Prototyping an All-terrain Capable Mars Rover as Robotic Platform for Field Exploration towards Smart Agriculture

Abqori Aula[1], Syaifurrahman[2], Fitriah[3]
Program Studi S1 Teknik Elektro, Fakultas Teknik
Universitas Tanjungpura Pontianak

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INTISARI

Robot rover penjelajah milik NASA terutama terkenal karena kemampuannya dalam menjelajahi permukaan kasar dan tak rata pada Planet Mars. Sistem suspense utama pada rover menjadi atraksi bagi para peminat robot dikarenakan rancangan yang sederhana namun efektif, yang disebut sistem rocker-bogie. Sejak peluncurannya, sistem suspense ini telah ditelaah, dijelajahi, dan dikembangkan untuk tujuan dan penerapan yang berbeda-beda. Artikel ini mengusulkan perancangan dan pengembangan wahana robot yang memanfaatkan kemampuan rover Mars yang disebutkan tadi, untuk menjelajahi permukaan lahan pertanian yang tak rata yang sering ditemukan di area sekitar. Robot yang diusulkan memiliki 6 roda penggerak semua. Dengan menggunakan wahana robot dengan 6 roda ini, sistem yang diusulkan ditugaskan untuk menjelajahi lahan pertanian secara otomatis. Wahana ini juga bisa ditugaskan untuk berbagai tujuan, seperti inspeksi tanah, memeriksa cuaca, pemetaan secara umum, dan pengambilan sampel. Beberapa purwarupa telah dirancang dan dibangun untuk menguji kemampuan jelajah, daya tamping sensor, dan juga perangkat elektronik dan kelistrikan. Hasil uji awal menunjukkan bahwa wahana robot dapat bekerja dengan baik dalam menjelajahi permukaan takrata dan mampu mengakomodasi berbagai jenis sensor, baik yang ditempatkan didalam selungkupnya ataupun yang ditempatkan pada lengan robot.

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ABSTRACT

NASA’s explorer robot rovers were primarily famous for its capability of exploring the rough and unknown terrain of planet Mars. The main suspension system of the rover has been an attraction for robotic enthusiasts due to its simple yet effective design, the so-called rocker-bogie system. Since its launch, this suspension system has been further researched, explored, and developed for different purpose and area of application. This paper proposes the design and development of a robotic platform utilizing the mentioned capability of Mars rover to explore the uneven terrain of farming field usually found in local precincts. The proposed robot has 6, all-driven wheels. Using the six-wheeled driven robot platform, the proposed system is tasked to autonomously explore the farming field. It can be tasked for a variety of purposes, such as soil inspection, weather checking, general mapping, and sample extraction. A couple of prototypes are designed and built to evaluate the exploring capability, the sensor accommodation capacity, as well as the electrical and electronic required. Preliminary results show that the robot platform can perform well in roving uneven terrain and can accommodate a variety of sensors either placed inside its enclosure or placed on its robotic arm.

Korespondensi Penulis:

Abqori Aula
Program Studi Teknik Elektro
Universitas Tanjungpura
JL. Prof. Dr. Hadari Nawawi, Pontianak, 78124
Email: abqoriaula@ee.untan.ac.id

1. INTRODUCTION

Tech-based smart agriculture is the integration of technology into farming practices in an effort to improve efficiency, sustainability, and productivity [1]. This method includes the use of various technologies such as sensors, robotics, drones, and big data analytics to collect, measure, and analyze agricultural data [2]. Smart agriculture aims to provide farmers with the tools and insights they need to make informed decisions that can improve crop yields, reduce resource consumption, and ultimately increase profitability [3].

The use of robots and automation in agriculture is not a new concept, but recent advances in robotics technology, artificial intelligence, and machine learning have revolutionized the agricultural industry [4][5]. These robots are equipped with a variety of state-of-the-art sensors, navigational tools such as LiDAR and GPS [6], cameras and computer vision technology, as well as manipulators for picking and/or pruning, allowing them to collect data on crop conditions and make autonomous decisions on crop interventions [7][8].

Some of the most common robotic applications in agriculture today include autonomous ground-based vehicles [9] and aerial drones [10]. In particular, agricultural ground-based robots are revolutionizing the agriculture industry, providing solutions to many of the problems faced by farmers today, such as steep terrain or wet conditions [11][12]. These robots are designed to operate in outdoor environments, navigate complex terrains, and perform a range of agricultural tasks [13], ranging from planting crops to monitoring soil and crop conditions, to harvesting and even weed removal [14].

Despite their promising potential, agricultural ground-based robots still face several challenges. The cost of acquiring and maintaining such machines can be high, and their effectiveness in different types of soil and weather conditions is still being evaluated [15][16]. However, ongoing research and development are addressing these challenges, and the robots' agricultural applications are being expanded continuously. As such, the future of agriculture with robot usage is looking bright.

In this paper, we focus on designing a ground-based robotic platform for exploring a rugged farming terrain. We also explore its potential for a variety of agricultural tasks. The mobile ground-based robotic platform is inspired by Mars rovers [17]. The effectiveness of its rocker-bogie suspension and its six-wheeled driven mobility have been proven against Mars' rugged and unknown terrain [18][19]. Since its launch, the effectiveness of this rocker-bogie suspension has been experimented for other purpose, such as stair climbing wheelchair [20][21], delivery vehicle [22], and even exploring body of waters [23]. Our end goal is inclined toward developing a multi-purpose ground-based robotic platform.

This paper is presented in the following manner. The next section elaborates the proposed design of rover-based ground robotic platform. Experimental results are analyzed and discussed afterward. Conclusive summary and future research path are showcased at the end of this paper.

2. METHODS

2.1. Design Requirements

The proposed design of the mobile ground-based robotic platform has the following requirements:

- Affordability—easy to build and cost effective;
- Mobility—able to explore rough terrain and other outdoor agricultural use;
- Small footprints—able to traverse between rows of crop;
- Payload capability—capable of carrying sensors and instruments;
- Functionality—easily add and replace sensor modules and manipulator.

Based on those criteria, we opted for the six-wheeled driven rover with rocker-bogie suspension. The conceptual design is shown in Figure 1.

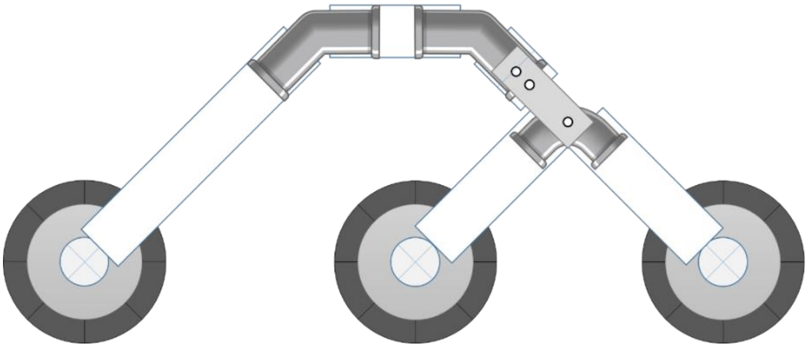

Figure 1. Conceptual design of rocker-bogie suspension.

This proposed conceptual design conforms one of the design requirements above, which has six-wheeled drive for high mobility and rocker-bogie suspension for exploring uneven terrain. While theoretically and technically, the structure of rocker-bogie suspension is many, the design shown by figure 1 is the basic structure [18].

2.2. Components / Materials

To align with the affordability requirement, materials for the chassis of the prototype are selected carefully. The chosen materials are made of ½ inch PVC pipe and a variety of socket connectors.

To accommodate the size of the PVC pipe used, the conceptual design in Figure 1 is redrawn and the result is shown in Figure 2.

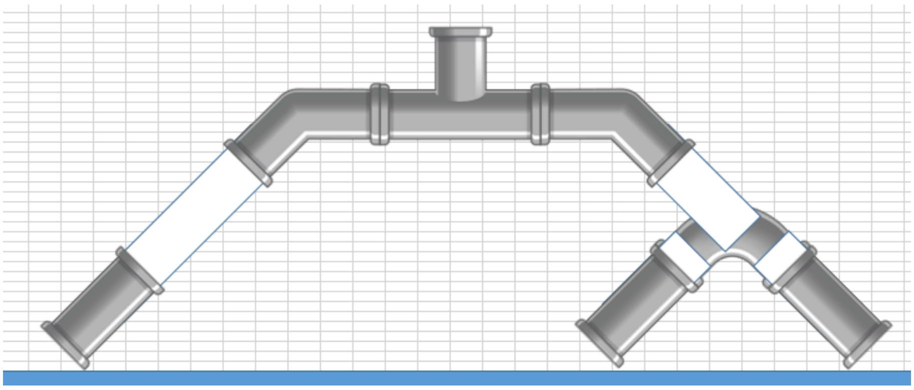

Figure 2. The conceptual design of rocker-bogie suspension is redrawn to accommodate the size of PVC pipes and sockets used

Other materials for the chassis include sets of screw, nut and washer, rubber wheel, acrylic plate, nylon cable ties and container to house electronics components. Materials for the control system consists of electronics components, such as battery housing for battery type 18650, jumper cables, breadboard, ESP32 microcontroller, L298N motor driver, and ON-OFF rocker switch. For mobility, DC motors are used. Some of these materials can be seen in Figure 3 below.

Figure 3. The half-assembled PVC pipes and sockets as well as other electronics and non-electronics materials for building the prototype of the proposed design

The ESP32 microcontroller is chosen for its WiFi and Bluetooth connection capabilities. This feature is necessary for wireless communication between robot-human supervisor and robot to computer controller. Each L298N motor driver is adequately competent to drive two brushed DC motors and is widely available in online marketplace with affordable price [24].

2.3. Mechanical Assembly

The rocker-bogie suspension of the chassis is then assembled as many as two. One for the port side of the robot and another for the starboard side. One of the assembled rocker-bogie suspension is pictured in Figure 4.

Figure 4. One of rocker-bogie suspension.

2.4. Operational Block Diagram

The prototype of the proposed design works by utilizing data from a variety of sensors as input for decision making. Current prototype involves only controlled decision making process. The framework of the proposed system is illustrated in Figure 5.

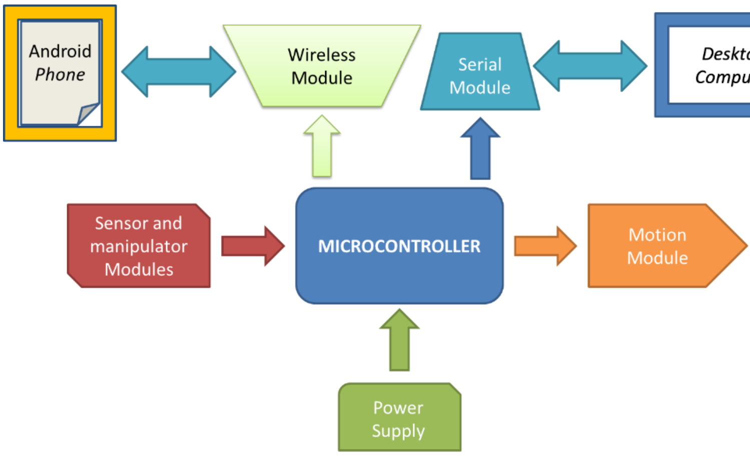

Figure 5. Operational block diagram of the proposed ground-based robotic platform.

The wireless module includes WiFi and Bluetooth connectivity. Though Bluetooth connection can be used as means to transfer sensor data for monitoring on mobile device, in this research, it is also used as means to remotely control the robotic platform via Android device.

2.5. Sensing Mechanism

At the time of writing this paper, the research has reached the stage of initial prototype development and soil moisture and weather analysis. Through harnessing data obtained from moisture, temperature and humidity sensing apparatus, important parameters are collected and then analyzed.

Using general purpose low-cost soil moisture sensor, the moisture of soil is periodically sampled. For weather forecasting, a digital temperature and humidity sensor is attached to obtain temperature and humidity of the surrounding area. With timestamp embedded to each sensor data, a time series of data can be created. This time series of data can be analyzed using artificial intelligent based method such as neural network to model the weather data and moisture data. Then, these data can be used to forecast weather on the farming site and to predict water requirements. A 4-DOF robotic manipulator with gripper attached is also added to the prototype as a basic robot arm for grabbing an object.

3. RESULT AND DISCUSSION

3.1. First Prototype

After assembling the chassis, the mobility first prototype of the proposed design was tested in indoor and controlled environment. Afterward, the electronic components such as microcontrollers and sensors are placed and tested. Figure 6 shows this first prototype. The complete build with housing and manipulator attached is shown in Figure 7.

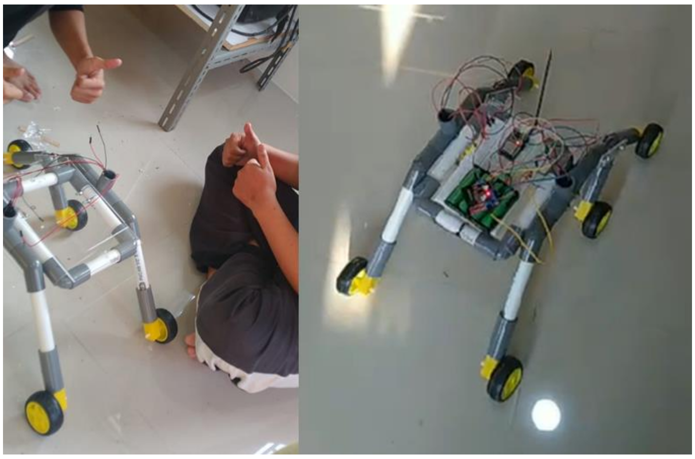

Figure 6. The finished initial assembly of the chassis of the first prototype on the left and circuit testing on the right.

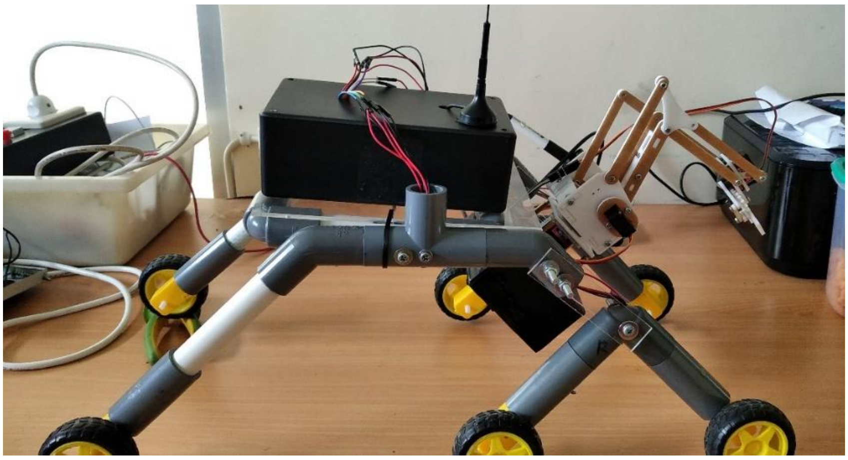

Figure 7. Fully built robotic platform with temperature and humidity sensor attached and mechanical 4-DOF manipulator attached.

The T-socket on each ‘leg’ is currently used as container for cables going to the black container at the top of the chassis. But, this T-socket is prepared for later use for housing differential bar of the platform. The black container at the top houses electronic modules. The smaller black container at the front of the platform act as housing for battery and placeholder for the manipulator. This battery housing is pertinent for platform’s wheels to have a proper grip on the ground by acting as additional weight. The antenna is used to gain an extended communication range between onboard controller module and mobile Android device.

The total weight of the prototype’s chassis without electronics is 2.6 kg, while with electronic sensors, modules, battery and manipulator is 3.3 kg. The physical parameters of the first prototype are presented by Table 1.

Tabel 1. Physical parameter of the first prototype

Parameter	Value
Weight (without payload)	2.6 kg
Weight (with payload)	3.3 kg
Width	34 cm
Length	51 cm
Height (to base)	13 cm
Height (to top container)	25 cm
Wheel diameter	6.8 cm

3.2. Outdoor Experiment

The prototype’s mobility is then brought outside and tested on actual uneven grassland. Colored markers are place on the ‘leg’ as tracking points on the position of the rocker-bogie suspension. Figure 8 shows the marker on the prototype’s leg while Figure 9 captures the platform’s effort to overcome a 15 cm grassy dune.

Figure 8. The prototype robotic platform with colored markers on the leg.

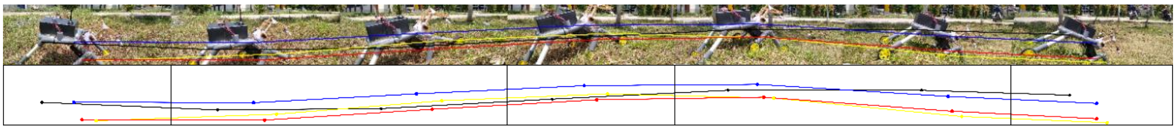
Figure 9. (Above) Frames capturing the prototype robotic platform’s effort to overcome a small dune. (Below) The same frames with traces of coloured markers only.

From figure 9, the agility of rocker-bogie suspension can be clearly seen. This also deduces that the prototype robot can overcome an uneven ground with a small dune that is higher than its wheel diameter.

4. APPLICATION SCOPE AND IMPROVEMENT

4.1. Sensing and mechanism capability

Currently the sensing and mechanism available on the first prototype are only temperature and humidity sensors and gripper on a 4-DOF manipulator. This sensor configuration is suitable only for measuring the temperature and humidity of the air surrounding the robot, whereas the manipulator can only grab small object.

However, the payload can be added or replaced with other type of sensors in accordance to the task needed. The gripper on the manipulator’s end can be replaced with other modules, such as soil moisture module, sprayer, cutter or soil sample collector.

With extra actuators, a ploughing, sowing and even rolling mechanism can be added onto the robotic platform to increase its functionality.

4.2. Off-road capability

By adding a differential mechanism on current rocker-bogie suspension, the independent motion of left and right ‘leg’ can be increased. This means the proposed robotic platform’s capability to explore rough and rugged surface will also increase.

4.3. Navigation

Additional sensors for navigation and localization can be added onto the platform, such as ranging sensors (ultrasonic, laser or infrared) and vision sensors (color camera or spectrometer camera). Obstacle perception and avoidance capability are inherently obtained if those sensor modules are available.

Autonomous navigation can be embedded into the prototype by adding computational processing power, such as adding Raspberry Pi as the second processing unit.

The range of distance traveled by the robot can also be increased by using battery with more capacity and coupled with battery management system.

4.4. Communication

The range of wireless internet is currently adequate for communication in small local farm. However, for a large scale production farm with wider area, additional means of communication is a must, to ensure a continuous data transfer. This capability can be obtained by adding stronger antenna, or LoRa module.

5. CONCLUSION

This paper presented a first prototype of ground-based robotic platform for agricultural application. Current setup utilizes temperature and humidity sensors and 4-DOF manipulator with gripper, WiFi and Bluetooth capable microcontroller, as well as outdoor external antenna for extended range, all mounted on a ground-based robotic platform with rocker-bogie suspension. With appropriate sensor modules and specially crafted mechanism, the functionality and capability of the proposed multi-purpose robotic platform can be increased significantly. Initial tests suggest that the proposed platform can perform well in roving uneven terrain and can accommodate a variety of sensors either placed inside its enclosure or placed on its robotic arm. Suggestions to improve current prototype have also been suggested.

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