Vision based agricultural harvesting using mobile robot

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ABSTRACT – Agricultural is considered to be the Back bone of our country. It involves several laborious works and costly man power for harvesting. Tomato cultivation is one of the most common perennial processes in India, in which labour cost is the most significant cost involved. The project focuses on developing a Mobile Robot, which can be operated virtually using joystick from the internet browser in a local computer with the robot and computer connected to the same network. This Mobile Robot has a camera attached to the front which records the live agricultural environment and send the image of the tomatoes to the local computer, where image processing is done to get position of the tomatoes. A Robotic arm is also controlled virtually to pick the fruit from the plant. The sensor readings are saved to the SQL Database for future analysis. This Robot can manoeuvre through the tough terrain and move about in the uneven surface using the Rocker – Boggie Mechanism.

Keywords – Rocker-Boggie mechanism, Computer vision, ESP32 Cam, Virtual Joystick control, Image byte array, Hyper-parameter tuning, Bitwise masking, HTTP communication protocol, Multicore processing.

I. Introduction

Agriculture business is the most important industry that drive the economy of India and hence the Backbone. Classical Agricultural harvesting techniques included using manual mechanization for cultivating and harvesting the crops, this also came along with a large need for farm labors and cost. Tomato is a very common ingredient in every home. It is grown all over the year in all seasons. In India, as per Indiastat, the tomato cultivation is 814000ha during the time period of 2018 to 2019 and the production is around 20515000 Metric tonnes. The average productions of the tomato by the Indian farmers is around 25.2 tonnes/ha. The total duration of Tomato crop cultivation is around 110 to 140 days.

Anmol Singh, et al., (2020) [1], has studied various rocker-boggie mechanism for the suspension framework used to establish very high steadiness and also a prototype of the rover mobile robot to manoeuvre in rough, uneven terrain. The suspension systems are used more for the space investigation applications. The Rocker boggie mechanism is an ideal choice for the Mars Pathfinder and Mars exploration Rover and Mars Science laboratory missions which was headed by zenith space investigation. The proposed rocker boggie arrangement is the widely used one. The mechanism comprises of the 2 arms and wheel mount to each of them, and the 2 arms linked with different joint. A comprehensive study was made on the current design development such as Planetary rover by soviets in 1970, Planetary rover by swiss using fork parallelogram rocker suspension and bilateral double parallelogram rocker suspension in 2002 and 2004 respectively, Planetary rover by Americans in 1987 (Rocky, Mule), Planetary rover by Chinese with folded deployed suspension and the different approaches to design the suspension.

Boaz Arad, et al., (2019) [2], has developed, tested and validated harvesting of sweet pepper fruit in the greenhouse environment. The robot is a six DOF robot with end effector and a high resolution RGB camera and a container to collect the fruit. The steps for harvesting involve detection of the fruit and locating them, grasping the fruit and motion control. Overall, 262 fruits were used in four-week testing period. The cycle time to harvest is around 24 seconds. Also laboratory test were conducted that showed the cycle time be reduced to 15 seconds by moving the manipulator at high speeds. Harvest success rate was about 61% for best fitted crop. The three-Dimensional information along with the color and depth is reported by the RGB-D Camera. Also, to facilitate the very higher frame of operation shape and color-based detection is done. The stems are detected using deep learning and further processed using the Canny edge detector, where the straight lines are detected from which the stem is cut along with the fruit. The results obtained by this experimentation showed that the performance of robot could be increased by clustering and occlusion of the fruit.

Simon Birrell, et al., (2019) [11], has developed a robot to harvest iceberg lettuce autonomously. The robotic platform named Vegebot was developed and tested in field, which has a vision based system, software and end effector which is damage free for the iceberg lettuce crop. Using two integrated convolutional neural network, classification and localization are done. The end effector has force feedback control which would aid in the detection of the ground. Also experimental validation has been done to validate the vision and localization accuracy.

Tatsuki Kamata, et al., (2018) [12], has studied and developed a controlling algorithm for harvesting heavy weight crop like Pumpkin. Robotic system consists of robotic arm, end effector and algorithm for controlling which is installed on robot tractor. The steps involve approaching the pumpkin accurately, then grasping the pumpkin without damaging them and transporting the robot to the truck. The robotic arm moves to object of interest by finding its coordinate using the Point to Point Control method. It involves getting and inputting Pumpkin position data to controller. Calculating all parameters and move to position of interest from the home position. Then move to pumpkin position2 with end effector opening. Then grasping the pumpkin and transporting it to the truck. For robotic arm movement inverse kinematics is used. The tractor for harvesting has a vision system to visually see and pick pumpkin, RTK GPS is used for accurate location, the controlling unit is placed inside tractor for the aforesaid functions and a robotic arm with end effector to grasp pumpkin. The Accuracy and Repeatability results were obtained for 11 such experimental positions.

Vikram Raja, et al., (2022) [13], has studied and implemented the Integrated robot system, which is an replacement to the existing tiresome manual methods, which is comparatively cost effective, viable and efficient process. The robot makes use of deep learning techniques for image detection and the targeted object is gripped using the robotic manipulator. The robot makes use of articulated and cartesian configuration for harvesting function. The robot is used to harvest carrots and cantaloupes, carrot, saffrom, chilli, paprika, radish. First step involves sending information to the cloud to begin the process. The robot moves from docking point to harvesting point. The vision system used for detection of vegetables and fruits and harvesting is YOLO-V3 (You Only Look Once) to acquire the exact position of fruit, it uses Darknet-53 feature extractor CNN. Once position is located the position coordinates is converted to G codes which is translated to pulse for stepper motor. Location is robot is by the GPS system. The algorithm was able to detect the vegetables in 93% in 4 seconds for carrots and cantaloupes has accuracy of 95% and able to detect in 2 seconds.

Yuki Onishi, et al., (2019) [14], has used a accurate and faster method of detecting and harvesting the fruits using the Single MultiBox Detector, which uses a stereo camera to get three dimensional position. The robot arm is moved to the targeted fruit's position after calculating the joint angles using Inverse Kinematics. The fruit is harvested by twisting the hand axis. The fruit used is Fuji apple which is grown in Miyagi Prefectural Agricultural and Horticulture Research Center. The V-shaped apple tree shape is used due to increased efficiency and mechanization. The Algorithm involves detecting 2D position initially from the images of stereo camera and next step uses detecting position based on CNN and extracted feature maps. The 3D construction of the apple were done using the triangulation from parallax of left and right images, then Inverse Kinematics was applied to move robotic arm to fruit position. The arm was moved to 10cm below the fruit, the arm held the fruit and the harvesting is done by twisting from peduncle by rotating for about four times around it. The algorithm was able to detect fruit 90% of the fruits used correctly. A single fruit was harvested in approximately 16 seconds.

II. Experimental

1. *Methodology*

(i) Overall view:

This All - terrain Mobile robot address the issue of Manual labors shortage for Tomato harvesting [8]. The robot can maneuver even in uneven terrain, accurately gather information of the Tomato and help is harvesting using the robotic arm. The Robot is navigated through virtual joystick control using internet. The robot has Camera to receive the real time video stream and estimate the position and location of the Tomato, using Image processing (Computer Vision). The miniature Robotic arm which can be operated manually using the virtual joystick, which helps in harvesting the Tomatoes. Ultrasonic sensor to get the depth information of the Tomatoes from the robot origin position. MPU6050 sensor to get the Gyroscopic, accelerometer and temperature values. All the sensor outputs are stored continuously in the SQL Database [14] for further analysis using Computer Vision. The Overall schematic of the All terrain Mobile Robot is as shown in Figure 1.

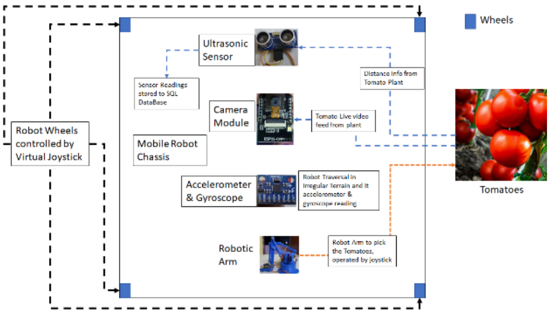

Figure 1 Overall All-terrain Robot Flowchart

(ii) Tomato Position estimation using Computer Vision:

The Figure 2. shows the flowchart starting from receiving the Live Video stream from ESP32 Cam Wi-Fi module which captures the environment video stream and the manoeuvrability of the robot is controlled using the virtual joystick created and accessed using Internet, the distance between the ESP32 Cam and the Mobile robot is adjusted based on the reading from the Ultrasonic sensor [9]. The raw bytes of the image captured is sent to local computer, Then the image is received. The image is converted from BGR image to HSV image. Then the Trackbar position in obtained to tweak with parameters and isolate the color of the tomato. Then Bitwise AND Operation is performed on image using masking techniques. Find the contours of the Tomato and locate the position. Tomatoes position estimates with the contour drawn on images are sent to SQL Database, which can be accessed and analyzed for further future use.

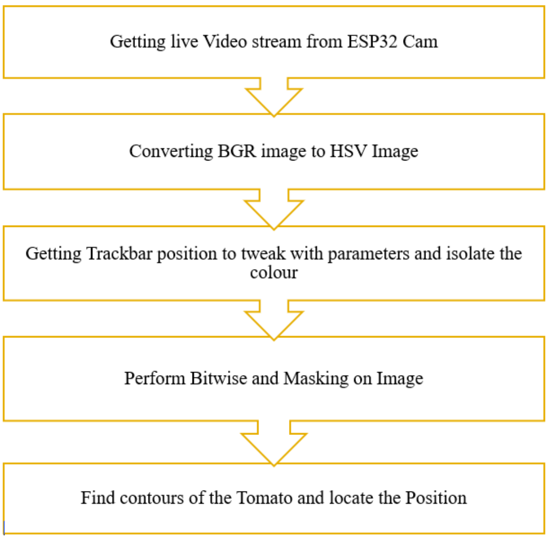

Figure 2 Tomato Image processing Flowchart

(iii) Robot Arm Actuation using the virtual joystick control:

The Figure 3 shows schematic used to control the joystick virtually using HTTP communication protocol. Firstly, the HTTP Server-Client communication is established with the IP address and the Port number. Then the slider position can be controlled from the client browser end. The slider position control is given for Gripper, Base and the Arm. Whenever the slider is moved, a event is said to have occurred. In the server end the HTTP end point of the particular event is received. The end point represents the angle for which the servo motor has to rotate. Based on the angle obtained the servo motor of corresponding part of the Robot arm is rotated.

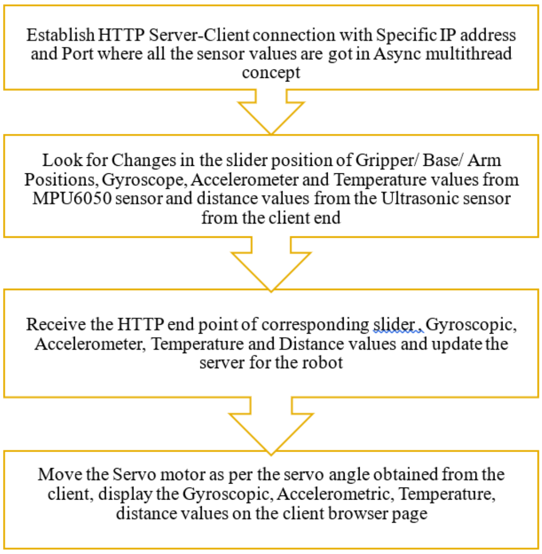

Figure 3 Robot Arm Actuation, MPU sensor, Ultrasonic Flowchart

(iv) Virtual joystick control of mobile robot:

The Figure 4 shows the Mobile Robot prototype that traverse around the environment with the inputs given from the joystick control using the internet. It shows the live camera feed of the environment which helps to move around in the Mining environment setup.

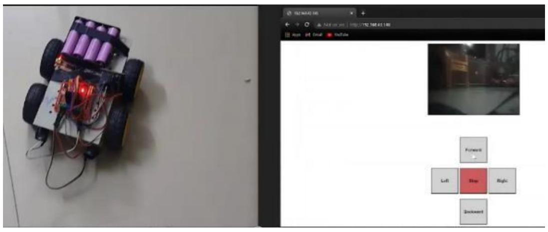

Figure 4 A demonstration of the mobile robot movement using the virtual joystick

Figure 5 shows in details how the simple dashboard is built. The Dash board is created using Java script which works on the Hyper Text Markup Language (HTTP) protocol to actuate the motor with 5 functions namely Forward, Backward, Left, Right. Additional functionality of Led Lights On and Led Lights Off are provided to operate mobile robot under the dark Environment.

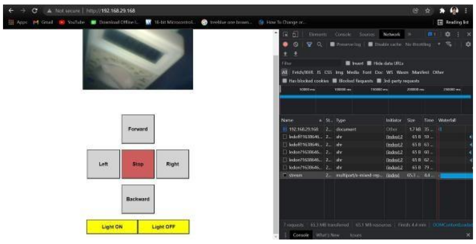

Figure 5 Virtual Joystick control of the Mobile Robot using Laptop

2. Model and Simulation

(i) Solidworks Model:

The All terrain Mobile robot is designed using the Soliworks software as shown in Figure 6. It consists of Upper Chasis, Rocker Arm, Suspension springs,

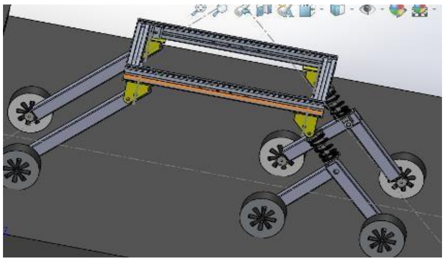

Figure 6 Rocker Boggie Model with suspension

(ii) Solidworks Simulation::

The different terrain traversal of mobile robot [15] is simulated in solidworks motion study to access the manoeurability of the robot. Figure 7 shows the Motion study analysis done in different bumpy terrain condition and stair climbing.

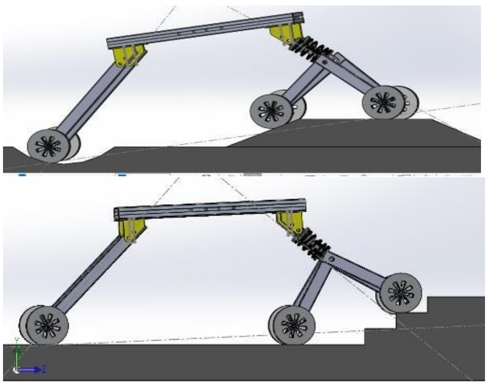

Figure 7 High and Low bump Traversal, Step traversal of Robot – Climbing up

3. Fabrication process

(i) Components:

Figure 8 shows the Upper Aluminum Chassis Frame which as a base structure over which the ESP32 camera, power supply, mounting brackets, Suspension springs and auxiliary components are placed. Reinforcing Aluminum frames are also placed to increase the stiffness of the structure and to resist against torsion.

Figure 8 Upper Chassis Frame

Figure 9 shows the Aluminum Rocker Arm, which is an important component that imparts the motion to the robot which have geared motors mounted onto them. It has the wheel mounting brackets attached on one end and other end is fixed to the Suspension spring. The Rocker arm angle is chosen in a way to facilitate the robot to maneuver uneven terrains

Figure 9 Rocker Arm

Figure 10 shows the Suspension Springs, they are used to take up sudden jerks or shock loads that is bound to occur when the robot is traversing in the uneven terrain. One end of Suspension spring is mounted to the Upper Chassis Frame and the other end is mounted to the rocker arm. Two suspension springs one on each side is connected by a M12 threaded screw for alignment and added stiffness against torsional loads

Figure 10 Suspension Springs

Figure 11 shows the wheel, which has rubber straps wrapped around the circumference to facilitate enhanced grip with road and rocky surface. The wheel is mounted to the geared motor using the 6mm shaft hole

Figure 11 Wheel

Figure 12 shows the DC Geared motor. It has an operating voltage of 12V, has metal Spur gears encased inside the gearbox. It has a torque of 3.5kgcm, no load current of 60mA and load current of 300mA. Motor shaft length is 24mm.

Figure 12 Geared Motor

Figure 13 shows ESP32 Camera WiFi Module. It is dual core LX6, 32 bit Microcontroller. It has integrated WiFi (802.11 b/g/n/), Bluetooth, Hall sensor, temperature sensor support. It has a built in 520 kB SRAM. Supports UART, SPI, PWM, I2C, ADC, DAC communication protocols. Supports Real Time Operating System. The camera is 5MP, with a dimension of 40X27 mm and a deep sleep current of 6mA

Figure 13 ESP32 Cam WiFi Module

The L298N driver module as shown in Figure 14. Each motor is individually powered by the L298N and it worked as the driver was able to supply required voltage and current.

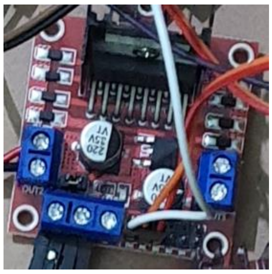

Figure 14 L298N Motor Driver Module

Figure 15 shows DC to DC convertor that converts 12V input voltage into 3.3V and 5V. It works on Buck convertor (Step Down Voltage Converter) principle. This Module is used to stepdown the voltage which is to be used as power source to the ESP32 Microcontroller. It outputs 3.3V at 800mA maximum current, 5V at 800mA maximum current. It supports 5.5mm Power jack.

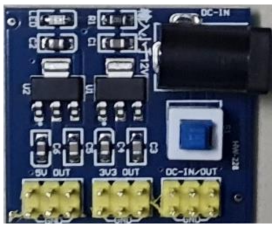

Figure 15 DC-DC 12V to 3.3V and 5V Power Module Multi Output Voltage converter

Figure 16 shows 8000mAh Lithium Polymer Battery Pack which supplies a voltage of 11.1V, maximum continuous discharge of 30C (240A) and maximum burst discharge of 60C (480A). It is a 3 cell battery pack. It supports heavy duty discharge leads that minimize resistance and can handle high current loads. It weighs around 600 grams.

Figure 16 8000mAh Lithium Polymer Battery Pack

Figure 17 shows the DC Power Jack Male connector 2.1X5.5 mm size. It is used to supply 12V DC input from LiPo battery to the DC-DC 12v to 3.3V and 4V Power Module. The jack can fit 5.5mm barrel jacks and have 2.1mm center pole.

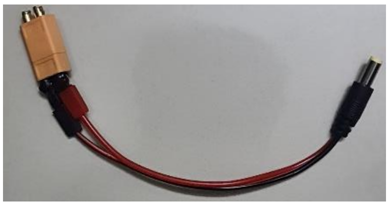

Figure 17 DC Power Jack Male connector

Figure 18 shows Two channel Logic Level converter. It is bidirectional logic level converter for stepping down 5V signals to 3.3V and stepping up 3.3V to 5V at same time. It works also with 2.8V and 1.8V devices. It supports I2C and UART communication protocols.

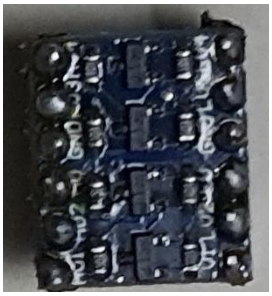

Figure 18 Two Channel Logic Level Converter

Figure 19 shows M12 threaded rod. It is used to provide as a guiding alignment locator for the two rocker arms and rear Aluminum tubes. It also provides extra torsional stiffness for the chassis frame. The rocker arm without these guiding rod lead to dislocation of the arms and thereby the two rocker arms were rotating about suspension springs which lead to issue of the robot not traversing straight path when moved front or back

Figure 19 M12 Threaded Guiding rod

Figure 20 shows mounting brackets that connects the Upper Chassis frame with the lower Suspension Springs also it holds the rear Aluminum tubes. It is a C shaped bracket that snuggly fits the Suspension springs and the aluminum frame thereby arresting the relative rotational movement.

Figure 20 M12 Mounting brackets connecting Upper chassis with Suspension spring

Figure 21 shows Suspension Spring – Rocker arm Bracket. It is a connecting member that connects the Suspension Spring on one side and Rocker arm on other side. It is used to firmly secure the two components and also to arrest the rotation of the rocker arm about its axis.

Figure 21 Suspension Spring – Rocker arm Bracket

Figure 22 shows Geared motor mounting bracket. It firmly secures the Geared motor at one end and wheel is attached to motor on the other end. The mounting bracket is attached to the aluminum tubes using bolts.

Figure 22 Geared Motor mounting bracket

Figure 23 shows Aluminum Reinforcing tubes, which adds extra Bending and Torsional stiffness to the Chassis frame thereby avoiding the deflection of the frame during higher loads.

Figure 23 Reinforcing Aluminum tube

Figure 24 shows USB to UART TTL 5V 3.3V FT232RL Download cable to Serial Adapter module. It is used primarily for downloading the program codes from the computer to the ESP32 Cam WiFi microcontroller, since this module doesn’t have internal programmer. The USB power has a current protection using 500mA self restore fuse. It has RXD/TXD transceiver for communication. It supports 3.3V and 5V

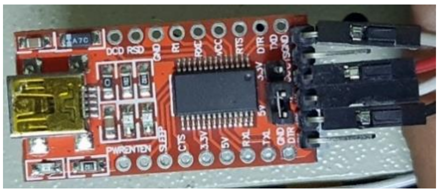

Figure 24 USB TO UART TTL 5V 3.3V FT232RL Download Cable To Serial Adapter Module

Figure 25 shows the assembled setup of the miniature robot arm. It has gripper arm to grab and hold the fruit in place. The Base plate is where the robot other links are mounted. The links are used to transfer motion for the robots like lifting the arm to raise the gripper position to grab the fruit.

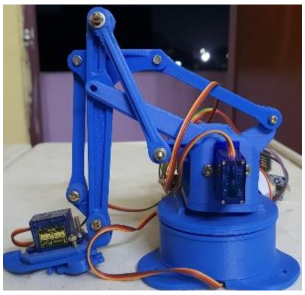

Figure 25 Miniature Robot Arm

Figure 26 shows the SG90 servo motor which is a three pole ferrite motor with nylon gears. It has an operating voltage of about 4.8 volts to 6.0 volts. It has operating speed of 0.12 sec/60 degree and a output torque of around 1.6kgcm at 4.8 voltage.

Figure 26 Tower Pro SG90 Servo motor

Figure 27 shows the Ultrasonic Range Finder sensor (model HC-SR04). The ultrasonic sensor has an operating voltage value of 5 Volts and a operating current is around 15mA. The effectual angle is less than 15°. The resolution is around 0.3 cm. Measuring angle is about 30°. The triggering pulse width is 10uS TTL pulse. The sensing sonar range varies between 2 cm to 400 cm. The maximum sensing range for the sensor is 450 cm. The operating frequency range is 40 kHz. The Echo signal output is TTL pulse which is proportional to the range of the distance.

Figure 27 Ultrasonic Range Finder Sensor (HC-SR04)

Figure 28 shows the MPU6050 sensor. It has a three axis accelerometer included in it along with the three axis gyroscope. The sensor uses the I2C protocol to establish connection between the microcontroller and the sensor. It operates at an input voltage range of about 2.3 volts to 3.4 volts. The three axis gyroscope has a sensitivity upto a value of about 131 LSBs/dps and has full operating range of ±250, ±500, ±1000 and ±2000 dps. The three axis accelerometer have a full scale programmable range of about ±2g, ±4g, ±8g and ±16g values. It has support for run time bias and calibration of compass. Along with Gyroscope and accelerometer it has support for the temperature sensing.

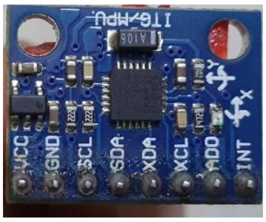

Figure 28 MPU6050 Sensor

Figure 29 shows the ESP32 microcontroller WROOM32 model. It has an inbuilt WiFi and BLE support. It has USB-UART port to upload program on to the board as it has inbuilt boot loader. Also, it has reset, boot modes, LDO regulator. It has greater support for the LWIP protocols and FreeRTOS. It also supports three modes namely AP, STA, AP+STA. It has 4MB Flash memory. 80mA current. It supports an input voltage range of 2.2 volts to 3.6 volts. Data Rate is about 54 Mbps and operating frequency of 2.4 GHz.

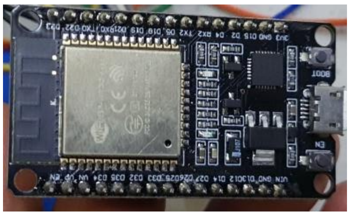

Figure 29 ESP32 Microcontroller

Figure 30 shows the Mobile robot with the Robot arm top for picking the tomatoes, ultrasonic sensor to get distance values, MPU6050 sensor to get the gyroscopic, acceleration and temperature values and ESP32 CAM to get live video stream of the environment.

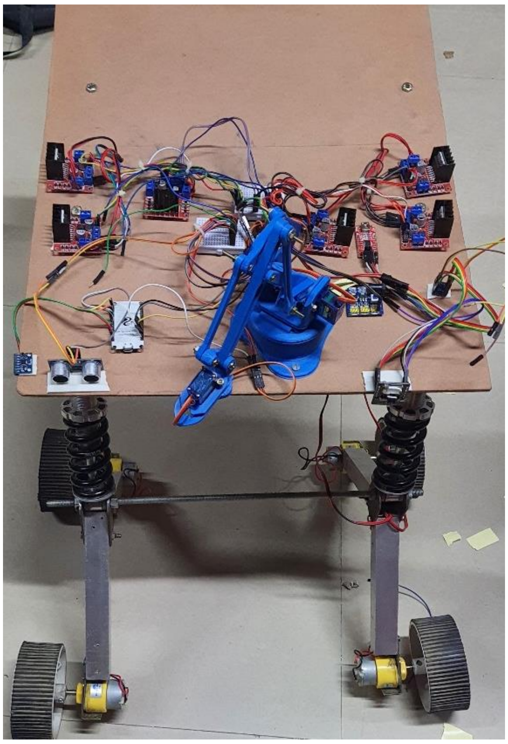

Figure 30 Mobile Robot with Robotics arm

4. Configuration and results

(i) Mobile Robot Manoeuvre:

Figure 31 shows the Overall Electric Schematic Connection. The program is uploaded to ESP32CAM via TTL, then the two channel logic converter steps up 3.3V from microcontroller to 5V, which then powers Motor Driver. All these are powered by LiPo Battery. At last the DC geared motor rotates based on joystick command.

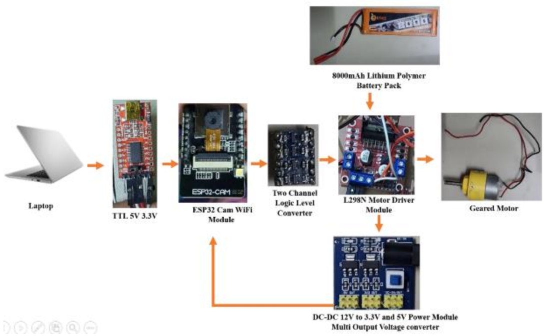

Figure 31 Overall Electric Schematic Connection

Figure 32 shows the forward and backward control of the Mobile robot from the mobile phone

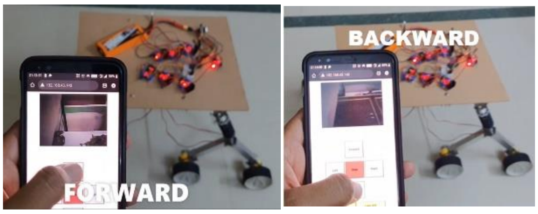

Figure 32 Forward and Backward control of Mobile Robot

Figure 33 shows Slope Climb control of the Mobile robot from the mobile phone

Figure 33 Slope Climb control

Figure 34 shows Bumpy Mud Terrain ride of the Mobile Robot from the mobile phone.

Figure 34 Bumpy Mud Terrain ride

(ii) Image processing for tomato detection

This image is sent as a byte array to the local computer as shown below in Figure 35. From the byte array the needed image byte array is trimmed (spliced) from the header messages and image processing is done using Computer vision, after applying all the filters

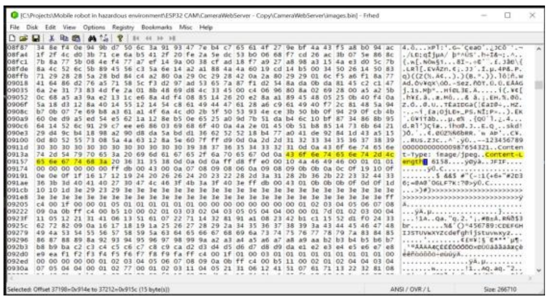

Figure 35 Image Byte array sent from ESP32 Cam to Local computer

Figure 36 shows the trackbar position that can be tweaked to isolate the red colour of the Tomato. The figure shows Hue minimum and maximum, Saturation Minimum and Maximum, Value Minimum and Maximum adjusting trackbars, adjusting by which the red colour can alone be separated.

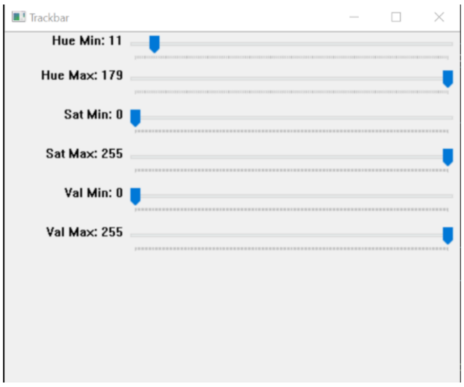

Figure 36 Hyper-parameters to isolate the colour

Figure 37 shows the image which is obtained from ESP32 Cam WiFi module which is in BGR which is converted to HSV which is used for further image processing

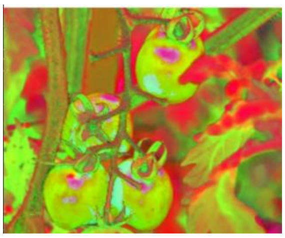

Figure 37 HSV Converted image from BGR

Figure 38 shows the image with Bitwise AND mask applied based on the HSV values noted for isolating the red colour of tomatoes.

Figure 38 Bitwise AND Mask applied to isolate the colour of interest

Figure 39 shows the image with Red colour of the Tomato isolated separately whose position is to be located in next step

Figure 39 Image with Red colour isolated

Figure 40 shows the image with Tomatoes' position located by the algorithm and indicated using the bounding box, also giving the 2D size of the Tomatoes.

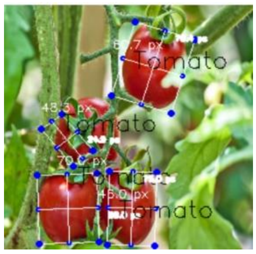

Figure 40 Tomatoes' position located and indicated using bounding box

Figure 41 shows the schematic image of the Multi core processing. Here the image is got in one processor from ESP32 Cam WiFi microcontroller and the image processing is done in another processor to make the work parallel and efficiently using octa core of the computer. It takes less time for processing a set of instructions and hence efficiency is maximum.

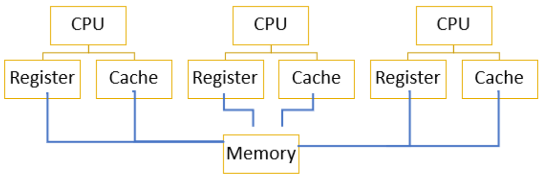

Figure 41 Multi Core Processing -schematic

(iii) Robotic arm actuation:

Figure 42 shows the Robotic Arm which are actuated by using the servo motors. There are three servo motors in total. One motor is to control Gripper adjustment, another servo motor is to control the base of the robot and third servo motor to control link lift adjustments [7]. The MPU sensor is used to get the Gyroscopic, Accelerometer and Temperature values from the sensor. The ultrasonic sensor is used to get the distance information from the fruits and the mobile robot [12]. The entire components are controlled by the ESP32 microcontroller.

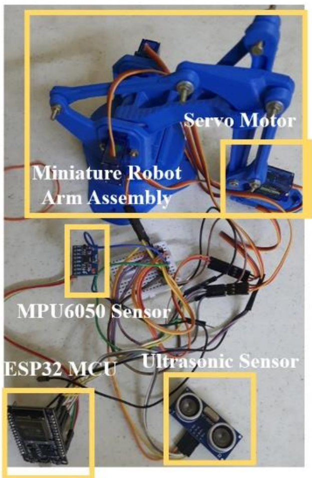

Figure 42 Overall Electric connection between miniature robotic arm, MPU6050 and Ultrasonic sensor

Figure 43 shows the Robotic Arm joint angle Control using the Gripper, Base, Arm servo motors along with Gyroscopic, accelerometer and temperature reading from MPU6050 [10] all these values are displayed in the client browser using the HTML, CSS, JS, C++ codes [11].

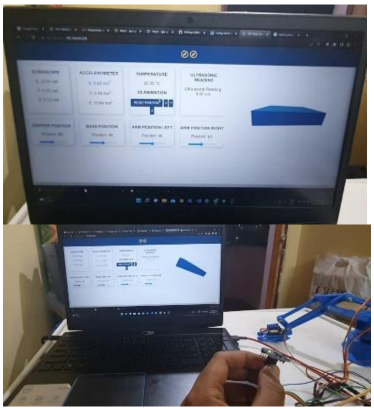

Figure 43 Robotic Arm Control with Gyroscopic, Accelerometer and Temperature, Ultrasonic readings

Figure 44 shows the sensors reading recorded in the SQL Database [13] viewed in the DB Browser software along with the time stamp.

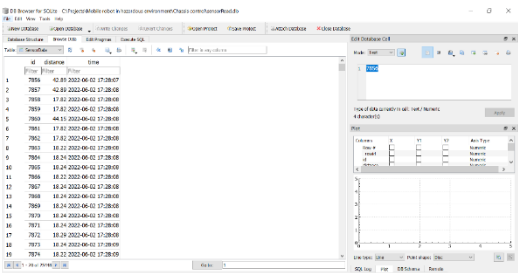

Figure 44 SQL Database to record Sensor Data

IV. Conclusion

Based on the experimental investigation of the All-terrain Mobile Robot system the conclusions are listed below:

- The model of the Robot was designed and simulated in Solidworks
- Full scale model of the All Terrain Mobile Robot was done
- Image Processing Algorithm to detect Tomatoes was done
- SQL Database was developed to store the sensor values to be used for future reference
- Robotic Arm Control Algorithm was developed to move the arms to desired position

Future scope

- An Algorithm to automate the robotic fruit detection and pick process is to be developed
- The full- scale robot arm is to be developed
- Present Robot has less Motor torques and Flat wheels which is to be replaced with high torque motors and bigger wheels to make left and right control more precise
- More scope of expansion for storing other sensor values to Database is to be done.

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