SIDDAGANGA INSTITUTE OF TECHNOLOGY, TUMAKURU-572103

(An Autonomous Institute under Visvesvaraya Technological University, Belagavi)

Project Report on

"Robotic Fish"

submitted in partial fulfillment of the requirement for the award of the degree of

BACHELOR OF ENGINEERING

in

ELECTRONICS & COMMUNICATION ENGINEERING

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DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

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DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

CERTIFICATE

Certified that the project work entitled "ROBOTIC FISH" is a bonafide work carried out by Asra (1SI17EC012), Bhavana S (1SI17EC016), Chinmai S Jeenakeri (1SI17EC020) and K Nandini (1SI17EC034) in partial fulfillment for the award of degree of Bachelor of Engineering in Electronics & Communication Engineering from Siddaganga Institute of Technology, an autonomous institute under Visvesvaraya Technological University, Belagavi during the academic year 2020-21. It is certified that all corrections/suggestions indicated for internal assessment have been incorporated in the report deposited in the department library. The Project report has been approved as it satisfies the academic requirements in respect of project work prescribed for the Bachelor of Engineering degree.

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Course Outcomes

CO 1 : Identify and formulate the problem through literature survey and knowledge of contemporary engineering technology.

CO 2 : Apply engineering knowledge to arrive at optimal design solutions for solving engineering problems in compliance with the prescribed safety norms/standards taking into consideration environmental concerns.

CO 3 : Select suitable engineering tools, platform, sub-system for solving identified engineering problem.

CO 4 : Implement the proposed solution on the selected platform, considering societal, health issues. Validate the design, analyse and interpret the results using modern tools.

CO 5 : Comprehend and prepare document as per the standard, present effectively the work following professional ethics, interact with target group.

CO 6 : Contribute to the team as a member, lead the diverse team.

CO 7 : Demonstrate engineering and management principles, perform the budget analysis through utilization of the resources (finance, power, area, bandwidth, weight, size, etc)

CO-PO Mapping

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
CO-1	3	3										2	3	
CO-2			3									2		3
CO-3			3											3
CO-4				3	3	2	2					2		3
CO-5								3		3		2		2
CO-6									3					3
CO-7											2		2	
Average	3	3	3	3	3	2	2	3	3	3	2	2	3	3

Attainment level: - 1: Slight (low) 2: Moderate (medium) 3: Substantial (high)

POs: PO1: Engineering Knowledge, PO2: Problem analysis, PO3: Design/Development of solutions, PO4: Conduct investigations of complex problems, PO5: Modern tool usage, PO6: Engineer and society, PO7: Environment and sustainability, PO8: Ethics, PO9: Individual and team work, PO10: Communication, PO11: Project management and finance, PO12: Lifelong learning

Abstract

Garbage and debris generated by human activities can be seen in various water environment such as lakes, ponds and rivers. Removal of marine debris is required to prevent threats to marine and human life and to maintain a sustainable environment. Detecting and collecting debris face various issues due to the unique difficulties of the water environment. Autonomous vehicular technology can be helpful to detect and collect debris in water sources. In this project, a robotic fish, which is a remotely controlled pilot less vehicle, is used to detect floating marine trash and eventually remove them. This intelligent robotic fish, which propels by using mechanical propellers, could help in addressing the problem of water debris by detecting and collecting the floating trash. You Only Look Once (YOLO) algorithm, which is based on Convolution Neural Networks (CNN), is used in detection of debris in the water environment. The system contains a garbage bin to collect the debris. The conveyor belt, which is driven by a DC motor, is responsible for the movement of trash from the surface of water to the garbage bin. The model has been tested in experimental water tank and results of detection and collection of trash has been presented.

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Chapter 1

Introduction

Trash accumulation in water bodies adversely affect the marine ecosystems and pose a long-term threat to aquatic species. This vast amount of trash in the water sources that injures aquatic life and contaminates the water must be removed periodically. An effective strategy for removing debris from marine environment is the use of autonomous underwater vehicles for trash detection and removal.

An autonomous underwater vehicle is a robot that travels on the surface and underwater which can be used to conduct underwater researches. Remotely Operated Underwater Vehicle (ROV) is an unoccupied vehicle, which is fitted out with sensors and other tools to collect various types of data. These vehicles provide a safe alternative to explore dangerous areas. ROVs, equipped with many tools, have applications in many fields including military and science.

1.1 Motivation

Trash enters water bodies in various ways and contaminates the water. Maintaining clean water is essential and involves the removal of debris more frequently. Out of various types of marine trash, plastic wastes are the most dominant waste material found on the water surface. Recycling and other activities to keep debris out of the water reservoirs are also very important but there is a need for an efficient strategy to remove the debris which are already in the water resource. One of the widely used techniques for collecting plastic from water source is refuse-removal vessel method. However, this method is appropriate only to large rivers with a significant accumulation of plastic and cannot be implemented to clean small water sources with low-density waste. Hence, a robotic system may be helpful to clean small water bodies like water tanks, swimming pools, small ponds, etc.

1.2 Objective of the project

There are mainly three objectives in the project. These objectives are listed below.

1. To build a robot that moves smoothly on the surface of the water.

2. To remotely control the robotic fish using Radio Frequency (RF) technology.

3. To make the robot capable of finding and collecting certain kinds of trash like small plastic covers and bottle caps floating on the surface of water.

The process of detecting the floating trash visually in natural water environments is achieved using deep learning algorithms. The convolutional neural network is one of the widely used deep learning networks for analyzing, processing and classifying visual data. CNN algorithm is used to achieve the trash detection task. The system consists of a garbage bin to collect the trash. The conveyor system efficiently transfers the floating trash into the garbage bin.

1.3 Organisation of the report

The project report is presented in a number of chapters, Chapter 1 comprises of introduction, motivation and objective of the project. Chapter 2 consists of literature review. Chapter 3 gives the information about the system overview. System hardware and System software are presented in Chapter 4 and chapter 5 respectively. Chapter 6 consists of details of experiments and results. Finally, the conclusion and scope for future work are presented in Chapter 7.

Chapter 2

Literature Survey

Bionic or biologically inspired engineering is covering all the fields and there has been a rapid increase in research and development of the bio-inspired mechatronic system. Robotic fish is an example of bio inspired AUV's and it is found that robotic fish performs better and are more competent than current AUV's in the field of underwater explorations [1]. Since 1993, the unmanned surface vehicles has been evolving for various missions such as navigation system, water environment exploration, scientific researches on aquatic species and various military applications. Robotic fishes have better propulsion capabilities, stability, efficiency and exhibits their vast potentials for researches.

Robotic technology is making exploration cheaper and more accessible with its ability to withstand harsh environments, tides and ocean currents [2]. Safety is the main advantage of utilizing robotics so that there will be no risk to human life. Robotic fish can record videos and take pictures. The robot can also gather information about artifacts and biological environment of the water body.

2.1 Robotic fish swimming modes

Generally, there are two ways of designing robots swimming on the water surface. The first technique employs fish like swimming modes which propels using fins attached to it. The second method is more like a robotic boat equipped with mechanical propellers for smooth motion.

2.1.1 Propulsion using fins

Generally, a robotic fish exhibits undulatory motion in either of the two ways:

1. Using the body and/or caudal fin (BCF) movements.

2. Using median and/or paired fin (MPF) movements.

BCF provides greater thrust and accelerations. Robotic fish depends on undulation movements to produce the main propel energy. This type of propulsion is less noisy, more effective and maneuverable.

The swim patterns of fish can be periodic or steady or unsteady (includes, fast start, sharp turns and brakes). Basic swim patterns can be divided as follows [3]:

1. Straight motion: The fish moves straight at a constant speed.
2. Turning: Fish turns at a small angular speed with constant linear speed.
3. Coast: Fish body is kept stationary.
4. Brake: The fish imparts a sudden de-acceleration.

All the swim patterns are generated by special tail motion and pectoral fin motion. Caudal/tail fin is used to produce propulsion. Pectoral fins are found in pairs which are used to maintain depth in water, turn and stop quickly [4].

2.1.2 Propulsion using mechanical propellers

Underwater vehicles achieve transmission with thrusters and propellers. These mechanical devices drive the underwater robot forward or backward which depends on the direction of rotation or pitch of the propeller [5].

Propellers are attached to the robot body via shaft arrangement. As shown in Figure 2.1, propellers consist of radiating blades which when rotated exerts linear thrust on the water. The blades are shaped in such a way that their rotational motion in the water creates a pressure difference between the two surfaces of the blade.

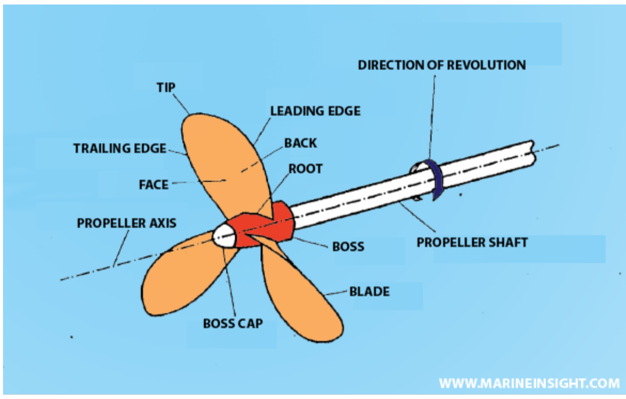

Figure 2.1: Parts of a 3 blade propeller.

As motor rotates the propeller, rotational motion is converted into thrust (linear in nature). The resulting force imparts momentum to the water and pushes the robot forward. In order to have backward motion, the motor and hence the propeller is rotated in opposite direction so that the thrust is reversed.

2.2 Object detection using CNN

The field of computer vision has been going through tremendous developments as the technology has enormous applications such as scene understanding, robotics, video surveillance, and self-driving systems [6]. Visual recognition systems, which is the core for all these applications, includes image classification, localization and detection. As significant developments in neural networks has been achieved, the visual recognition systems have reached exceptional performance. Object detection is one among these domains witnessing great success in computer vision.

Convolutional neural network can be considered as a class of deep learning network. It employs feed-forward approach. This algorithm has been efficiently used to produce accurate results in computer vision tasks, such as image classification and detection [7]. CNNs are like traditional neural network, but they are composed of deeper layers. Figure 2.2 shows the CNN architecture. It is made up of three important layers namely, convolutional layer, pooling layer and fully connected layer. Convolutional layer and pooling layer are alternated and hence the depth of each filter keeps on increasing from left to right and the output size (height and width) decreases eventually. The fully connected layer is the final stage in the network which is similar to the last layer of the conventional neural networks. The input to the model is an image that consists matrix of pixel

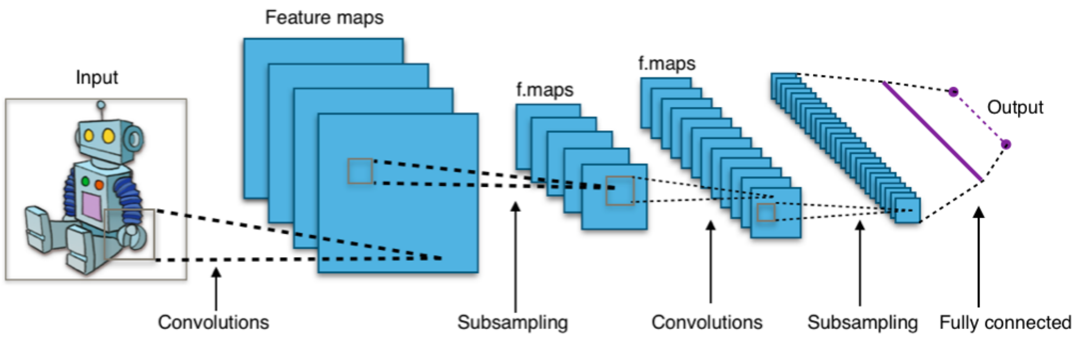

Figure 2.2: CNN Architecture.

values. A neuron in CNN is similar to biological neurons and produces the sum of its input values. In convolutional layer, neurons are connected to the local regions in the image. The convolutional layer's parameters are made up of a set of learnable filters, also called as kernels. These filters are convolved across the width and height of the input volume. Scalar product of the input values and the filter values is computed. This process results in a 2-dimensional activation map of that kernel. In this way the network learns the filters. After the model learns about the features, if it finds some particular type of feature at some spatial position in the input frame, a trigger is initiated. This is how the convolutional neural network learns and detects objects in the input images.

2.3 Mechanism for Debris Collection

Robotics has seen various applications in industrial automation as robotic manipulators and automatic guided vehicles have proved to improve efficiency in industrial automation applications. A robotic arm is one of the widely used efficient and preferred electromechanical machines for many applications in most of the industrial and dangerous areas [8]. Most of the floating debris are small and deformable. Therefore, it is ineffective to use robotic arms or manipulators to pick the trash one by one.

Conveyor systems are reliable, durable and less expensive component to move or carry various things. This system is labor saving and used in automated distribution and warehousing. The system consists of two or more pulleys. The belt rotates about them and forms a closed loop [10]. Figure 2.3 shows the conveyor system in which pair of tongs helps to move the trash to the front of the conveyor belt. The belt lifts the trash and dumps it in the garbage bin. The conveyor belt mechanism has the advantages of being simple, easy to control, suitable for collecting different types of waste and cost effective.

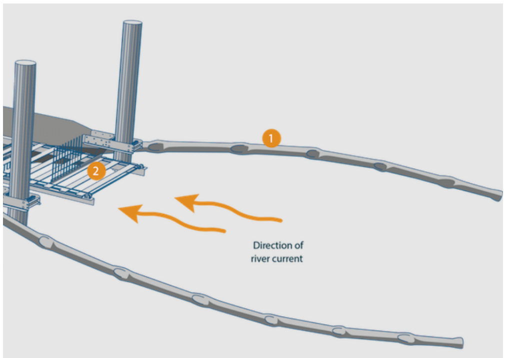

Figure 2.3: Conveyor System.

Chapter 3

System Overview

The project can be divided into mainly three parts. First part is the robot design which includes motion control of the robot. Second part is to detect the debris and the third part is to collect the debris based on the detection results. The overall block diagram is show in Figure 3.1.

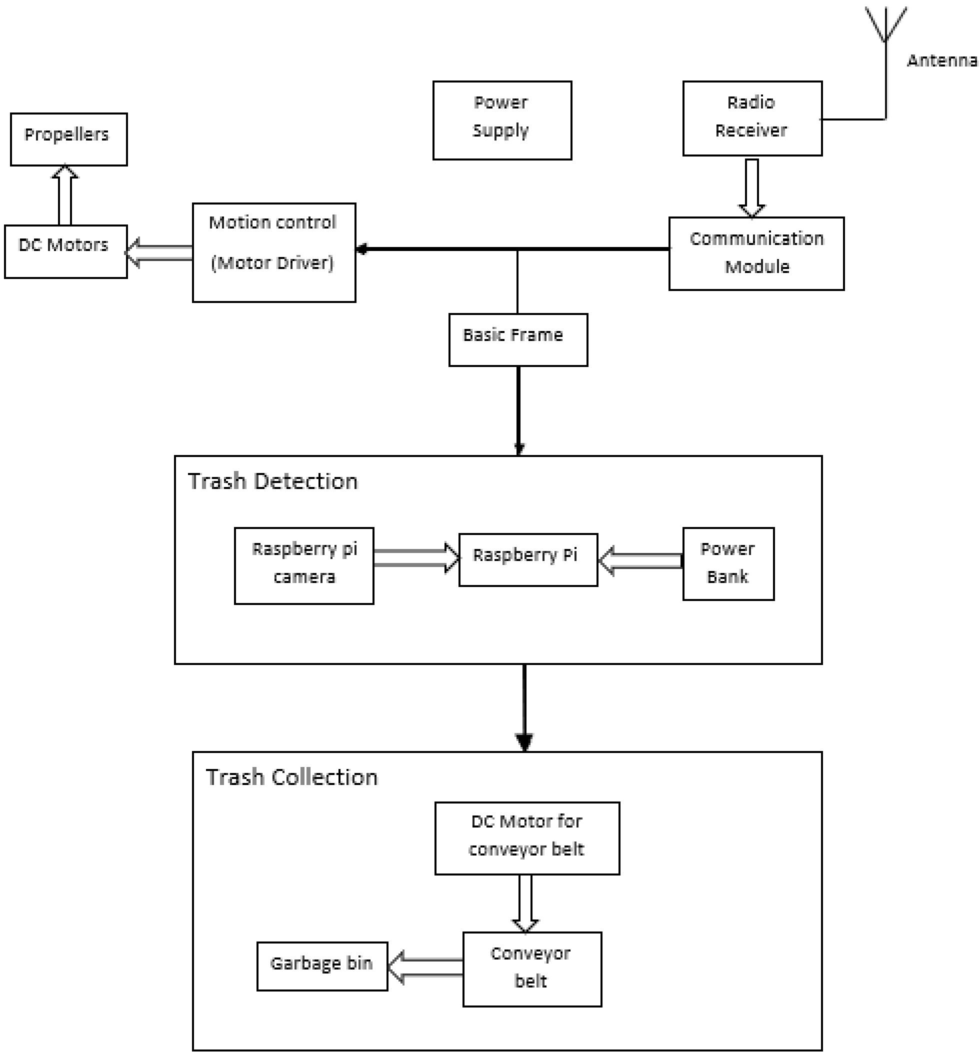

Figure 3.1: Block Diagram.

3.1 Design Requirements

Several factors and requirements are to be considered to design the robot and achieve trash cleaning in small tanks and swimming pools. Major design requirements are listed below:

- Should be capable of exhibiting undulatory motion in the small water reservoirs.
- Should light in weight be and compact in size .
- System should be able to collect various kinds of small sized trash.
- Should be capable of working continuously for 3-4 hours after fully charged.

3.2 Propulsion control

A pair of mechanical propellers connected to either side of the robot are responsible for the movement of the robot on the surface of water. Propellers are driven by 60 rpm DC motors. As the motors rotate, propellers also rotate and the blades exerts linear thrust on the water. This leads to pressure difference between the surface in front and back of the propeller. As a result, water is accelerated in one direction creating a reactive force which makes the body attached to the propellers to move. Similarly, for backward movement, the propellers are made to rotate in opposite direction and hence, reverse thrust is applied which leads to backward movement. In case of left and right turn, one of the two propellers is made stationary and other propeller is rotated. Hence, displacement of water occurs only on one side which results in the turning of the body. Figure 3.2 depicts the forces acting on the propeller blades in a 3 blade propeller. DC motors are the electrical devices that transforms electrical energy into mechanical energy. The DC motor driver acts as an interface between the motors and the control circuits.

3.3 Communication Module

Robotic fish is remotely controlled using radio technology. The block diagram of the emote module is shown in Figure 3.3. There are four switches on the remote module to control the movement of the fish. Whenever one of these switch is pressed by the user, the corresponding information is transmitted at a frequency of 2.4GHZ through antenna. The radio receiver receives the transmitted message through its antenna. Based on the

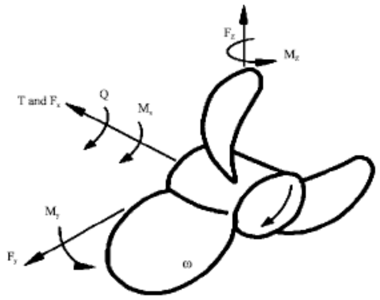

Figure 3.2: Forces and moments for marine propeller.

control information required action is taken to change the direction of the robot. Four control switches to change the direction of the robot are listed below.

- Forward
- Backward
- Left
- Right

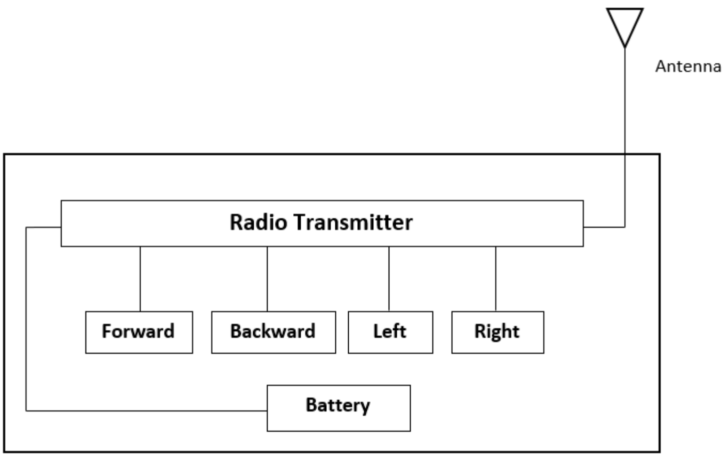

Figure 3.3: Remote Module.

3.4 Debris Detection

The input video from robotic fish is converted into frames. Frame is given as input to convolution neural network classifier to detect the debris in the image. A CNN works by extracting features from images. This eliminates the requirement for manual feature extraction. As the network trains on image dataset, the features are learnt by the model. This makes deep learning models highly accurate and suitable for computer vision tasks. CNN learns feature detection through several hidden layers. Each layer increases the complexity of the learned features. Dataset of actual debris in open-water locations is used for training CNN based detector for object detection in real time. The trained network is then evaluated on test dataset that are not used for training the network.

3.5 Debris Collection

Conveyor belt mechanism is used to collect the floating debris. Conveyor belt brings small sized trash which is present on the surface of water into the garbage bin. Conveyor system consists of a head pulley, a tail pulley and mesh-like belt as shown in Figure 3.4. A DC motor drives the head pulley. Mesh-like belt is used in order to reduce weight. During the process of collecting trash, mesh-like structure prevents water entering the bin.

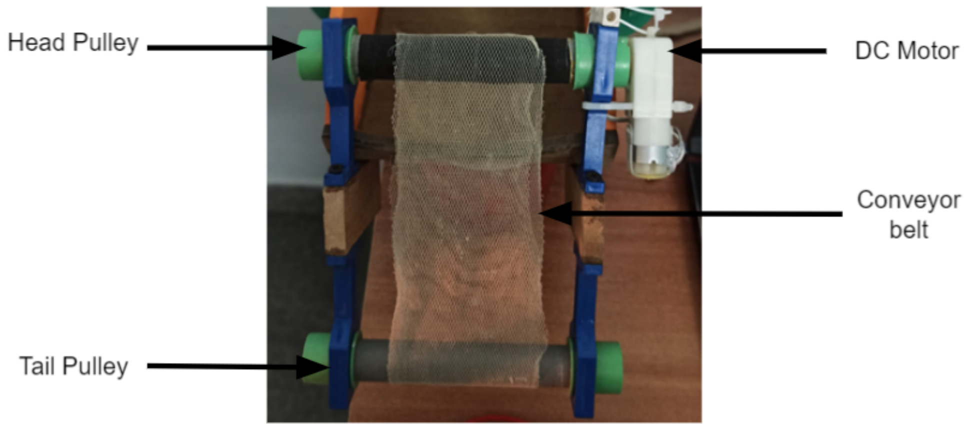

Figure 3.4: Conveyor belt system.

Chapter 4

System Hardware

Description of hardware components used in the project is given in detail.

4.1 Raspberry Pi 3 B+

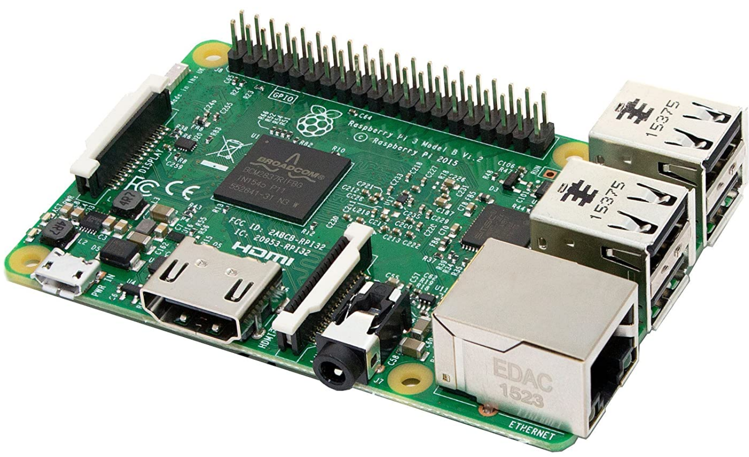

Figure 4.1: Raspberry Pi.

Raspberry Pi is a small single-board computer which is shown in Figure 4.1. The Raspberry Pi, which is the latest product in the Raspberry Pi 3 range, is a small sized computer that plugs into a computer monitor. Raspberry Pi is flexible and features a row of general purpose input/output pins (GPIO), that can be used to interact with the external environment.

4.2 DC Motor Driver

DRV8833, shown in Figure 4.2, is a dual H-bridge motor driver IC which is employed for bidirectional control of two DC motors at 2.7 V to 10.8 V. Motor driver is similar to a bridge between the control commands and the motor. The module is compact in size and all components are pre-soldered.

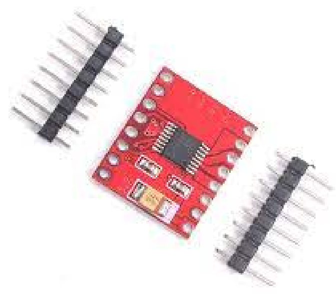

Figure 4.2: DRV8833 2 Channel DC Motor Driver.

Figure 4.3: 60 RPM BO Motor.

4.3 Motors

DC Motor, shown in Figure 4.3, can be considered as a class of electric motor that are used as actuators. DC motor converts electrical direct current to mechanical energy. The DC motor generates continuous angular rotation which can be used to rotate various kinds of engines, compressors, fans, axes etc. A stator, which is stationary and a rotor are the main two components of the DC motor.

4.4 Battery

Battery is made up of one or more electrochemical cells that have external contacts for operating electronic components. In this project 9V power battery is used as power supply to DC motors and 5V power bank, shown in Figure 4.4 is used for raspberry pi.

4.5 Raspberry Pi Camera

The Raspberry Pi camera module is one of the products from the Raspberry Pi foundation, shown in Figure 4.5. Raspberry Pi cameras can take high-resolution photographs with full HD 1080p video, and can be fully controlled programmatically. The camera module

Figure 4.4: 5V power bank.

Figure 4.5: Raspberry Pi Camera.

is portable and light weight. It communicates with the raspberry pi by using the MIPI camera serial interface protocol. It is very frequently used in image processing, machine learning or surveillance projects.

4.6 RF Module

An RF module is an electronic device, shown in Figure 4.6 which is designed to transmit and/or receive radio signals between two devices. It is used to achieve wireless communication among several devices. The frequency of operation is 2.4GHz. There are two ways to achieve wireless communication, optical communication and radio frequency communication. RF technology is chosen as the medium of communication for several applications

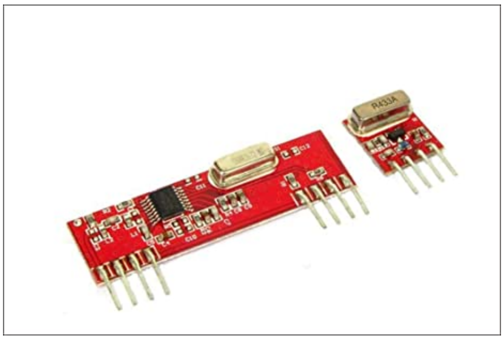

Figure 4.6: Radio Transmitter and Receiver.

as line of sight between the transmitter and receiver devices is not required. A basic RF communication module incorporates a transmitter, receiver and antennas.

4.7 Boat Propellers

Figure 4.7: Boat propellers.

A mechanical propeller is a device consisting of a rotating hub and several radiating blades. When these blades are rotated, they exert linear thrust upon a working fluid, such as water. The blades are designed such that their rotational motion through the fluid results in a pressure difference between the two surfaces of the blade and exerts a force on the fluid. Most marine propellers belong to the class of of screw propellers. It consists of helical blades rotating on a propeller shaft with an approximately horizontal axis. The propellers used in the project are shown in Figure 4.7 and the diameter of the propellers used in the project is 12cms.

Chapter 5

System Software

5.1 Python

Python is a high-level, interpreted as well as general-purpose programming language. This language is used in software development, web development (server-side), mathematics, and machine learning algorithms. Python's design philosophy aims to improve code readability with the use of significant white space. The language follows an object-oriented approach. This language helps programmers to write clear and logical code for small as well as large-scale projects.

5.2 OpenCV

OpenCV (Open Source Computer Vision Library) is a library of python that is designed with an aim to address computer vision problems. It is a cross-platform library using which real-time computer vision applications are developed. Image processing is one of the applications in which OpenCv is widely used.

5.3 Python Libraries

5.3.1 NumPy

NumPy is the crucial bundle for logical registering in Python. It is a Python library that gives a multidimensional cluster object, different inferred objects, and a collection of schedules for quick procedure on exhibits, including numerical, intelligence, shape control, arranging, choosing, I/O, essential straight polynomial math, fundamental measurable tasks, irregular reenactment and substantially more.

5.3.2 Argparse

In python standard library, rgparse is the recommended command-line parsing module. Argparse lets the user of a program to provide values for variables at run time. It is a method of communication between the writer of a program and the user.

5.3.3 Imutils

Imutils are a set of functions used in basic image processing algorithms such as translation, rotation, resizing, and displaying matplotlib images. These functions are generally used with OpenCV and python versions 2.7 and above.

5.4 Object Detection

Deep learning is used in the applications of real-time object detection and to work with video streams and video files. This will be refined using the highly efficient video stream and measure the FPS processing rate.

5.4.1 Algorithm

1. Import the necessary packages.
2. Construct the argument parse to pass the input arguments using argparse function.
3. Define a list of class labels consisting of class labels for which MobileNet SSD has been trained to detect.
4. Initialize the input queue (frames) and the output queue (detections).
5. Initialize the video stream, allow the camera sensor to warm up, start the FPS counter and loop over the frames from the video stream.
6. Consider the frame from the threaded video stream, resize it, and take its dimensions.
7. Verify whether there is any frame in the input queue. if it is empty, then construct a blob from from the input frame.
8. Give the generated blob as input to deep learning model and obtain the detections. Write the detection results to the output queue.
9. Extract the index of the class label and draw a box and label on the frame.
10. Show the output frame, update the FPS counter and stop the timer and display FPS information

5.5 YOLO v3

You Only Look Once is one of the object detection algorithms. It uses single Convolutional neural network which simultaneously predicts multiple bounding boxes and class probabilities for these boxes. First the input image is converted into number of grids. Each grid cell has the responsibility to predict some number of boundary boxes around objects. These boundary boxes are sometimes referred as anchor boxes. Confidence score is associated with every boundary box that that tells how accurate it assumes that prediction and only one object is detected for each bounding box. The boundary boxes are generated by combining the dimensions of the ground truth boxes from the original dataset. YOLOv3 performs better and is trained faster when pre-trained network is used.

5.6 MATLAB

MATLAB is an efficient programming language and numeric computing environment widely used by engineers and scientists. It is developed by MathWorks and used for image processing, video processing, machine learning, deep learning, control systems, signal processing and communications, computational finance, and computational biology. MATLAB provides several toolboxes which are package of MATLAB files that may contain MATLAB code, apps, data, documentation, and examples. In this project image processing toolbox, parallel computing toolbox and computer vision toolbox are used.

5.6.1 Image Labeler

Image labeler is MATLAB app used to draw bounding boxes and label data in the image dataset. Image labeler app allows to write and use custom automation algorithm to automatically label the ground truth data. After labelling, labeled ground truth data is exported as a groundTruth object. In this project, using imageLabeler app, 440 images are manually labeled into three different classes: Bottle, Cap and Plastic. The generated ground truth data is used for training the detector.

5.6.2 Algorithm to train object detector using matlab

1. Load the ground truth data using load function.

2. Create datastore objects for image data and bounding box labels using imageDataStore function and boxLabelDatastore.

3. Use transform function to apply custom data augmentations to the training data to improve network accuracy.

4. Use transform function to preprocess the training data for computing the anchor boxes

5. Load the SqueezeNet network that is pre-trained on Imagenet data set

6. Specify the class names: Bottle, Cap and Plastic.

7. Create the yolov3ObjectDetector object.

8. The augmented data is prepossessed before giving it to the training.

9. Set the training options: number of epochs, mini batch size, learning rate, warm up period, L2 regulization factor.

10. Train the model.

11. Test the model using detect function.

Chapter 6

Results

The robot system is tested in water tank with calm water. Robot is powered on by connecting the power supply. The robot starts moving as soon as it receives command from the remote module operated by the user. Figure 6.1 and 6.2 are the snapshots of robot module. System can be used only in still water, without any high waves. Based on the control switch pressed, the robot changes its direction of motion. The remote module is shown in Figure 6.3.

Table 6.1: Robot specifications

Sl No	Specification	Value
1	Weight	600grams
2	Overall size	32*25*16 (cms)
3	Size of garbage bin	14*15*16 (cms)

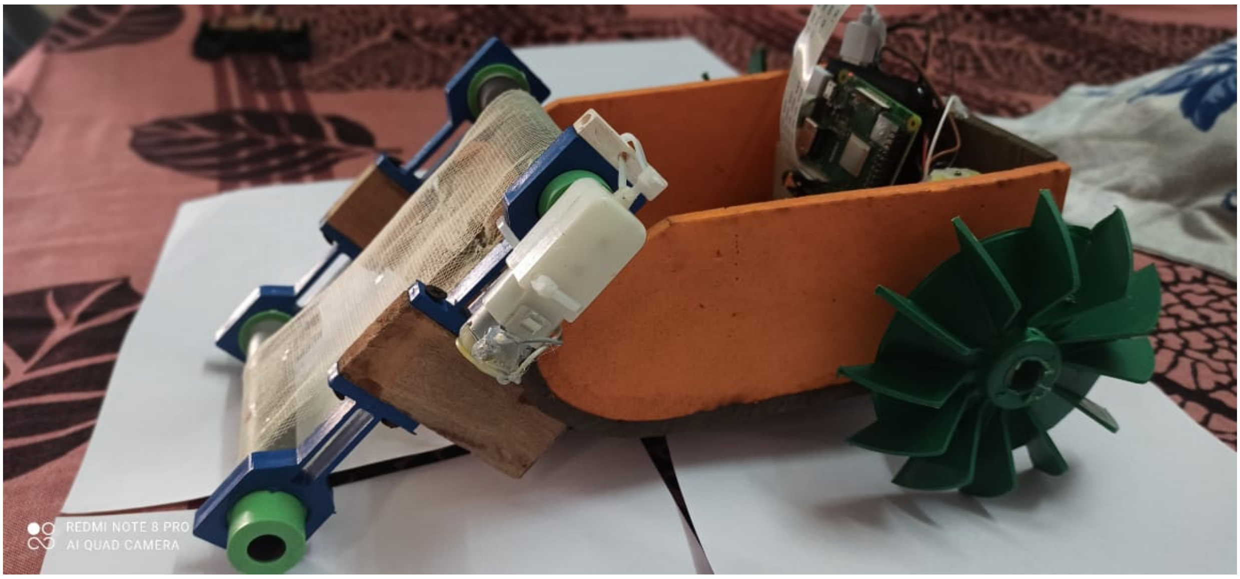

Figure 6.1: Side view of robotic module.

Conveyor belt smoothly transfers the trash from the water surface to the garbage bin. This mechanism is shown in Figure 6.4.

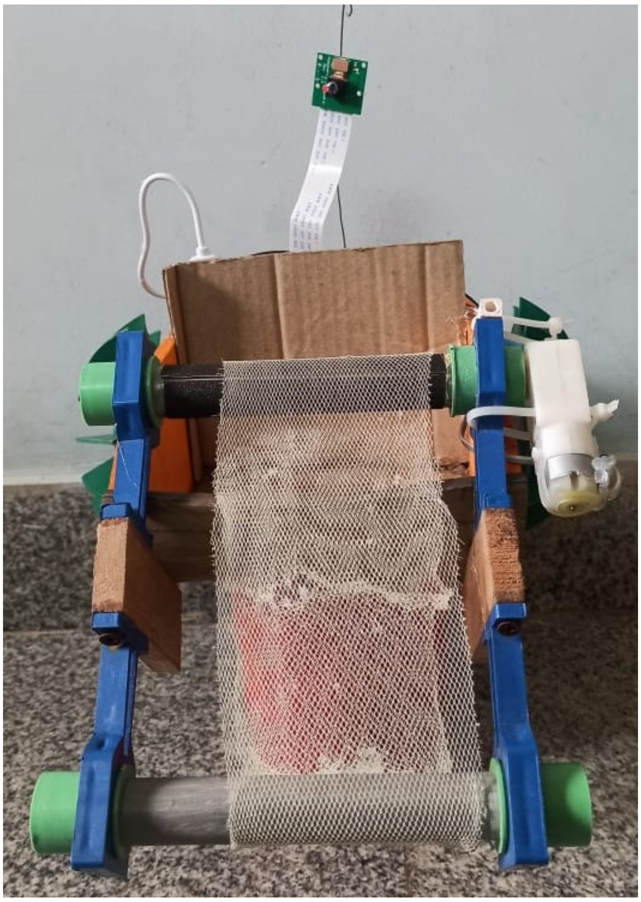

Figure 6.2: Front view of robotic module.

6.1 Object detection Results

YOLOV3 object detector is trained with data set containing variety of images. The model is trained to detect objects of three classes; plastic bottle, plastic cap and plastic cover bag. Matlab detection results are shown in Figure 6.5 and Figure 6.6. Real time object detection by the model is shown in Figure 6.7.

Figure 6.3: Remote module.

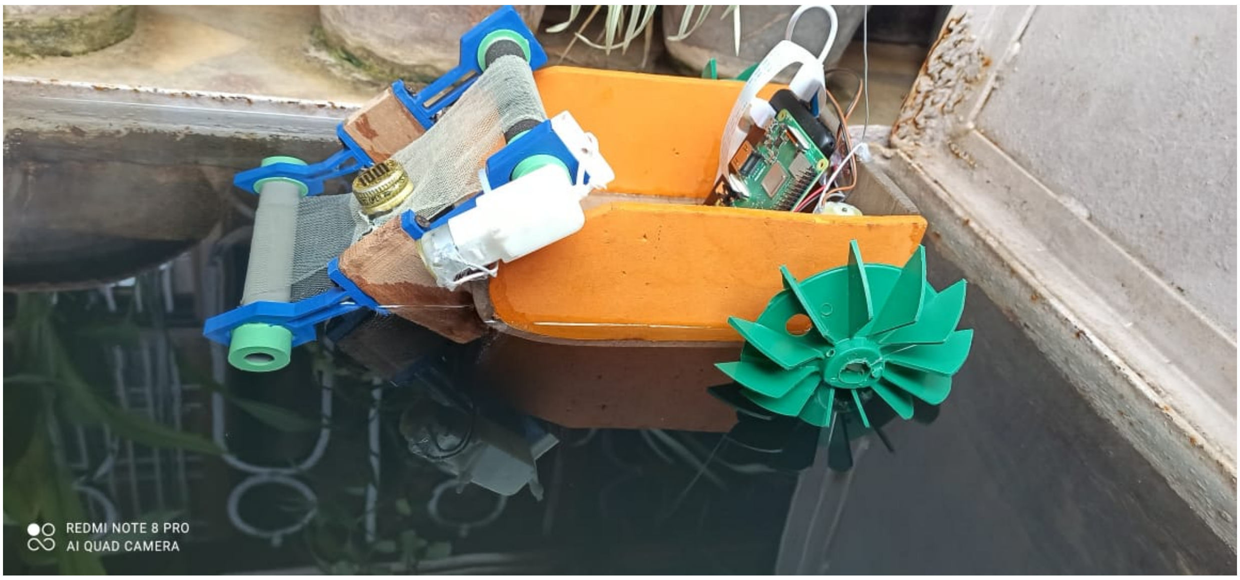

Figure 6.4: Trash collection mechanism.

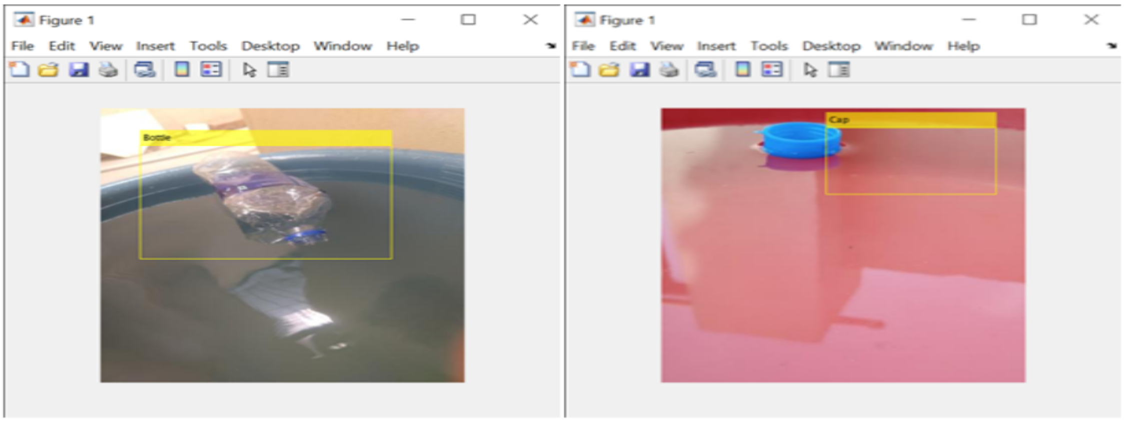

Figure 6.5: Matlab detection results of plastic bottle and cap.

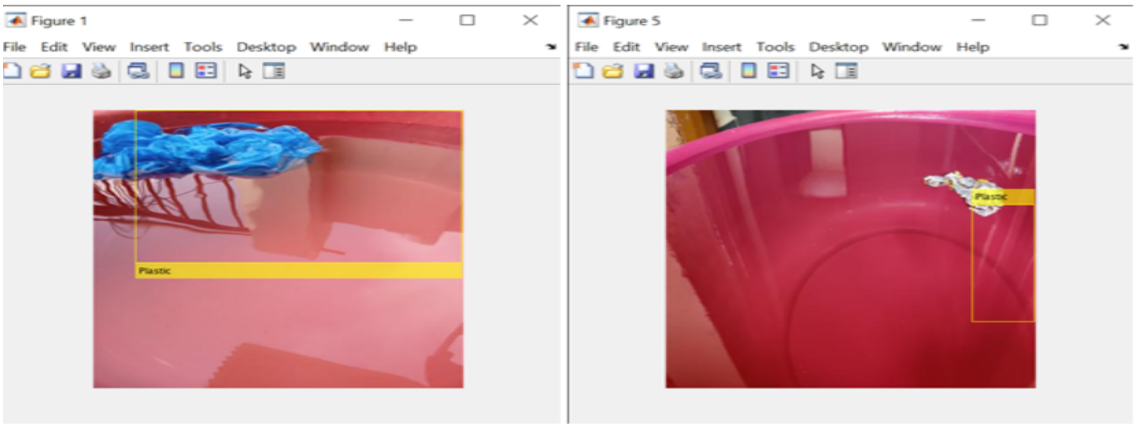

Figure 6.6: Matlab detection results of plastic covers.

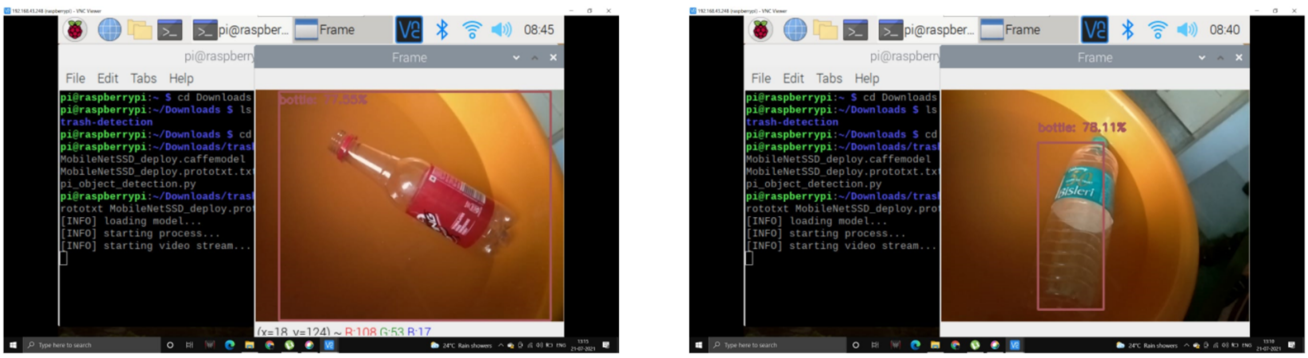

Figure 6.7: Real-time detection results.

Chapter 7

Conclusion

A robotic fish for water surface cleaning task is developed and tested in an experimental water tank setup. The robot, with the use of mechanical propellers, has an undulating motion on calm water surface. A remote module, which uses the radio frequency technology, is used to control the movement of the robot system. Four control switches namely, forward, backward, right turn and left turn, are used to control the movement of the system. The robot is capable of detecting trash like water bottles, plastic caps and plastic bags floating on the water. The model collects small sized trash like small plastic covers and bottle caps and is dumped into the garbage bin. The detection of trash is achieved through YOLO model which is based on deep neural network. The conveyor system aids in collecting the trash. The developed model can be useful in cleaning water bodies like water tanks and swimming pools.

7.1 Scope for future work

1. The motion of the robot is manually controlled. Obstacle avoidance mechanism can be implemented to make the robot autonomous.

2. The detection and collection mechanism can be extended to more variety of trash.

3. The project is confined to detection and collection of floating water debris. The problem of submerged marine debris can be addressed by making the robot capable of diving inside the water.

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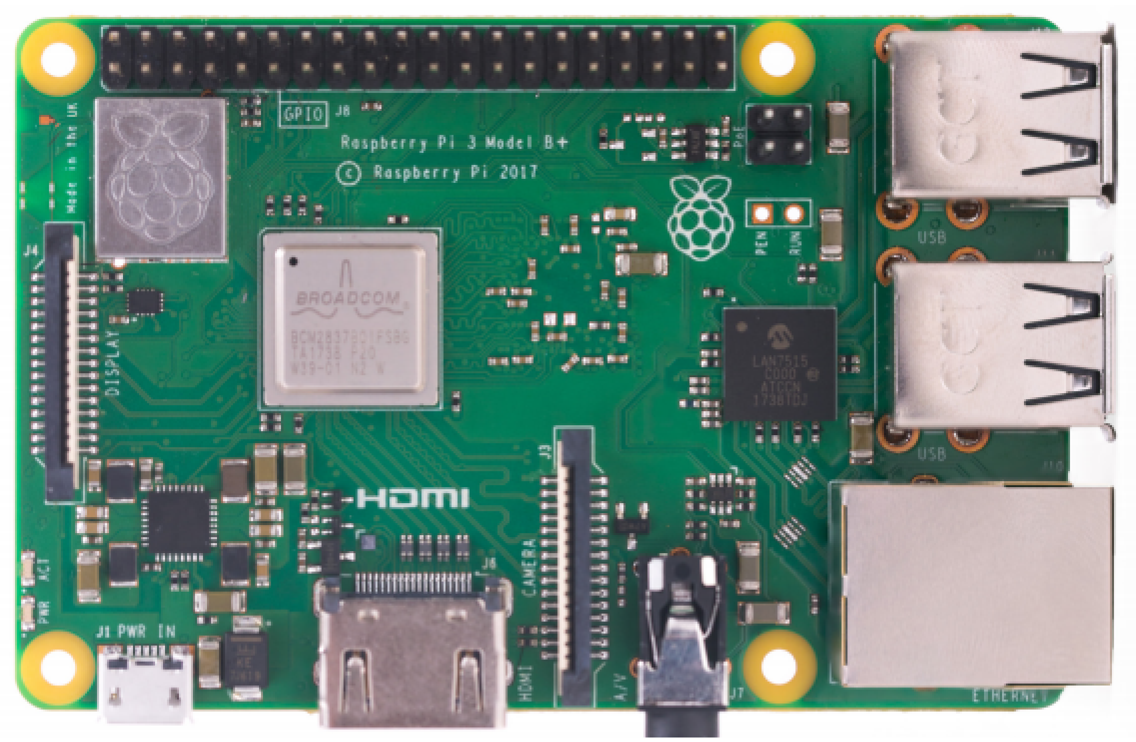
Appendices

Appendix A

Raspberry Pi 3 Model B+

Overview:

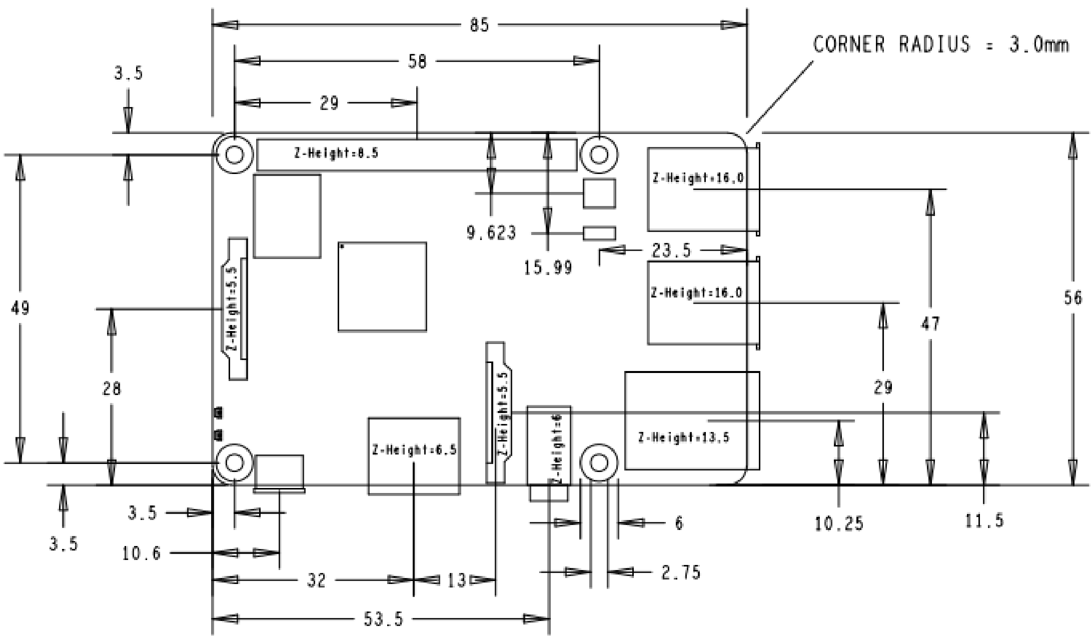
The Raspberry Pi 3 Model B+ is the latest product in the Raspberry Pi 3 range, boasting a 64-bit quad core processor running at 1.4GHz, dual-band 2.4GHz and 5GHz wireless LAN, Bluetooth 4.2/BLE, faster Ethernet, and PoE capability via a separate PoE HAT. The dual-band wireless LAN comes with modular compliance certification, allowing the board to be designed into end products with significantly reduced wireless LAN compliance testing, improving both cost and time to market. The Raspberry Pi 3 Model B+ maintains the same mechanical footprint as both the Raspberry Pi 2 Model B and the Raspberry Pi 3 Model B.



Specifications:

Processor:	Broadcom BCM2837B0, Cortex-A53 64-bit Soc @ 1.4GHz
Memory:	1GB LPDDR2 SDRAM
Connectivity:	2.4 GHz and 5 GHz IEEE 802.11 b/g/n/ac wireless LAN
	Gigabit Ethernet over USB 2.0 (maximum throughput 300 Mbps)
	4 USB 2.0 ports
Access:	Extended 40-pin GPIO header
Video & sound:	1 × full size HDMI
	MIPI DSI display port
	MIPI CSI camera port
	4 pole stereo output and composite video port
Multimedia:	H.264, MPEG-4 decode (1080p30);
	H.264 encode(1080p30); OpenGL ES 1.1, 2.0 graphics
SD card support:	Micro SD format for loading operating system and data storage
Input power:	5V/2.5A DC via micro USB connector
	5V DC via GPIO header
	Power over Ethernet (PoE)–enabled (requires separate PoE HAT)
Environment:	Operating temperature, 0–50°C

Physical Specifications:



Appendix B

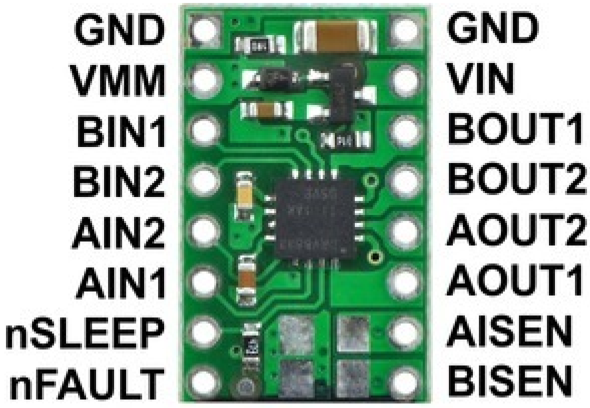
Dual H-Bridge Motor Driver

Description:

The DRV8833 device provides a dual bridge motor driver solution for toys, printers, and other mechatronic applications. The device has two H-bridge drivers, and can drive two DC brush motors, a bipolar stepper motor, solenoids, or other inductive loads. The output driver block of each H-bridge consists of N-channel power MOSFETs configured as an H-bridge to drive the motor windings. Each H-bridge bridge to drive the motor windings. Each H-bridge includes circuitry to regulate or limit the winding current. Internal shutdown functions with a fault output pin are provided for overcurrent protection, short-circuit protection, undervoltage lockout, and over temperature. A low-power sleep mode is also provided.

Features:

- Dual-H-bridge motor driver: can drive two DC motors or one bipolar stepper motor
- Operating voltage: 2.7 V to 10.8 V
- Output current: 1.2 A continuous (2 A peak) per motor
- Motor outputs can be paralleled to deliver 2.4 A continuous (4 A peak) to a single motor
- Inputs are 3V- and 5V-compatible
- Under-voltage lockout and protection against over-current and over-temperature
- Reverse-voltage protection circuit
- Current limiting can be enabled by adding sense resistors



Electrical Specifications:

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
POWER SUPPLY						
I_{VM}	VM operating supply current	V_M = 5 V, xIN1 = 0 V, xIN2 = 0 V		1.7	3	mA
I_{VMQ}	VM sleep mode supply current	V_M = 5 V		1.6	2.5	µA
V_{UVLO}	VM undervoltage lockout voltage	V_M falling			2.6	V
V_{HYS}	VM undervoltage lockout hysteresis			90		mV
LOGIC-LEVEL INPUTS						
V_{IL}	Input low voltage	nSLEEP			0.5	V
		All other pins			0.7	
V_{IH}	Input high voltage	nSLEEP	2.5			V
		All other pins	2			
V_{HYS}	Input hysteresis			0.4		V
R_{PD}	Input pulldown resistance	nSLEEP		500		kΩ
		All except nSLEEP		150		
I_{IL}	Input low current	VIN = 0			1	µA
I_{IH}	Input high current	VIN = 3.3 V, nSLEEP		6.6	13	µA
		VIN = 3.3 V, all except nSLEEP		16.5	33	
t_{DEG}	Input deglitch time			450		ns
nFAULT OUTPUT (OPEN-DRAIN OUTPUT)						
V_{OL}	Output low voltage	I_O = 5 mA			0.5	V
I_{OH}	Output high leakage current	V_O = 3.3 V			1	µA

Appendix C

Raspberry Pi Camera

Description:

High definition camera module compatible with all raspberry pi modules. Provides high sensitivity, low crosstalk and low noise image capture in an ultra small and lightweight design. The camera module connects to the raspberry pi board via CSI connector designed specifically for interfacing to cameras. The CSI bus is capable of extremely high data rates, and it exclusively carries pixel data to the processor.

Specifications:

Image sensor:	Sony IMX 219 PQ CMOS image sensor in a fixed focus module
Resolution:	5-megapixel
Still picture resolution:	3280 x 2464
Max image transfer rate:	1080p : 30fps
	720p : 60fps
Connection to Raspberry Pi:	15-pin ribbon cable, to the dedicated 15-pin MIPI