Towards Autonomy in Agriculture: Design and Prototyping of a Robotic Vehicle with Seed Selector

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3 authors:

Masood Ul Hassan
UNSW Sydney

Mukhtar Ullah
National University of Computer and Emerging Sciences

Jamshed Iqbal
University of Hull

Towards Autonomy in Agriculture: Design and Prototyping of a Robotic Vehicle with Seed Selector

Masood Ul Hassan, Mukhtar Ullah*, Jamshed Iqbal
Department of Electrical Engineering,
FAST National University of Computer and Emerging Sciences,
Islamabad, Pakistan
*Corresponding author: mukhtar.ullah@nu.edu.pk

Abstract—**Traditional method of seeding by farmers demands laborious work and is now becoming story of the past. Technological revolution in mechatronics and allied areas is reshaping the agricultural processes, making the robots an integral part of this automation. This paper presents design details of an autonomous robot developed keeping in view the constraints imposed by an agricultural field. The novelty of the proposed low-cost indigenously developed modular vehicle lies in design of its seed selector. The simple but efficient mechanism of the single seed selector with extremely low miss rate distinguishes the vehicle from other designs. Hardware details including sensing, actuation, processing and communication modules and software architecture are detailed in the paper. Results of trajectory tracking obtained by implementing the proposed scheme on a mini-robot and functionality of seed selector demonstrate potential of the presented robotic vehicle.**

Keywords— Agricultural automation; Mobile robot; Single seed selector; Seed sowing; Space farming

I. Introduction

Robotics is a multi-disciplinary research domain whose applications are incredibly extending during the last two decades [1]. Application areas where robots are now being deployed include but not limited to; space [2], industrial [3, 4], nuclear [5], haptics [6, 7], medical [8] [9], cognition [10], agriculture [11] etc. Research in agricultural automation is not yet saturated primarily due to the fact that most of the reported works did not meet the complexity of real agriculture problems.

Large heavy machines are designed to move in agricultural fields now a day, which tend to compress the soil. Due to continues motion of heavy machines a layer of compressed soil is created underneath, which has very low ability to absorb water that leads to erosion and floods [12].This paper presents the design of a robot inspired by the actual constraints in real agricultural fields. The robot is light weight which solves the problem of soil compression. The main problem on which this paper focuses is the seed sowing mechanism of maize crop. The field consists of rows and hills (Fig. 1) which offers major hindrance in the mobility of huge mechanical machines in the fields. Due to this constraint, conventional way of seeding has been historically in practice for a long time. In the conventional manner, farmers manually walk around each row and column to sow the seeds approximately at required distance and target place. Failure to maintain the optimum distance or inability to sow the seeds on the required place deteriorates the overall efficiency significantly [13]. In addition to the above mentioned problem, various types of fertilizers and pesticides are being used in the field crops to kill insects thereby enhancing the overall production. These chemicals have direct implications on the health of farmers and may introduce new diseases or lead to other dire consequences.

Fig. 1. Maize crop field

Seeding and fertilization using automated robots was not a good practice in the past [14]. An autonomous prime mover can be made which will automate the field work and reduce the labor cost. This mover will work on cheap sensors which will detect the path and help the mover to move around and turn from one row to another [15]. Instead these machines have numerous problems like high cost and large size which creates problem in turning and positioning due to lack of enough space between rows. These machines become too much expensive for the small and medium sized farms [16]. If one part of the mechanization system breaks down then all field operations will stop [17]. Moreover, most of the reported mechanical machines also have the issue of precision and accuracy. There are no electrical sensors used in these machines to achieve the required target of accuracy and precision. So seeding process through advanced machines could not practically beneficiate the farmers.

In the present paper, we present solutions to the above mentioned problems by designing the automated robot that has a potential to sow the seeds, track the lanes and follow the path automatically. It also has the ability to wirelessly communicate the owner in case of error or emergency situation using Bluetooth and Global System for Mobile communication (GSM) [18].

II. Design Details

The modular design of a robot offers several benefits as highlighted in [19]. The design of the robotic vehicle in the present study is based on ten separate modules which implements locomotion, sensing, actuation, seed handling, data processing, communication etc. Fig. 2 shows the overall block diagram of the robot.

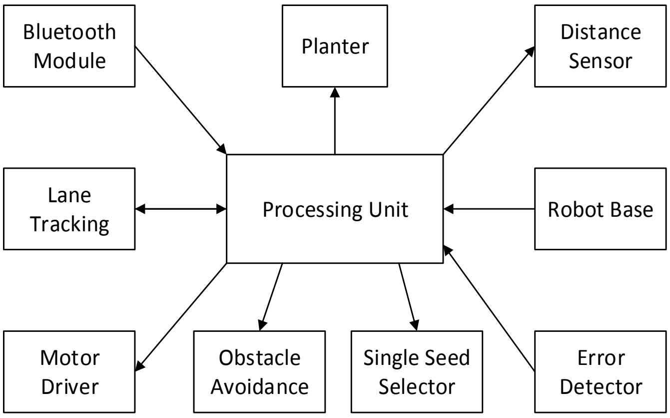

Fig. 2. Higher-level block diagram of the robotic vehicle

A. Robot Base and Structure

As illustrated in Fig. 1, the field of maize crop consists of rows and columns formed by ploughing the soil using tractor. Keeping in view the field structure the robot is designed in such a way that it will move on the row hills with its left and right wheels on both sides of the row hills as illustrated in the Fig. 4. Two nozzles are placed to move into high soil in order to create the space where the seed is to be thrown. On top of the nozzles, two single selectors are installed in order to pick the single seeds one by one and send to the planter for sowing. Fig. 3 shows schematics of the proposed robotic vehicle.

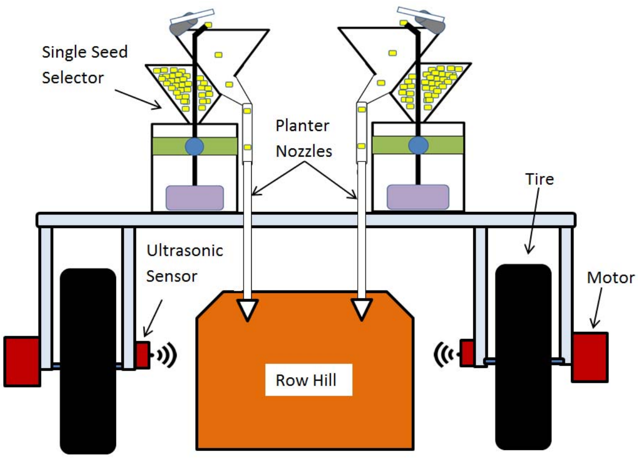

Fig. 3. Overall robot design and structure

Fig. 4. Fabricated prototype

B. Single Seed Selector

One of the main modules of this paper is the single seed selector. Its function is to pick up a single seed from the bulk of seeds to sow in the soil. Maize crop requires that one seed should be sown at a single place so that there is no congestion of the crop. As the corn leaves are larger in size and are spread so their seeds are required to be sown one seed at a single place maintaining a particular seed to seed distance. The seeder has to pick up a single seed from the bulk and then transfer it to the planter which helps to sow the seed in the soil. As illustrated in Fig. 5, the seed selector consists of a linear actuator, vacuum pump, 2 funnels, DC motor, nozzle and a small plastic fan. The nozzle is attached to vacuum pump and linear actuator in order to suck a seed and move up and down inside the funnel. The suction force created by vacuum pump sucks the seed to the open end which fogs the nozzle. Consequently, this up-down motion separates the seed out of the bulk. Fabricated prototype of seed selector is shown in Fig. 6.

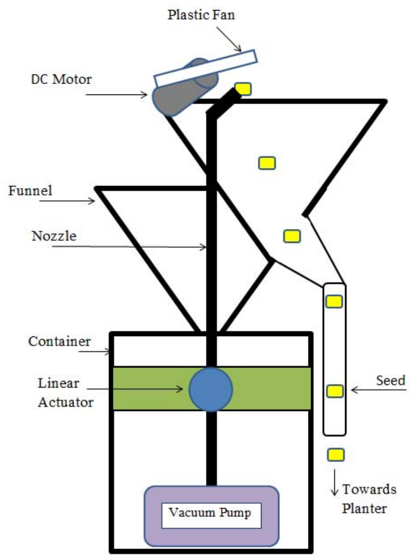

Fig. 5. Schematics of the proposed design of single seed selector

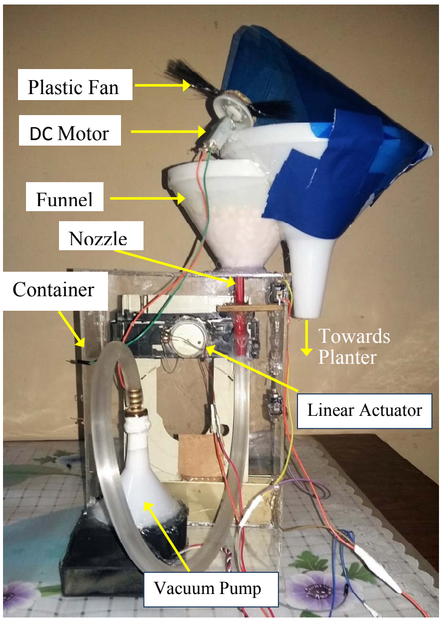

Fig. 6. Fabricated prototype of the proposed single seed selector

C. Planter

Seeds may be planted by using a dedicated robotic manipulator; however this solution suffers from unnecessary complexity thus posing various implementation challenges. In contrast, we proposed two possible mechanisms to design a planter; Hammer type model (Fig. 7a) and Nozzle type model (Fig. 7b).

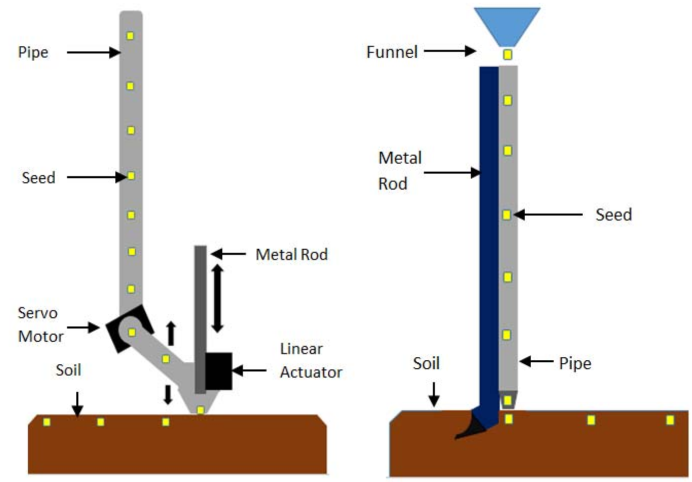

Fig. 7. Planter models (a) Hammer type model (b) Nozzle type model

In the former type, a single seed is picked and throw down a narrow pipe at the end of which an opening is present to throw the seed into the soil for sowing. A metallic rod then pushes the seed. In nozzle type model, the sowing mechanism is replaced by a simple curved nozzle which will continually move into the soil making a narrow line and from the pipe next to the nozzle, the seed will dropped and the soil will automatically covers the seed.

D. Distance Measurement

It is possible that the field at some places is damp usually when there is dew on the ground at dawn. The dampness can cause the robot wheels to slip away. Rate of distance covered by each wheel with respect to time was required to know about the slipping caused due to the soft surface under the wheels [20]. Encoders are used for the purpose to resolve the issue of wheel slipping by measuring the angle of rotation. Each rotation is then multiplied with the circumference of wheel in order to get the distance covered by each wheel. If the difference between each wheel rotation is detected then surely there is a slippage and the controller will send the commands to wheels in order to solve this issue.

E. Lane tracking and following

From Fig. 1 which shows the nature of rows and columns in the field. So we have to make a high torque robot that would automatically move in the field and exactly follow the lanes by making sure that it provides no damage to any hill row or a lane. Therefore initial problem is to state how robot automatically follows path exactly i.e. following a lane in the field by avoiding the damage to the hills and rows.

We go for image processing [21-23] and G.P.S [24] at first, to make robot able to follow lane in field, but these solutions are expensive, complex and need a strong processing unit which indirectly increase the cost of the project. So, research was conducted about the use of ultrasonic sensors in the path following. As shown in Table I ultrasonic sensors offer several benefits over image-processing counterpart in terms of cost, complexity and easiness in usage without requiring intensive analytical equations [25].

TABLE I. COMPARISON BETWEEN PROPOSED METHOD, IMAGE PROCESSING AND GPS

Factor	Comparison between alternatives		
	Ultrasonic Sensor	*Image Processing*	*GPS System*
Cost	Low	High	High
Complexity	Low	High	High
Accuracy	High	High	Low
Precesion	High	High	Low

Two sensors are placed on both sides of the robot which are used to measure the distance between wheel of the robot and the hill row. The sensors used continuously send their measured data to the ADC which is used to covert analog signal in to digital which further passes it to the controller. This controls the lane following and tracking of the robot by generating special commands to the motor driver based on the measured values. The motor driver controls the speed and direction of motors based on the commands from controller to avoid robot damaging the hill rows and inappropriate sowing of seeds.

The use of ultrasonic sensors take some to measure values which create delay in the decision process due to which small oscillations are produced in the robot's motion and the system quickly goes to overshoot condition. This issue was resolved by implementing a PID controller which reduces the overall fluctuations and results in the steady state motion.

F. Obstacle Avoidance

As the robot is moving in the field made of rough soil, so there are very high chances that the robot will face some obstacles in his path. These obstacles block the path and if the robot does not stop its motion then the obstacles will destroy the whole system. In order to protect the robot from obstacles and hurdles we use the ultrasonic sensors, the sensors will record the distance to obstacle and send the values to the controller which makes the decision and generate commands to stop all the running functions of the robot and sends an error signal GSM module to the user's mobile [26].

G. Bluetooth Module for Android Base Movement

Wheels are embedded with Gear Motors; they are unable to move until the motor are electrically energized. So to manually control the movement of robot, Bluetooth module is used to communicate to the Android Mobile. Fig. 8 shows the android application which is used to send signals to the robot [27]. The controller receives the signals and generates commands accordingly.

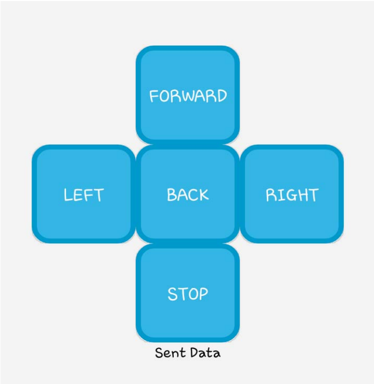

Fig. 8. Android Application

H. Motor Driver

Relays are used to make H-bridges in order to control the motion of the gear motors used to move the robot. An H-bridge is an electronic circuit that enables a voltage to be applied across a load in both directions. These circuits are often used in robotics and other applications to allow DC motors to run forwards and backwards. The H-bridge arrangement is generally used to reverse the polarity or direction of the motor, but can also be used to 'brake' the motor, where the motor comes to a sudden stop, as the motor's terminals are shorted, or to let the motor 'free run' to a stop, as the motor is effectively disconnected from the circuit.

The difference in the speed of both wheels will vary the direction of robot there are three different ways to control the robot's movement [28]:

- When left wheel moves faster the robot will turns to right as shown in Fig.9 (a).
- When right wheel moves faster the robot will turns to left as shown in Fig.9 (b).
- When both wheels are at same speed, robot will move in a straight direction.

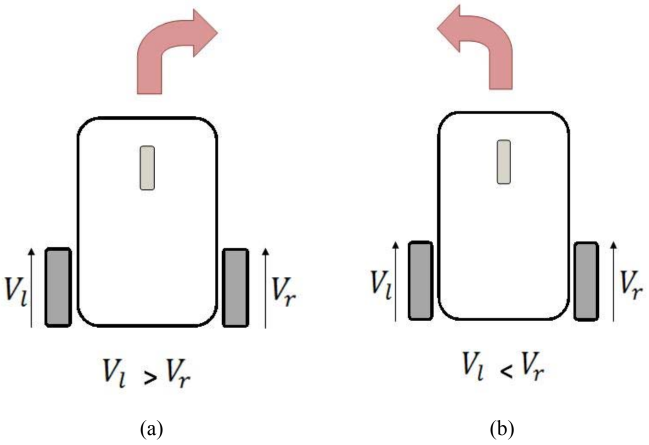

Fig. 9. Robot movement (a) Left wheel is faster (b) Riiht wheel is faster

I. Error Detector

While the robot is being working automatically, there are some possibilities when the robot causes an error and the system will stop working. So in order to resolve this issue we are using Sim 900 GSM modules. GSM/GPRS is a 2G technology and has an uplink bandwidth of 890-915 Mega Hertz and the downlink bandwidth of 935 -960 Mega Hertz. Hence the controller will detect the error and then send commands to the GSM module in order to send the error message to the owner.

J. Processing Unit / Controller

The main processing unit used in this research paper is Arduino Mega 2560. It is an open-source prototyping platform based on easy-to-use hardware and software [29]. Over the years Arduino has been the brain of thousands of projects, from everyday objects to complex scientific instruments. It is used as an input and output device to get continues readings from sensors and based on these readings generate corresponding control signals to ensure the accurate working of the robot. All the modules like single seed selector, ultrasonic sensors, GSM and Bluetooth module etc. directly communicate with Arduino using I/O ports.

III. Software Design

Flow chart of the overall software architecture is detailed down in Fig. 10.

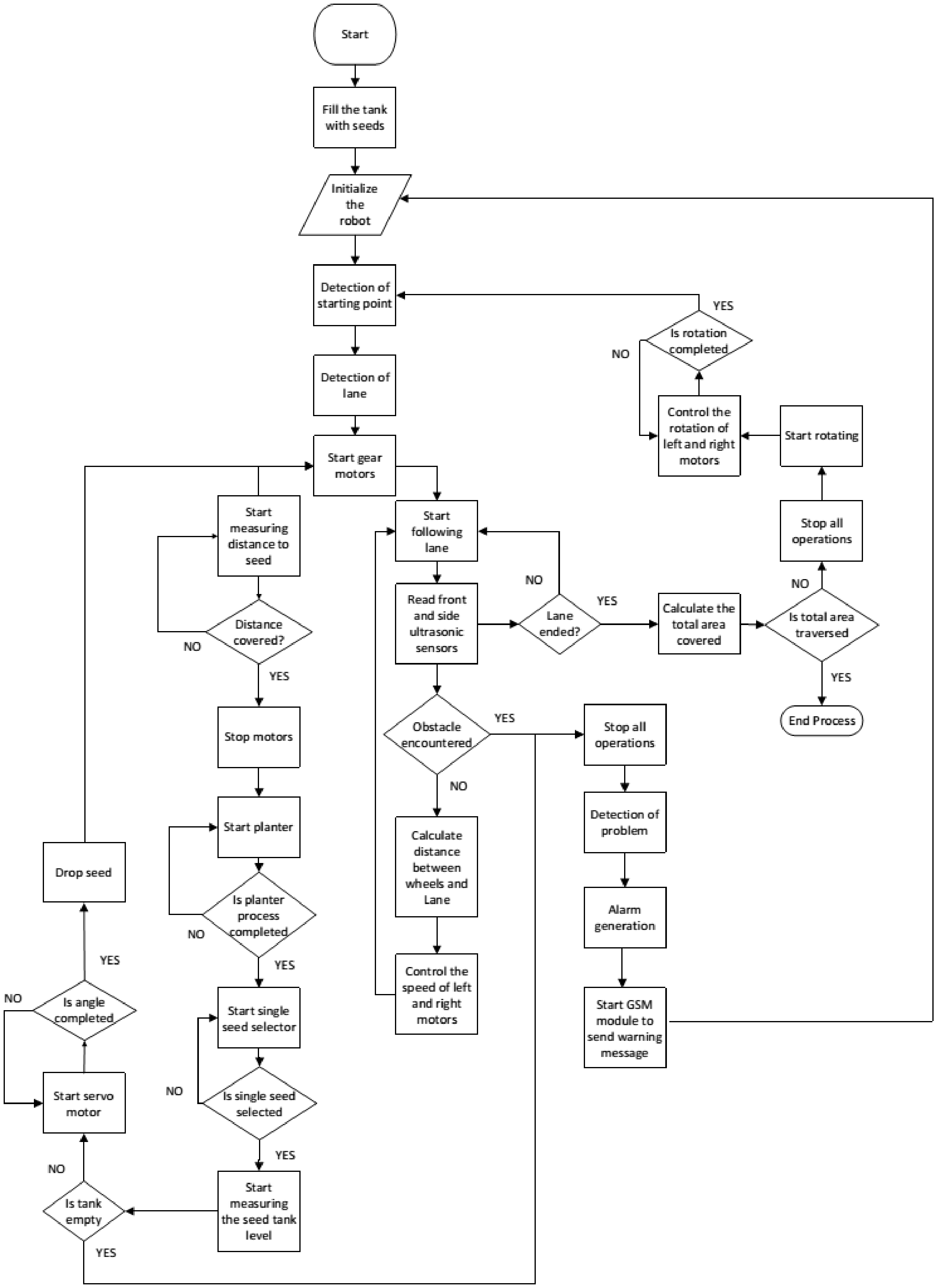

Fig. 10. Flow chart of the proposed software architecture

IV. RESULTS

The aforementioned strategy for tracking a lane was initially validated using a mini-robot as illustrated in Fig. 11 where the robot is tracking a wall as shown in [30]. The actual path followed by the robot, demonstrates the tracking effectiveness. The working of single seed selector is illustrated in Fig. 12, where single seed is being picked and thrown down through the funnel as shown in [31].

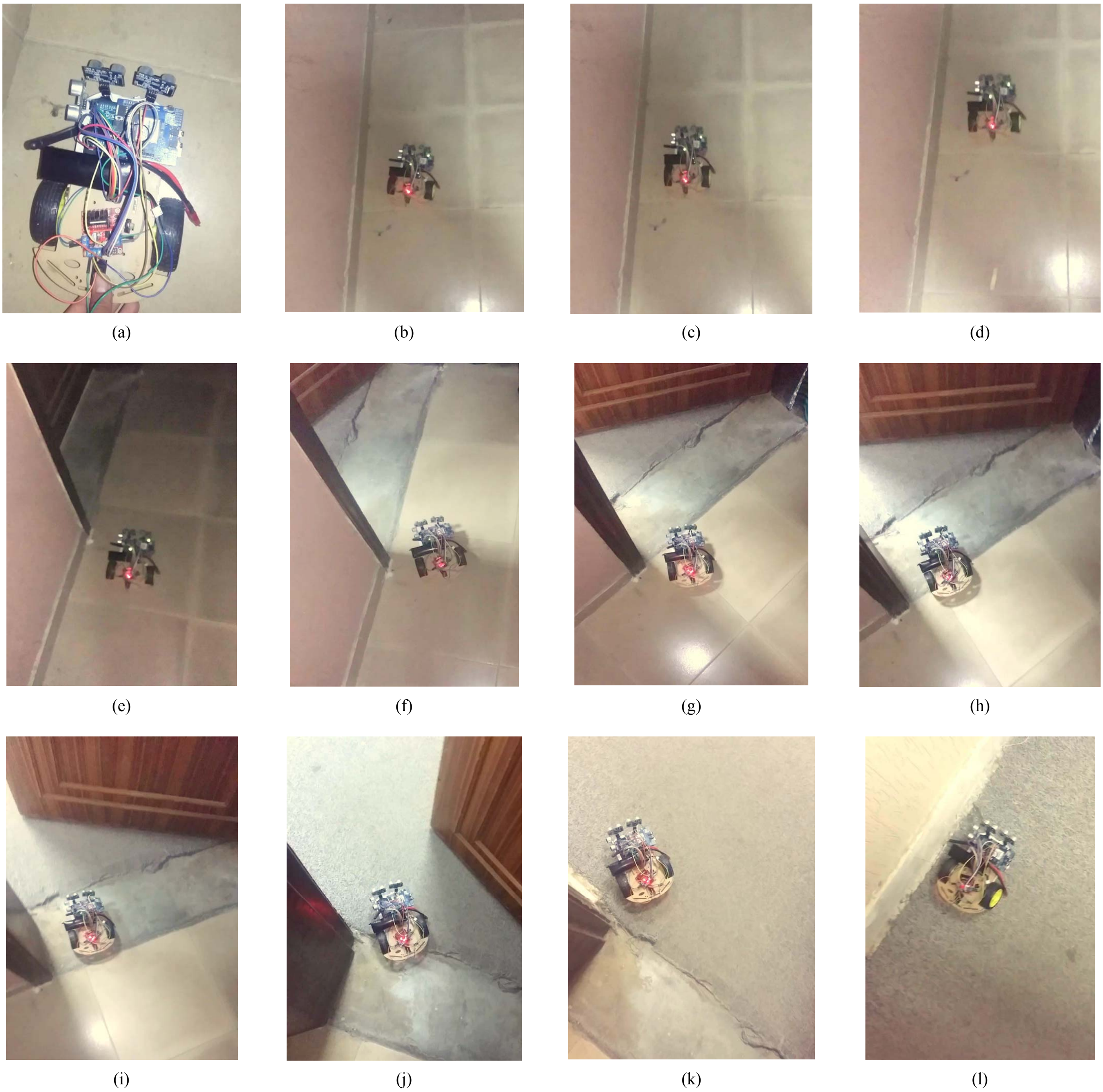

Fig. 11. Shows the robot's path following mechanism while maintaining specific distance and its autorotation at the end of row. (a) Shows the initialization of robot. (b) Shows the step when it starts to rotate in order to correct its direction for wall following (c) Shows the step when it corrected its direction (d) Shows the step when it starts to follow the wall maintaining specific distance. (e) Shows the step when it reaches at the end of wall (the point when it needs to rotate to move on the other side of wall). (f) Shows the step when it starts to rotate. (g-j) Show different positions of robot while rotation. (k) Shows the step when it completed rotation and starts to correct its direction to move forward. (i) Shows the step when it starts to follow the wall again.

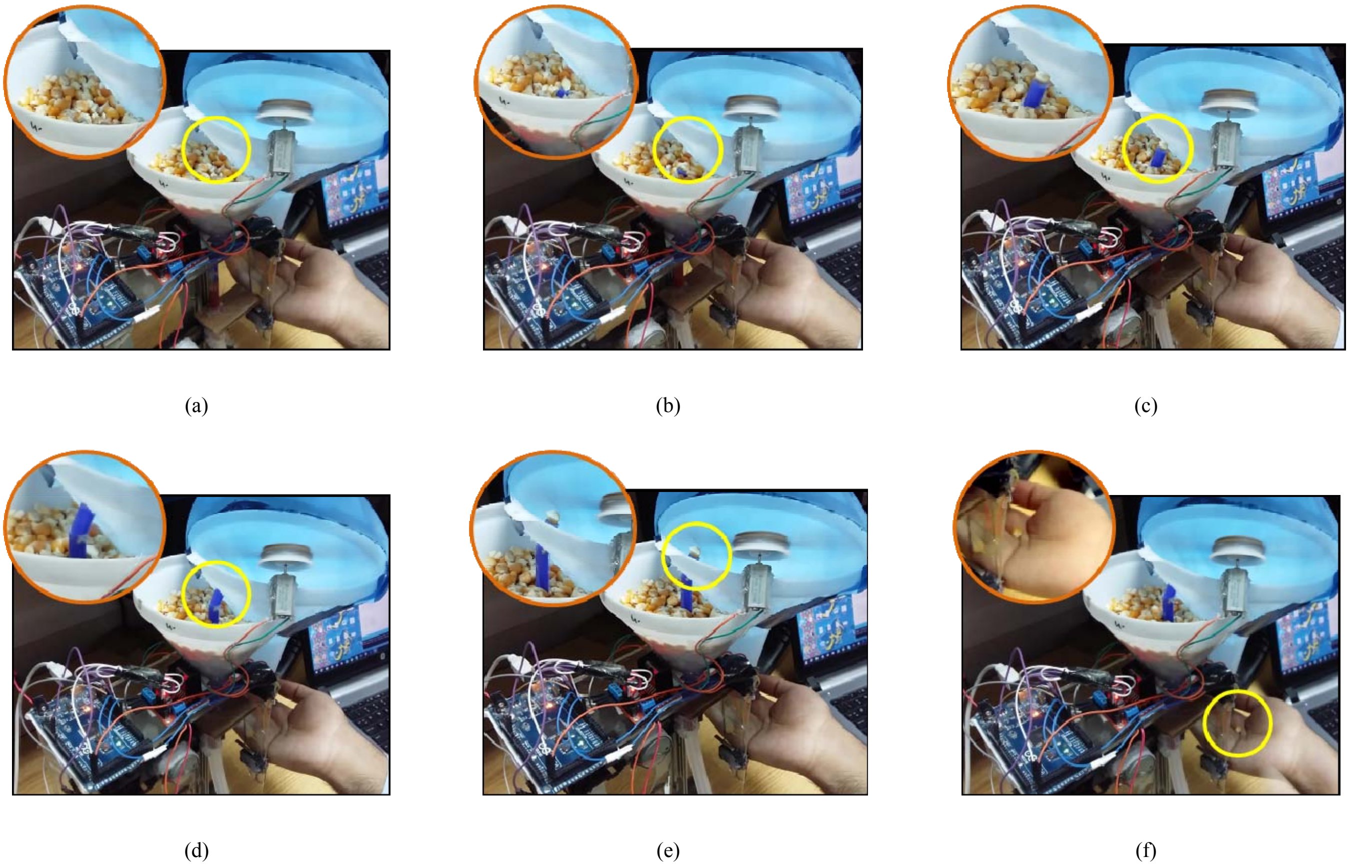

Fig. 12. Operation of single selector picking the single seed from the bulk. (a) Shows the step when the selector starts its process. (b) Shows the step when selector starts to separate the single seeds from the bulk. (c) Shows the step when the selector separated the single seed and nozzle goes upward to through it in to the other funnel. (d) Shows the step when the nozzle is about to enter the next funnel. (e) Shows the step when the nozzle take the selected to the next funnel in order to through it down using the plastic fan. (f) Shows the step when the single seed is successfully reaches down through the funnel

The design and implementation of autonomous robot is very accurate and efficient. We tested the results and the single seed selector gives the 98 percent efficiency in selecting the single seed. Also the mechanism used in the lane following is reliable and cost efficient. The designed system proposed in this research paper covers seeding sowing 5 times much faster as compared to the conventional way of seeding. The average rate of picking single is 90 seeds per min and the time required by the robot to sow one acre of field is 1.5 hours.

V. Cost

Table II enlists the price of items used to make the actual robot.

TABLE II. PRICE OF ROBOT

Sr. No.	Actual price of the robot		
	Item	***Quantity***	***Price (PKR)***
1	Robot Structure	-	2500
2	Gear Motor	4	2000
3	Wheel	4	3200
4	Motor Driver	2	1200
5	Linear Actuator	1	300
6	Vacuum Motor	1	150
7	Ultrasonis Sensor	4	1000
8	GSM Module	1	3000
9	Processor	1	1300
10	Battery	1	2000
11	Bluetooth Module	1	900
12	Wire	-	200
13	Misc.	-	1000
14	Total	-	18750

VI. Conclusion

This robot is designed using DC components and the whole system is battery operated. So solar panels might be used to charge the batteries at the locations where people face electricity problem and where there is no availability of electricity [32]. As a future enhancement, the robot is also designed in such a way that it will not only be used for the seed sowing process of maize crops but will also be used for some other crops like Bean, Cotton and Grain. The robot can also be used for fertilizing and spraying pesticides to the crop fields. As the robot sow the seeds after specified distance so weed detection and recognition also become easier in such a way that every plant that grows between specified distance is unwanted [33].

VII. Acknowledgement

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VIII. References

[1] J. Iqbal, O. Ahmad, and A. Malik, "HEXOSYS II - Towards realization of light mass robotics for the hand," in *14th IEEE International Multitopic Conference*, 2011, pp. 115-119.

[2] J. Iqbal, S. Heikkilä, and A. Halme, "Tether tracking and control of ROSA robotic rover," in *10th IEEE International Conference on Control, Automation, Robotics and Vision*, 2008, pp. 689-693.

[3] A. Meddahi, K. Baizid, A. Yousnadj, and J. Iqbal, "API based graphical simulation of robotized sites," in *14th IASTED International Conference on Robotics and Applications*, 2009, pp. 485-492.

[4] M. F. Khan, R. U. Islam, and J. Iqbal, "Control strategies for robotic manipulators," in *IEEE International Conference on Robotics and Artificial Intelligence (ICRAI)*, 2012, pp. 26-33.

[5] J. Iqbal and A. M. Tahir, "Robotics for nuclear power plants — Challenges and future perspectives," in *2nd IEEE International Conference on Applied Robotics for the Power Industry*, 2012, pp. 151-156.

[6] J. Iqbal, N. Tsagarakis, A. E. Fiorilla, and D. Caldwell, "Design requirements of a hand exoskeleton robotic device," in *14th IASTED International Conference on Robotics and Applications*, 2009, pp. 44-51.

[7] J. Iqbal, N. Tsagarakis, and D. Caldwell, "Human hand compatible underactuated exoskeleton robotic system," *Electronics Letters,* vol. 50, pp. 494-496, 2014.

[8] J. Iqbal, N. Tsagarakis, and D. Caldwell, "Design optimization of a hand exoskeleton rehabilitation device," in *Proceedings of RSS workshop on understanding the human hand for advancing robotic manipulation*, 2009, pp. 44-45.

[9] A. A. Khan, R. U. Nabi, and J. Iqbal, "Surface estimation of a pedestrian walk for outdoor use of power wheelchair based robot," *Life Science Journal,* vol. 10, pp. 1697-1704, 2013.

[10] K. Naveed and J. Iqbal, "Brain controlled human robot interface," in *IEEE International Conference on Robotics and Artificial Intelligence*, 2012, pp. 55-60.

[11] S. A. Ajwad and J. Iqbal, "Recent advances and applications of tethered robotic systems," *Science International,* vol. 26, pp. 2045-2051, 2014.

[12] S. Blackmore, B. Stout, M. Wang, and B. Runov, "Robotic agriculture– The future of agricultural mechanisation," in *Proceedings of the 5th European Conference on Precision Agriculture*, 2005, pp. 621-628.

[13] B. Shivaprasad and M. Ravishankara, "Design and implementation of seeding and fertilizing agriculture robot," *International Journal of Application or Innovation in Engineering & Management (IJAIEM),* vol. 3, 2014.

[14] C. H. Divya, H. Ramakrishna, and G. Praveena, "Seeding and fertilization using an automated robot," *International Journal of Current Research,* vol. 5, pp. 461-466, 2013.

[15] M. Bergerman, S. Singh, and B. Hamner, "Results with autonomous vehicles operating in specialty crops," in *Robotics and Automation (ICRA), 2012 IEEE International Conference on*, 2012, pp. 1829-1835.

[16] S. D. Sambare and S. Belsare, "Seed sowing using robotics technology," *International Journal of Scientific Research and Management,* vol. 3, pp. 2889-2892, 2015.

[17] S. M. Pedersen, S. Fountas, H. Have, and B. Blackmore, "Agricultural robots — System analysis and economic feasibility," *Precision Agriculture,* vol. 7, pp. 295-308, 2006.

[18] R. B. Babu, C. JonathanSoumith, T. C. S. Lakshmi, and R. K. Rao, "GSM Based Agriculture Monitoring and Controlling System," *Global Journal of Computer Science and Technology,* vol. 15, 2015.

[19] J. Iqbal, R. U. Nabi, A. A. Khan, and H. Khan, "A novel track-drive mobile robotic framework for conducting projects on robotics and control systems," *Life Science Journal,* vol. 10, pp. 130-137, 2013.

[20] H. Khan, J. Iqbal, K. Baizid, and T. Zielinska, "Longitudinal and lateral slip control of autonomous wheeled mobile robot for trajectory tracking," *Frontiers of Information Technology and Electronic Engineering,* vol. 16, pp. 166-172, 2015.

[21] M. Z. Ahmad, A. Akhtar, A. Q. Khan, A. A. Khan, and M. M. Khan, "Low Cost Semi-Autonomous Agricultural Robots In Pakistan-Vision Based Navigation Scalable methodology for wheat harvesting," *arXiv preprint arXiv:1501.02378,* 2015.

[22] J. Xue and L. Xu, "Autonomous agricultural robot and its row guidance," in *2010 International Conference on Measuring Technology and Mechatronics Automation*, 2010, pp. 725-729.

[23] C. Tu, B. J. Van Wyk, K. Djouani, Y. Hamam, and S. Du, "An efficient crop row detection method for agriculture robots," in *Image and Signal Processing (CISP), 2014 7th International Congress on*, 2014, pp. 655-659.

[24] M. Li, K. Imou, K. Wakabayashi, and S. Yokoyama, "Review of research on agricultural vehicle autonomous guidance," *International Journal of Agricultural and Biological Engineering,* vol. 2, pp. 1-16, 2009.

[25] M. Zohaib, S. M. Pasha, N. Javaid, and J. Iqbal, "IBA: Intelligent Bug Algorithm – A novel strategy to navigate mobile robots autonomously," in *Emerging Trends and Applications in Information Communication Technologies, Communications in Computer and Information Science, Springer-Verlag Berlin Heidelberg* ed, 2013, pp. 291-299.

[26] M. Zohaib, S. M. Pasha, N. Javaid, A. Salaam, and J. Iqbal, "An improved algorithm for collision avoidance in environments having U and H shaped obstacles," *Studies in Informatics and Control,* vol. 23, pp. 97-106, 2014.

[27] A. Dey, A. Pal, S. Nandi, and L. Roy, "Three way controlled android Smartphone based robotic vehicle via Bluetooth," 2015.

[28] M. Zohaib, S. M. Pasha, H. Bushra, K. Hassan, and J. Iqbal, "Addressing collision avoidance and nonholonomic constraints of a wheeled robot: Modeling and simulation," in *International Conference on Robotics and Emerging Allied Technologies in Engineering*, 2014, pp. 306-311.

[29] M. Banzi and M. Shiloh, *Getting Started with Arduino: The Open Source Electronics Prototyping Platform*: Maker Media, Inc., 2014.

[30] M. U. Hassan. (2016, 24 Sep). *"Path following prototype of an Agriculture Robot" (Ist ed.).* Available: https://youtu.be/CfxyqGwtKdA

[31] M. U. Hassan. (2016, 24 Sep). *Single Seed Selector Designed for Agriculture Robots (1st ed.).* Available: https://youtu.be/btDntlOtagA

[32] S. S. Warekar and B. Salokhe, "Solar powered robotic vehicle."

[33] S. M. Pedersen, S. Fountas, and S. Blackmore, "Agricultural robots-Applications and economic perspectives," in *Service robot applications*, ed: I-Tech Education and Publishing KG, 2008.