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DEVELOPMENT OF 4-LEGGED WALKING ROBOT AND MOVEMENT ALGORITHM

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ABSTRACT

(Keywords: cooperative mobile robots, distance maintenance, infra-red sensor, ultrasonic sensor)

This project focused on designing and developing a 4-legged walking robot prototype. The robot can move forward according to a unique pattern of movement using three servo motors for each leg. Firstly, the design of this robot was draw using SolidWorks Software and then being fabricate using rapid prototyping machine. Then the structure of the body and leg was analyzed in order to find a correct balance and to make sure the servo motor was capable to move the robot. The prototype robot consists of servo motors, Li-Po batteries and Mini Maestro 18 servo controller as the robot's brain. The experimental studies were carried out to get the correct gait algorithm for the robot to be able to move forward and avoid obstacles. Then the robot accuracy and repeatability had been tested. This robot was able to move forward, detect and avoid obstacles without falling and able to move at different surface or different terrain.

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CHAPTER 1

INTRODUCTION

1.1 Background

Robotic technology has increasing rapidly. Mobile robots and artificial intelligence era had colored the robotic field nowadays. A lot of research had been conducted by researchers in university and multinational companies, and even the military, to understand the high mobility and stability of autonomous robot on rough terrain. Mobile robots are very useful in a situation when human are impossible or dangerous to operate. An example of the application using mobile robot is the scanning of buried land mine (T.W.Lee et al. 2002).

Mobile robots consist of two types which are wheel and legged robot. Wheeled robots are more common as they are easier to design and build. The cost of building a wheeled robot is generally low or cheaper. However, the wheeled robots are more suited to application on fairly even terrains as they are less adept when crossing uneven or rough terrains. Legged robots are trickier to design and built as compared to the wheeled robot. This is due to the complexity in designing the actuator and joint. But to build a leg robot, the stability factor and also the coordination of movement of the leg robot must be consider (T.W.Lee et al. 2002).

There are many types of leg robots. Famous types of the robot that many researchers tend to build are bipedal robot, 4-legged robot and 6-legged robot. There are many four legged animals that have ideal mobility traits, thus a large number of four legged robots have been built in an effort to emulate nature's proven techniques. An attractive aspect of such a platform is that they can achieve static stability by planting at least three of their legs on the ground and maintaining their center of mass over this three leg tripod. With such a gait, the robot may stop and hold its position at any instant of its execution without losing stability. These robots are inherently slow and have poor power efficiencies not only from the requirement of static stability, but also owing largely to the many degrees of freedom in their legs. Their legs' complexity, coupled with the large mass of many actuators, limit the robot's behavior and lend the robots to frequent breakdowns.

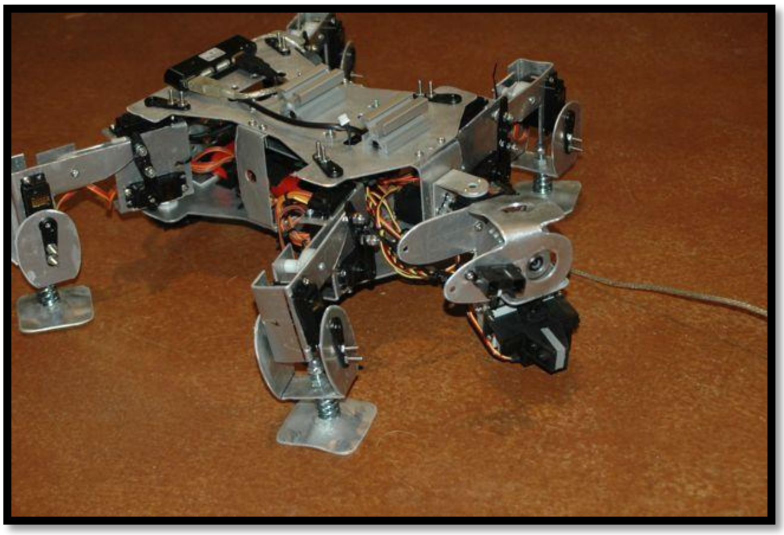

Figure 1.1: Example of 4-legged Robot (Courtesy from Robot Trossen forum, 2010)

Figure 1.2: Example of 6-legged Robot (Courtesy to Curious Inventor Website)

1.2 Problem Statement

Legged robot is tough to build because of stability factor and also the unique pattern of movement. The difficulty of building a legged robot lies in the number of actuators used and also the programming of the robot's microcontroller. Most of researchers tend to build a 6-legged robot since it quite easy to find the right balance for their robot. For a 4-legged robot, when one of the legs is lift to move forward, stability of the whole robot will affected. Therefore, to drive the robot forward, unique kinematics coordination is needed. Good planning and programming will maximize the robot's movement in the aspect of speed, distance and strength. The implementation of four legged actuated by 8 to 12 servomotors is clearly difficult to program and very expensive. Studies on the center of gravity for designed robot need to be carried out to ensure the robot will move properly and not falling (T.W.Lee et al. 2002).

1.3 Objectives

The main objectives in this project are:

i. To design and fabricate a legged robot.
ii. To develop gait for the robot so the robot can move forward.
iii. To develop an algorithm for obstacle avoidance during forward movement

1.4 Scope

The scope on this projects covers on:

iv. Design and analysis of 4-legged walking robot.
v. One leg consists of three servo motors which mean the leg has three degree of freedom (DOF) each. Therefore the total amount of servo motors used in this robot is 12.
vi. The robot controlled by Pololu Maestro 18-servo controller.
vii. Rechargeable Li-Poly battery as power supply.
viii. Structure of the robot's body and leg fabricated using rapid prototyping machine.

CHAPTER 2

LITERATURE REVIEW

2.1 Preview

A robot is a machine that senses, thinks, and acts. Thus, a robot must have sensors, processing ability that emulates some aspects of cognition, and actuators. Sensors are needed to obtain information from the environment (David Wettergree, 1995). Reactive behaviors such as the stretch reflex in humans do not require any deep cognitive ability, but on-board intelligence is necessary if the robot is to perform significant tasks autonomously, and actuation is needed to enable the robot to exert forces upon the environment. Generally, these forces will result in motion of the entire robot or one of its elements such as an arm, a leg, or a wheel.

An extract from the award-winning robotic science fiction book, 'I-robot' by Isaac Asimov:

1. A robot should never harm a human being.

2. A robot should obey a human being, unless this contradicts the first law.

3. A robot should not harm another robot, unless this contradicts the first or second law.

The British Robot Association (BRA) defines robot as:

"A programmable device with a minimum of four degrees of freedom designed to both manipulate and transport parts, tools or specialized manufacturing implements through variable programmed motion for the performance of the specific manufacturing task".

2.2 Example of Legged Robot

Nowadays, there are many types of robots that have been used to simplify human task by using a robot. The current states of the art of robot are divided into several categories which are wheel and legged robot.

2.2.1 Andy Droid Robot

Based on past project by A. Boeing et al.(2004), Andy Droid robot is a bipedal robot which is weight around 1.4kg and 350mm tall. Andy has ten servo motors which mean the robot has ten degree of freedom (DOF) at its legs.For the structures of the robot, all links are made from 3mm thick aluminium flat plate and used to connect the plastic shafts of the servos directly to the next link. These connections result in a substanstial amount of inherent flexibility. Andy can be equipped with a number of sensors, including a color camera, PSDs, inclinometers, gyroscopes and pressure sensors. The pressure sensors are permanently mounted as Andy’s feet, which are constructed from three metal “toes”. Each toe has two strain gauges that are used to produce a voltage in proportion to the applied force.

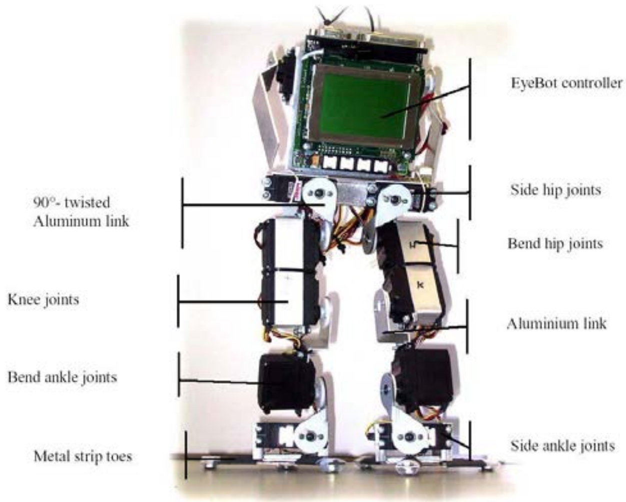

Figure 2.1: Andy Droid Robot

2.2.2 Mechanically Adaptive All Terrain Robot (MAAT-1)

Mark A. Tecson is a researcher and designer robot from Philippine had created MAAT-1 during his study in local university. Figure show the schematic design of MAAT-1. The MAAT – 1 has been designed to walk on all kinds of terrain. Its current design can enable it to scale up to 3 inch high obstacles. It was supposed to be capable of scaling up to 5 inch but due to its shifting center of gravity it slips under its own weight. He has no reliable measurement of the torque of the motor but he believes it can climb vertically if it uses suction cups. The limiting factor is the strength of the shafts and keys. He believes that if the robot use a much lighter aluminum angle bar instead of a flat bar it will be able to do so. It can only walk 20 degrees lateral to a slope the limit is due to the bending of the legs. Using lighter materials will also solve this problem. The robot has a maximum speed of 2 meters per minute; increasing the voltage up to 40 volts will further increase its speed. Finally, the legs are still subject to modifications which will increase its mobility, durability and reliability. (Mark A.Tecson, 2009).

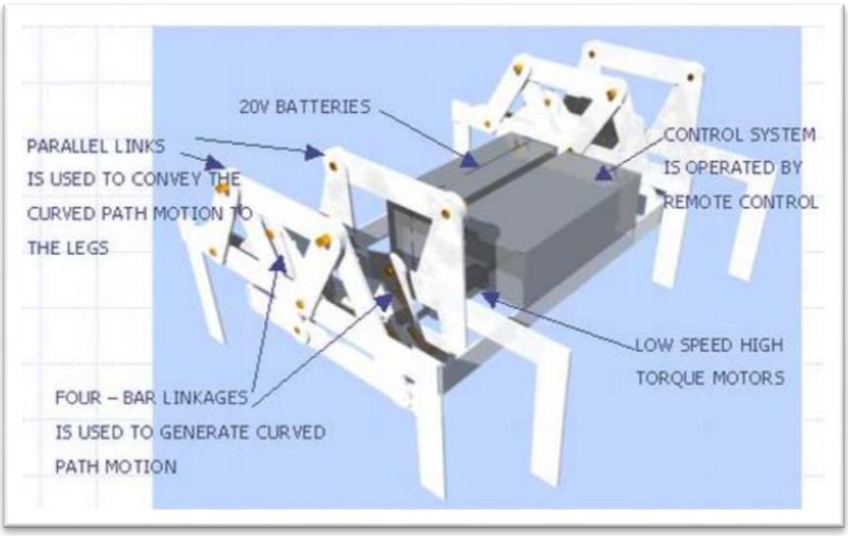

Figure 2.2: MAAT-1

2.2.3 R-hex robot

The RHex robot as in figure, designed by the roboticist Martin Buehler (then a professor at McGill University, in Montreal) and Koditschek's group in 1999, took running robots to the next level This autonomous machine, inspired in part by integrative biologist

Robert Full, of the University of California, Berkeley, has six legs that are attached outside its center of mass. This sprawled configuration grants the robot greater stability as it bounces over natural terrain.

"RHex is the only legged machine that can traverse rugged, broken ground rapidly (at or above the pace of one body length per second)"(Goldman, et.al ,2009)

In a typical jog, the legs support and propel the body by coordinating as two tripods—the two outer legs on one side and the middle leg on the opposite side.

"The hexapod RHex exhibits unprecedented mobility for a legged autonomous robot. Using an open loop feed forward control strategy, the machine runs at speeds exceeding five body lengths per second on even terrain, and negotiates badly broken and unstable surfaces, as well as stairs."(Lin, et al, 2006)

RHex has become the model for a family of robots of Kodlab. Its progeny include, among others, the Aqua robot, which is basically Rhex with flippers for swimming; a two-armed, wall-climbing robot name d Dynoclimber; and SandBot.

Figure 2.3: R-Hex Robot

Kaxuo Morita and Hidenori Ishihara (2005) made comparison between bipedal, 4-legged robot and 6-legged robot in term of motion, weight, stability and speed. The comparison between the robots shown at the table below:

Table 2.1: Comparison between Robots

	2 legged	**4 legged**	**Multi-legged**
Motion	Dynamic	Static and Dynamic	Static
Weight	☼	☾	✕
Stability	✕	☼	☆
Speed	☼	☼	✕
☆ Very good	☼ Good	☾ Fair	✕ Not Good

2.3 Locomotion Technique

The term locomotion actually means ability or the power to move. So, locomotion technique can be concluded as a method for something to move. For legged robot, basically there are two types of locomotion techniques which are static and dynamic locomotion.

2.3.1 Static Locomotion

For static locomotion, because of their center of gravity is always within their ground contact base, robots that use this type of locomotion are always balanced. There are many robots that have been successfully develop using this technique but since it is more similar to wheel movement, it can only retain fewer advantages. Even though legged robot that use this techniques can move and walk at uneven terrain compared to wheel robots but this type of robots are very inefficient as power is put into every movement. However, robots that use static locomotion are a lot easier to control rather than robots that use dynamic locomotion techniques.

Static locomotion has only a kinematics measure of stability and can result in very slow forward movement. The legs of the robots can be considered manipulators so all manipulator's math models can be applied. To solve the direct kinematics problem we used the model of Denavit-Hartenberg. The inverse kinematics is in general more complex than the direct one, due to the fact that there isn't only one solution and in some cases there are an infinity number of solutions. To solve this problem the Jacobian's Math Method is the most used. (Kurt S. Aschenbeck et al).

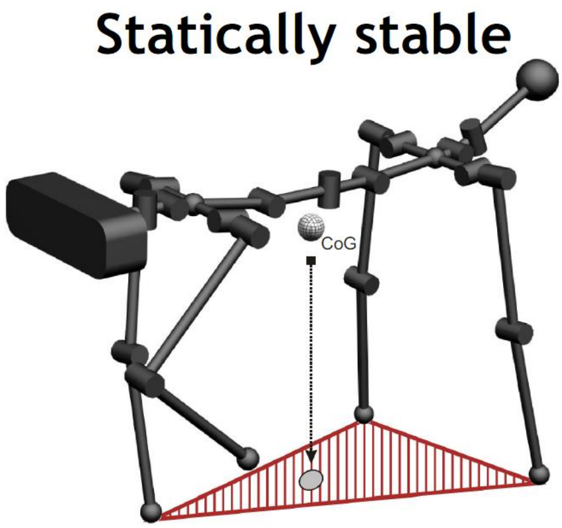

Figure 2.4: Static Locomotion

For static locomotion technique, while lifting one of the legs, the other three legs are supporting the whole body weight. Even if all the joints not moving, the robot will not fall. However, this type of locomotion is slow and not efficient.

2.3.2 Dynamic Locomotion

Dynamic locomotion are unstable and often fall because the robots is not always in balance. Many robots that use dynamic walking are continually “falling” and thus much more energy efficient. So in order to control the robot using this technique, it require much more complex control systems to avoid falling. However, robots that use this technique canachieve many more advantages over wheeled locomotion.

A subset of dynamic walking is called passive dynamic movement. Most dynamic walking systems use active control to move the legs to the correct orientations for walking (hence active dynamic walking). Passive dynamic walking is characterized by a system where "gravity and inertia alone generate the locomotion pattern."Passive dynamic movement can be achieved with maximum efficiency, as the vehicle uses its own forward momentum to propagate its next movement. Very little energy is lost from the system.

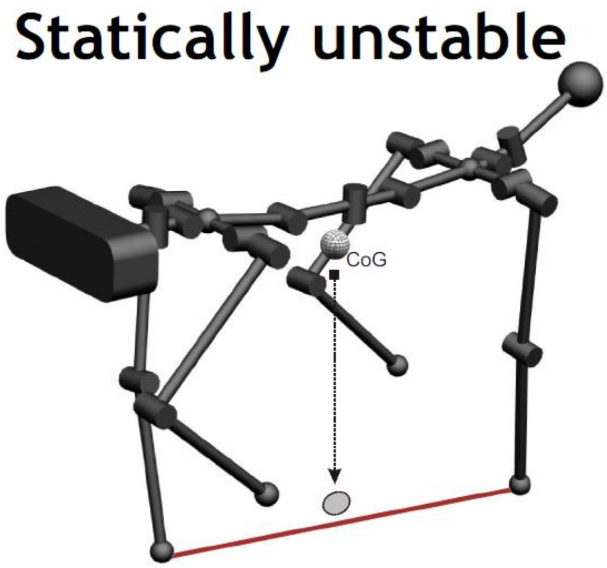

Figure 2.5: Dynamic Locomotion

Dynamic gait requires extremely little control in order for them to walk, and rely largely on the "natural" physics (mostly the effects of gravity) of the walker in order to produce a stable gait. This class of walkers demonstrates the fact that a walk need not have any gait planning, and requires very little energy. Basically, the model for dynamic gait planning is very complex and requires much time and experience in order to produce the motion stability of a quadruped robot.

For this project, a 4-legged robot with 3 DOF was built and this robot able to move forward without falling, able to detect obstacles thus avoid it and also can move on different surfaces.

CHAPTER 3

METHODOLOGY

To develop this 4 legged robot from scratch, there are several numbers of tasks involved. Figure 3.1 shows the general idea about methodology in this project.

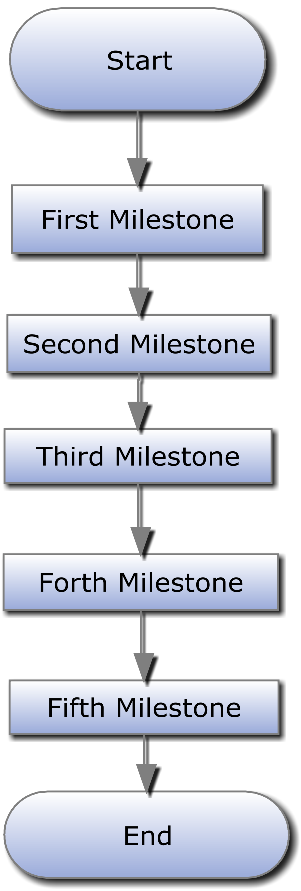

Figure 3.1: Methodology Flowchart

3.1 First Milestone

- Activity 1: Project Objectives
  Discuss with supervisor about the objectives of the project. So it is decided that the objectives of the projects are design and fabricated a legged robot and created gait of the robot so that the robot can move forward without falling.

- Activity 2: Literature Review
  To get general idea on how to build a legged robot, research about past projects and journal have been made. Several papers have been studied and compared.

3.2 Second Milestone

- Activity 3: Design/Sketch the robot
  Design robot leg and body structure using Solid Work software. One legged contains three joints which mean the robot has 3degree of freedom per leg. The robot design must considered basic stability factor in order to prevent the robot from falling if the robot not balances. The sketching of the robot was made part by part. After finished drawing all the part, all sections were then assembled into a complete robot.

- Activity 4: Propose and discuss the design with supervisor
  The design was shown at supervisor to get his opinion on what improvement can be made and also suitability of the design whether the design is possible to fabricated or not. The material selection of the structure of the robot also been discussed.

3.3 Third Milestone

- Activity 5: Selection of component
  Based on the design, torque of the robot was calculated to select suitable servo motors. Electrical component such as battery and servo controller were taken into account in term of suitability, performance and others.

- Activity 6: Fabricated the robot
  Discuss with supervisor to determine which method was suitable to fabricate the body and other part of the robot. So it is decided to fabricate the robot using rapid prototype machine (RPM).

- Activity 7: Integration of electric/electronic and hardware to the robot
  All the parts were implemented on the robot. These parts were placed carefully so that it does not affect whole robot stability. After completely assembled, all the parts were tested in order to verify functionality of each part.

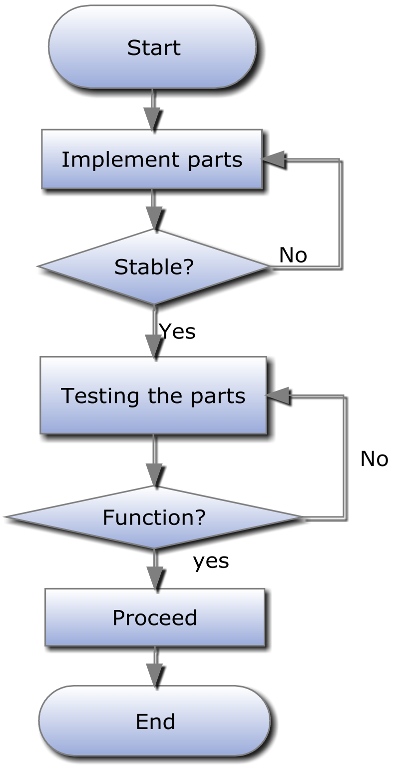

Figure 3.2: Integration Flowchart