Development of Theo Jansen inspired all-terrain quadruped mini mobile robot

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Abstract. This paper discusses an ongoing project of building a quadrupedal robot designed for operations in rugged terrain by using Theo Jansen's linkage mechanism. The robot is unguided, but it is still able to maintain the ability to evade obstacles and change its course automatically. The robot utilizes Jansen's linkage mechanism for all four legs to mimic a four-legged animal's movement and stability. Due to the smooth motion nature, it can provide a very high degree of stability, enabling it to carry items that require a smooth and stable motion. Jansen's linkage mechanism is also easy to operate and design; a pair of legs could also be powered by one rotational movement, reducing overall energy consumption. The quadrupedal robot's goal was to maintain a smooth and stable motion even when navigating obstacles and could ensure item delivery safety. The fabricated robot's average speed is 0.02178 m/s, and the power consumption is 5.71 W.

1. Introduction

This article discusses the development of a quadrupedal mobile robot inspired by the Theo Jansen linkage mechanism. The quadruped robots are one of the best choices of all legged robots related to cost, ease of control, stability, and mobility of its locomotion [1]. The developed robot should provide a closed-loop system to walk in the desired heading correctly [2]. Therefore, a microcontroller, actuators, and several sensors are the main electronics components needed in designing a mobile robot.

Legged robots can be used in many applications, such as the rescue robot after the disaster occurred [3-11]. The dangerous and complex environment post-incident can be inaccessible to the Search and Rescue team, especially after the earthquakes and nuclear accidents [3]. The 4-legged walking robot can replace the rescue workers to complete the search-and-rescue mission in the complex environment [4]. The risks in rescue operations can be reduced, as the robot is able to overcome the obstacles in the unsafe and unreachable environment due to its lightweight, small, low center of gravity, and a high degree of freedom of motion. The rescue efficiency can also be improved if the 4-legged autonomous walking robot is designed to be having multitasking performance, such as real-time environmental monitoring and victim searching [5]. Other types of recently developed legged robots can be found in [12-20].

2. Methodology
2.1. Robot Design
This work's main components include Arduino Mega, DC geared motor SPG30, L298N motor drivers, IR sensor modules, and 18650 batteries for power.

The walker robot's leg mechanism is designed based on the Theo Jansen mechanism, a crank-based mechanism consisting of links connected with joints. Theo Jansen linkage was chosen due to its advantages. The whole mechanism is controlled by a leading joint which rotates accordingly to the direction motor rotation. The mechanism has fluent and smooth mobility, which enables it to move on uneven ground swiftly. The crank-based locomotive walking mechanism has six links with joints and only has a limited degree of freedom in mobility, hence the simple and robust movement.

Figure 1 shows the robot leg, which was designed based on Theo Jansen linkage's dimension and ratio. The length of links: \( b = 41.5 \text{ mm} \), \( c = 39.3 \text{ mm} \), \( d = 40.1 \text{ mm} \), \( e = 55.8 \text{ mm} \), \( f = 39.4 \text{ mm} \), \( g = 36.7 \text{ mm} \), \( h = 65.7 \text{ mm} \), \( I = 49.0 \text{ mm} \), \( j = 50.0 \text{ mm} \), and \( k = 61.90 \text{ mm} \). All links are 5mm thick. Four similar legs were built. To increase stability, the legs were paired symmetrically, as shown in Figure 2.

Figure 3 depicts the top view of the assembled Theo Jansen quadruped walking robot. The width of the walking robot is 254 mm. The height and length vary when the legs move. The approximate length is 187.90 mm. The walking robot model is then printed out using a Flashforge Professional 3D Printer.

2.2. Robot behavior
Figure 4 shows the flowchart of the proposed Theo Jansen quadruped walking robot. The blue square shows the flowchart of initializing the position of the legs before the walking robot moves. When the green button is pressed, both motors will stop. We can then push the red button to let the right DC
motor be 180 degrees out of phase with the left DC motor. When the legs' position is initialized, both encoder readings will be written as 0 (initial condition).

The red square shows the flowchart when the IR sensor detects an obstacle. When there is an obstacle less than 8cm in front, the walking robot will move backward to open its right legs. Because one rotation is equivalent to 1600 encoder reading, thus we reverse until the encoder reads multiply of 1600. After that, the left DC motor will continue to change for four rotations (90 degrees). When the turning process has over, the encoder values will be set to the value before turning. The reason is the encoder reading is necessary for the next process.

![Figure 3. Top view of the proposed quadruped walking robot](image)

The green square shows the flowchart of how the walking robot walks in a straight line. When one of the encoder values is bigger than the other, it means the DC motor's speed is not synchronous. Thus, we need to slow down the faster side until the encoder values become equal. This process runs continuously throughout the flowchart.

2.3. Circuit design

**Figure 5** shows the circuit diagram of the Arduino Mega, IR sensors, L298N motor driver, DC motor with encoder, and batteries. Arduino Mega functions as the CPU, which identifies the signals received from sensors and provides compatible responses via the DC motor's application to control the walking robot's direction and movement.

**Table 1** depicts the connections between Arduino Mega and other components used in this work. The interrupt pin from the encoders is Pin 2, Pin 3, Pin 18, and Pin 19. The IR sensor input pin is pin 12, and the _input_pullup_ pins for buttons are pin 4 and pin 5. Pin 6 and pin 11 are enabled pins for DC motors. Pin 7 and pin 8 control the right motor directions, whereas pin 9 and pin 10 control the left motor directions.
Figure 4. Flowchart of the proposed quadruped walking robot
Table 1. Pins connection between Arduino Mega and components.

| I/O                              | Arduino Mega pins | Connection          |
|----------------------------------|-------------------|---------------------|
| The output from Arduino Mega to motor driver L298N | Digital pin 6     | Connected to enA pin of L298N |
|                                  | Digital pin 7     | Connected to in1 pin of L298N |
|                                  | Digital pin 8     | Connected to in2 pin of L298N |
|                                  | Digital pin 9     | Connected to in3 pin of L298N |
|                                  | Digital pin 10    | Connected to in4 pin of L298N |
|                                  | Digital pin 11    | Connected to enB pin of L298N |
| Input from the encoder to Arduino Mega | Interrupt pin 2   | Connected to chA pin of right encoder |
|                                  | Interrupt pin 3   | Connected to chB pin of right encoder |
|                                  | Interrupt pin 18  | Connected to chA pin of left encoder |
|                                  | Interrupt pin 19  | Connected to chB pin of left encoder |
| Input from IR sensors to Arduino Mega | Digital pin 12    | Connected to out pin of IR sensor |
| Input _pullup from buttons to Arduino Mega | Digital pin 5     | Connected to a button |

3. Result

3.1. Robot prototype

Figure 6 shows all the components of the prototype of the walking robot. Jumper wires connected the connections. The batteries were installed in front of the robot to lower the center of gravity. This can increase the stability of waling robot. There is a third DC motor installed on it for future implementation. DC motor couplings were used to connect DC motors with the legs to prevent slipping. The joints of the legs are locked by using M3 bolts and lock nut. The IR sensor is placed at the front position because it must be the first component to sense obstacles to prevent a collision. The
green button is to stop DC motors, and the red button is to initialize the position of the legs. The weight of the walking robot is 1.3 kg.

Initially, the walking robot must set to 180° out of phase as it is a must for the Theo Jansen linkage. Thus, as shown in **Figure 7** and **Figure 8**, the walking robot's right side is set to 180°, whereas the left side is set to 0°. When the motor is not out of phase (either motor moves faster), the closed-loop feedback system will slow the faster motor. The technique used is by comparing both encoders reading time to time. The feedback system is very important because it keeps the walking robot walks in a straight line.

**Figure 6.** Components placement on the walking robot

**Figure 7.** Initial position for the right side of the robot

**Figure 8.** Initial position for the left side of the robot

**Figure 9** shows the LED indicator lights up when there is an obstacle. The IR sensor is working. When the IR sensor senses an object, the DC motor reverses to open the right leg to the initial position (**Figure 7**). Then the left DC motor reverses four rotations to turn 90°.
3.2. Speed
The robot's speed to walk in a straight line and turn 90° is calculated by measuring the robot's time to walk 1 m and turn 90°. The experiments were conducted ten times. The robot's time to complete the tasks is recorded and tabulated as shown in Table 2 and Table 3. From the calculation, the average speed of the robot is deemed at 0.02178 m/s.

Table 2. Time taken for the robot to walk 1 m straight ahead.

| Attempt | Time taken (s) |
|---------|----------------|
| 1       | 46.86          |
| 2       | 45.84          |
| 3       | 46.21          |
| 4       | 45.84          |
| 5       | 46.21          |
| 6       | 44.96          |
| 7       | 45.66          |
| 8       | 46.86          |
| 9       | 44.96          |
| 10      | 45.66          |
| Average | 45.94          |

Table 3. Time taken for the robot to turn 90°.

| Attempt | Time taken (s) |
|---------|----------------|
| 1       | 13.78          |
| 2       | 13.68          |
| 3       | 13.45          |
| 4       | 13.48          |
| 5       | 13.45          |
| 6       | 13.78          |
| 7       | 13.57          |
| 8       | 13.48          |
| 9       | 13.68          |
| 10      | 13.57          |
| Average | 13.59          |

3.3. Power consumption
The robot's DC motors' voltage and current were recorded while experimenting with walking 1 m in a straight line. The measurements are tabulated in Table 4 & Table 5. In normal conditions (both motors run at maximum speed), the left motor's power consumption is 5.709 W, and the right motor is 5.718 W. The power consumption is similar because the design of the walking robot is symmetric.

Table 4. The voltage and current for the left DC motor without load.

| Attempt | Voltage (V) | Current (A) |
|---------|-------------|-------------|
| 1       | 11.26       | 0.513       |

Table 5. The voltage and current for the right DC motor without load.

| Attempt | Voltage (V) | Current (A) |
|---------|-------------|-------------|
| 1       | 11.30       | 0.508       |
4. Conclusion
The overall performance of the walking robot is satisfactory. Because of the designed robot having a low center of gravity, the robot is relatively stable. Furthermore, the proposed walking robot can walk in a straight line by comparing the encoder’s value and the Arduino Mega control and feed the DC motor to either speed-up or slow-down. Moreover, the walking robot can sense obstacles by IR sensor before the walking robot collides with it. Then, the walking robot will reverse to open one leg first to prevent toppling over. The walking robot can turn 90° entirely because of the use of an encoder. In short, the overall performance of the walking robot by using Theo Jansen linkage is good.

In the future, the camera can be installed on the robot to monitor its environment and explore dangerous places. This is why the legged robot is built instead of a wheeled robot because of its ability to explore many terrains. Additionally, humidity sensors or temperature sensors can be mounted onto the robot body based on tasks. For instance, archeologists can utilize a walking robot attached to a humidity sensor to know the place's humidity.

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