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Design and Test Performance of Weeding Robot using Circular Cutter and Pixy 2 Sensor

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ABSTRACT

Farm machinery is the backbone of agricultural mechanization in mitigating labour shortages and making farm work easy to handle. Automation in agriculture can solve labour shortages problem, reduce crop production cost, sustains agricultural land and the environment, to increase farmer income. Automation is a very key factor in achieving agricultural mechanization revolution for increase in crop yield per hectare and quality food produce. The research presents a suitable design and model of a weeding robot to assist farmers control farm weeds effectively, to increase productivity. The study proposes a better way of fighting farm weeds instead of the gruesome attack on farm weeds. It can also promote commercial agriculture, release manpower for non-agricultural purposes, and facilitates organic farming. The proposed weeding robot uses a circular cutter with the blade having an angle that enables it cut/clear weed through centrifugal force power by continuous rotation servo motor. The mechanical part of the robot is designed with AutoCAD, and cross-checked for various actions. The components are print with 3D printer. Even though using a circular cutter for controlling weeds on farm fields was amongst the first step of development, techniques of perception, innovations, positioning, and cutting have been developed and or improved upon for resilient weed control. Further work development will be making the best of the vision control system using deep learning techniques and artificial intelligence. The deep learning techniques will be a vision and action control system to establish a more capable and accurate model for agricultural farm weeds detection.

INTRODUCTION

According to Hiroyuki Takeshima *et al.* (2016), agriculture mechanization is one of the main processes that affects the future development of smallholder farming systems in Asian countries like Nepal. Agricultural mechanization in some developed countries, like the United States, resulted in considerable growth in farm sizes, crop productivity, and food quality over time. Notwithstanding the numerous aids carried out to the developing countries by the developed world, their development remains a challenge if agricultural mechanization is not fast track in these areas. Farm machinery is the backbone of agricultural mechanization in mitigating labour shortages, making farm work easy to handle, and helps hard working towards achieving good yield. A farmer trying to secure family food security, pay off bills, and cater for himself/herself in social functions needs to get massive farm size. This poses to farm weed control challenge, which he/she will have no option than to rely on chemicals to control the farm weed. In Ghana, agrochemicals are applied in vegetable, coffee and cotton farms, cola nut, cocoa, oil palm, and fruit production, mixed-crop farming method requiring legumes, cereals, and tuber crops (Fianko *et al.*, 2011).

For efficient and excellent mechanical weeds management, rotary weeder and cono weeder have been considered to be good in controlling weeds. In Japan, median farm size has been much slight than that of the United States, it has

increased gradually from one hectare in the 20th century to two hectares in the 21st century (Takeshima, *et al.* 2016). With mechanical weeds control, the adoption of robot technologies can play an effective role where sensors can be used to detect weeds from crop plants; to curve the problems of food supply instability due to lack of labour, and the aging workforce. In specific, to be price better with farm products on international markets, Japan have to promote the development of robots for farmers to reduce production expenses (Noguchi *et al.,* 1996).
Weeds detection among crops using machines like robots, involve employing sensor to carefully and clearly distinguish between weeds and crops. There are many techniques used for weed detection in automation applications for farm weeds control such as photoelectric, ultrasonic, microwave, and image processing detection techniques. The techniques of weed detection use the reflectance of both crops and weeds spectral which is measured in the range of 400 ~ 900 nm in cotton fields.
Automation is a process where two or more control systems are combined to form a technology (such as Computer-Aided Design/Computer-Aided Machining). The purpose of automation includes handling agricultural machinery and processes to reducing the need for human labour and farmers' struggle. Automation enables agricultural mechanization where machines are applied to do work considered tedious to humans and promoting efficiency and productivity.
In agriculture, automation (farm mechanization) is needed because of the difficulties involved in all the crop cultivation processes. And in a particularly weeding activity where every part of the cropped area has to be scratched/weeded (cultivated) and in two or more times before harvesting. There are several advantages of automation in farm mechanization including drudgery reduction, increase in productivity and promotes energy diversification promotion.
In this technologically advanced era can we afford to continue to imagine the consequences of these climate change fingerprints we are witnessing our farming sector? Its effects in the agriculture sector require a tangible influence on our farmers' practices of crop cultivation to ensure our health and safety of our agricultural land as well the environment at large is safe without any future danger?
The study sought to design a weeding robot using a circular cutter with a weed detection mechanism. The specific objectives were; to carry out an experimental test on the weeds detecting mechanism using a camera sensor, and to carry out a test with the robot cutting/clearing weeds using the cutter with its sensor autonomously/wireless means.

MATERIALS AND METHODS

Design of Weeding Robot System

Mechanical and Hardware System

Since laboratory scaling is a concern, components of the weeding robot were scaled not more than 240 mm. The mechanical structure parts include; chassis, four wheels, four standing bars, base arm/first part arm actuator, elbow arm/second part arm actuator, and end effector (cutter). Figure 1 presents the mechanical components indicating the 3D models of each of the components forming the circular cutter weeding robot.

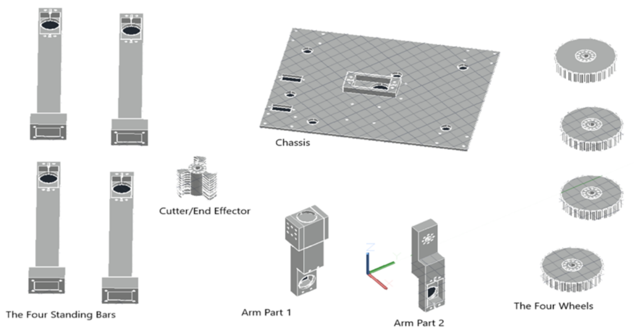

Figure 1. Mechanical components of a weeding robot

The chassis is the main part of the robot's body. It bears the weight of the devices like transmission mechanism, microcontroller, sensor, and the battery placed on it. It provides solutions for forming both minor and major joints. This implies the chassis needs to be large enough to provide adequate fixtures of all the necessary joint parts. Also, the chassis has to be thick and strong enough to enable it carry weight load as well as withstand dynamic conditions such as vibrations, shocks from chassis torsion, and torque by actuators. The material used for the printing of the part is filament. The standing bars are known as the robot legs. Like the chassis, the bars carry the load placed on the chassis. The load carrying by the standing bars requires that the standing bars be strong to take the task of load, torques, and vibrations emanating from the arm during the working process.

The wheels bear the load of both the standing bars and the chassis. The weight of microcontrollers and other electronic devices including the bars are all carried by the wheels. The wheels also suffer from friction due to ground contacts that enable movement and necessary navigation instructions from microcontrollers (the robot brain). The arm is the robot actuator. It is the arm that carries out significant part of the study (cutter). The arm is situated in the middle of the chassis. This is to allow the cutter to access both sides (left and right) and to position between (in the row) crops after weeding to prevent crop damage. The arm consists of three parts qualifying its three-degree of freedom (3DOF). These include the first part/base arm, the second part/elbow arm, and the elbow arm.

The cutter of the weeding robot has a simple design construction for the study and an easy to learn navigation control system. This part is responsible for cutting or clearing the weed. It has three blades per the 60.2 mm circumference and ten blades along the horizontal length of the cutter.

Table 1. Mechanical parts specifications of the weeding robot

S/N	Part	Material	Dimensions (mm)
1	Chassis	Filament	230x185x4
2	The Standing Bar	Filament	26x14x220
3	The Standing Bar's head	Filament	40x28x20
4	The wheel	Filament	61x20
5	First part arm	Filament	26x14x115
6	Second part arm	Filament	26x14x132
7	End Effector (Cutter)	Stainless steel	60.2x40
8	Aluminum-U Shaped Bracket	Aluminum	40x2x20x27

Figure 2. Electrical components of the weeding robot

The microcontroller used for this study is the Arduino Uno board ATmega328P. The microcontroller board comprises of 14 digital input/output pins and 6 pins that can be used for PWM outputs. It also has 6 analog input pins, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a USB link, a power jack, an ICSP header, and a reset button. It is very versatile in supporting microcontroller either by USB cable connection or power through AC-to-DC adapter or battery to be powered. Arduino Uno has a Software (IDE) for programming communication. The reference versions of Arduino were the Uno board and version 1.0 of Arduino Software (IDE).

In this study, there was no motor driver used for the robot movements. The robot navigation is achieved by Bluetooth/sensor communications with the microcontroller. This was done through signals sending to the microcontroller to move forward, backward, left, and right. The Bluetooth 4.0 HM-10 master-slave module enables the data transfer complete and convenient remote control. It uses AT command that allows choosing between master and slave. It works at a power designed with a 662K regulator chip and performs at both 3.3V and 5V.

Motors used for this study consider the robot function, power, speed, and precision. The motor used to drive the wheels and the cutter for cutting/clearing of the weed is 360 degrees continuous rotation servo motors (FS5106R). Because of the standard-sized nature servo motors are made, it was found quite convincing that they were used for this study. Taken into consideration gears and an axle speed that does not alternate with regard to the top of a hill or downhill a gearbox motors were used instead of DC motors. For better manoeuvring, the robot uses two motors and two wheels on both rear and front. At 6 V, it gives a maximum rotation speed of 95 RPM (no-load) and produces up to 83 oz-in/6 kg-cm of torque. For the base joint and the elbow joint 180 degrees, a servo motor is used. 180 degrees servo motor was taken into account the torque, precision, and standardized nature of servo motors.

The circular cutter weeding robot uses a Pixy2 CMUcam5 sensor to detect weeds. This sensor is small, very fast capable of detecting objects you teach it. Pixy2 sensor has a new algorithm enabling it to detect objects, track lines, and follow them. The Pixy2 camera sensor has interfaces like SPI, I2C, UART, and USB for simple communications. It uses the principle of a color-based filtering algorithm in detecting objects making it fast, efficient, and relatively robust. It computes the hue and photography of every RGB pixel from the image camera sensor as the primary filtering parameters. The object hue is unchanged upon lighting and exposure.

Cutter Design for Automation System

Cutters are cutting systems that cut objects of materials less hard than them. The engineering disciplines have applied the principle of the cutter in many different areas like manufacturing industries, the agricultural sector to achieve many cutting aims. In the agriculture sector, engineers have developed cutting tools and machines like stem cutting, cutting edge technology, disc plows system, and moldboard plows system. Cutter when rolled or drag by force against a surface it cut into it due to the blade's sharpness and design. The cutting mechanisms are applied in harvesting machines, for instance, the cutter-bar cutting system (CCS) which uses the scissor shearing method for cutting. This cutting machine is used for cutting annual plant stalks. Rotating cutting system (RCS); this uses the impact and shear method also for materials cutting like saw cutting mechanism (SCM), disk cutting mechanism (DCM) and coulter cutting mechanism (CCM)

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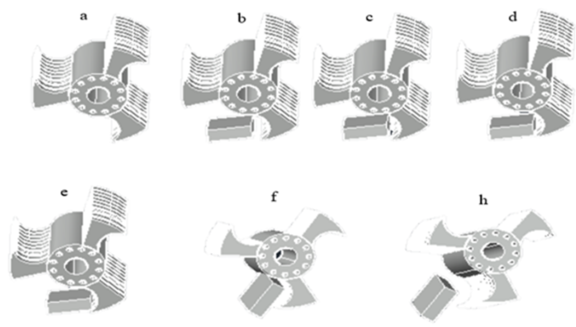


Figure 3. Various cutting actions for spherical cutter

The cutter's ability to cut/clear weed is influenced by centrifugal force empowered by a 360-degree continuous rotation servo motor. In this study, seven action steps have been identified by the cutter in cutting/clearing the detected weeds. When the motor starts; the cutter's blade is in free motion as showing in Figure 3a. As the cutter rotates the blade gets close to the weed but not contacting/cutting which is showing in Figure 3b. Due to the cutter's continued rotation, the cutter's blade started cutting partially seen in Figure 3c. It is then in a cutting motion as the centrifugal force continues indicated by Figure 3d. Getting to 270 Degrees rotation, a lifting action is created resulting in vacuum air (figure 3e). The kinematics energy due to circular motion force developed pressure ready to cause displacement (Figure 3. f). The pressure increment coming from the circular motion force courses a displacement media because of the cutting /clearing of the weed object is achieved (Figure 3g).

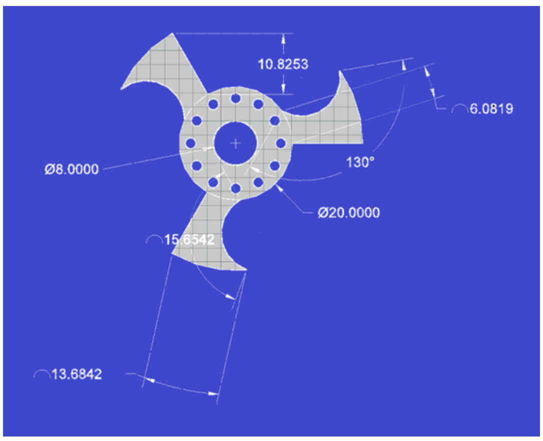


Figure 4. Cutter Design

The cutter's kinematics is a reflection of its design making it easy to be driving by motor for the weeding excellence. The cutter blades are designed such that it obeys the weeding principles exactly like a hoe for good weeding purposes. The blades are made up of length 10.8253 mm enabling penetration into the soil during cutting and a width of 3 mm to facilitate holding of the soil for proper displacement. The blades' faces are also designed with an arc of 15.6542 mm which produced an angle of 130 degrees to help allow the cutter to travel into the soil, enable the cutter clinging to the soil, and hence completely clearing or uprooting of the weeds. Figure 3.4 above is shown more of the schematic diagram of the cutter.

Design and Development Procedures

The subsystems and their design environment include the following:

1. System Design
2. Modeling of components (AutoCAD)
3. Parts/device ordering
4. Physical assembly into Prototype robot and cutter
5. Robot simulation
6. Control and monitoring performance testing and evaluation

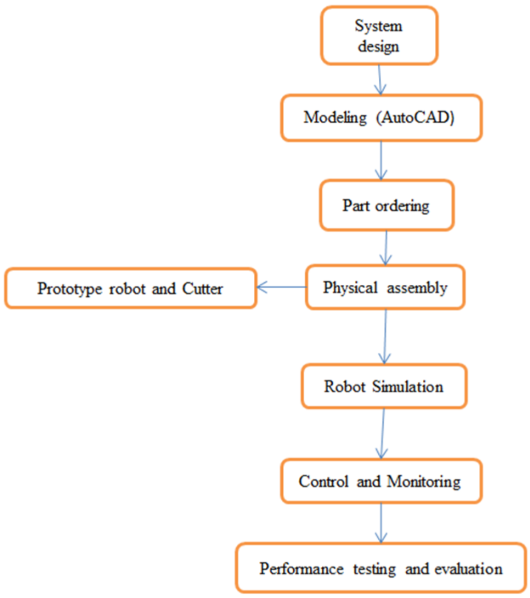


Figure 6. Block diagram of design and development procedures

First and foremost was the robot system design model consideration. In the design plan, the robot was proposed to have four standing bars also known as the robot legs powered by servo motors to drive it. It is found out that the robot must be taller than the crop and the weeds to prevent crop damage to facilitate the sensor vision and detection, and good weeds control. To enable two or more rows weeding per phase, the robot arm is situated at the center of the chassis to access left and right weeds when moving for weeding. After these were fixed, the design was subsequently modeled into 3D models through AutoCAD system software and later printed using a 3D printer.

Parts particularly electrical devices/components were ordered after carefully planning and selection. These together with the mechanical components were then assembled into a physical robot. It was simulated base on the initial idea planed for its design using the robot parameters, and its devices. The robot navigation for the experiment is achieved by the control and monitoring system that involves the microcontroller also known as the brain of the robot and the Bluetooth/Pixy2 sensor. Control and sensing of the robot were also examined for weed detection purposes using the Pixy2 camera sensor. Performance test and evaluation of the robot was performed to see subsystems working capabilities and testing for its ability to cut/clear weeds.

Robot Simulation

The cutter is the end effector of the robot arm situate in the middle of the chassis (center of the robot). The cutter works when the continuous servo motor is rotating. The arm is a 3-degree freedom comprising; the base joint being operated by a 180-degree servomotor, the elbow joint also using a 180-degree servomotor, and the cutter join, 360 degrees continuous rotation servomotor. The robot is a four-wheel-drive mechanism powered by four (4) 360-degree continuous rotation servo FS5106R also with precise positioning. The cutting phenomenon is achieved through a linear motion as a result of circular motion. The principle behind this is that, when the servomotor is in rotation, the cutter also turns around continuously, and with the blade's angle and edges it clears or cuts what is within the circular motion magnetism. At six voltages, the servo motor has a highest rotation velocity of 95 RPM (no-load) and can produce up to 83 oz-in (6 kg-cm) of torque.

Table 2a. 180 Degree rotation servomotor specs

Parameter	Specification
Dimensions	40.8mmx20.1mmx37.6mm
Weight	58grams
Operating speed	0.18sec/60degree(4.8v), 0.16sec/60degree(6v)
Tall torque	12.5kg/cm/173.9ozin(4.8v),13. 5kg/cm /187.8ozin(6v)
Operating voltage	4.8v~6v
Control system	Analog
Direction:	CCW (counter clockwise)
Operating angle	180°
Required pulse	500us-2500us
Bearing type	2BB
Gear type	Metal
Motor type	Carbon
Connector wire length	30 cm

Figure 8. 360 degrees continuous rotation servomotor

Table 2b. 360 degrees continuous rotation servomotor specification

Parameter	Specification
Dimensions	40.8mmx20.1mmx38mm
Weight	40 grams
Operating Speed	0.18sec/60° (4.8v), 0.16sec/60° (14v)
Stall Torque	5 kg/cm/69.56ozin (4.8v), 6 kg/cm/83.47ozin (6v)
Operating Voltage	4.8v~6v
Control system	Analog
Direction	CCW (counter clockwise)
Operating Angle	360°
Required Pulse	500us-2500us
Bearing Type	2BB
Gear Type	Plastic
Motor Type	Metal
Connection Wire Length	30 cm

Figure 9. 180 Degree rotation servomotor

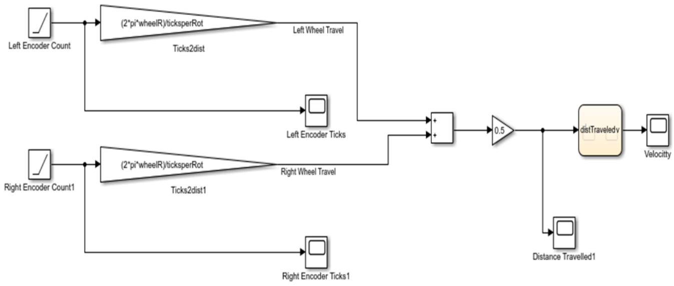


Figure 10. Robot modeling flow chard algorithms

Calculating the distance traveled using the encoder (odometer): Distance traveled = number of wheel rotations x 2 x π x R, where R is the robot wheel radius but the number of rotation = total encoder ticks/ticks per rotation and 1 rotation was taken to be 9 ticks.

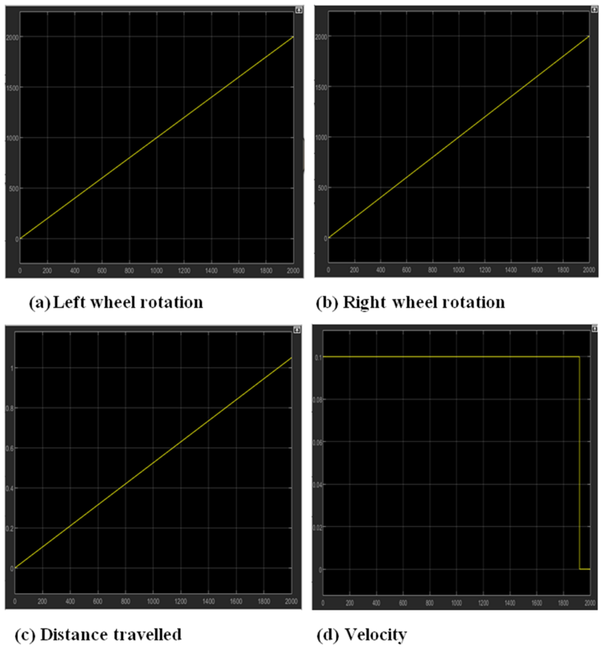
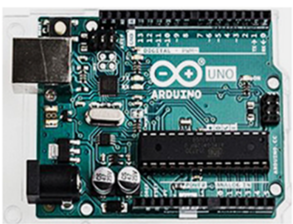


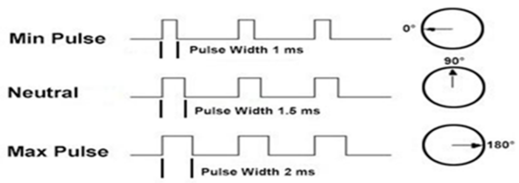
Figure 11. Robot modelling result

Control and Monitoring

The robot navigations together with the arm and its cutter are controlled by an embedded system microcontroller. C language is used to code the microcontroller. The C programming language is a computer language for programming computers which was made to do system programming for the working system UNIX. It is an imperative programming language; a procedure language that means people can write down their programs in a sequence of step-by-step order. The sketch written is uploaded to an embedded system - microcontroller; Arduino Uno's IDE which is verified by the compiler. IDE (Integrated Development Environment) is Arduino Software that haves a text editor for sketch writing, an area for message, a text console, a toolbar containing buttons for some simple functions, and a series of menus. Servo motor has electronics, which are internally turning the DC motor on and off as obligatory to handle the correct location. In the case the target is not matching with the present position, it continues to rotate the motor till the two equal. The loop is normally running while contrasting the shaft position to the target set for and this is control by the servo. The main programs developed for operating both the robot navigation and the arm is generally automated. When the sensor detects weed it communicates to Arduino which positions the cutter there for clearing/cutting to be affected.



(a) Arduino Uno boart



(b) Variable pulse width control servo position
(https://www.jameco.com/jameco/workshop/howitworks/how-servo-motors-work.html)

Figure 12. Arduino Uno board and variable pulse width control servo position

Table 4. Specification of Arduino Uno

Parameter	Specification
Microcontroller	ATmega328
Operating Voltage	5v
Input Voltage(recommended)	7-12v
Input Voltage (limits)	6-20v
Digital I/O Pins	14 (6 pins PWM output)
Analog Input Pins	6 pins
DC Current per I/O Pin	40 milliampere
DC Current for 3.3V Pin	50 milliampere
Flash Memory	32 KB (ATmega328) and 0.5 KB used by the boot loader
Sram	2 KB (ATmega328)
Eeprom	1 KB (ATmega328)
Clock Speed	16 megahertz
Clock Speed	16 megahertz
Length	68.6 mm
Width	53.4 mm
Weight	25 grams

Sensors are electronic devices used to measure a physical quality like images, light, or temperature which are then converted to a voltage. Classification of sensors can be categories into two different kind thus digital and analog sensors. The digital sensor can only have one of two possible states; these are output-ON (1), +5V, or OFF (0), 0 V. Majority of digital sensors work with a threshold, if it below the incoming measurement the sensor will output the one state; if above the threshold it will output the other state. For analog sensors; output can assume any possible value for a given range. Most times analog sensors output are variable resistance used to control voltage but not been able to toggle between two states. The output of an analog sensor is almost an infinite fluctuate of values. For the simplest digital sensor, when the switch is open, no current flows but when the switch is closed, current flows (closed = ON). is called A latching switch. This is switch that remain in a location it was placed. Switches can be described as momentary switches when it can be loaded with spring for instance micro switches/snap action switches. A switch that is simple can have a normally open (NO) or normally closed (NC). Some image sensors are incorporated with algorithms that enable them to detect objects accurately.

Pixy2 CMUcam5

Pixy2 CMUcam5 is a smaller, faster, and more capable image sensor. Pixy2 camera sensor can practice to discover objects which you teach it. Pixy2 camera sensor has creative algorithms which uncover and trace lines for line-following robots application. With pixy2 algorithms, you can detect intersections and road signs as well. Pixy2 camera sensor detects images at 60 frames-per-second. Pixy2 camera sensor comes with a special cable to plug directly into an Arduino via USB cable or a microcontroller like a Raspberry Pi. The pixy2 camera sensor has several interfaces like SPI, I2C, UART, and USB with simple communications for microcontroller connections. It uses a color-based filtering algorithm to detect objects. Color-based sieving systems are well liked due to their relatively robust and efficient. Pixy2 camera sensor works out the hue and degree of every RGB from the image sensor and takes these as the first discovering variables. The color of an object endures mostly unaltered when it comes to changes with lighting and exposure. Changes with lighting and exposure do have a disappointment on color sieving algorithms, making them to break. Pixy2's sieving algorithm is robust if it comes to lighting and exposure altering.

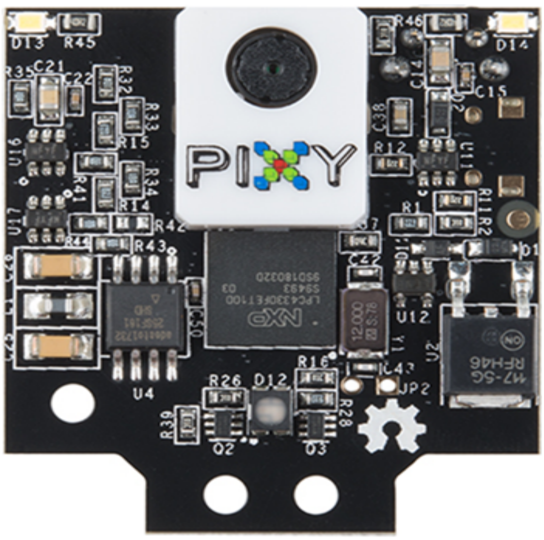


Figure 13. Object sensor module Pixy2 CMUcam5

Specifications of Pixy2 CMUcam5 are as follow:

- Processor: NXP LPC4330, 204 megahertz, dual-core
- Image sensor: Aptina MT9M114, 1296×976 resolution plus integrated image flow processor
- Lens field-of-view: 60° horizontal, 40° vertical
- Power consumption: 140 milliampere typical
- Power input: USB input (5v) or unregulated input (6v to 10v)
- RAM: 264K bytes
- Flash: 2M bytes
- Available data outputs: USB, UART serial, I2C, SPI, analog, digital.
- the integrated light source, approximately 20 lumens
- Dimensions: 1.5" x 1.65" x 0.6"
- Weight: 10 grams

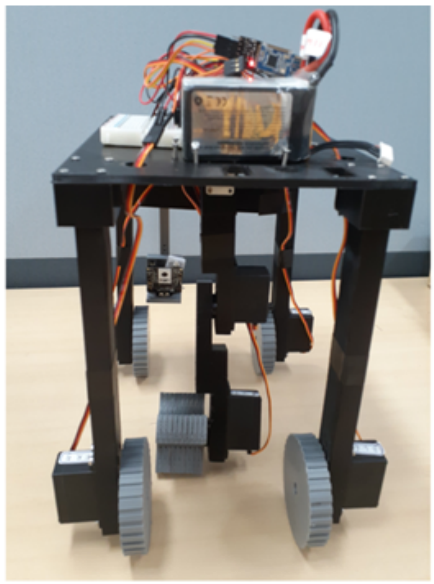


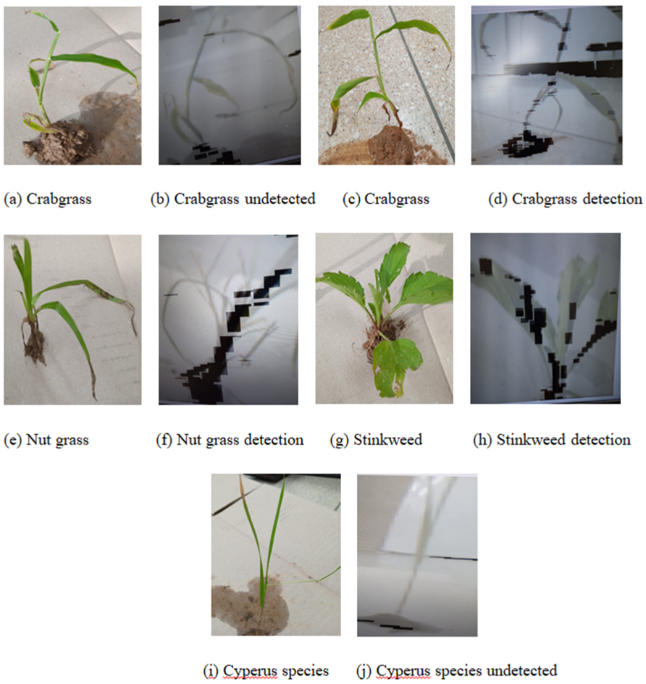
Figure 15. Protype of a weeding robot

RESULTS AND DISCUSSION

The robot design model was carefully examined and uniquely chosen with the cutting system well modelled and simulated in AutoCAD neatly. The planned style of the weeding robot and its application for the arm and the cutter system has a lot of usefulness and benefits that can control farm weeds either on ridges or flat land with much more efficiency.

Weeds Detection using Pixy2 Camera Sensor

The arm has three degrees of freedom (3DOF) to enable it to turn to the left and right, front and back any time there is a weed to cut/clear (the base joint motor function). The elbow's joint on the other hand function as a regulation of the depths of the cutter. In other words, the cutter's blades traveling deep down the soil for weeds uprooting. This is handled by decreasing the rotation degrees of the elbow motor which courses the cutter's blades to cut deep into the soil or increasing the rotation degrees for shallow cutting/clearing. The cutter's blades are more than one to ensure complete/proper cutting or clearing of the weeds. Also, the 130° angle forming 15.6542 mm arc of the cutter's blade is to make gaging or capturing of the weed properly and convenient. The width of the cutter's blade is to create room for scooping to be well done/accomplish. The arm is situated at the center of the robot to enable a two-row weeding to be achieved in a phase weeding.



(a) Crabgrass (b) Crabgrass undetected (c) Crabgrass (d) Crabgrass detection (e) Nut grass (f) Nut grass detection (g) Stinkweed (h) Stinkweed detection (i) Cyperus species (j) Cyperus species undetected

Figure 16. Weeds detection using Pixy2 camera

A test was conducted to detect weeds using a pixy2 camera sensor. Weeds used for the experiment include crabgrass, nut-grass, stinkweed, stinkweed2, and cyperus species. The weed that the Pixy2 sensor was trained on includes Stinkweed, crabgrass, and nut-grass. The sensor was able to detect weeds that it was trained on, successfully. Figure 16(a) crabgrass; shows the normal picture of the weed. Figure 16(b) crabgrass undetected; the picture of the undetected phenomenon of the crabgrass; when pixy2 camera sensor object detection mood is activated but the weed is not trained on it to detect it when the camera sight it. Figure 16(c) crabgrass; is another normal physical picture of the crabgrass before training it with pixy2 camera sensor. Figure 16(d) crabgrass detection; is the detection image of the crabgrass after training it with the sensor and activating the pixy2 camera object detection mood which was successfully detected. Figure 16(e) nut-grass; also shows a normal physical image of the nut-grass. Figure 4.1 (f) nut-grass detection; is the detection picture of the nut-grass that was trained with the pixy2 camera sensor and object detection mood activated. Figure 16(g) the stinkweed; also shows the real physical image of the stinkweed. Figure 16(h) stinkweed detection; is the detection image of the stinkweed after training it on the Pixy2 camera sensor and its object detection mood activated.

Included in the experiment to establish pixy2 camera detection more evidence base is the cyperus species. Figure 16(i) cyperus species where the pixy2 camera sensor was not trained with the cyperu species but the object detection mood is activated. And really during the experiment, cyperus species was not detected- Figure 16(j) cyperus species undetected as shown above. Table 5 below shows experimental results of detecting four (4) different kinds of weeds using the pixy2 camera sensor.

Table 5. Experiment results for trained and non-trained four different weeds detection using Pixy2 camera sensor

Experiment materials	Diameter (mm)	Height (mm)	No. of leaves	Test 1 (%)	Test 2 (%)	Test 3 (%)	Test 4 (%)	Test 5 (%)	Test 6 (%)
Crabgrass	3.5	118	4	90	90	90	90	90	90
Nut grass	4	114	7	90	90	90	90	90	90
Stinkweed	3	125	6	90	90	90	90	90	90
Cyperus species	4.3	136	3	0	0	0	0	0	0

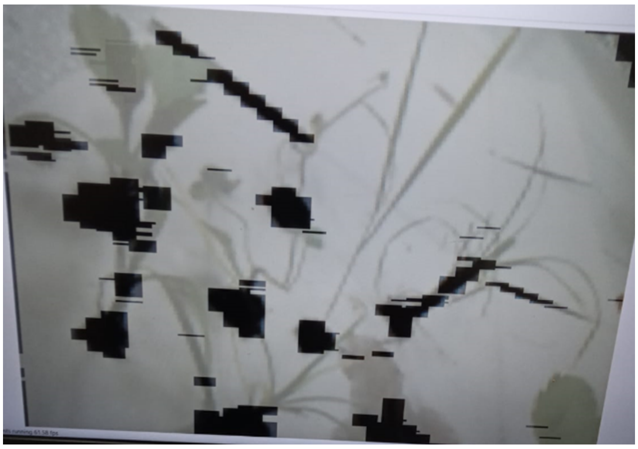


Figure 17. Group weeds detection

Experiment on four (4) different kinds of weeds detection shows success since the sensor was able to detect each of the weeds individually and in a group trained on it. Figure 4.2 above shows the detection of the weed in a group by the pixy2 camera sensor. In Figure 17, it is seen clearly that the pixy2 camera sensor did not detect the cyperus species. And this is because it is not part of the train weeds with the Pixy2 camera sensor. The sensor is mounted on the robot and connects to the Arduino Uno through the UART serial interface with the program uploaded to detect the weeds on which the cutter is position for cutting/clearing them. Weed detection, localization, cutter positioning, and cutting/clearing are the main functions of controlling farm weeds using automation (circular cutter weeding robot system). The simulation for this paper is achieved by a Pixy2 camera sensor. Pixy2 camera sensor has a tracking algorithm that can track a line and follow it as well as to detect objects. And for that matter was used to experiment successfully. To detect the object with good accuracy the Pixy2 camera sensor was employed. The simulation tests replications were six (6) in number and on each replicate the simulation test were done three times. The result showed a 90% detection success with the test carried out.

Table 6. Experiment results for trained and non-trained weeds group detection using Pixy2 camera sensors by six tests

Experiment materials	Diameter (mm)	Height (mm)	No. of leaves	Test 1 (%)	Test 2 (%)	Test 3 (%)	Test 4 (%)	Test 5 (%)	Test 6 (%)
Crabgrass	3.5	118	4	90	90	90	90	90	90
Nut grass	4	114	7	90	90	90	90	90	90
Stinkweed	3	125	6	90	90	90	90	90	90
Cyperus species	4.3	157	3	0	0	0	0	0	0

Stinkweed 2   Stinkweed 2 detection

Figure 18. Detection weeds indirectly trained

Another experiment is the inclusion of weed not trained by Pixy2 camera sensor but is of the same species with one of the weeds (stinkweed) train by Pixy2 camera sensor. This weed is term as control experiment weed (stinkweed 2). The control experiment weed is the stinkweed 2 not trains physically with the Pixy2 camera sensor but added to those weeds trained to test Pixy2 camera sensor detection algorithm. This is to demonstrate that, on the farm, not every weed can be trained with the pixy2 camera sensor to be detected but once the weed species is trained all other species not trained practically with the camera sensor can be detected. The control experiment weed is of the same species with one of the trained weeds to see if the Pixy2 camera sensor can detect it as well even though it was not trained directly with the pixy2 camera sensor and it was also successfully located and tracked (detected). This confirms pixy2 camera sensor detection during the experiment to be 90%. As shown in the figure above, stinkweed2 was not trained with the Pixy2 camera sensor but was detected (Figure 18 stinkweed detection) when the pixy2 camera sensor was in a tracking mood and pointed to it.

The five (5) different kinds of weeds used for experiment also comprise the non-trained weed but the same species as one of the trained weeds to test the sensor detection sensitivity. The sensor is first connected to the computer, and train on each of the weeds after which the sensor is point on them for detection and it successfully detects them as well as the stinkweed 2, which is not directly trained. This was the results:

1. When the weeds were in the group and the pixy camera sensor point on them, it tracked the four weeds (crabgrass, nut-grass, stinkweed, stinkweed 2) and locked on them.
2. When each of the weeds was separated for individual locating and tracking by pixy2 camera sensor, it gets lock on all the four trained weeds.
3. In the real field experiment, the pixy2 camera sensor detected each of the trained weeds and lock on each of them.
4. The sensor was able to locate and track weeds that it is taught, and the weed it was not trained but are of the same species as those it has been trained on. Table 4.2. is showing the experiment results of pixy2 camera sensors detection on trained, indirectly trained, and untrained weeds by six tests.

Table 7. Experiment results for trained, indirectly trained and non-trained five weeds, six tests using pixy2 camera sensors.

Experiment materials	Diameter (mm)	Height (mm)	No. of leaves	Test 1 (%)	Test 2 (%)	Test 3 (%)	Test 4 (%)	Test 5 (%)	Test 6 (%)
Crabgrass	4.5	118	4	90	99	90	90	90	90
Nutgrass	3.2	114	7	99	90	90	90	90	90
Stinkweed	4.1	125	6	90	90	90	90	90	90
Stinkweed 2	3.3	105	5	90	90	90	90	90	90
Cyperus species	4.3	157	3	0	0	0	0	0	0

In an experiment of five (5) weeds, it is observed that the sensor detection was done successfully by 90%. It is again seen that getting the accurate camera focus and light source on the weed gives good detection results. The cutter drawn pattern is of the consideration that it should be able to properly cut/clear the weeds. The cutter positioning action on the weed was successful, and the cutting/clearing action is well done. The results of the cutter action are presented in Table 8.

Table 8. Test results of weeding robot with action by 6 tests (T)

Cutter action	T1	T2	T3	T4	T5	T6
Total number of weeds	9	9	9	9	9	9
Correctly cutter positioned	7	8	8	8	8	8
Correctly cut/cleared	8	8	8	8	8	8

Figure 19. Performance testing and evaluation result of the weeding robot

The robot is position facing the row before starting to move along the row. As the robot moving, the arm signal through the microcontroller communication to turn either left or right. Whenever there is a weed found, it positions the cutter on it for immediate cutting/clearing. The experiment result shows that apart from the cyperus weed all the other weeds were completely cleared.

CONCLUSION

Considering the agricultural potentials of Ghana, the circular cutter weeding robot can help farmers increase their farm sizes and hence productivity. The circular cutter weeding robot can also replace the labor force shortages due to youth migration to urban centers and the aging population. It can reduce the chemical usage in controlling farm weeds, minimize the difficulties involved in the farming industry explicitly weed control activity; promote organic farming, and enables sustainable agriculture practices among others. This study examined the new design and mechanism of the automated circular cutter weeding robot that serves a single specific purpose of weed control on different types of crops in different fields. It was found that the circular cutter weeding robot is more cost-effective and farmers can afford either acquiring it personally and by renting. More research is required to improve upon it and increase the benefits to farmers. The research revealed farm weed control through an automated system will undercover benefits in crop production. Even though using a circular cutter for controlling weeds on farm fields was amongst the first step of development, techniques of perception, innovations, positioning, and cutting have been developed and or improved upon for resilient weed control. Further work development will be making the best of the vision control system using deep learning techniques (artificial intelligence). The deep learning techniques will be a vision and action control system to establish a more capable and accurate model for agricultural farm weeds detection.

CONFLICT OF INTEREST

The authors have declared no conflict of interest regarding the publication of the paper.

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