TCTD Challenge

7th Inter IIT Tech Meet

Farm tools that reduce drudgery and provide intelligent automation

IIT KHARAGPUR

Introduction

Human species have dominated the planet earth because of one crucial attribute that distinguishes us from other living forms is to build tools to overcome and extend our biological limitations. This quest has led to the invention of the wheel, controlling of fire and many more history defining moments. Fast forwarding to a time of industrial age automation has been the key concept behind developing tools that reduce human intervention. Automation dates back as early as 1450s with the invention of a printing press which lays the foundation behind synergy of human minds to grow exponentially.

Automation in industries is mostly programmed to carry out a specific work. But the exponentially growing semiconductor industry has led to the development of economically viable sensors with pinpoint accuracy combined with the internet gives a whole new dimension to the world of automation. The direct consequence being machines getting intelligent and very versatile. Our work here is an attempt to extend this automation quest.

India: A perfect country for solving this challenge

Agriculture is the most crucial sector of Indian Economy. Indian agriculture sector accounts for 14.4 percent of India's gross domestic product (GDP) and employs 58.2 percent of the country's workforce. India has emerged as the second largest producer of fruits and vegetables in the world, and thus it also ranks second worldwide in farm outputs. India has over 145 Million agricultural labourers/workers and 31 percent of the total workforce is involved only in farm activities.

The primary reason for this is the remarkably disguised primary sector with more than 52 Million people are doing low-productivity work that withdrawing them would not make a difference to the output. Underemployed & Informal Secondary Sector and Large dependence of people on agriculture at the same time makes people do menial work, a dull work not requiring much skill and lacking prestige. Because of heavy dependence of the economy on agriculture, it is one of the drudgery prone occupation of the unorganized sector due to lack of access to improved agricultural technologies.

Survey

We identified the drudgery areas/activities in agriculture by secondary research and surveying the nearby small and large-scale farmers. It was pointed out in a study that various agricultural projects were formulated keeping in mind men with the assumption that they would automatically give an advantage to women though men have different physiological and ergonomic characteristics than women. The tools or equipment which is designed considering men's physiological, anthropometric and ergonomic parameters, increase workload and occupational disorders in spite of decreasing, if not fit for the women.

We provided participatory field level skill training for proper use of the ergonomically improved farm technologies was given to men and women in separate groups. We tried to quantify the impact of the intervention on the level of the drudgery of the worker before and after the technology intervention from the sample of 40 respondents (20 male and 20 female) selected randomly. The gain in knowledge and change in awareness level were calculated after the training. Evaluation of field validation of technology on the drudgery of men & women was done after its use in the field conditions. In the evaluation of field validation of technology on drudgery, it was found that all the three technologies reduced the drudgery of men as well as women. A hypothetical intervention package consisting of various agriculture activities such as rice transplanting, weed remover, seeding etc. was introduced to the farmers employed in the farms of the Agricultural and Food Engineering Department, IIT Kharagpur. Following is the analysis of survey data and the results of the questionnaire.

Farm Activities	**Number of Respondents**
Fruits and Vegetable Plucking	23
Sowing	7
Weedicide Spraying and Weeding	6
Rice Transplanting	1
Other Activities (Timeliness Factors)	3

Designing and standardizing appropriate tailor-made tools and equipment for women can reduce or entirely prevent physical fatigue, which is linked to farm work. The same is the case with farmers working in different countries under the influence of various internal and external factors. Hence, we brainstormed to designed a bot with the broad objective to equip farmers technologically for reducing their drudgery during the engagement in agriculture and for enhancing their productivity. To understand the major problems and develop a solution we dug more around them.

Key Areas With Menial Labour Work

1. Harvesting of fruits and vegetables
2. Weeding and Weedicide Spraying
3. Sowing of seeds

How deep is the problem?

The conditions of seasonal work – low pay, physically demanding, long and unsociable hours – do not help. They are far from the expectations of a worker, who is now culturally tuned to a 60-hour weekly schedule. There is also a greater desire for career progression, which is unlikely to occur in the world of fruit picking. Due to rising labour costs and the shortage of such laborers in recent years the agriculturist has found it necessary to seek ways for increasing substantially the harvesting volume per man hour worked. Usually, people pluck the fruit with a pair of scissors. The plucking person grasps the fruit in his left hand, for example, and cuts the branch supporting the fruit with the scissors held in his right hand. The crucial thing in the process is to ensure the fruit is not damaged during picking.

The major problem faced by the fruit growers is the shortage of skilled labor due to which the fruit grower is unable to harvest the fruits at the right time. As a result, the fruit gets over-ripe and becomes useless which also results in loss to the fruit grower. It is a proven fact that 9 farmers out of 10 have musculoskeletal disorders. Manual weeding takes up a large amount of time to produce growers, whether they work traditionally or organically and thus that number is so high.

Repetitive hoeing is difficult, hard work but that's not the only work that's required. According to Armstrong (1983), inappropriate design and excessive use of hand tools were found associated with an increased incidence of both acute and sub-acute cumulative trauma of hand, wrist, and forearm. A solution which can automatically spray weedicide without much of a manual intervention will free up time for the farm worker to accomplish more diversified and interesting tasks. Moreover, the robot will also reduce the time farmers spend on manual weeding and leave more time for tasks that actually help bring in money. The stakes are the same for the sowing operation. It is the most important process in farming and at the same time, a very tiring and time-consuming process that requires a lot of human effort.

What about the existing solutions?

Some of the existing pluckers are very large, weighing hundreds of pounds and therefore expensive to purchase and maintain. Thus, it is not practical to use them in any largest farming or harvesting operations. Also, such equipment is too complex to be operated by the normal laboring force available to the fruit agriculturist and even much too large to use by the women and children who provide much of this labor force. Moreover, it cannot be maneuvered between the bushes on many farms. Also, fruits fall to the ground which cause obvious permanent fruit damage.

Smaller hand-operated plucking devices have also been proposed and although these devices may be more desirable in the normal farming operation than the very large plucker yet they have had certain disadvantages. For example, many such plucking devices tend to remove all of the fruits, failing to discriminate between ripe and unripe fruits. The existing machines are not suitable for Indian conditions in several parameters and generally consume a lot of fuel which does not help the current problem of fuel crisis in India along with their contribution to greenhouse gas emission. On the other hand, sowing and weeding operations are mostly done manually. Manual weedicide spraying is hazardous because of the toxic chemicals coming in regular contact of the farmer's body.

Discussion with Relevant Stakeholders

To validate our ideation, we discussed the prototype, and its possibilities with experts from each domain, Farm Machinery and Power, Innovation and Finance, and Strategy. Following people were the primary point of contact for us throughout the brainstorming sessions:

1. **Dr. Manoj K Mondal**, Senior Financial Professional; Academician
   Gold medal for Best Innovation (2008), Lockheed Martin, Stanford, University of Texas
2. **Mr. Abheet Dwivedi**, Principal Investment Specialist, Startup India
   Aide to Hon'ble Suresh Prabhu Strategic Consultant, Invest India Ex-Investment Banker
3. **Dr. Virendra K. Tewari**, Agricultural and Food Engineer
   Specialist, Farm Machinery & Power; Ex HoD, Agricultural & Food Engg. Department

After getting the different perspectives from domain experts, we went back to the farmers which we previously surveyed and refined our ideas according to on-ground experience.

The Solution

Before designing and developing the prototype, we conceptualised that the solution should be sustainable, economical, reliable, viable, eco-friendly and scalable. Only the development of villages can lead to the development of the nation. India is an agricultural country, and this field contributes 1/3rd of Indian economy. The fact is that every entity had always neglected the farmers who are feeding us for centuries. Increasing rates of suicides of farmers are also not hidden from anyone. Lack of labors in the field is also a big problem.

So by making the farmers rich not only economically but also by providing some useful, economical, easy to use, compact, efficient and time-saving accessories/ machines to make real progress without depending on anyone is what our robot does. The best way to address a large chunk of people is to design a semi-automated & intelligent robot which plucks & picks fruits from the gardens and carries to the essential place and dumps in a container. Most importantly, the same robot can be used in order to eliminate the intensive human labor involved in the seeding process and weeding activity, either in the same fruit garden or on any other field.

Mechanical Design

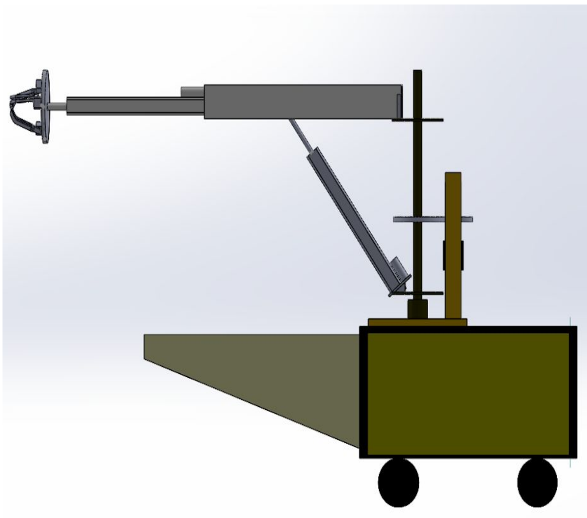
Subsystems:

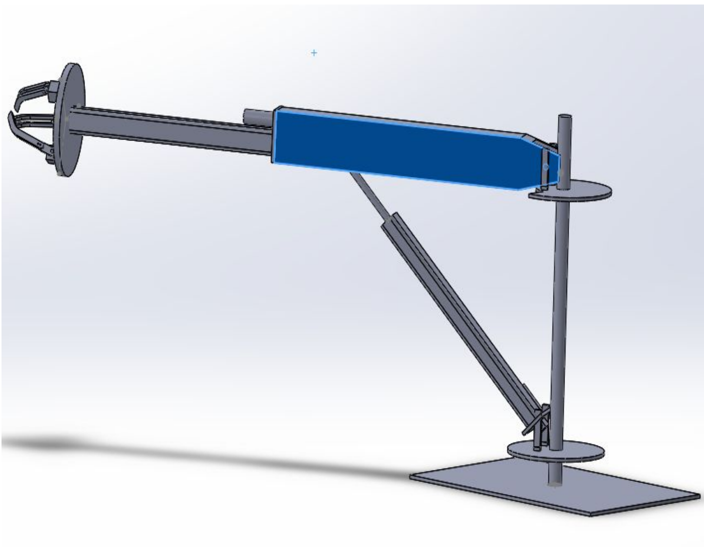
- **Chassis:** The chassis is designed to support the basic fruit plucking module and additional modules such as seed sowing and pesticide spraying. The dimensions of the frame are 55cm*42cm* 27cm. The chassis has been designed such that the robot can travel between two rows of plants and can pluck fruits of 30 plants in a row continuously.

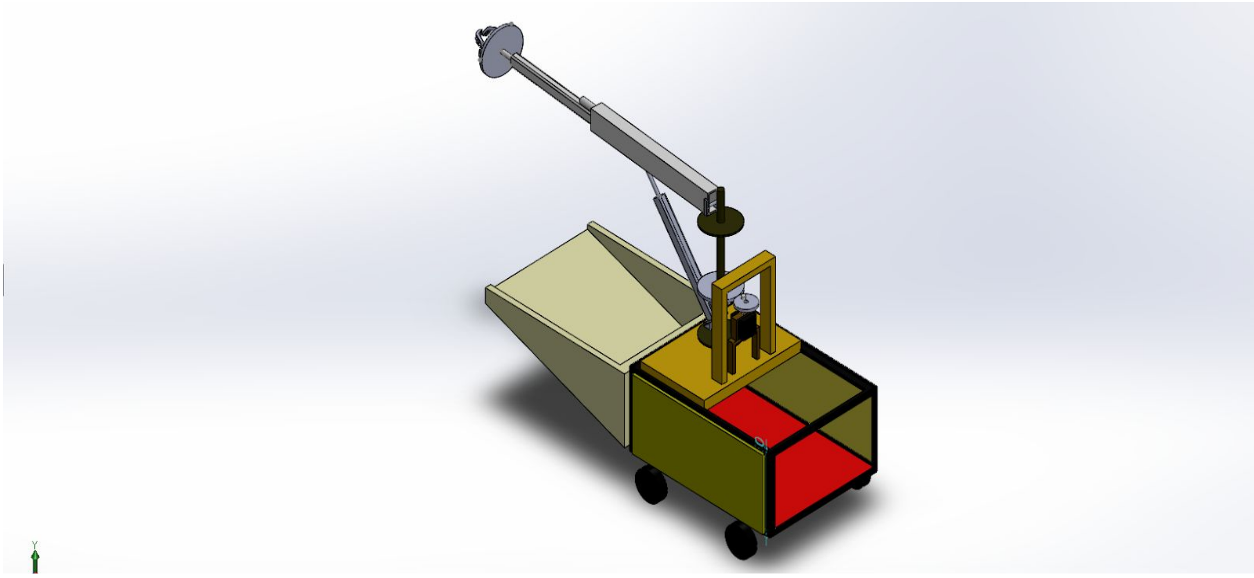
- **Drive System:** The drive system of our bot is a four-wheel differential drive which can take a zero radius turn with drift. Four high torque geared motors are used which give the sufficient torque to drive the bot. Motors works on 30 RPM 12V DC Motors with Metal Gears with shaft diameter 6mm and 60 kg-cm torque.

- **Actuation:** The design of the robot provides height adjustability. The design is such that the robot can pluck fruits at different heights according to requirement. The mechanism used here is the 3-bar mechanism in which it can change its pitch angle by increasing the length of the one actuator and also increase the range of the gripper. This can be achieved by the 2 actuators which give us 2 degrees of freedoms. The arm extension velocity is 1.4 cm/sec and the maximum extension would be 25 cm. The maximum load that the actuator can bear is 200 N. Also, it has rotation provided by the servo motor and transmitted by the gears. So, it adds one degree of freedom. Thus it provides a large plucking height range from 30 cm to 94 cm. It can be used to pluck fruits in different areas.

- **Gripper:** The gripper being used is a three claw gripper that has been 3D printed. The individual claws are straight at bottom and curve at a particular angle at a particular height to maximize the surface area. Thus, this design of the claws offers sufficient grip on the fruit of diameter 4 to 8 cm.







Modules:

- **Fruit Plucking:** The robot is capable of plucking fruits autonomously at the required height. The robot has two cameras mounted on it to detect fruits. When fruits are detected the required height is achieved by the use of two actuators and further has a plate with grippers mounted on it which perform the job of holding the fruit and detaching it from the stem. The actuators then retract, and the fruit is dropped in a collection net that has been attached below the platform to facilitate the collection and storage of fruit without damaging it.

- **Seeding:** To eliminate the intensive human labor involved in the seeding process in farms, the robot provides a complete solution to seeding in farms. The robot will be placed at starting of row, and it will sow seeds at a consistent distance in the row. It has a furrow opening attachment and a seed dispenser mechanism. A servo motor combined with a pocketed turbine is used to dispense seeds to the soil at the required distance.

- **Weedicide spray:** The robot has a mechanism of spraying weedicides to further reduce the efforts of the farmer. It is a completely different module needs to be mounted on the chassis. The farmer should remove the fruit plucking module to mount it. The weedicide containing tank is to be placed at the fruit storage unit. A pump draws weedicide from the storage tank, and the flow rate is divided by using nozzles. This entire module will sit at the rear part of our robot, where electronic modules are present.

Material Consideration

Chassis is made of mild steel frame while the platform is wooden. Cardboards are used to cover the sides and for making partitions. The collection net used is a commonly available mosquito net. The grippers have been 3D printed out of Polylactic Acid.

Embedded Systems

The mechanical design incorporates various motors which need to be adequately actuated, along with the capabilities of plucking the fruits, sowing seeds and spraying weedicides and thus required electrical and electronic peripherals were added to complete the automation process. The complete Embedded System is divided into following parts:

Brain:

The model houses a Raspberry Pi 3B+ and an Arduino Mega 2560, which are responsible for efficiently operating the model. The Raspberry Pi along with Intel Movidius is accountable for running computer vision algorithms for fruit detection and localization. It also shares a reliable communication link with the low-level controller - Arduino Mega to accomplishing the job of getting sensor data from various sensors using different protocols and outputting appropriate signals according to planner output received from the Raspberry Pi to the motor drivers which actuate the motors.

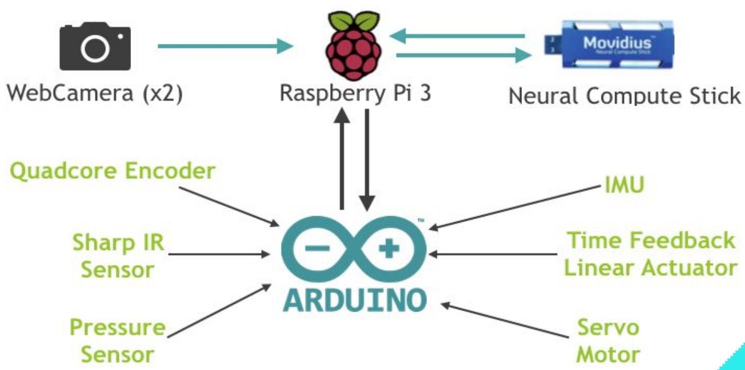
Sensors:

The model is equipped with some sensors for estimating the state of the robotic arm and the precise location of the fruit.

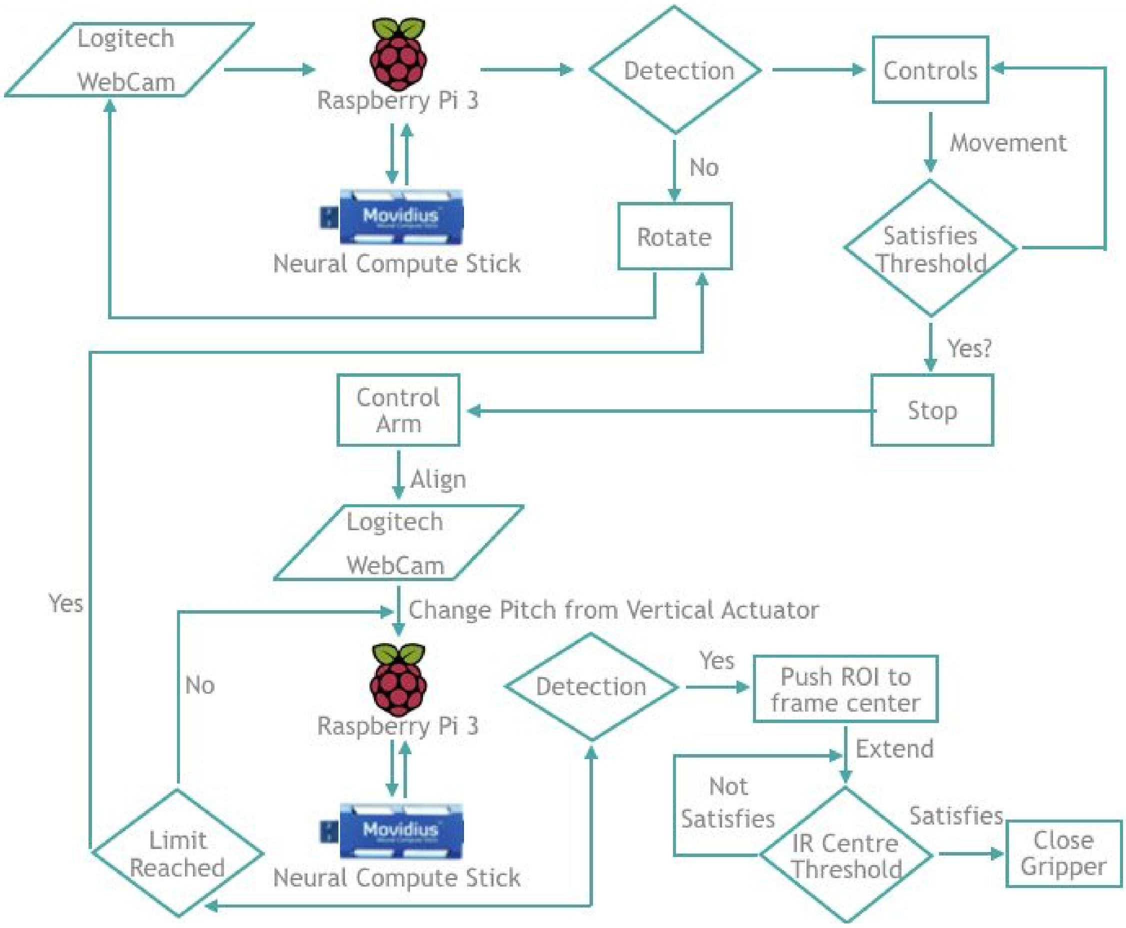
- **IMU:** It consists of three different sensors namely, accelerometer, gyrometer, and magnetometer for calculating the linear and angular acceleration along with the orientation of the robot in the 3D coordinate system.
- **Sharp IR(GP2Y0A21YK0F):** It is a distance measuring sensor unit, composed of a position sensitive detector, IRED (infrared emitting diode) and the signal processing circuit. It is used to identify the precise distance of the fruit from the center point of the gripper and in calculating the pitch angle of the robotic arm along its axis of rotation.
- **Encoders:** It is integrated with the high torque DC motors to calculate the speed of the robot.

Actuators:

- **Servo motors:** Servo motors prove useful to control the orientation of an object about a specific axis. In our robot, it is used to control the yaw angle of the robotic arm with high accuracy. It works on 5V DC voltage.
- **Linear actuators:**
  It is used to create motion in a straight line with stroke length 25cm and works on 12V DC voltage. It is used to control the pitch angle of the robotic arm and extending its range. It takes around 17 seconds for the linear actuator to reach from 0 to 25 cm which is irrespective of the external load.



Algorithm



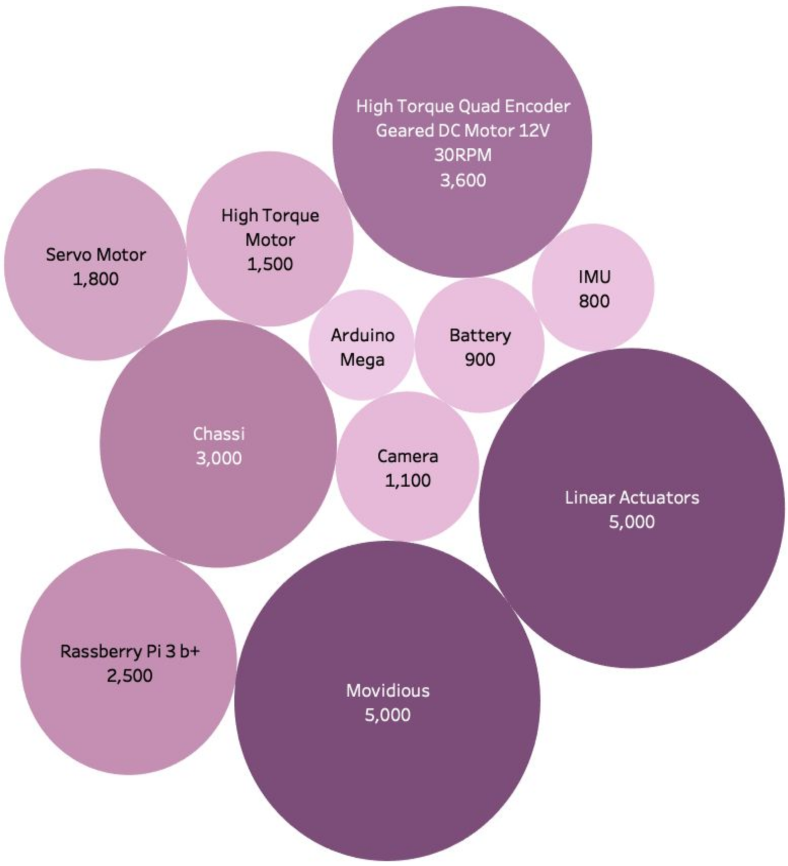
The Picam mounted on the front part of the robot starts taking images which are then transferred to the Raspberry Pi 3B+. Due to the low computational power of raspberry pi, we cannot run deep learning algorithms on it. So we have attached a Vision Processing Unit (VPU) to it which is the Movidius Neural Compute Stick. The images are then fed to movidius which is having the computational graph of MobileNet SSD which is trained on the MS-COCO dataset. The detector has been trained using transfer learning with the base net as MobileNet, and the weights of the last softmax layer are updated. It returns the class, confidence, and coordinates of the object detected. If the fruit is present in the frame, then the robot starts moving towards the fruit, otherwise it rotates around the axis and the camera tries to find the nearest fruit.

The robot moves until we pass a threshold area of the Region Of Interest (ROI). After crossing the threshold value the robot stops and the arm gets aligned with the robot's orientation. Starting with the vertical linear actuator is in its initial position, the vertical actuator starts to extend which moves the arm in the vertical direction. When the Logitech webcam detects the fruit, the arm stops moving. Now the ROI is moved towards the center of the frame through movements of a servo motor and both the actuators. Then the arm moves towards the fruit by the extension of the second linear actuator. Thresholding, the sharp IR sensor data, decide to stop the arm movement. After all the fruits are plucked in single vertical motion of the actuator, the robot rotates around its axis and tries to find another fruit.

Cost Analysis

The proof-of-concept costs **₹ 27,000** to be developed from scratch. The price can be brought much down if the production is ramped up. At the same time, there is a scope of increasing the efficiency of the bot and keeping the price same by having add-ons such as solar panel, heavy battery, motors, etc.

Components	Quantity	Price
High Torque Motor	2	1500
High Torque Quad Encoder Geared DC Motor 12V 30RPM	2	3600
Chassi	1	3000
Servo Motor	5	1800
Linear Actuators	2	5000
Arduino Mega	1	600
Rassberry Pi 3 b+	1	2,500
Camera	2	1100
Sharp IR sensor	1	400
IMU	1	800
Movidious	1	5000
Pump	1	150
Motor Driver 20 A	1	400
Motor Driver 5A	1	250
Battery	1	900
		27,000



Even if we consider the labor wages are minimum as per the government regulations i.e. ₹ 350 per day and a very generous maintenance & recharging cost of ₹ 500 per month, this product will achieve break-even point just after the 3rd month of usage. The price will be even lowered on large scale manufacturing. On a commercial basis, this bot can be employed on a B to C model. Small-scale farmers can procure the bot collectively or by taking a loan against a cooperative.

Future Aspects

This bot can be employed in the fields to ensure no shortage of skilled labor, no damage and no over-ripening of fruits, no high labor costs and most importantly no risk to farmers health. However, there are many things which can be done in future and are we haven't done in the prototype because of time and location constraints such as:

1. Skid drive or caterpillar drive could be used instead of 4 wheel differential drive
2. Redesigning the gripper with pressure sensors for plucking different sizes of fruits
3. Different thresholds of the pressure sensor can be set for different fruits
4. The range of fruit plucking arm can be extended to reach heighted trees
5. The bot can be made completely solar powered for self-sustainable & long run system

References

1. Ministry of External Affairs (2017) India in Business: Investment and Technology Promotion Division, Govt. of India
2. Indian Brand Equity Foundation(2018) Indian Agriculture Industry: An Overview
3. Department of Agriculture and Cooperation. Ministry of Agriculture, Govt. of India
4. Pandey MM (2009) Indian Agriculture–An Introduction.Fourth Session of the Technical Committee of APCAEMChiang Rai, Thailand, pp. 1-39
5. ArjunKM (2013) Indian Agriculture- Status, Importance andRole in Indian Economy.International Journal of Agriculture and Food Science Technology 4:343-346
6. https://www.naio-technologies.com/en/reduce-drudgery-in-agriculture/
7. https://www.ncbi.nlm.nih.gov/pubmed/22317495
8. Agriculture Role on Indian Economy, Madhusudhan, Department of Biotechnology https://www.omicsonline.org/open-access/agriculture-role-on-indian-economy-2151-6219-1000176.pdf
9. Drudgery Reduction Of Farm Women Through Improved Tools, Surabhi, Ahlawat https://bioinfopublication.org/files/articles/8_14_4_IJAS.pdf
10. https://content.iospress.com/download/work/wor0793?id=work%2Fwor0793
11. http://theconversation.com/the-real-reasons-why-british-workers-wont-pick-fruit-80152
12. https://forums.ni.com/t5/General-Academic-Projects/Fruit-Plucking-Robot-for-Student-Design-Competition-2013/ta-p/3516727
13. http://nevonprojects.com/automatic-seed-sowing-robot/
14. Device for picking fruit, Ernest H Shaff, 1970, [Portable motorized fruit pickers] https://patents.google.com/patent/US3522697