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Mechatronics System Design for Weed Management and Soil Condition Monitoring Within the Rows of Vineyards

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Abstract: ***Weed management always has been a vigorous task for farmers. Grapevines and weeds compete for water, nutrients, sunlight and have an unfavorable impact on berry size and sugar contents, if uncontrolled. More than 95% of herbicides are reported to reach a destination other than the targeted crops, resulting in wastage and many undesirable effects on the humans, other living organisms and the environment. Mechatronic system on agriculture vehicle is proposed for weed management and soil condition monitoring within the rows of the vineyards. Heavy and dense vegetation is first removed mechanically using a rotating knife and then herbicides are sprayed on the identified weeds, which enable it to reach up to the roots of the weeds for complete removal using image processing techniques. The designed Mechatronics system correctly identifies the different weed species and sprays the right quantity of herbicides at the right place and at the right time using the principle of Precision Agriculture. The proposed system also monitors the different parameters of the soil using a variety of sensors.***

Keywords: **Grapes, *Mechatronics, Precision Agriculture, Vineyards, Weed management,***

I. INTRODUCTION

The Mechatronics system design approach is used for the design of an optimal solution to various electromechanical products. It includes the synergetic amalgamation of various components of multidisciplinary engineering like sensors, actuators, control systems, and computers during the design process. Robotics is also a part of the Mechatronics system as it involves the interaction between mechanical, electronics, computer, and control engineering fields. However, inputs are provided to a Mechatronics system and those are acquired on their own in Robotics systems.

Grape is one of the most important horticultural fruit crops grown in India which is also 3rd most widely cultivated fruit after banana and citrus.

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Grapes are widely consumed as fresh fruit in India and also used for producing other byproducts like jams, beverages, raisins, juice, wine, juice concentrate, marmalades, and squash. Viticulture is the branch of the science of horticulture that mainly deals with the cultivation of vines and harvesting of grapes. FAO has estimated the surface area of 7.49 million hectares being used for grapes cultivation in the world during 2014, in 100 different countries. Grapes have been reported as one of the top fruit crops as compared to apples, watermelons, bananas, mangoes, guavas, and oranges by the Food and Agriculture Organization (FAO) of the United Nations. About 75 million tonnes of grapes production has been reported in the year 2014, out of which 42% was produced in Europe, 28% in Asia and 20% in the Americas and 10% in the remaining part of the world. Maharashtra state (74.93 %) has reported the largest producing state of grapes in India. Maharashtra and Karnataka states together contribute about 88.35 % of India's total grapes production. About 26.8 million tonnes which are up to 81 percent of total grapes production in 2014, consumed as fresh grapes[1].In the last few years, robotic technology has been increasingly employed in agriculture to develop Mechanical and other intelligent vehicles with very less crop damage and improved productivity [2]. However, considering India's share of grapes produced in the global market, it has been reported that the use of automation or robotic technology is very less for various agricultural tasks that have been performed in the vineyards in spite of facing many challenges in the agricultural sector of the country. The proposed Teleported Mechatronics solution will help to overcome a few of the problems like availability of skilled labor, higher labor costs, increasing weed control cost in vineyards, adverse effects of pesticides on humans, animals, and the environment.

II. LITERATURE REVIEW

Weed detection remains the greatest challenge and its management with effective control is a noteworthy issue in agricultural fruit crop production. The majority of weeds carry fungal and insect pests and act as an alternative host. Many Researchers have reported higher yield loss associated with weed competition with the farm produce [3]. Weed may define as any plant species amidst cultivated plants belonging to other species and which caused economic and

health hazards to a crop in the field. Weeds threaten the native plants by choking them and destroy native habitats.

Weeds reduce productivity, invade crops and endanger the survival of the crop. They compete aggressively with the plants for space, nutrients, water, and sunlight, resulting in loss of crop yield and poor, low-quality fruit crops if uncontrolled. It also adversely affects the size of berries of the grapes and loss of sugar content during the maturity period. Control of weeds in the grape is very important to maintain the yield and quality of Export quality grapes. Weed growth in vineyards mainly depends on season, training system of vines and irrigation system of vineyards. Naturally, the weed growth is high in the rainy season compared to winter and summer season. Out of the total amount spent by the farmer from cultivation till the harvesting period of the Grapes, a total of 25 to 30 % amount is spent on the weed removal within the vineyards. Also if weeds are detected within the rows of the vineyards, then farmer spreads excessive herbicides, urea, and other weed control chemicals throughout the field. It results in wastage of herbicides, excessive money spending on the herbicides, weed resistance and human health problems, degrading soil health also leads to environmental pollution with degraded fruit crop quality[4]. Conventionally, vegetation removal within the vineyards is done manually by women labor by using small hand-operated implements called "Khurpi". This is the most effective method but it requires more manpower but, this trained manpower is not available every time. Weed control and its removal have to be done in repetition after 22-26 days regularly during the one entire life cycle of the grapes cultivar. Approximately 45 to 55 labors are required for one hoeing over an area of one hectare and 8-10 times hoeing is required every year. This conventional method is a costlier and time-consuming weed control method for farmers as shown in Fig. 1 (a). The mechanical method of weed control is popular in India which uses Tractor drawn Implements, an alternative method for bullock drew implements, which is also an effective method to overcome the problem of availability of labors, but it can disturb the soil structure and soil microorganisms [8]. Fig. 1 (b) shows the Mechanical method using a tractor to save huge investment in labor. In young orchards, the root system of grape being shallow, mechanical methods using machinery becomes difficult [13] [17].

Herbicide-resistant weeds are a continuous and growing concern for farmers. In the proposed Mechatronics design, mechanical weed removal (rotating knife) is used which first removes the weeds up to few centimeter heights, and then the specified type of pesticides or chemical is being sprayed in the right quantity, at the right place to reach up to the roots of the weeds for its complete removal.

Fig. 1. (a) Hand weeding by women in orchard

Fig. 1. (b) Mechanical hoeing using the tractor

Savings in the huge investment done by farmers for weed control shows that the application of herbicides using the proposed Mechatronic system is a more effective and efficient method to control the weeds within the rows of vineyards [5][10] [6].

Modern agricultural practices include the application of various new technologies. One such a new technology is Precision Agriculture technology that includes the precise identification of weeds and targeted variable spraying of pesticides and herbicides to provide effective protection to the crops in the field. Weed identification model with K-means clustering and feature learning, combined with CNN shows good accuracy [7]. During the weed management, more than 95% of herbicides reach a destination other than their target crops. The literature shows the reason for the same as these herbicides are spread everywhere in the field resulting in the degrading level of soil in the form of nutrients and other minerals. This causes many undesirable effects on humans, other living organisms and causes environmental pollution[8]. It has been reported that the use of half the dosage of herbicides produces the same effect as the whole dosage of chemicals in low-density weed areas [9] [11]. This suggests that herbicide spraying at the targeted locations can be adjusted as per the weed density using variable flow control nozzles. The proposed Mechatronics weed control system provides an effective solution to weed management within the rows of the vineyards.

III. MATERIALS AND METHODS

For efficient detection and differentiation of different weeds species within the rows of vineyards, the Machine vision system has been providing a promising solution. The stereovision camera is mounted on the rear side of the teleoperated vehicle which performs the scouting operation within the rows of vineyards. The acquired image of vegetation or weed is of green color and then the pesticides are sprayed for a short duration of time at the location of the vegetation. If the height of weed is up to one foot and above, then it is very difficult to spray the pesticides near to the roots of the vegetation.

Pesticides will be get sprayed on the leaves of the vegetation instead of roots of vegetation and the purpose of effective pesticide spraying will not be achieved. Fig.2 shows the vegetation captured at the NRCG field, Manjari Farm, Pune. Hence, mechanical rotating hoe first removes the weeds up to a few centimeters of heights, which enables the pesticides to reach up to the roots of the weeds for its complete removal. Table 1 shows the details about the specifications of various Mechatronics components used for prototype deployment.

Fig. 2. Non-uniform Weeds within the rows of vineyards

A. First Approach using MATLAB:

Color is a vital characteristic of the plant and weed identification [8,17]. During the experimental work, different images of different types of vegetation are captured, which is easily affected by various environmental factors (Refer to Fig. 2). Hence, for accurate identification of weeds and the implementation of an identification algorithm, the most effective color feature vector model selection is a very crucial and right color space that is important [12]. Color space is also reported as a color model in a few kinds of literature. In our present system, we have used the most common color space models out of available RGB, HSI, and YCrCb color models. Fig. 3 shows the overall architecture of the system.

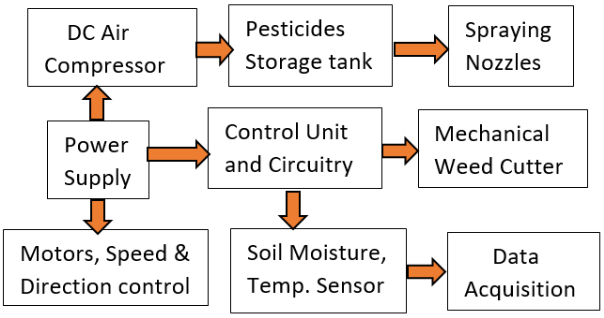


Fig. 3. (a) Overall Architecture of the System

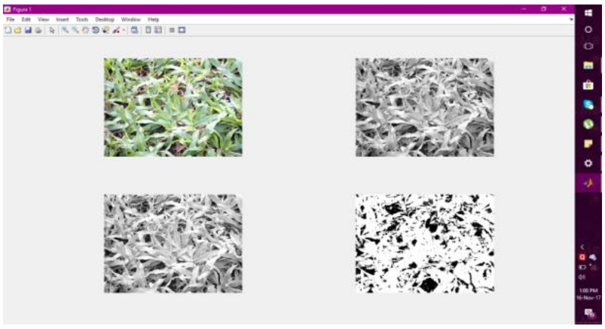


Fig. 3. (b) Image Acquisition of Weeds [16]

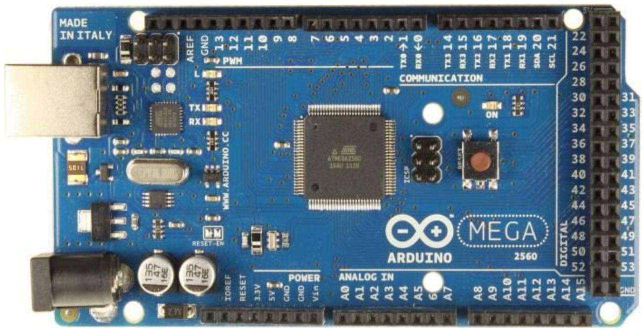


Fig. 4 (a) Arduino Mega 2560 controller

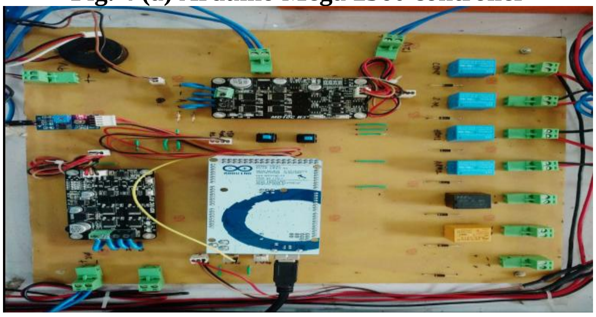


Fig. 4 (b) PCB with Controller, Relay and driver Circuit

For the detection of weed, MATLAB software R2016b version is used [16]. Image acquisition camera is interfaced with the MATLAB software using Image Processing Tools and Packages built in the software. When the stereovision camera detects weed (i.e. green patch), as shown in Fig. 3 (b), then the controller turns the dedicated relay ON which in turn starts the compressor, which further sprays the herbicide using the Atomization technique. Fig. 4 (a) and (b) shows the Controller circuitry for the given applications.

The Stereovision camera used for weed detection has the following specifications.

1. Focus Range: 4cm to infinity.
2. Interpolated to 25 MP
3. Frame Rate: 30 fps (MAX).
4. Special Visual Effects.
5. True Motion Picture.
6. Night Vision: 6 lights.
7. Inbuilt Sensitive Microphone.

The stereovision camera used for weed detection has a focus range of 4cm to a few feet, a frame rate of 30 fps, resolution of 500K pixels, etc. The first image of weeds is captured using the stereovision camera and this image is stored as Image “I”. Then conversion of this RGB Image “I” into gray image “G” is done using Matlab function “rgb2gray”. Then the values of green color are detected from the original image “I” and this image is then further stored as Image “A”. Then image “A” is subtracted from image “G”. The subtracted image is then converted into a black and white image using 'im2bw' function. Then the image is scanned for white pixels and if white pixels are found then the relay is turned ON. This relay will start the weed cutter and then the spraying system will spray the herbicide. Fig. 5 shows an algorithm implemented for Weed detection. The image acquisition and processing are carried out through the Arduino Mega controller, shown in Fig. 4(a) which takes an approximate time of 4-6 seconds for image acquisition and image processing. Using Image Processing tools and packages built in the software, when the stereovision camera detects weed (i.e. green patch) the controller turns the dedicated relay ON which in turn starts the weed cutter to cut the weeds up to few centimeter heights.

Fig. 4(b) shows the PCB with a relay that drives the cutter. Next with a certain delay of say of 2 seconds, another relay starts the pump, which sprays herbicide at the root of weeds. Hence within 8 -10 seconds, the image acquisition and pesticides spraying operations are carried out.

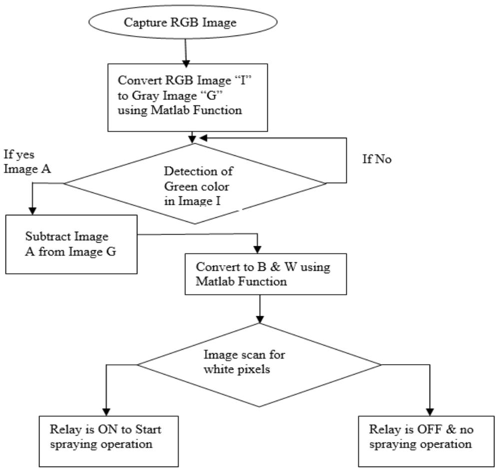


Fig. 5 Weed detection and spraying algorithm

B. Second Approach Using Raspberry Pi:

Here HSV color model is used and its algorithm is as follows

- The stereovision camera is switched on and the image frame from the video is captured.
- The unwanted green color vegetation is detected by defining the boundaries of HSV over the frame. The green shade of the vegetation varies from the pixel size of 125 to 255. Any green color shade between these two limits will be detected and accordingly, the pesticide spraying pump will be switched "ON".
- The pump is switched on for a max. of 5 seconds and the herbicides are sprayed over the detected area.
- If the height of the weeds or vegetation is up to a few feet, then based on the farmers' judgment, he will switch on the mechanical hoe or cutter to cut the vegetation up to few centimeter heights.
- Once the vegetation is removed using a mechanical cutter, then the green color is still present, which is detected by the stereovision camera and the pesticides will be get sprayed over the vegetation patch with a Mist spray.

A high flow Booster water pump has been used to achieve the result of precision spraying on weeds.Fig.7 (a)-(d) show the various system components.

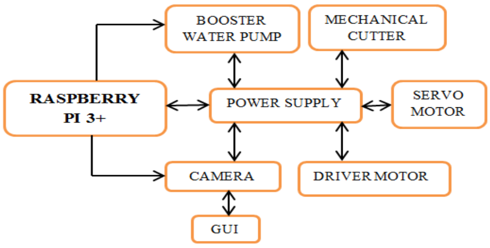
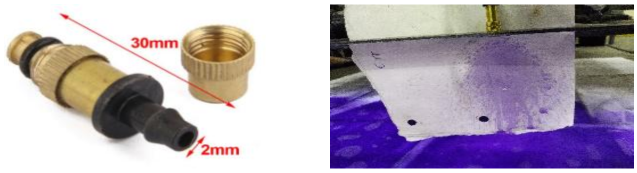


Fig. 6 HSV Algorithm for weed management

(a) **(b)**



(c) **(d)**

Fig. 7 (a) Battery, (b) Battery Charger, (c) Mist spray nozzles, (d) Nozzle Spray Pattern

Table- I: Specification of Mechatronics System Components

Battery	**Voltage**	24 V
	Type	Sealed Lead Acid
	Make & Model	AMARON-CRTD
Battery Charger	**Voltage Range**	12 / 24 V
	Type	Trickle Type
	Make & Model	Bosch- C7
Pump	**Volts**	24 V D.C
	Ampere Rating	1.0 A
	Max. Pressure	120 PSI
	Flow rate	1.2 LPM
	Make & Model	Aqua HMR-1050
Nozzles	**Spray Angle**	Variable up to 75^0
	Max. flow rate	1 LPM
	Pipe Fitting	PU-6
	Make & Model	Agro tech :AM-26
Raspberry Pi-3 –MODB Motherboard Circuit	**Specifications**	64-bit CPU, 1 GB RAM,1.2GHz,100Mbps LAN speed, 40, HDMI & USB Port, GPIO pins
Camera	**Image type**	HD 1080P ,30 FPS
	Make & Model	Stereovision Logitech C922
Compressor	**Type & Voltage**	12 V, DC
	Current	1.5 A
	Max. Pressure	150 PSI
Pneumatic system Components	**Cylinder Type and Make**	Double Acting, Piston OD: 25 mm Stroke: 250 mm Make: Janatics
	DCV type and Make	5/3, ¼", Lever operated, Janatics
	Air Storage type & Pressure	20 Liter Water Jar tested up to 8 bar
Main Drive Motor with Driver Circuit	**Volt**	24 V
	Current	3.7 A
	Power	90 W
	RPM	1500
	Frame Class	F Class
	Type	Geared PMDC
	Make & Model no.	Revolution Tech ELIMO90-4PH

C. Soil Condition Monitoring

The soil moisture sensor is interfaced with the MATLAB software using Image Processing Tools. When the vehicle comes near to the root of each plant, then the pneumatic cylinder will be extended and the soil moisture sensor will make the contact with the soil. Hence the soil moisture sensor is moving with the vehicle and it measures the soil moisture at each plant (Fig.8 b). When the sensor is penetrated inside the soil, it measures the level of moisture and the controller actuates the dedicated relay, which in turn sets an alarm to the farmer if the moisture level doesn't match the desired value. A soil moisture sensor (Fig. 8 a) is used to read the amount of moisture or wet part present in the soil near the sensor location. It is most commonly used for maintaining the urban gardens, gardens in hotels and commercial buildings. When the two probes of the sensors are connected to the source of power then the current passes through them as soil completes the circuit using moisture present in it. The corresponding increase in the resistance value gives the amount of moisture present in the soil. As the wet soil contains more amount of moisture as compared to the dry soil, hence the wet soil offers minimum resistance to the flow of current as compared to the dry soil which offers maximum resistance to the current flow. An immersion Gold plating is used for soil moisture sensors to safeguard the nickel part of the sensor from oxidation to avoid the false output of the system.

Fig. 8 (a) Image Acquisition & Soil Moisture Sensor

Fig. 8 (b) Soil condition monitoring system

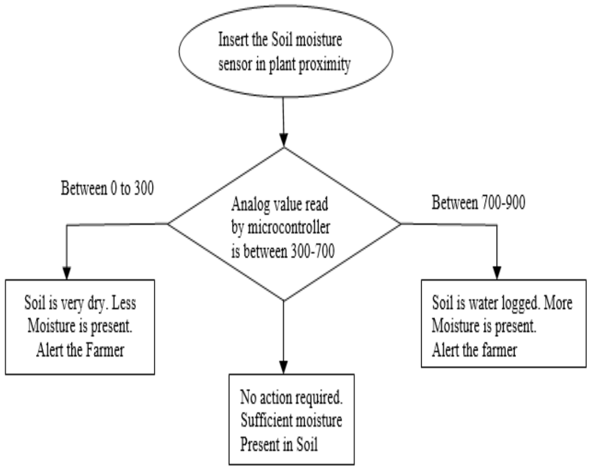


Fig. 9 Soil condition monitoring algorithm

The moisture sensor is interfaced with Arduino Mega Controller on the analog pin. High speed is achieved using a flow control valve for a pneumatic actuator to quickly reposition the Soil Moisture sensor (Refer Fig. 8 (a) & (b)) at the root of each plant [9,17]. Fig.9 shows the algorithm for monitoring the soil moisture condition. The soil moisture sensor YL-69 is penetrated in the soil at each stop near the plant by actuating a pneumatic cylinder. The sensor gives back analog values to the microcontroller; which will be read and compared for the desired results. The moisture sensor is interfaced with Arduino Mega Controller on the analog pin. The pneumatic cylinder is used to quickly reposition the Soil Moisture sensor at the root of each plant [10].

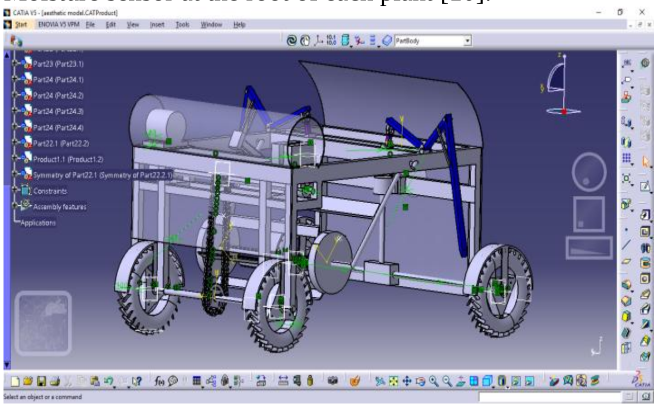


Fig. 10 (a) Proposed Mechatronics system Model [14] [15]

Fig. 10 (b) Actual Prototype Testing [14] [15]

Intra-row weeds management and weed control within the rows of crop production and vineyards has always been a challenging task [15]. For the implementation of automation for weed control, the reported solution is the use of robots that can serve as co-workers and work beside or cooperatively with people called co-robots [6]. These co-robots are user-friendly and have a symbiotic relationship with farmers or operators. During a challenging task, these co-robots combine their relative strengths with farmers to cooperatively perform a task. This co-robotics system should be user-friendly and available at a low cost. An attempt has been made in the proposed system to meet a few of the said requirements.

IV. RESULT AND DISCUSSION

The solid model of the proposed Mechatronics system is as shown in Fig.10 (a) and the actual prototyped developed for weed management is as shown in Fig. 10 (b). The fieldwork, validation, and testing are carried out at Indian Council for Agricultural Research, National Research Centre for Grapes (ICAR-NRCG) Manjari Farm, Pune.

The code written for weed detection first consists of capturing the image through the stereovision camera. This image is first converted from an RGB image to a Gray image using the built-in function in MATLAB. The weed pixels are separated from the soil brown color background using a color change of green weeds and brown soil [8,12].

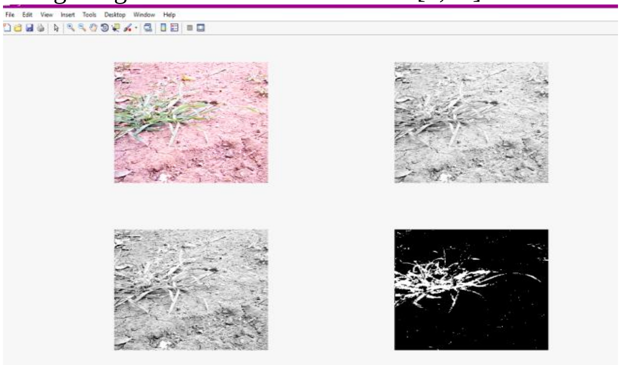


Fig. 11 (a) Medium to dense Weed detection [16]

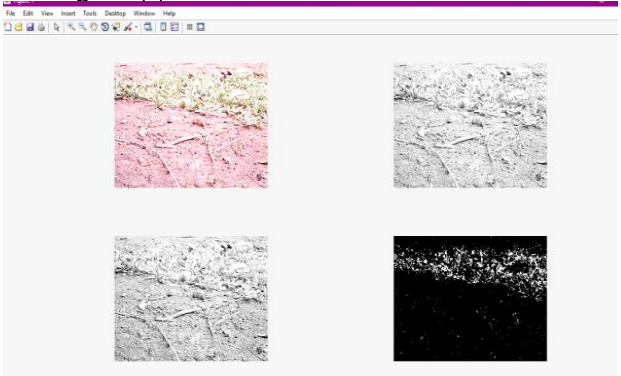


Fig. 11 (b) Variety of Weed detection [16]

This function converts the pixel values of RGB to gray values which are between 0-255; where 0 = white and 255,= black and the intermediate values are shades of Gray (consider it as image G). Then the value of green color from the original image is detected (as the weed to be detected is in the shades of green) using functions in MATLAB. This function makes all the green parts in the image white and the background is in shades of Gray (consider image A).

Then we apply a filter by subtracting image A from image G. The resultant image of this subtraction will display green-colored parts in gray color and everything else will be black. This image is then converted to a black and white image wherein the green parts will be white and all the background will be black. Thus by analyzing a processed image in the mentioned way we can say that weed is present if the image consists of a pixel whose value is 0 (i.e. white). Refer Fig. 11 (a) and (b). After the detection of the weed, the herbicide will be sprayed. Image processing in the vehicle is mainly used for the detection of weed [16].

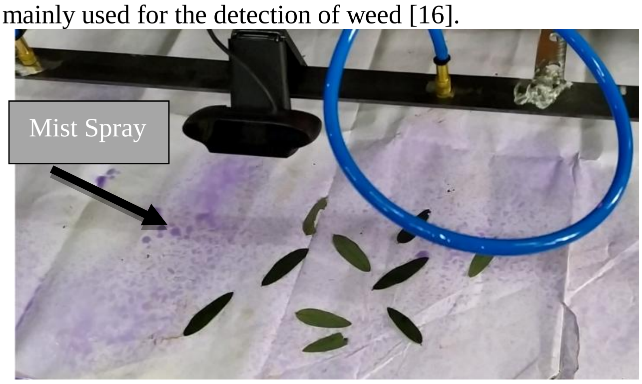


Fig. 12 (a) Low-density weeds detection & Mist spraying

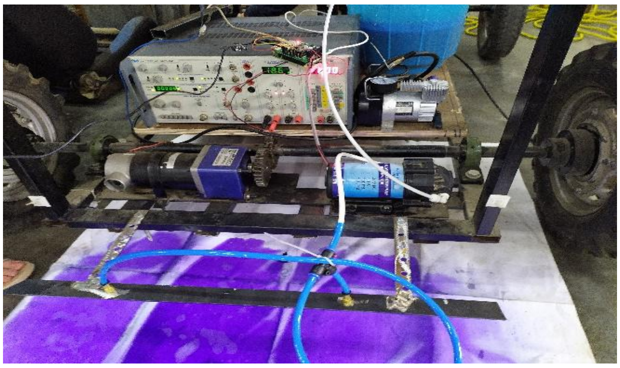


Fig. 12 (b) High-density weeds detection and spraying

The said Mechatronics system can work for longer hours at constant speed giving the same or even greater output as compared to the conventional method [9]. Automation of vehicles includes traversing of the vehicle through the vines, spraying of herbicides when weed is detected and detection of soil moisture [14].

The vehicle will traverse through the rows of grapevines automatically and will stop at every plant in the vine to detect the quantity of moisture available in the soil and alarm the farmer if the moisture is below a specific value. A rotary encoder has been used for this purpose. A soil moisture sensor is used for moisture content detection. A relay is used for powering up the pump for herbicide and pesticides spraying through a controller command. The entire image processing results are communicated to the Arduino controller through a special interface package in MATLAB. Fig.12 (a) and (b) shows the proposed implemented Mechatronics model and its actual testing and validation. Fig.11 shows the results obtained after image acquisition which is displayed on GUI.

V. CONCLUSION

In the presented work, new innovative techniques and modern practices are used for weed management by introducing semi-automatic, teleoperated, user-friendly Mechatronics systems in agriculture which are mounted on the vehicle that can move within the rows of vineyards and orchards for inspection, scouting operation. It has been observed that weeds are dispersed non-uniformly within the rows of the vineyards and if it is detected by farmers, then they take the corrective action as spraying of hazardous pesticides and herbicides everywhere, resulting in the degrading quality of soil, which further affects the fruit quality. The weed control method based on the conventional practice of spreading of herbicide within the rows of vineyards is therefore ineffective, in both ecological and economic conditions. A robotic platform with a Mechatronics module along with an image processing technique is used to identify the weeds. Initially, mechanical hoe (rotating knife) is used to cut the weeds up to few centimeters heights and then Herbicides or pesticides are sprayed which will reach up to the roots of the weeds. This method saves the excessive use of herbicides and amounts spend on weed management by Indian farmers.70-85 % of the cost for herbicides has been saved when only vegetation patches have been treated, where weeds grow using the current robotic platform for weed management. Better results are obtained in RGB image pre-processing as compare to that of Grayscale image pre-processing.

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The user-friendly GUI ensures that every patch of weeds is detected and treated by pesticide spraying. An attempt has been made to relieve the farmers from spraying of Poisonous pesticides and herbicides in the vineyards.

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