDistance function (solitary testing)
- **TEST** (calculateDistance, productPerformanceTest_1)
Test for PERFORMANCE in terms of execution time for test image 1.
- **TEST** (calculateDistance, productPerformanceTest_2)
Test for PERFORMANCE in terms of execution time for test image 2.
- **TEST** (calculateDistance, productPerformanceTest_3)
Test for PERFORMANCE in terms of execution time for test image 3.

5.9.1 Function Documentation

5.9.1.1 TEST() [1/13]

```
TEST (
    Face ,
    setterTestForLeftCoordinates )
```

Test for face left coordinates.

5.9.1.2 TEST() [2/13]

```
TEST (
    Face ,
    setterTestForRightCoordinates )
```

Test for face right coordinates.

5.9.1.3 TEST() [3/13]

```
TEST (
    Face ,
    setterTestForTopCoordinates )
```

Test for face top coordinates.

5.9.1.4 TEST() [4/13]

```
TEST (
    Face ,
    setterTestForBottomCoordinates )
```

Test for face bottom coordinates.

5.9.1.5 TEST() [5/13]

```
TEST (
    Face ,
    setterTestForFaceDistance )
```

Test for face Distance.

5.9.1.6 TEST() [6/13]

```
TEST (
    calculateDistance ,
    TestForCalDist )
```

Test for calDist function The focal length is set as per camera specs if width and known width are passed as 1, the return should be 1.

5.9.1.7 TEST() [7/13]

```
TEST (
    calculateDistance ,
    TestForFocalLength )
```

Test for calculate focal length. focal length of the camera from camera specifications. This should match with the return value from calculateFocalLength.

5.9.1.8 TEST() [8/13]

```
TEST (
    calculateDistance ,
    productAccuracyTest_1 )
```

Test for ACCURACY with test image 1 Took a test image with known distance of person from camera ran get↵ Distance function (solitary testing)

5.9.1.9 TEST() [9/13]

```
TEST (
    calculateDistance ,
    productAccuracyTest_2 )
```

Test for ACCURACY with test image 2 Took a test image with known distance of person from camera ran get↵
Distance function (solitary testing)

5.9.1.10 TEST() [10/13]

```
TEST (
    calculateDistance ,
    productAccuracyTest_3 )
```

Test for ACCURACY with test image 3 Took a test image with known distance of person from camera ran get↵
Distance function (solitary testing)

5.9.1.11 TEST() [11/13]

```
TEST (
    calculateDistance ,
    productPerformanceTest_1 )
```

Test for PERFORMANCE in terms of execution time for test image 1.

5.9.1.12 TEST() [12/13]

```
TEST (
    calculateDistance ,
    productPerformanceTest_2 )
```

Test for PERFORMANCE in terms of execution time for test image 2.

5.9.1.13 TEST() [13/13]

```
TEST (
    calculateDistance ,
    productPerformanceTest_3 )
```

Test for PERFORMANCE in terms of execution time for test image 3.

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