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Design and Prototyping of a Motorized Legged Robot with Klann Linkage Mechanism

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ABSTRACT

This paper focuses on the design and prototyping of a legged robot with Klann linkages, which are powered by two DC worm gear motors. The aims of the project are to understand the detailed prototyping process, and to demonstrate the functionality of the Klann linkages for the legged robot. The prototyping process involves 3D modelling using Solid Works, selecting material and motor, performing fabrication and assembly and carrying out walking and load transfer test. Results show that the legged robot, which was built using PolyEthylene Terephthalate Glycol (PETG), can succesfully walk at a speed of 33 cm/s while carrying a 1 kg load.This study opens up other opportunities to fully utilize the benefits of Klann linkage's walking robot by integrating practical sensors or cameras.

Keywords: Klann linkage, legged robot ,load transporting, robotics.

1 INTRODUCTION

Legged robots are attracting more attention nowadays due to its added benefit of increased mobility in all terrains. It is complicated to build legs for a robot because stability of the robot is the main concern, especially during motion. A statically stable robot is a robot that can maintain upward when standing and well balanced. The center of gravity of the robot is within the ground contact base. For example, a robot with three legs, which form a shape of triangle, can stand balanced as long as its mass is within the triangle. This triangle is called the "support polygon" which is a horizontal region over which the center of mass lies to achieve static stability. In a nutshell, the support polygon is a projection between all the support points of a robot onto the surface it is standing. The minimum number of ground contact points required for a statically stable robot is three [1].Figure 1 shows an example of a three legged robot called as Self-excitedTripedal Dynamic Experimental Robot (STriDER), which is developed by the University of California Los Angeles (UCLA) research group[2].

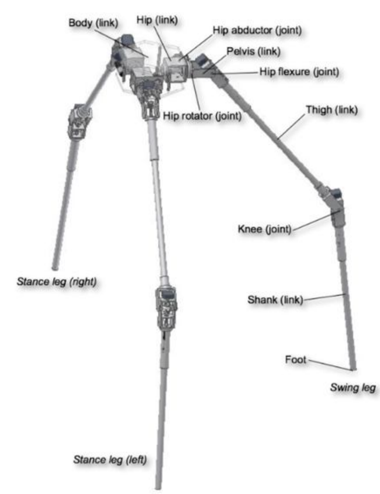

Figure 1: Example of a three legged robot, STriDER[2]

Legged robots have valuable benefits as they can,

- step over obstacles,
- carry a vehicle over wide chasm or broken ground,
- achieve a smooth ride on rough ground,
- save power in extreme terrain condition compared to using wheels (e.g., climbing),
- cause less damaged to the grounds compared to wheels.

Based on the advantages above, this project focuses on creating a small legged robot for indoor load transportation. The robot is designed to carry1 kgload, which is an approximate weight of a ream of A4 size paper. The legs of the robot are designed with Klann linkages, which will be powered by motors. It is known that this mechanism has suitable walking gait motion for climbing and walking applications. Although a navigation system for such mobile robot is important [3], this work will not focus on a complex navigation or automated control system.

Klann mechanism, which was invented by Joseph C. Klann,is a planar mechanism designed to simulate a smooth walking step of an animal with only one actuator [4]. The Klann mechanism is formed by connecting six bars using pin joints as shown in Figure 2.The pin joints provide single-axis rotation function[5].Figure 3 shows another example of Klann mechanism used for an underwater walking robot, which is developed by the Bristol Robotics Laboratory, University of the West of England[6].For t, a Klann linkage is used for each leg to provide a walking and climbing motion.

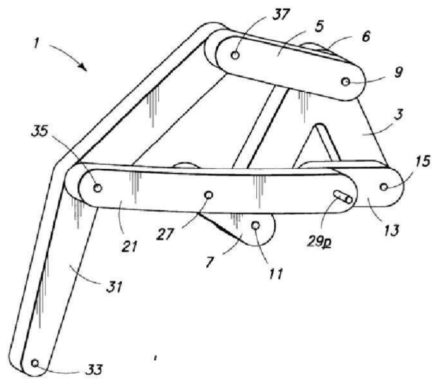

Figure 2: Klann linkages [4]

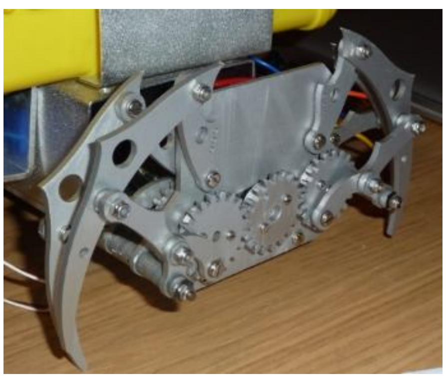

Figure 3: Example of Klann linkage mechanism of a robot [6]

2 METHODOLOGY

Figure 3 shows the important stepsinvolved in designing and prototyping the robot.

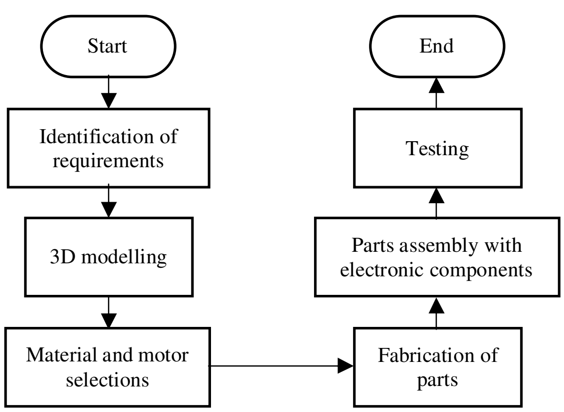

Figure 2: Process flow chart for the design and prototyping processes

2.1 Design requirements

For this study, the main design requirements of the legged robot are first identified and listed in Table 1.

Table 1: Main design requirement

Design Requirement	Description
Material	Strong, lightweight and easy to fabricate.
Number of legs/Klann linkages	Minimum four legs/linkages for stability.
Number of motors	Two motors are needed as having additional motors will increase the weight. Each motor is used to drive one side of the robot. Hence, the robot can be easily controlled to manoeuvre to left or right when using two motors.
Total mass of the robot	2 kg
Maximum carry load	< 1 kg
Velocity, V	Minimum of 10 cm/s for stability during motion

2.2 3D Modelling of the robot

The legged robot with Klann linkages is primarily designed and modelled using SolidWorks. This solid modeling computer-aided design (CAD) computer program is used to create three dimensionally (3D) models of main components of the robot which are chassis, main legs, connecting legs, crank arms, upper and lower rocker arms.

The main supporting frame is made of steel rods that will be connecting all the chassis and the legs together. The linkages will be fastened with bolts and nuts to secure them in place while providing sufficient rotational movement at the connecting rod and links.

2.3 Material Selection

There are three materials tested for the robot, namely acrylic, aluminum and PolyEthylene Terephthalate Glycol (PETG). One leg or a set of Klann linkages will be built using each material and evaluated based on three criteria, which are strength, lightweight and ease of fabrication.

2.4 Motor Selection

Motors are required to move the linkages of the robot. To find the right motor size, required torque needs to be calculated with a given safety factor of 2. Following equations are used to find the required torque that need to be overcome before the robot can move. The selected motor needs to have a larger rated torque than the calculated required torque. Equation (1) to (3) show the simplified method to calculate load torque,T_L, and required torque, T_M[7].

$$F = mg \tag{1}$$

$$T_L = \mu F \times L_{robot} \quad (2)$$

$$T_M = T_L \times F.S \quad (3)$$

The explanation and values of the variables of the equations above are listed in Table 2below.

Table 2: Variables for required torque calculation[7]

Variables	Values
Robot height, L_{robot}	0.20 m
Friction coefficient, μ	0.05
Total mass including load, m	3 kg
Safety factor, F.S	2

This simplified calculation provides a rough estimation of the required torque by only considering the length of the crank that is connected to the shaft motor. Other factors such as internal friction of the connection, motor and gear head efficiencies are not considered.

2.5 Parts Fabrication, Assembly and Electronic Components

The fabrication process depends on material types. Cutting and drilling processes will be the main methods for fabrication for aluminum and acrylic sheets. For PETG, components may be fabricated using 3D printing.

The crank arm is linked to a rotating shaft of a DC motor. The crank is then transferring the power from the motortothe main leg, which will touch the ground to produce movement. For assembly, the whole legs, arms and cranks will be linked with pin fasteners that will be used with steel bearing rods and bearings to provide frictionless motion between the links. For the chassis, it will create six sections or compartments, four of which are the housing for the Klann mechanism and the other two sections for the storage unit for the electronics, motors and load storage.

This robot is designed to be almost fully mechanical so that it only requires simple programming. There will be a total of eight legs connected to two DC motors together with electronics to generate forward, backward and turning movements. These movements will be programmed via electronics, which include an Arduino microcontroller[8], batteries, motor drivers, voltage regulators and a Bluetooth controller. The Bluetooth controller is used to control the robot.

2.6 Procedure for Load Transfer and Movement Test

The test is carried on a soft carpet floor. The first step is to put the robot on the floor and put the load on top of the robot, which is a stack of A4 papers with varying weights up to 1 kg. Then, the next person will control the robot to make it travel for 1 meter while stably transfer the load to the end of destination. The time taken for the robot to travel for 1 meter is recorded and test is repeated to get an average reading. Only successful load transfer test runs will be considered.

3 RESULTS AND DISCUSSION

3.1 3D Model of the Design

The 3D model of the robot has been successfully created using SolidWorks as shown in Figure 4.

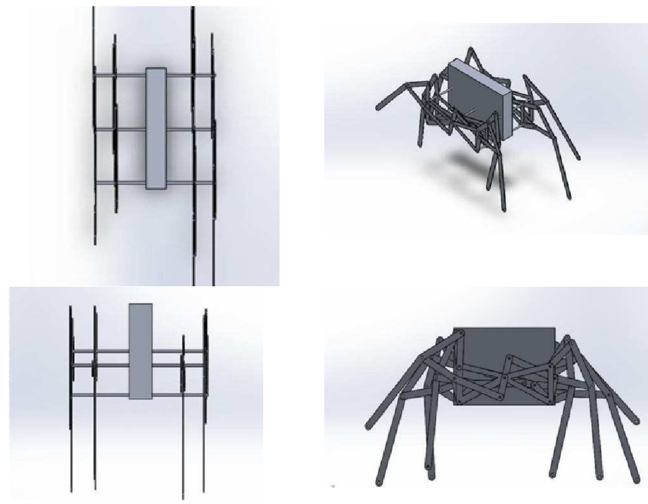

Figure 4: Orthographic and isometric views of the robot final design. From top left (clockwise) top view, isometric view, side view and front view of the robot.

3.2 Final Material of the Robot

The first material tested was acrylic as shown in Figure **5**. A large sheet of acrylic was measured and cut according to the dimensions of the designed Klann linkages. It was observed that the cutting step of the acrylic sheet was significantly challenging because the material sheet would snap when more force was applied during the cutting motion. Furthermore, during the cutting process, the acrylic sheet had tendency to melt.

Since the acrylic sheet was thin, bolts and nuts were initially used to connect the bars, without inserting any bearings. Due to that, another problem was observed. The nuts and bolts had to be loosened to allow for parts to move. Nonetheless, with the loose bolts and nuts, the linkages seemed to be easily detached by the continuous rotational motion of the whole mechanism. The acrylic linkages worked but did not provide a smooth motion as the linkages would collide with each other. In addition, the material was seen to bend at certain parts of the motion, causing the linkages to misalign and simulate a different motion than what it was supposed to do.

Figure 5: Acrylic Klann linkages

The second tested material was aluminium as shown in **Figure 6**, where the fasteners were swapped with bearings. Aluminium flat bar was cut according to the dimensions of the linkages. They were then drilled with a 17mm drill bit to fit those bearings at connecting joints. Although aluminum is a strong material, the main issue encountered during the process was that all the connectedlinkages would be too heavy for the DC motor. High curent was required to turn the motor and move the connected linkages. If batteries were used,they could have been easily depleted in a short period of time.

Figure 6: Aluminium Klann Linkages

Lastly, the final tested material was PolyEthylene Terephthalate Glycol (PETG). Using PETG, major parts of the robot (Figure 7) were easily fabricated using a 3D printer. No cutting nor drilling process was required as the parts were all fabricated specific to their dimensions and shapes to high precision. This high precision fabrication allows the bearings to be fitted firmly into connecting holes. PETG was also significantly lighter and comparably strong compared to aluminium and acrylic. Due to its lightweight, it draws less current to run at the same speed as the aluminium linkages does. Hence, PETG was ultimately chosen and considered as the most suitable material for the robot.

a) b)

Figure 7: a) 3D printed parts of the robotmade using PETG material. b) Parts were assembled with rods.

3.3 Selected Motors

The calculated required torque was 0.58 Nm. Hence, two readily available12V worm gear high torque DC motors with no load speed of 27 RPM and a rated torque of 7 Nm have been selected. Each motor weighs around 0.4 kg. The motor does indeed have more than enough power and torque to move the robot with much higher load.

3.4 Completion of Fabrication and Assembly

Once all the parts were 3D printed, the bearings were installed into the connecting holes of the parts by using an epoxy glue. The glue was carefully applied to avoid excessive usage and to prevent the bearings from getting stuck, creating more frictional resistances. The assembly of the linkages was done by blocks or sets of Klann linkages, starting from the side blocks (Figure 7b). Steel bearing rods were used as the main supporting structure for all the chassis. When two blocks or sets of Klann Linkages were assembled, the motors were then installed at the middle chassis, making sure the centre of gravity is closer to the centre of the robot The motors were positioned side by side(Figure 8).Once the motors were installed, the other sets of the linkages were assembled. Above the motors, there is a compartment for electronics and load (Figure 9).

Figure 8: Two motors are placed at the centre of the robot. Each motor drives four Klann linkages.

Two motors were attached to eight Klann linkages, controlling the left and right legs of the robot. Each of the four pairs of legs were assembled with a 90° phase angle difference between them. Thus, one of four legs will always be contacting the ground every 45°rotation of the motor. The design of the moving mechanism will provide a clearance height of 20cm.There were six motions programmed into the motor. The robot can move forward and backward, turn right and left and finally rotate clockwise and anti-clockwise.

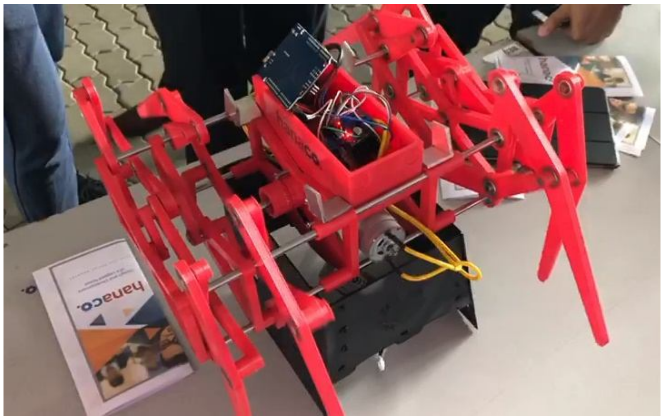

Figure 9: A compartment at the centre of the robot to store electronic components and battery

3.5 Load Transfer and Movement Test

Several walking tests were carried out to test the motion of the robot. In the walking test, the robot was able to travel about 1 m distance in 3 seconds, while still stably carrying the 1 kg load. Nonetheless, some noticeable problems were noted. These include the weak connecting points at some linkages, which were due to the lack of epoxy glue. Besides, epoxy glue residues were providing resistances to the linkages that made the motors harder to move. In general, the robot can walk and carry the load from one place to another but the walking movement was not fully straight nor flawless due to friction between linkage bars and joints.

4 CONCLUSION

This study is useful in understanding the thorough design and prototyping process of a legged robot. Additionally, this work has successfully showcased and demonstrated the useful functions of Klann linkages as a moving mechanism for the legged robot. We managed to provide a working prototype that can easily demonstrate the motion and capabilities of the Klann mechanism. The walking mechanism can be smoother by paying more attention to the assembly process especially during the bearing and rod connection. Good assembly will reduce internal friction, allowing the robot to walk straight flawlessly during the load transfer process. Other future improvements that can be done for the robot include adding practical components such as sensors and cameras. Fireproofing materials can also be used for building the robot so that the robot can be used for firefighting or in any hazardous situations, where the environment could be dangerous for humans.

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