CHAPTER ONE
INTRODUCTION

1.1 Overview

The invention of wheels was a turning point in the history of civilization. The main drawback of the wheeled vehicles is that they are unable to move on rough terrain and need paved surface to operate smoothly. Consequently, the mankind continuously destroyed the natural environment for making paved surfaces for wheeled locomotion of carts and vehicles. Approximately half of the Earth’s land surface is inaccessible to either wheeled or tracked vehicle. Legged animals are capable of legged locomotion and as a result they can access any part of the Earth’s land surface without much difficulty. This was a motivation to develop artificial legged locomotion system[1].

1.2 Problem Statement

The reason for exploring the use of legs for locomotion is mobility. There is a need for vehicles that can travel in difficult terrain, where existing vehicles cannot go. Wheels excel on prepared surfaces such as rails and roads, but most places have not yet been paved.

Only about half the earth's landmass is accessible to existing wheeled and tracked vehicles, whereas a much larger fraction can be reached by animals on foot. It should be possible to build legged vehicles that can go to the places that animals are already able to reach.

1.3 Objectives

- To build a robot that has the ability to overcome all type of terrains.
- To program multiple walking gaits to adapt to all types of terrain.
- To test the robot performance in real time.
- To build a robot that is ready for different tasks.

1.4 Methodology

The robot design was inspired by insects' movement. The insects have an amazing ability to adapt to different kinds of terrain. The robot was designed to mimic these movements. The design is then realized and subjected to multiple walking gaits.

1.5 Project Layout

Chapter one represents the introduction that contains background, problem statement, research objectives and research methodology. Chapter two represents robots' construction and applications. This chapter contains introduction, robot construction and purposes of robots. Chapter three represents robots' locomotion and application which contains introduction, types of robots' locomotion, the advantages of legged robot locomotion, stability, speed of a walking robot, hexapods, walking gaits, potential and real uses for walking robots and examples of existing legged robots. Chapter four represents design and implementation of hexapod robot which contains introduction, system components, Arduino Mega 2560, SSC-32U servo controller, HiTEC HS-645MG servomotor, robot platform, power supply circuit, Arduino connection to SSC-32U, Arduino connections to PS2 receiver and hexapod movement. Chapter five consists of conclusion of the research and recommendations.

CHAPTER TWO
ROBOTS CONSTRUCTION AND APPLICATIONS

2.1 Introduction

Robot is an intelligent mechanical creature which can function autonomously. “Intelligent” implies that the robot does not do things in a mindless, repetitive way. The “mechanical creature” portion of the definition is an acknowledgment of the fact that scientific technology uses mechanical building blocks. A robot may use a computer as a building block, equivalent to a nervous system or brain, but the robot is able to interact with its world: move around, change it, etc. “Function autonomously” indicates that the robot can operate under all conditions without requiring recourse to a human operator[2].

2.2 Robot Construction

In man, the muscles are controlled by the brain, which sends electrical signals along the nerves to the muscles. The brain also receives information from man's senses and from other sources. The brain assembles data from the senses, processes that information, and transmits commands resulting in motion of the arm. In robots, the function of the brain is fulfilled by a computer. This computer sends electrical signals which actuate the motors. Like the human brain, it is also capable of receiving information from sensors, processing that information, and deciding where the robot should move. The robot also consist of Power source and body structure[3].

2.2.1 Body structure

Robots can be made out of just about anything. The environment and the mission of the robot often pose severe constraints on the materials that can be used. Many different materials are available for new robot design like metals, plastics, composite materials and wood. Many considerations must be made when choosing the materials strength to weight, machining and formation, cost, availability, tensile strength, compression, flexibility and shock absorption[4].

2.2.2 Robot actuators

An actuator is a component of machines that is responsible for moving or controlling a mechanism or system. An actuator requires a control signal and source of energy. The control signal is relatively low energy and may be electric voltage or current, pneumatic or hydraulic pressure, or even human power. The supplied main energy source may be electric current, hydraulic fluid pressure or pneumatic pressure. When the control signal is received, the actuator responds by converting the energy into mechanical motion[5].

- Air muscles

An air muscle is a simple pneumatic device developed in the 1950s by J. L. McKibben. Like biological muscles, as shown in Figure 2.1 air muscles contract when activated. An interesting fact about air muscles is that they provide a reasonable working copy of biological muscles, so much so that researchers can use air muscles attached to a skeleton at primary biological muscle locations to study biomechanics[5].

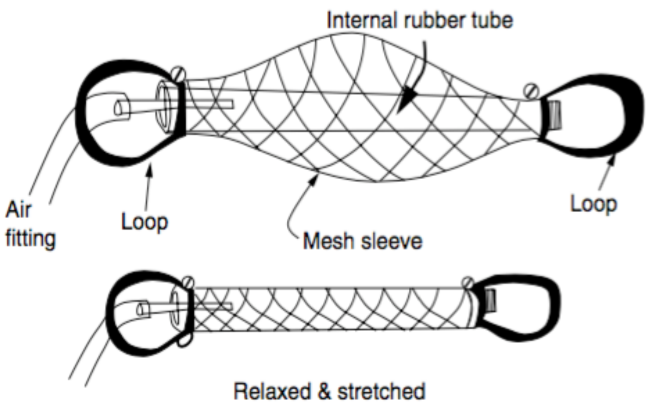

Figure 2.1: Air muscles

- Solenoids

Solenoids are electromechanical devices. As shown in Figure 2.2, a typical solenoid consists of a coil of wire that has a metal plunger through its center. When energized, the coil creates a magnetic field that either pulls or pushes the metal plunger. The metal plunger is mechanically connected to the robotic device that needs movement[5].

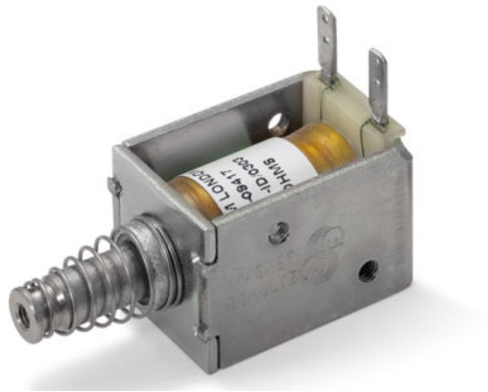

Figure 2.2: Solenoid

- Stepper motors

Stepper motors may be used for locomotion, movement, steering, and positioning control. These motors are used as integrated components in many commercial and industrial computers controlled applications. Stepper motors are unique because they can be controlled using digital circuits. They are capable of precise incremental shaft rotation. This makes stepper motors ideal for rotary or linear positioning. Figure 2.3 illustrates the stepper motor[5].

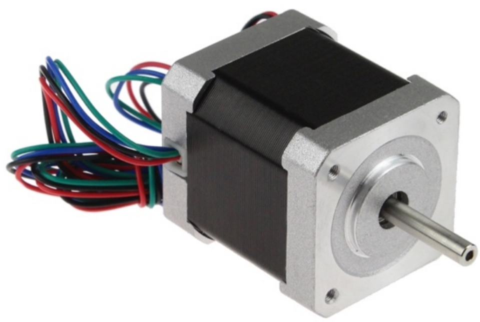

Figure 2.3: Stepper motors

- Servomotor

A servomotor is a closed-loop servomechanism that uses position feedback to control its motion and final position. The input to its control is some signal, either analogue or digital, representing the position commanded for the output shaft. The motor is paired with some type of encoder to provide position and speed feedback. In the simplest case, only the position is measured. The measured position of the output is compared to the command position, the external input to the controller. If the output position differs from that required, an error signal is generated which then causes the motor to rotate in either direction, as needed to bring the output shaft to the appropriate position. As the positions approach, the error signal reduces to zero and the motor stops.

The very simplest servomotors use position only sensing via a potentiometer; the motor always rotates at full speed (or is stopped). This type of servomotor is not widely used in industrial motion control, but it forms the basis of the simple and cheap servos used for radio controlled models. Figure 2.4 shows a sample of servo motors[5].

Figure 2.4: HiTEC servomotor

- DC motors

DC hobby motors can be applied to movement and locomotion. Specifications of most DC motors show high revolutions per minute (rpm) and low torque. Robotics need low rpm and high torque. Gearboxes can be attached to motors to increase their torque while reducing the rpm. The gearbox usually specifies a ratio that describes the rpm in to the rpm out. For instance, a DC motor with an rpm of 8000 is connected to a 1000:1 gearbox. The output rpm 8000 rpm/1000 8 rpm. The torque of the motor is substantially increased. It could be estimated that the torque will increase by the same value the rpm decreased. In reality, no conversion is 100 percent efficient; there always will be efficiency losses. Some DC motors as shown in Figure 2.5, called gearhead motors, are built with a gearbox attached[5].

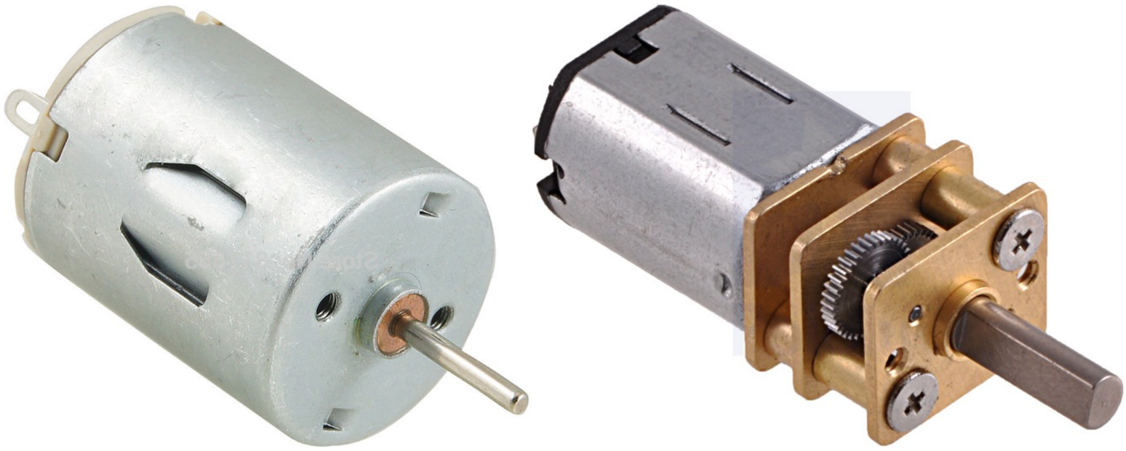

Figure 2.5: DC motor and DC gearhead motor

2.2.3 Robots sensory

There are a wide variety of sensors used in mobile robots. Some sensors are used to measure simple values like the internal temperature of a robot's electronics or the rotational speed of the motors. Other, more sophisticated sensors can be used to acquire information about the robot's environment or even to directly measure a robot's global position. Because a mobile robot moves around, it will frequently encounter unforeseen environmental characteristics, and therefore such sensing is particularly critical.

Sensors are classified using two important functional axes: proprioceptive/exteroceptive and passive/active. Proprioceptive sensors measure values internal to the system (robot); for example, motor speed, wheel load, robot arm joint angles and battery voltage. Exteroceptive sensors acquire information from the robot's environment; for example, distance measurements, light intensity, sound amplitude. Hence exteroceptive sensor measurements are interpreted by the robot in order to extract meaningful environmental features.

Passive sensors measure ambient environmental energy entering the sensor. Examples of passive sensors include temperature probes, microphones, and cameras. Active sensors emit energy into the environment, then measure the environmental reaction. Because active sensors can manage more controlled interactions with the environment, they often achieve superior performance. However, active sensing introduces several risks: the outbound energy may affect the very characteristics that the sensor is attempting to measure. Furthermore, an active sensor may suffer from interference between its signal and those beyond its control. For example, signals emitted by other nearby robots, or similar sensors on the same robot, may influence the resulting measurements. Examples of active sensors include wheel quadrature encoders, ultrasonic sensors, and laser range finders[6].

2.2.4 Power supply system

The power systems of a robot are central to its health, reliability, and effectiveness. The power systems include all the elements of the robot that work together to generate, use, and conserve power. There are many characteristics to be considered when selecting power source: Weight versus energy, capacity, peak currents, life time, operating temperature ranges, recharging, cost, safety, metering, and availability[4].

2.2.5 Brain system

The computer is the robot "brain." Like the human brain, the computer sends motion commands to the motors, controls their rate of movement, and actuates the end effector. It is therefore referred to as the "controller". The basic operating program is stored in the controller memory. On receipt of an instruction from the human operator to start an activity, the program is retrieved from the memory and processed by the central processing unit and, as a result, the appropriate signals are sent to the output unit of the computer. These signals are fed to the motor drivers, and as a result, the motors will execute movements whose extent and rate comply with those dictated by the program stored in the memory. The robot will be able to repeat the program a great number of times, with a high degree of accuracy. In fact, the movements of the robot arm will be almost identical each time the program is repeated[3].

2.3 Purposes of Robots

Robots are mainly built to perform tasks that is considered dangerous and/or complicated. When tasks have threats for safety, demand high level of accuracy and need to be performed in a short period of time. It is more convenient to perform these tasks by robots instead of humans[5].

2.3.1 Exploration

NASA routinely sends unmanned robotic explorers where it is impossible to send human explorers. Because sending robots instead of humans is much cheaper. Humans require an enormous support system to travel into space: breathable atmosphere, food, heat, and living quarters. And, quite frankly, most humans would want to live through the experience and return to Earth in their lifetime. Explorer spacecraft travel through the solar system where their electronic eyes transmit back to Earth fascinating pictures of the planets and their moons. The Viking probes sent to Mars looked for life and sent back pictures of the Martian landscape. NASA is developing planetary rovers, space probes, spider-legged walking explorers, and underwater rovers. NASA has the most advanced tele robotic program in the world, operating under the Office of Space Access and Technology (OSAT)[5].

2.3.2 Industrial robots

Robots are indispensable in many manufacturing industries. For instance, robot welders are commonly used in automobile manufacturing. Other robots are equipped with spray painters and paint components. The semiconductor industry uses robots to solder (spot weld) micro wires to semiconductor chips. Other robots called “pick and place” insert Integrated Circuits (ICs) onto printed circuit boards, a process known as “stuffing the board.” Robots are ideally suited for performing repetitive tasks. Robots are faster and cheaper than human laborers and do not become bored. This is one reason manufactured goods are available at low cost. Robots improve the quality and profit margin (competitiveness) of manufacturing companies[5].

2.3.3 Design and prototyping

Some robots are useful for more than repetitive work. Manufacturing companies commonly use Computer-Aided Design (CAD), Computer Aided Manufacturing (CAM), and Computer Numerical Control (CNC) machines to produce designs, manufacture components, and assemble machines. These technologies allow an engineer to design a component using CAD and quickly manufacture the design of the board using computer controlled equipment. Computers assist in the entire process from design to production[5].

2.3.4 Fire-fighting robots

Fire-fighting robots are so attractive that there is an annual national fire-fighting robot competition open to all robotics. The fire-fighting home robot contest is sponsored by Trinity College, the Connecticut Robotics Society, and a number of corporations. Typically, a fire fighting robot becomes active in response to the tone from a home fire alarm. During the competitions, its job is to navigate through a mock house and locate and extinguish the fire[5].

2.3.5 Maintenance

Maintenance robots specially designed to travel through pipes, sewers, air conditioning ducts, and other systems can assist in assessment and repair. A video camera mounted on the robot can transmit video pictures back to an inspecting technician. Where there is damage, the technician can use the robot to facilitate small repairs quickly and efficiently[5].

2.3.6 War robots

One of the first applications of robots is war. And if forced into a war, we can use robots to help us win, and win fast. Robots are becoming increasingly more important in modern warfare. Drone aircraft can track enemy movements and keep the enemy under surveillance Smart bombs and cruise missiles are other examples of “smart” weaponry[5].

2.3.7 Civilian uses

Robotic drones and lighter-than-air aircraft (blimps) developed by the military could be put to civilian use monitoring high-crime neighbor-hoods and traffic conditions. Because the aircraft do not have any human occupants, they can be made much smaller. Robotic blimps will be used more often than robotic aircraft because they will be safer to operate, they could also be used to monitor traffic, apartment buildings, and street activity in high crime areas[5].

2.3.8 Domestic

Applications for domestic robots are numerous. Robots Could be used to clean windows and floors, report and/or do minor home repairs, cook, clean the upholstery and wash clothes. This raises a debatable point. Are current labor-saving devices like dishwashers, ovens, washing machines, and clothes dryers should be classified as robots or machines? At the point that they autonomously gather the materials needed to perform their functions, like getting food from the refrigerator for cooking or picking up clothes around the house for washing, they will have passed from the machine stage and become robots[5].

2.4 Control systems

Automatic control is essential in any field of engineering and science. Automatic control is an important and integral part of space-vehicle systems, robotic systems, modern manufacturing systems, and any industrial operations involving control of temperature, pressure, humidity, flow, etc. It is desirable that most engineers and scientists are familiar with theory and practice of automatic control[7].

There are two types of control system: open loop and closed loop control systems. Open loop control system is a system in which the output has no effect on the control action. For a given input the system produces a certain output. If there are any disturbances, the output changes and there is no adjustment of the input to bring back the output to the original value. A perfect calibration is required to get good accuracy and the system should be free from any external disturbances. No measurements are made at the output.

Closed loop control systems also known as feedback control systems are systems which maintain a prescribed relationship between the controlled variable and the reference input, and uses the difference between them as a signal to activate the control. The output or the controlled variable is measured and compared with the reference input and an error signal is generated. This is the activating signal to the controller which, by its action, tries to reduce the error. Thus the controlled variable is continuously fedback and compared with the input signal. If the error is reduced to zero, the output is the desired output and is equal to the reference input signal[8].

2.5 Control techniques

There are two main control techniques: centralized control and Distributed Control. In centralized control, all the computation required for the generation of control input vector is performed in a single computer. Therefore, the computing power, computing speed, and hardware resources required by the central computer may be quite huge and economically impracticable.

In distributed control, instead of a central controller, there are individual controllers for controlling the motion of each part of a robot. Distributed control may be implemented in a single high-end computer or on distributed computing platform consisting of different smaller computers connected in network. There may be a supervisory controller to coordinate the functioning of the individual controllers or the individual controllers may cooperate with each other through some communication network. Nowadays, distributed control is becoming popular for the drastic reduction in the cost of the embedded computers and equipments needed for establishing communication network[1].

CHAPTER THREE
ROBOTS LOCOMOTION AND APPLICATION

3.1 Introduction

Nature is made up of great creatures and human beings have always been curious, interested or excited about their behavior and have tried to understand, enjoy or imitate them. Emulating live creature performances is an attractive idea but extremely difficult to accomplish. Generally, one has to settle for building some simple apparatus that can imitate only minute aspects of what one ordinarily senses from the surroundings: creatures that can see, smell, manipulate and walk[9].

3.2 Types of Robots Locomotion

Various types of locomotion mechanisms can be imagined. However, they can be divided broadly into four categories in terms of their movement in environments where the ground is solid[1].

3.2.1 Wheeled robots locomotion

The wheeled-type mechanism has characteristic advantages over other types of locomotion mechanisms, such as the fact that it allows for stable movement at high speeds, exhibits a high level of energy efficiency, is simple and easy to control, and can incorporate a whole wealth of automobile technology that has already been built. A limitation of the wheeled-type mechanism is that it is confined to moving on flat road surfaces; however, when certain amounts of level differences or steps exist, travel can be enabled by adding certain degrees of freedom to the wheeled mechanism[1].

3.2.2 Crawler robots locomotion

Crawler robots are also known as caterpillar robots. The most significant feature of a crawler robot is that its multiple wheels do not make direct contact with the road surface because they are wrapped in circular caterpillar tracks. It can function in various terrain conditions because the caterpillar tracks mitigate the effects of unevenness of road surfaces. Crawler robots exert less pressure on the ground surface than wheeled robots because they have a large area of contact with the ground; in addition, crawler robots have strong surface grip. Other advantages are that they are highly capable of traveling over road surfaces and can, to a certain degree, traverse uneven ground and surmount level differences and ditches. However, because there is high resistance to track motion, owing to a large track–ground contact patch, this type of robot would damage floor surfaces if it has metal tracks. Furthermore, this type of robot is inferior to the wheeled robot in terms of energy efficiency. Both abovementioned types of locomotion mechanisms necessitate that there be continuous contact between the robot and the ground surface[1].

3.2.3 Legged robots locomotion

The legged robot has the highest level of adaptability to terrain, in that it can surmount level differences, step over ditches, and go up and down stairs. These characteristics give the legged robot an advantage over the wheeled and crawler robots in terms of movement in complex environments[6].

3.2.4 Special types locomotion

There are special types of robots such as trunk-type robots (snake robots) and hybrids that are composed of a combination of the abovementioned mechanisms[1].

3.3 The Advantages of Legged Robot Locomotion

Apart from the interest in creating machines to imitate natural motion, some researchers envisaged the potential advantages of legged systems over traditional vehicles, based on wheels or tracks, for use in industry or services. Some of these advantages are discussed below[9].

3.3.1 Mobility

Legged robots exhibit better mobility than wheeled robots because they are intrinsically omni-directional systems. That is, a legged robot can change direction independently of the direction of the main body axis, just by changing its footholds. On the other hand, a conventional wheeled robot would have to do some maneuvering to be able to change direction. Likewise, a legged robot can move and orientate its body while maintaining the footholds just by changing its leg extension. This feature provides the robot's body with six additional Degrees Of Freedom (DOF). Figure 3.1 illustrates these features that require legs based on 3-DOF mechanisms. It is worth noting that a wheeled robot that has wheels with traction and directional motors can substantially improve its directionality, but with the added cost of making the system more complex. There are also robots that use special wheels, such as the Ilonator wheel, which provide omni-directionality, but only on flat surfaces[2].

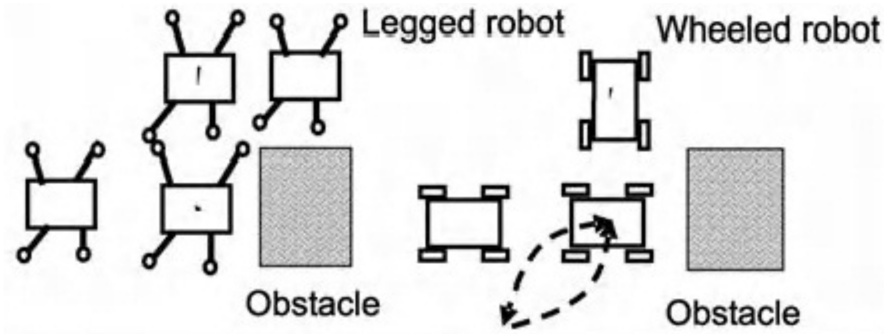

Figure 3.1: Mobility

3.3.2 Overcoming obstacles

A legged robot can overcome obstacles that are at a lower level than the maximum ground clearance, just by stepping on them. On the other hand, a wheeled robot can only overcome obstacles with heights of up to half of the wheel radius. The tracks consist of a virtual wheel with a radius of half the track length; so a tracked vehicle can surmount higher obstacles than a wheeled one, but using large body motions. Figure 3.2 illustrates overcoming obstacles[9].

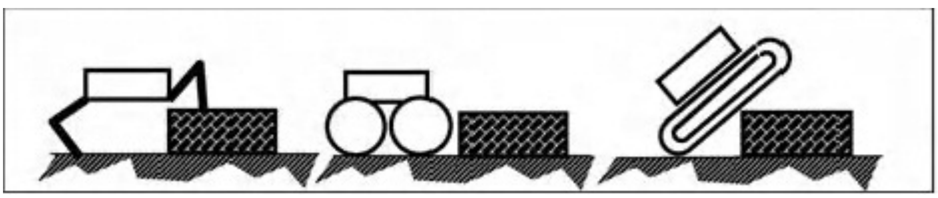

Figure 3.2: Overcoming an obstacle

3.3.3 Active suspension

A legged robot provides intrinsically active suspension by adapting the leg lengths to terrain irregularities. In this manner, a legged robot can cover highly irregular terrain with the body levelled. Thus, legged systems provide riders with smooth and comfortable motion. In contrast, the body of a wheeled robot is always parallel to the terrain and adopts similar tilts to the ground as shown in Figure 3.32.4[9].

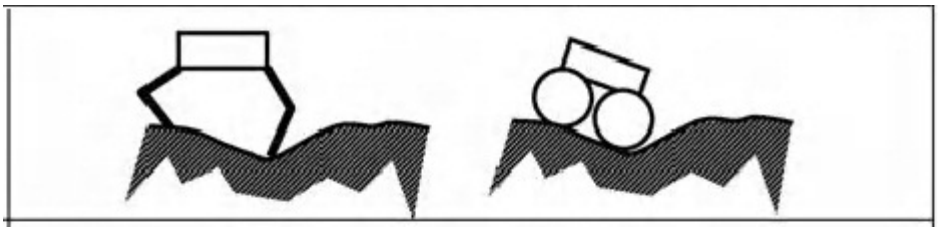

Figure 3.3: Active suspension

3.3.4 Energy efficiency

Hutchinson suggested in 1940 that the efficiency of very heavy legged vehicles might be better than that of wheeled vehicles. Later, Bekker proved through experiments that Hutchinson was correct in asserting that legged systems under very irregular terrain conditions are more efficient than wheeled or tracked systems[9].

3.3.5 Slippage and jamming

Wheels tend to sink in soft terrain, which makes it difficult for wheeled vehicles to move. However, if one leg is placed vertically on the ground it only compacts soft ground in the same direction. Leg lifting is performed vertically, without interfering the ground. When the body is propelled, feet rotate around their joints; therefore, legs do not interact with the ground and do not cause any jamming problems. The same is true for vehicle slippage when propelling forward/backward. Figure 3.4 shows the motion in soft terrain[9].

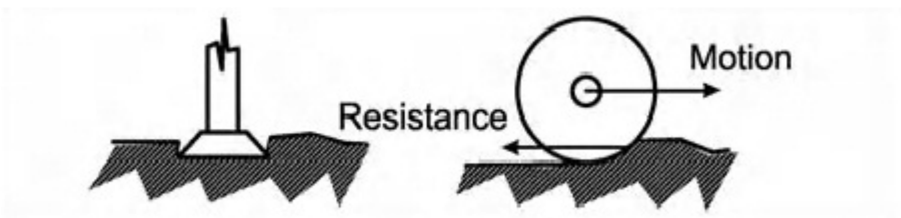

Figure 3.4: Motion in soft terrain

3.3.6 Natural terrain

Wheeled vehicles require very expensive, continuous paved surfaces to move efficiently. In principle, legged systems do not require prepared terrain, like wheeled vehicles do, and they can move on sandy, muddy, stiff, and soft terrains with similar efficiency, as shown in Figure 3.5. Another advantage of legged systems is that they do not need continuous terrain to move[9].

Figure 3.5: Motion in unpaved surfaces

3.3.7 Environmental damage

Legged vehicles require discrete contact points with the ground, while wheeled or tracked vehicles use a couple of continuous paths along the ground. Therefore, legged robots touch the ground less than traditional vehicles do as shown in Figure 3.6, thereby causing less environmental damage[9].

Figure 3.6: Environmental effect

3.3.8 Average speed

Traditional vehicles can move at high speeds on prepared surfaces. However, when the terrain is more uneven, the vehicle speed decreases rapidly. Legged systems (mammals, for instance) are able to adapt quite well to terrain irregularities, and they are able to maintain similar average speed over very different kinds of terrain. Figure 3.7 shows motion in unprepared surfaces[9].

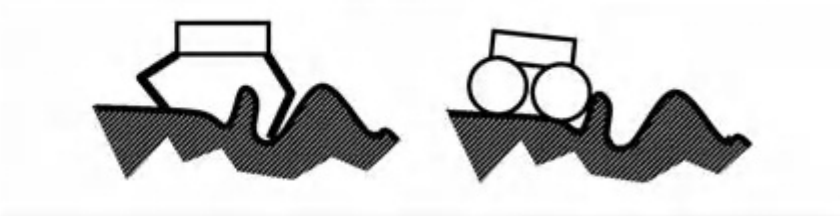

Figure 3.7: Motion in unprepared surfaces

3.4 Stability

Stability is a major concern in walking robots, because they tend to be tall and top heavy. Some types of leg geometries and walking gaits prevent the robot from falling over no matter where in the gait the robot stops. They are statically stable [10]. Research on walking-robot stability began in the mid-1960s, when McGhee and Frank (1968) first defined the static stability of an ideal walking robot. Following their definition, an ideal robot is statically stable if the horizontal projection of its Center Of Gravity (COG) lies inside the support pattern. The ideal robot is supposed to have massless legs, and system dynamics are assumed to be absent. The idea of static stability was inspired by insects. These arthropods feature an exoskeleton composed of a segmented body and jointed appendages. Insects use their massless legs to simultaneously support their body during walking and provide propulsion. Hence, in order to move the body while maintaining balance, their sequence of steps is arranged to ensure static stability.

The first generation of walking machines emulated this principle of locomotion. Early walking robots were huge mechanisms featuring heavy limbs too difficult to control. The adoption of statically stable gaits could simplify their control. However, during the motion of the heavy limbs and body some inertial effects and other dynamic components (friction, elasticity, etc.) were found to arise, restricting the robot's movements to low, constant velocities. Thus, the adoption of static stability facilitated motion control at the price of speed[9].

3.5 Speed of a Walking Robot

Speed is also an extremely important factor for robot locomotion. It may be the main reason for the poor state of legged robots in industry and services. Waldron and his colleagues demonstrated that the speed of a legged robot, V. Performing a wave gait depends on the leg stroke, R, the leg return time, τ, and the duty factor, β, which directly depends on the number of legs.

$$V = \frac{R}{\tau}\left(\frac{1-\beta}{\beta}\right) \tag{3.1}$$

The minimum duty factor of an n-legged robot is β_n =3/n. That is, β_4=3/4, β_6=3/6, and β_8=3/8, respectively. Therefore, the robot speed is determined by V_4 =0.333(R/τ), V_6 =R/τ and V_8 =1.67(R/τ). Hexapods can clearly achieve higher speeds than quadrupeds, and octopods are even faster. More legs mean a more complex mechanism and larger electronic and sensor system. Thus, the likelihood of failure is increased and therefore the likelihood of mission success is decreased[9].

3.6 Hexapods

Hexapod robots belong to the group of joint leg walking robots having six legs where the legs are consisting of multiple servo joints. The legs of the robot are usually symmetrically distributed in two different groups spatially located on the two opposite sides of the robot's body. The design of hexapod robots is often inspired by locomotion systems seen in insects like cockroaches, stick insects, and the like.

In comparison with the four legged walking robots or quadruped robots, hexapod robots have intrinsically more redundancy due to the higher number of the legs and thus can be theoretically more flexible over uneven terrain. Hexapod robots differ from robots that have “native” spider-like biomimetic design having eight legs distributed on the two sides of the robot’s body. Although the eight legged robots may have higher degree of redundancy and perhaps provide better agility for the robot over rugged terrain, they also need more energy for their functioning, which in turn affects the size and mobility of the robot[11].

3.7 Hexapods Walking Gaits

There are several walking gaits, which might be generated by insects have been observed: Wave gait, Ripple gait, and Tripod gait. Figure 3.8 illustrates these gaites [11]. A gait of any legged system is the corporate motion of the legs coordinated with the motion of the body in order to move it from one place to another in such a manner that stability is always maintained. The condition for static stability of the system is that the vertical projection of its center of gravity folds inside the support pattern[1]. The legs of the robots alternate between swing phase and stance phase. Stance phase of a leg is the period in which the leg is on the ground and the swing phase of a leg is period in which the leg is in the air[1].

3.7.1 Wave gait

Wave gait is the slowest gait where one leg is in swing phase while the other legs are in the stance phase. This gait is characterized as the most stable one, since all the other legs are on the ground and supporting the robot's body. However, this is also the slowest walking gait, since only one leg is in the air at a time, while the others are on the ground [11].

3.7.2 Ripple gait

In Ripple gait, there are two independent gaits from both sides of the body. The stance phase is usually double the swing phase and the opposite legs are 180 degrees out of phase [11].

3.7.3 Tripod gait

The research on walking gaits of six legged insects, for example a cockroach, has indicated that the Tripod walking gait provides the six-legged insect with the fastest speed over the ground. Tripod walking gait is a gait by which at any moment of time three of the robot's legs are in the swing phase, while the other three legs are in the stance phase. The three legs on the ground provide the insect with static and dynamic stability while walking[11].

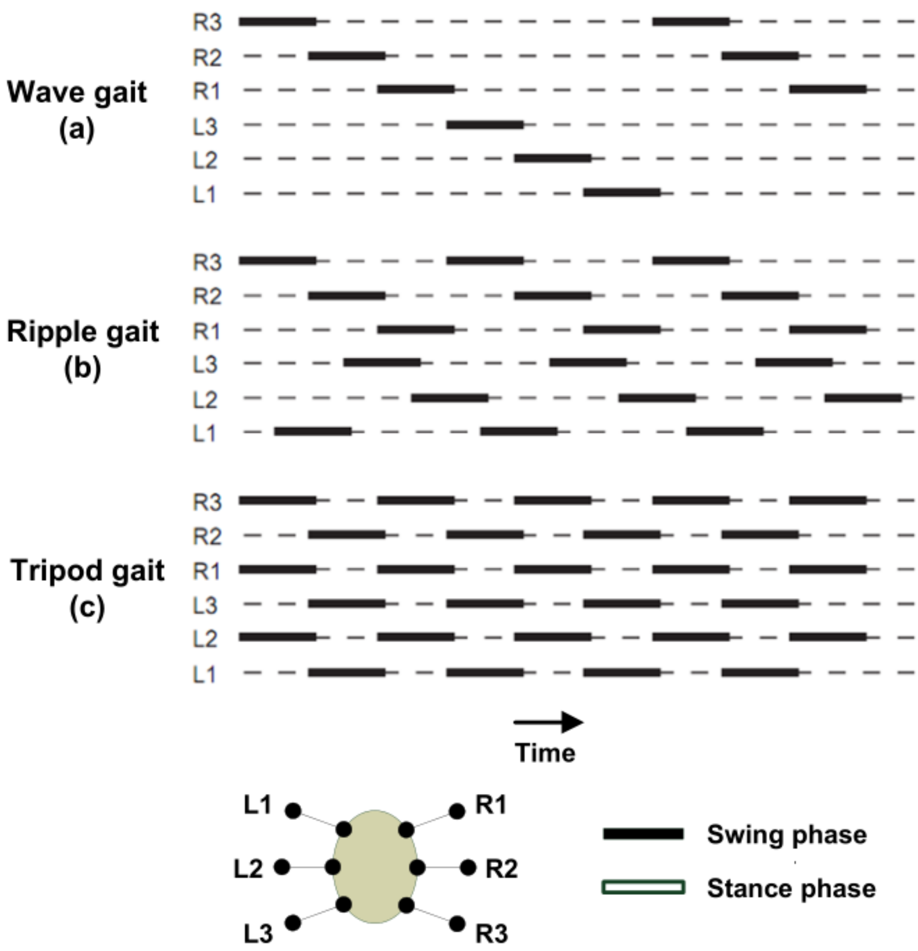

Figure 3.8: Hexapod walking gaits

3.8 Potential and Real Uses for Walking Robots

Potential uses for walking robots are based on their advantages over wheeled or tracked vehicles for each specific task. Thus, there are some advantages to using legged robots in traditional vehicle applications, such as military missions, inspection of complex or dangerous scenarios, terrestrial, underwater and space exploration, forestry and agricultural tasks, construction activity, and civil projects, for example. Nevertheless, legged robots can also be used as the perfect experimental testbed for studying the behavior of live animals and for testing Artificial-Intelligence (AI) techniques. Finally, legged robots are also used for social activities, including humanitarian assistance in de-mining and disabling bombs[9].

3.8.1 Military applications

Military transport activities require vehicles that are highly efficient on a broad variety of terrain: irregular, inclined, sandy, muddy, paved, etc. In addition, these vehicles must drive over obstacles such as ditches and anti-tank obstacles. legged vehicles are theoretically capable of walking on this type of terrain and obstacles. Thus, there have been attempts to build legged robots with the support of military institutions[9].

3.8.2 Inspection of nuclear power plants

Another possible use for walking robots is the operation and inspection of nuclear power plants. Nuclear plants have areas that are not equipped for wheeled robots (with pipes on the floor, stairs, etc.), that are easily handled by walking robots[9].

3.8.3 Land, submarine and planetary exploration

The ability of legged robots to adapt to different unknown types of terrain, to overcome obstacles, and to use discrete contact points with the ground, makes them perfect candidates for planetary, land and submarine exploration. Some robots have already been specifically built and tested for these uses[9].

3.8.4 Forestry and agricultural tasks

Walking robots can be very useful in the forest, where it is necessary to move machinery or to chop down tree trunks. In this case, the trunks themselves are natural obstacles. Forests are normally sloped or mountainous. A legged robot can level its body, maintaining stability in this type of terrain. Wheeled robots do not have this ability, and they are prone to rolling on this type of terrain. Plustech Oy, a Finish company that is part of John Deere’s Construction and Forestry Division, has developed a machine called the Timberjack for this type of terrain. The Timberjack is a six-legged robot that resembles an agricultural tractor and carries a manipulator to handle tools or grippers. As shown in Figure 3.9, a similar machine would be very useful for agricultural tasks because it could move by simply using discrete contact points and therefore protecting the crops. On the other hand, an analogous wheeled or tracked vehicle would destroy crops along the wheel paths[9].

Figure 3.9: Timberjack hexapod robot

3.8.5 Construction

Construction is an important task for legged robots, especially for activities related to motion in complex environments. One such environment is that of ship building processes for connecting consecutive blocks at the dry-dock by welding together all of the longitudinal reinforcements and all of the vertical bulkheads[9].

3.8.6 Help for disabled people

The lives of handicapped people would surely be improved by legged wheelchairs. Although there is great societal interest in eliminating barriers for handicapped people, it is difficult to overcome the obstacles of buildings with stairs and the uneven terrain of the countryside. Legged robots could move the handicapped over these obstacles[9].

3.8.7 Support for AI techniques

Significant Artificial Intelligence (AI) testing was conducted on robot manipulators some years ago, but mobile robots were extremely important to the development of these techniques. Mobility allows us to learn and decide.

Naturally a rover learns from more situations than a manipulator. Legged robots have the same major problems as rovers, as well as problems related to gait generation. Thus, many AI researchers have used legged robots to test their theories and methods[9].

3.8.8 Study of living creatures

Over the last two decades, zoologists and biologists have conducted a great deal of research for understanding the biological aspect of walking. Certain researchers have concluded that a few simple rules are enough for defining a sequence of stable motions These rules can be verified in simulations, but implementing them in real robots that emulate the behavior of insects is of paramount importance for these researchers. Thus, a few robots whose legs imitate the leg structure of a stick insect, have been built for this purpose. It is also possible to find some robots that attempt to emulate extinct species. This has become very important for educational and entertainment purposes[9].

3.8.9 Humanitarian de-mining

Detection and removal of antipersonnel land-mines is an important concern worldwide. An enormous number of land-mines have been deployed over the last 20 years, and de-mining will take several more decades, even if no more mines are deployed in the future. An adequate mine-clearance rate can only be achieved by using new technology, such as improved sensors, efficient manipulators and mobile robots. Any potential vehicle can theoretically carry sensors over a mine-field; however, legged robots provide some potential advantages[9].

3.8.10 Cargo application

Hydraulically actuated hexapod robots can also be applied for cargo applications. The commercial shipment of goods is becoming costly for the involvement of human labor and in many countries human labor is becoming expensive because of falling population. Therefore, hydraulically actuated hexapod robot can offer an economically viable solution for cargo industry. It can perform the loading and unloading of heavy goods quite fast and can easily be programmed for such repetitive operation. It can be tele operated for more complex operation[1].

3.8.11 Underwater operation

hexapod robot can also be applied for underwater operation with proper design. The mechanical design of the robot may need minor modification as the water pressure and buoyancy will affect the motion of the robot. Underwater operation like seafloor exploration, underwater construction, and undersea cable laying require skilled workers and special techniques so that their life remains safe and secure. Hydraulically actuated hexapod robot can be applied to perform these jobs without worrying about the safety and security of the life of the operating personnel[1].

3.9 Examples of Existing Legged Robots

Various types of legged robots exist. However, they can be divided into four main categories in term of their number of legs.

3.9.1 One-leg hopper

The 3D one-leg hopper was built for experiments on active balance and dynamics in legged locomotion. As shown in Figure 3.10, The machine has a leg that changes length, a body that carries sensors and interface electronics, and an actuated 2-axis hip. The hip is powered by hydraulics and the leg by compressed air. The machine has an overall height of 1.10 m and a mass of 17.3 kg.

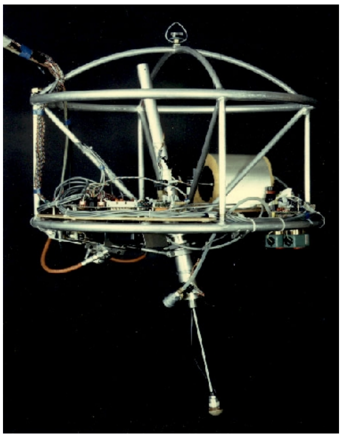

Figure 3.10: 3D one-leg hopper

3.9.2 Two legged robots

ASIMO, an acronym for Advanced Step in Innovative Mobility, is a humanoid robot designed and developed by Honda. Introduced on 21 October 2000, ASIMO was designed to be a multi-functional mobile assistant. With aspirations of helping those who lack full mobility. ASIMO has a walking speed of 2.7 kilometers per hour and a running speed of 6 kilometers per hour. Its movements are determined by floor reaction control and target Zero Moment Point control, which enables the robot to keep a firm stance and maintain position. Figure 3.11 shows ASIMO.

Figure 3.11: ASIMO

3.9.3 Four legged (quadruped) robots

- Another famous design is AIBO which is an iconic series of robotic pets designed and manufactured by Sony. AIBOs were marketed for domestic use as "Entertainment Robots". They were also widely adopted by universities for educational purposes (e.g. Robocup) and research into robotics and human-robot interaction. Figure 3.12 shows AIBO.

Figure 3.12: AIBO

- There are several designs for quadruped robots. One of the most impressive examples is the BigDog robot. BigDog is a dynamically stable quadruped robot created in 2005 by Boston Dynamics with Foster-Miller, the NASA Jet Propulsion Laboratory, and the Harvard University Concord Field Station. It was funded by DARPA, but the project was shelved after the BigDog was deemed too loud for combat. Figure 3.13 shows the BigDog.

Figure 3.13: BigDog

3.9.4 The six legged (hexapod) robots

- RHex is an autonomous robot design based on hexapod with compliant legs and one actuator per leg. A number of US universities have participated, Versions have shown good mobility over a wide range of terrain types at speeds exceeding five body lengths per second (2.7 m/s), climbed slopes exceeding 45 degrees, swims, and climbs stairs. Figure 3.14 shows the RHex.

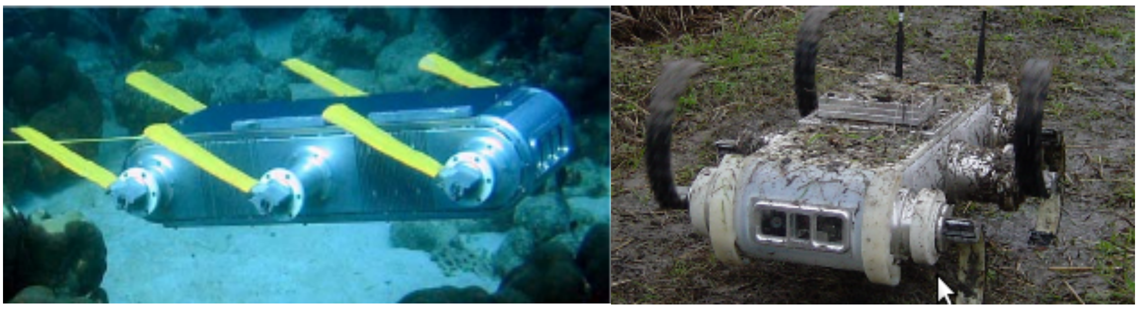

Figure 3.14: RHex

- The All-Terrain Hex-Limbed Extra-Terrestrial Explorer (ATHLETE) vehicle concept is based on six 6 DoF limbs, each with a 1 DoF wheel attached. ATHLETE uses its wheels for efficient driving over stable, gently rolling terrain. Wheels can be locked and used as feet to walk out of excessively soft, obstacle laden, steep, or otherwise extreme terrain. Figure 3.15 shows ATHLETE.

Figure 3.15: ATHLETE

- A group at Chiba University, Japan, have worked on development of six-legged land mine detection and removal robot for humanitarian demining. They developed a series of robots called COMET (Chiba University Operating Mine Detection Electronics Tools). In this series COMET-I, COMET-II, COMET-III, and COMET-IV have already been developed and successfully tested in various terrain conditions with various robust and intelligent control algorithms for its effectiveness in locomotion. Figure 3.16 shows COMET-IV.

Figure 3.16: COMET-IV

3.10 Arduino Mega 2560

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack and a reset button. The ATmega2560 has 256 KB of flash memory for storing code (of which 8 KB is used for the bootloader), 8 KB of SRAM and 4 KB of EEPROM.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may become unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts. Figure 3.17 shows the Arduino Mega 2560.

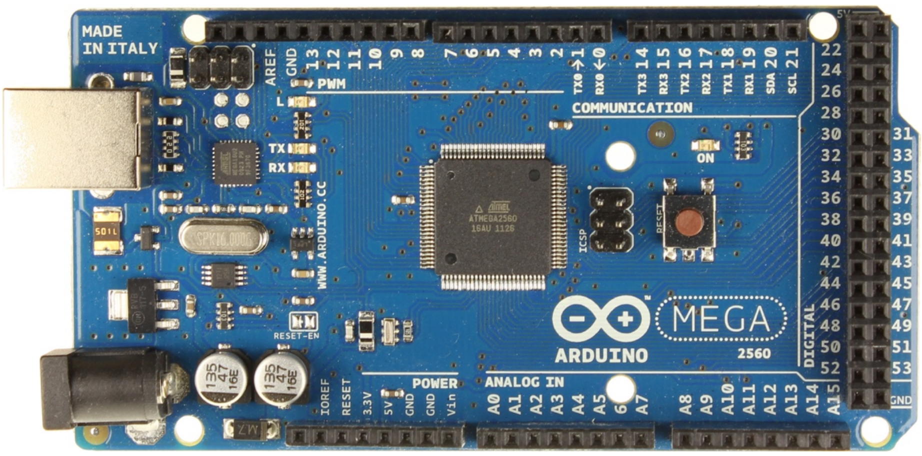

Figure 3.17: Arduino Mega 2560

3.11 SSC-32U Servo Controller

The SSC-32U USB servo controller is a dedicated RC servo controller with some big features. It has high resolution (1µs) for accurate positioning, and extremely smooth moves. The range is 0.50ms to 2.50ms for a range of about 180° (for most R/C servos). There are also 8 separate analog input pins which allow you to query sensor values. There are three terminal blocks for powering options. The board has pins for communicating with other boards such as microcontrollers (like Arduino).

The motion control can be immediate response, speed controlled, timed motion, or a combination. A unique "group move" allows any combination of servos to begin and end motion at the same time, even if the servos have to move different distances. This is a very powerful feature for creating complex walking gaits for multi-servo walking robots. The servo's position or movement can be queried to provide feedback to the host computer. Figure 3.18 shows SSC-32U Servo controller.

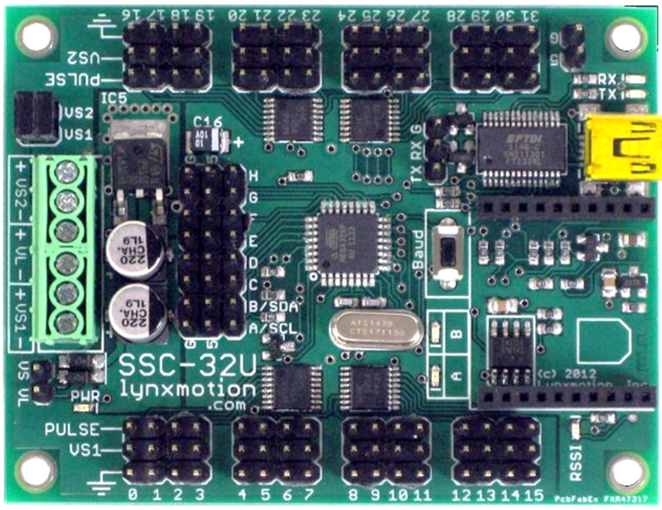

Figure 3.18: SSC-32U servo controller

3.12 HiTEC HS-645MG Servomotor

The HiTEC HS-645MG Servomotor was chosen for the high torque that it is capable to provide and the reasonable power consumption compared to the other servos from the same category.in addition to the metal gears that it uses which provide it with high durability. Other servo’s specifications are shown in Table 3.1.

Table 3.1: HiTEC HS-645MG servomotor specifications

Control system	+Pulse width control 1500 µsec Neutral	
Operating voltage range	4.8V to 6.0V	
Operating temperature range	-20 to +60 C	
Test voltage	At 4.8V	At 6.0V
Operating speed	0.24sec/60 at no load	0.2sec/60 at no load

Stall torque	7.7 kg.cm	9.6 kg.cm
Operating angle	45 /One side pulse 400 μsec	
Direction	Clock wise/pulse traveling 1500 to 1900 μsec	
Idle current	8.8 mA	9.1 mA
Running current	350 mA	450 mA
Dead band width	8 μsec	
Connector wire length	300 mm	
Dimension	40.6x19.8x37.8 mm	
Weight	55.2 g	

3.13 LM7806 Voltage Regulator

The LM78XX series of three-terminal positive regulators is available with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut-down, and safe operating area protection. If adequate heat sinking is provided, they can deliver over 1 A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components for adjustable voltages and currents. The LM7806 voltage regulator delivers an output voltage of 6 ± 0.25V with maximum current 1 A when connected to a (10-18) V input source.

CHAPTER FOUR

DESIGN AND IMPLEMENTATION OF HEXAPOD ROBOT

4.1 Introduction

The development of robot is often inspired by moving living beings such as mammals and insects. The design procedure for the robots involved mimicking their body parts and movement. The number of actuators installed in the robot platform determines the robot degrees of freedom. Depending on the number of actuators installed the robot must be supplied with a suitable power source to maintain its operation for a reasonable period of time. The operation of the robot can be controlled by using an appropriate controller.

The hexapod robot design procedure went from firstly determine the required components. Then the robot body is designed using design softwares such as Auto-CAD and then the body is fabricated using CNC machines. And then the body parts were assembled and the components were connected to make the hexapod robot. This hexapod is designed basically in order to reach a desired destination, through an uneven terrain. The capability of moving through uneven terrains is achieved by altering the gaits of locomotion to match the terrain.

4.2 System Components

- Arduino Mega 2560.
- SSC-32U servo controller.
- Eighteen HiTEC HS-645MG servomotor.
- Robot platform.
- LM7806 voltage regulator.
- Two MJE13005 transistors.
- Play station two controller.
- Circuit board.

- Lithium-ion battery.
- Switches.
- Wires.

4.3 Robot Platform

The hexapod robot body is constructed from an acrylic sheet that is 4mm thick. Acrylic is known for being durable, strong and stiff, has broad temperature range for application use and machinability. Thus the acrylic has an advantage over other conventional materials. The sheet was cut using laser cutting machine. The robot body consists of two frames (upper – lower) these frames are shown in Figure 4.1 and Figure 4.2 respectively. Also it has three legs on each side to have six legs in total, each leg consists of four parts (coxa, femur, knee and tibia) as shown in Figure 4.3. The femur and tibia as shown in Figure 4.4 and Figure 4.5, were connected with a servomotor that works as a knee joint. The leg is connected to the body with two servomotors installed in two brackets welded together with 90° between the servomotors axis making the coxa part. These brackets were made of steel sheets and were cut by using CNC router machine as shown in Figure 4.6. This design gives the robot three Degrees Of Freedom (DOF). In the front of the body there is an extra space for a servo connection to be used in a variety of applications like adding a gripper or a camera for example.

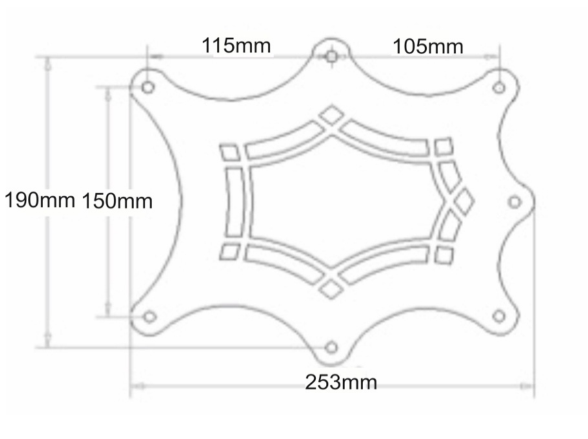

Figure 4.1: Upper frame

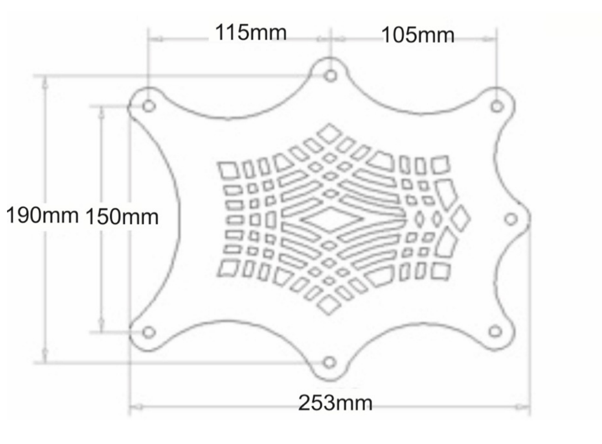

Figure 4.2: Lower frame

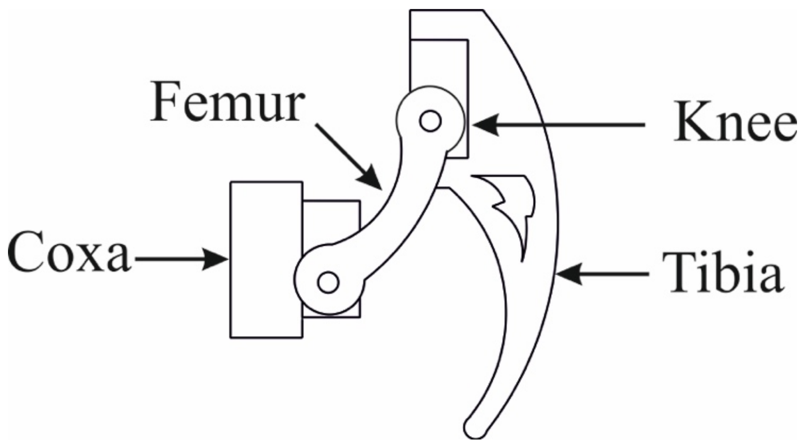

Figure 4.3: Leg anatomy

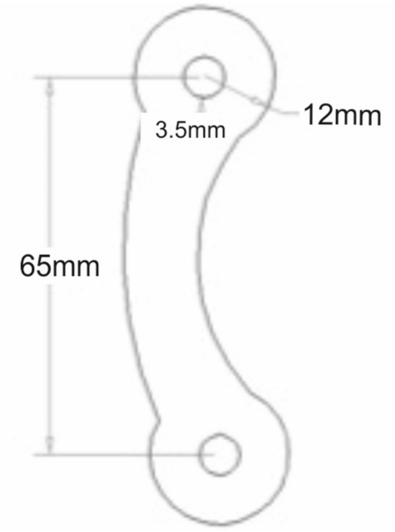

Figure 4.4: Femur

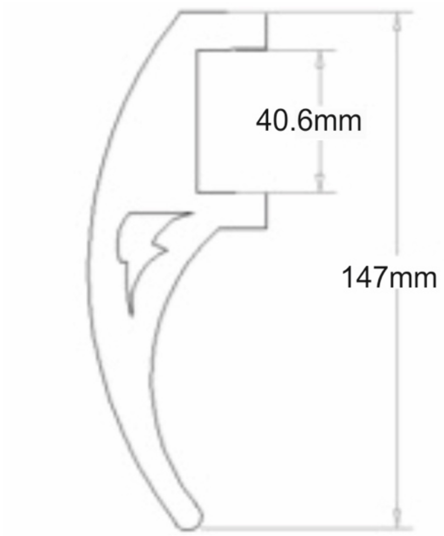

Figure 4.5: Tibia

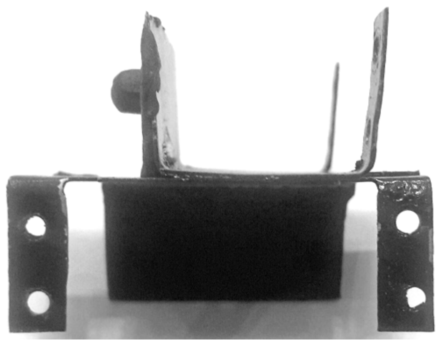

Figure 4.6: Servo bracket

4.4 Power Supply Circuit

A simple power supply circuit can be made with a component called three-terminal regulators provide a very low ripple output. These regulators are called linear regulators and drop about 4V minimum across them. The output current of these regulators can be increased by including a pass transistor. This transistor simply allows the current to flow throw the collector-emitter leads. The output voltage maintained by the three-terminal regulator but the current flows through the pass transistor. This transistor is a power transistor and must be adequately heatsinked.

This electrical circuit was designed to provide a constant voltage of 5.2V at the output terminals when connected to a 10V to 18V voltage source. The voltage source used for this circuit is three lithium-ion battery cells as shown in Figure 4.7. These cells were connected in series each cell provides 4.2V separately. Thus the output voltage is 12.24V. The circuit was designed to meet the robot's power requirement which is 36 Watts (6.93 A at 5.2 V). This voltage and current values is achieved using linear regulator and power transistors. This circuit provides these values in order to provide the required voltage and current to supply a total of 18 servomotors in addition to the other components.

Figure 4.7: 18650 lithium-ion battery cell

4.4.1 MJE13005 transistor

The MJE13005 is a NPN, 75 Watts, power transistor. The output of this type of transistor circuit is the emitter and the input is the base. The transistor MJE13005 was set in common collector configuration as shown in Figure 4.8. Since V_{bb} and V_{be} are constants, do not change with the input voltage V_{cc} or load current. Therefore, V_L remains constant.

$$V_L + V_{be} - V_{bb} = 0 \quad (4.1)$$

$$V_L = V_{bb} - V_{be}$$

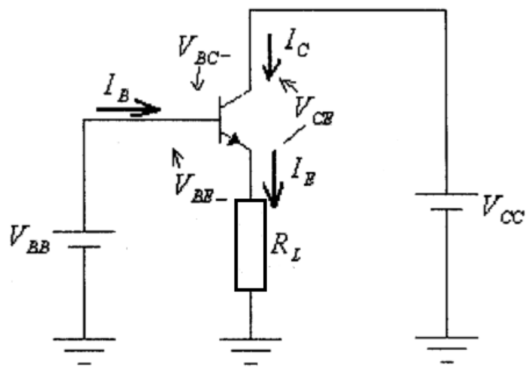

Figure 4.8: Common collector circuit

4.4.2 Circuit operation

Firstly, the batteries were connected to the input terminals IN1 and IN2. When the switch SW1 is turned on the current flows through the voltage regulator RG1 and it regulates the voltage down. the output of the regulator acts as an input to the base of the two transistors Q1 and Q2. Two transistors are used to provide the ability to use two separate power sources to increase the capacity of the power supply circuit. The collectors of transistors Q1 and Q2 were connected to IN1 and IN2 respectively. The common-collector configuration was set to deliver a high current and a fixed voltage at the output terminals OUT1 and OUT2. The LEDs D1 and D2 were connected to the emitter of the transistors Q1 and Q2 through the resistors R1 and R2 respectively to indicate the state of the circuit. The capacitors C1, C2 and C3 were connected to remove any ripple in the voltage. Cooling fans were installed to dissipate heat. Figure 4.9 shows the circuit operation.

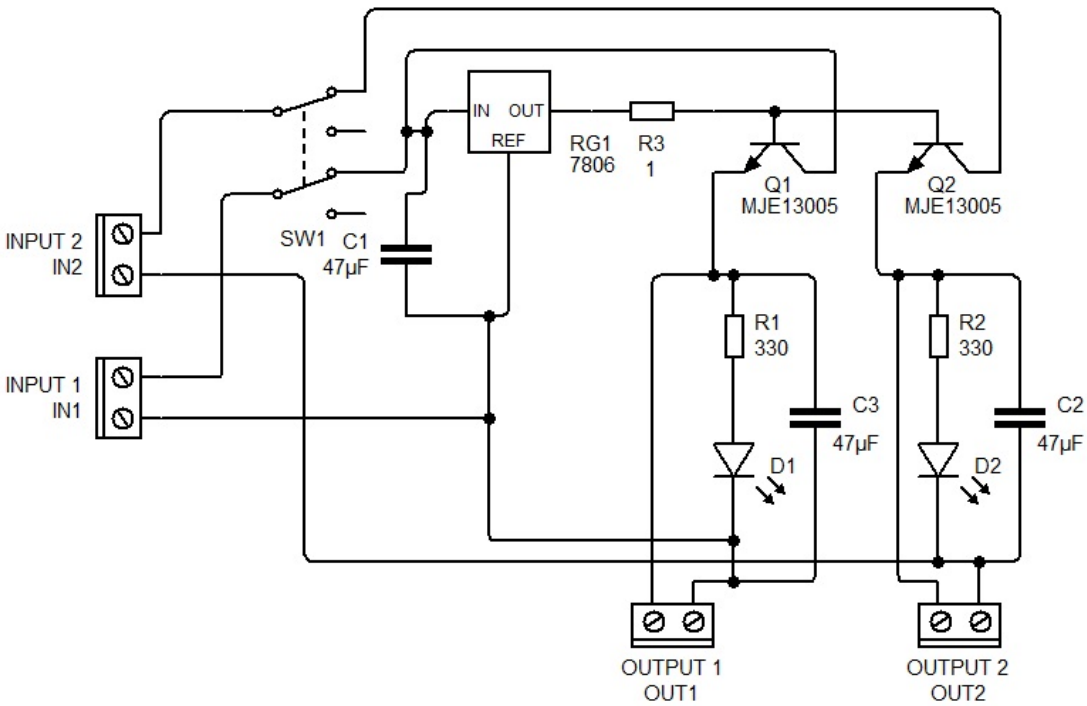

Figure 4.9: Power supply circuit

4.5 Arduino Connection to SSC-32U

There are three pins connected to initiate serial communication between Arduino mega 2560 and SSC-32U servo controller which are T_x, R_x and GND.

Commands sent from the SSC-32U are done using the T_x pin while commands to be received by the SSC-32U are done via the R_x pin and vice versa. These pins allow to easily send commands to the servo controller from the Arduino mega. To do so, the T_x pin on the Arduino mega is connected to the R_x pin on the SSC-32U, the R_x pin on the Arduino mega is connected to the T_x pin on the SSC-32 and GND to GND. Figure 4.10 shows Arduino connection to the SSC-32U.

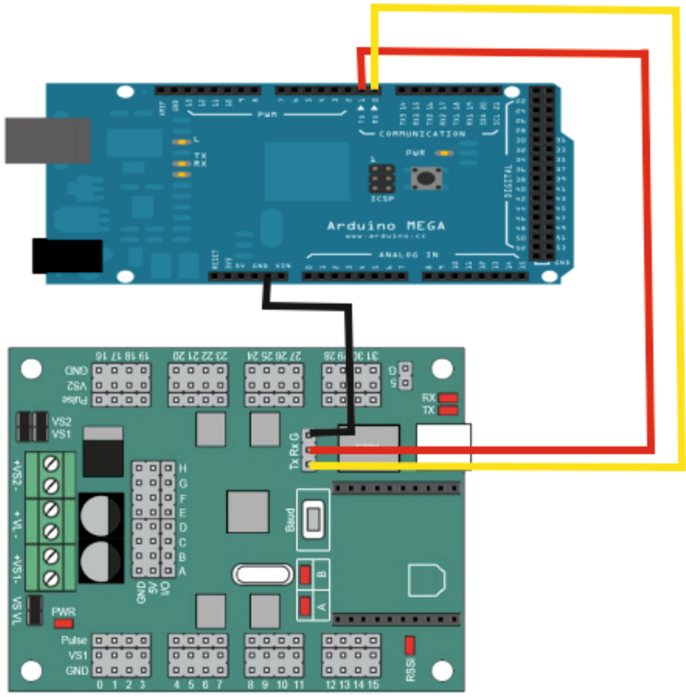

Figure 4.10: Arduino connection to the SSC-32U

4.6 Arduino Connections to PS2 Receiver

The attentiont pin in the receiver was connected to pin number 10 in the Arduino's PWM pins. The command pin in the receiver was connected to pin number 11 in the Arduino's PWM pins. The clock pin in the receiver was connected to pin number 12 in the Arduino's PWM pins. The clock pin in the receiver was connected to pin number 13 in the Arduino's PWM pins. The power pin in the receiver was connected to the 5V pin in the Arduino. The ground pin in the receiver was connected to the GND pin in the Arduino. Figure 4.11 shows Arduino connection to PS2 receiver.

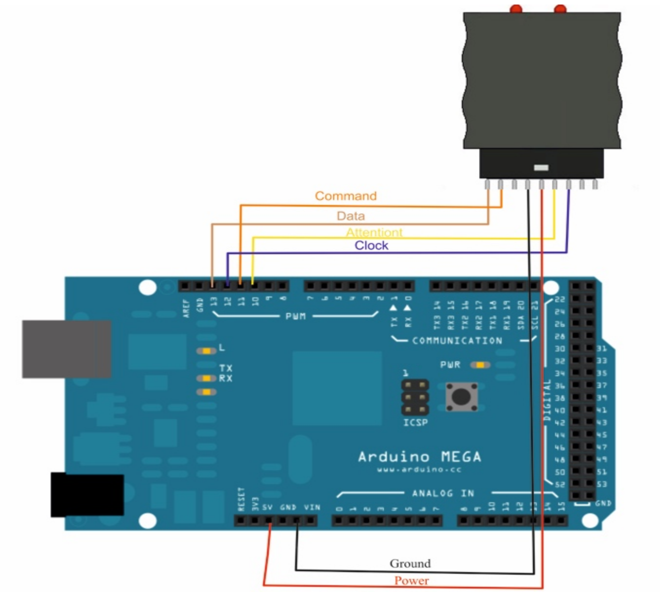

Figure 4.11: Arduino connection to PS2 receiver

4.7 Hexapod Robot Assembly

The hexapod body parts were assembled and bond together using 3 mm screws. The pins of the servomotors were connected to the SSC-32U servo controller. The servo controller was connected to the Arduino Mega 2560 micro controller and the output terminals of the power supply circuit OUT1 and OUT2 were connected to the input ports VS1 and VS2 of the servo controller respectively. Three series connected 18650 lithium-ion battery cells were connected to the input terminals IN1 and IN2 of the power supply circuit. The PS2 wireless controller receiver was connected to the Arduino micro controller. Figure 4.12 shows the hexapod robot after been assembled.

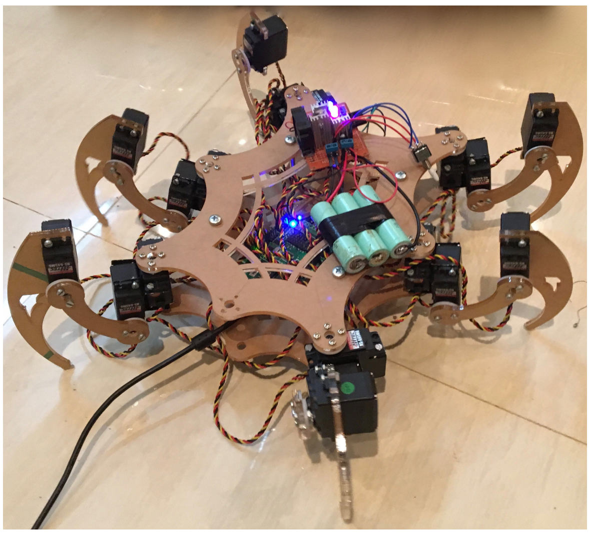

Figure 4.12: Hexapod robot fully assembled

4.8 Hexapod Movement

The hexapod is designed to be able to walk in various gaits. Each one of These gaits provides advantages over the other gaits in terms of stability, speed and overcoming a certain terrain. Before the gaits movement planning is executed, All the servomotors range of motion is determined.

4.8.1 Legs range of motion

The hexapod legs are designed to achieve a certain range of motion, the hexapod robot legs divided into two groups: left side and right side, each contains three legs. In each leg the range of motion of each servomotor has been determined in PWM as shown in Table 4.1. Figure 4.13 illustrates the legs range of motion in degrees. The hexapod has a minimum altitude from ground of 3.7 cm and a maximum altitude of 16.4 cm. The idle altitude is 5.5 cm.

Table 4.2: Servomotors range of motion in PWM

Legs	Servo	Pin	Idle µsec	Min µsec	Max µsec
Left Leg front(L1)	1	28	1500	2300	860
	2	29	900	2500	500
	3	30	900	2500	500
Left leg center(L2)	1	20	1500	2250	1050
	2	21	900	2500	500
	3	22	900	2500	500
Left leg back(L3)	1	16	1500	2450	690
	2	17	900	2500	500
	3	18	900	2500	500
Right leg front(R1)	1	12	1500	640	2200
	2	13	2100	500	2500
	3	14	2100	500	2500
Right leg center(R2)	1	8	1500	900	2085
	2	9	2100	500	2500
	3	10	2100	500	2500

Right leg back(R3)	1	0	1500	690	2290
	2	1	2100	500	2500
	3	2	2100	500	2500

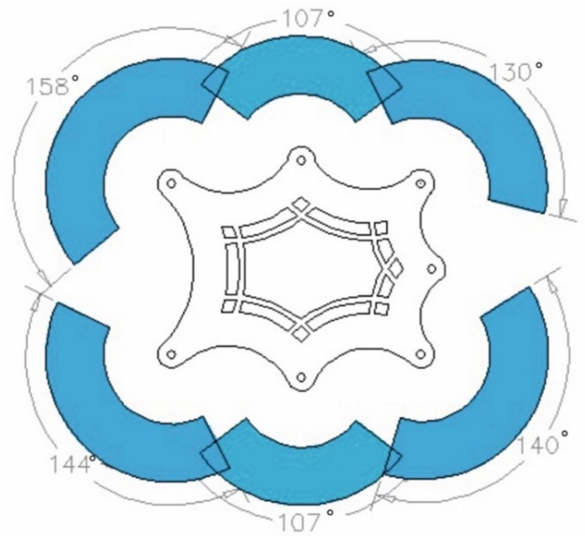

Figure 4.13: Legs range of motion in degrees

4.8.2 Tripod gait movement planning

The tripod walking gait provides the hexapod with the fastest speed over the ground. To perform this gait, the hexapod legs are divided into two groups: right triangle group and left triangle group. The right triangle group consists of right front leg, right back leg and left center leg. And the left triangle group consists of left front leg, left back leg and right center leg as shown in Figure 4.14. In the forward movement at any moment one of the two groups is in the swing phase performing protraction (the forward movement of the group relative to the body and the ground), while the other group is in the stance phase performing retraction (the backward movement of the group relative to the body with no movement relative to the ground).

In order to turn the hexapod to the left, the left triangle group is in the swing phase protracting in anticlockwise direction, while the right triangle group is in the stance phase retracting in clockwise direction. In order to turn the hexapod to the right, the left triangle is in the swing phase protracting in clockwise direction, while the right triangle group is in the stance phase retracting in anticlockwise direction.

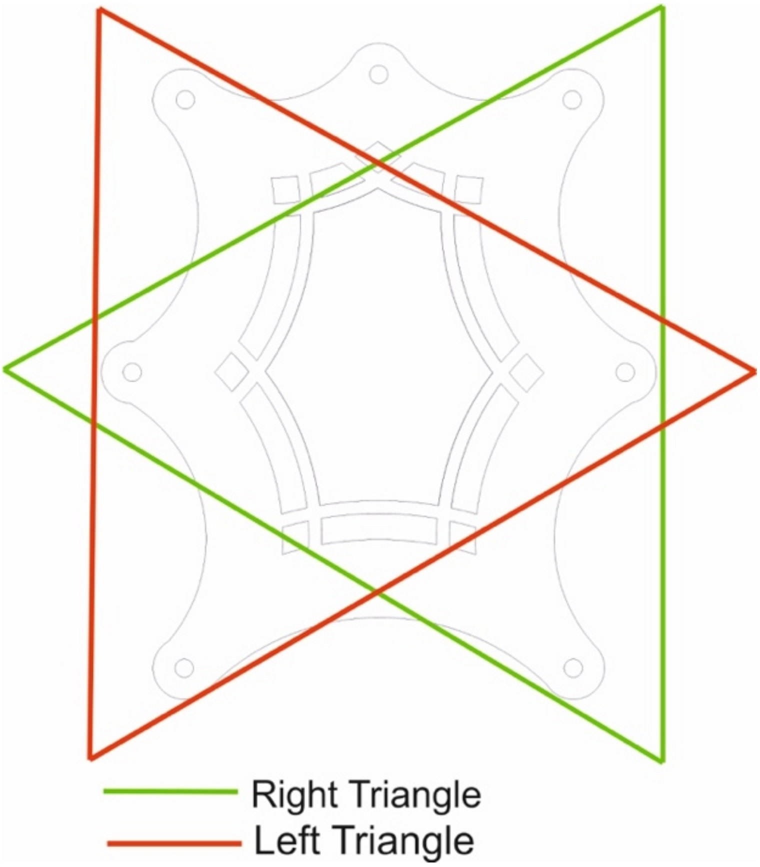

Figure 4.14: Tripod gait leg grouping

4.8.3 Hexapod robot tripod gait walking

The hexapod robot was adjusted to perform different modes: sleep and idle. In sleep mode, its legs are contracted to the body and its body is lowered to the ground, indicating that it is in sleep mode as shown in Figure 4.15. In idle mode, its legs are stretched and the body is raised form the ground as shown in Figure 4.16. Indicating that it is ready to walk and execute tripod gait planning and therefore maneuver over the surface or terrain it is subjected to. Figure 4.17 illustrates hexapod robot while walking forward or backward. Figure 4.18 illustrates hexapod robot while turning left or right.

The hexapod robot was subjected to various types of terrain in order to test its capability. Although it was using tripod walking gait which is the least effective in terms of rough terrain. The hexapod performance was acceptable. Figure 4.19 shows the hexapod maneuvering over various types of terrain.

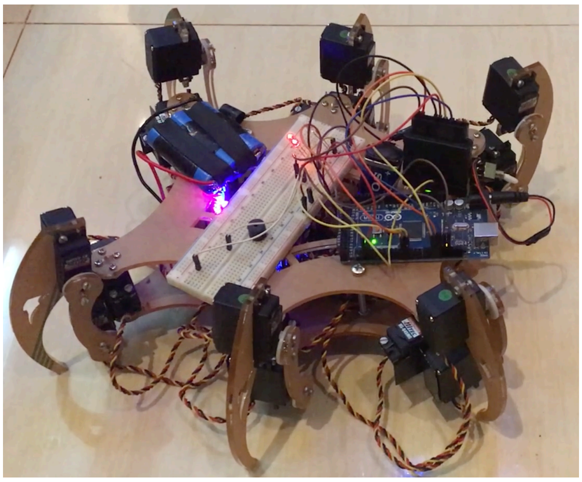

Figure 4.15: Sleep mode

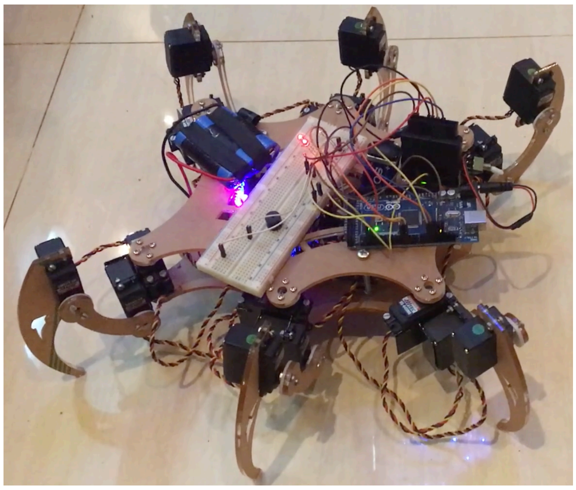

Figure 4.16: Idle mode

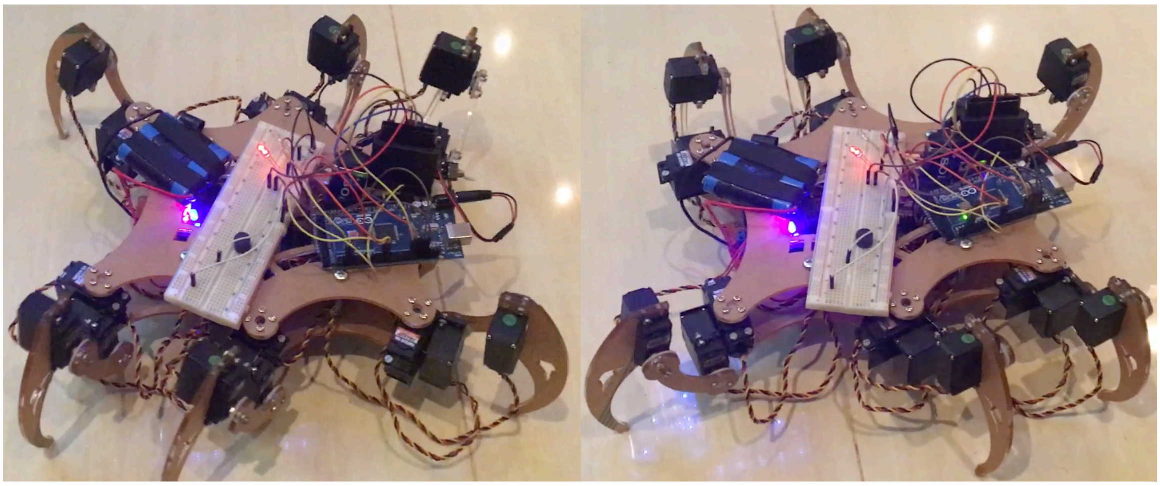

Figure 4.17: Hexapod robot walking

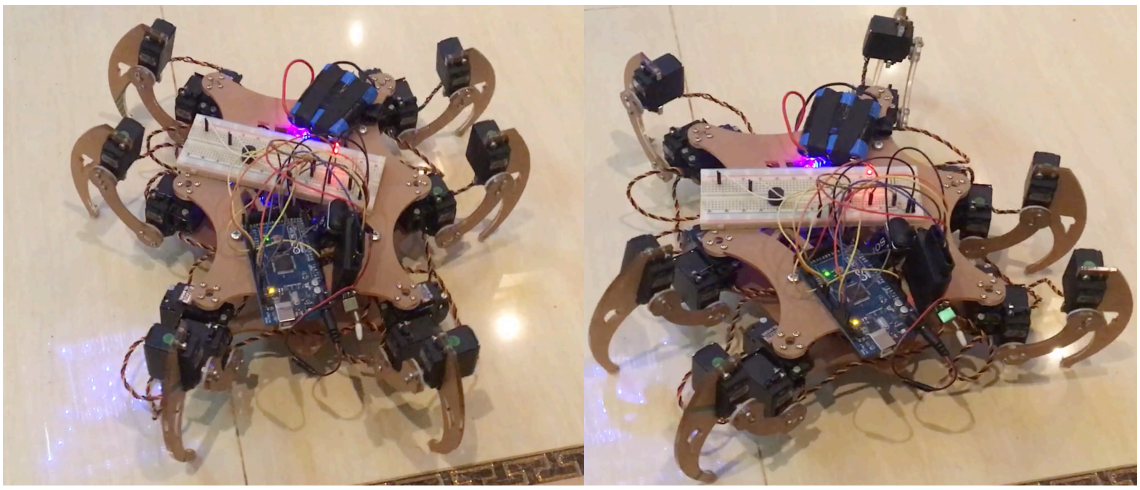

Figure 4.18: Hexapod robot turning

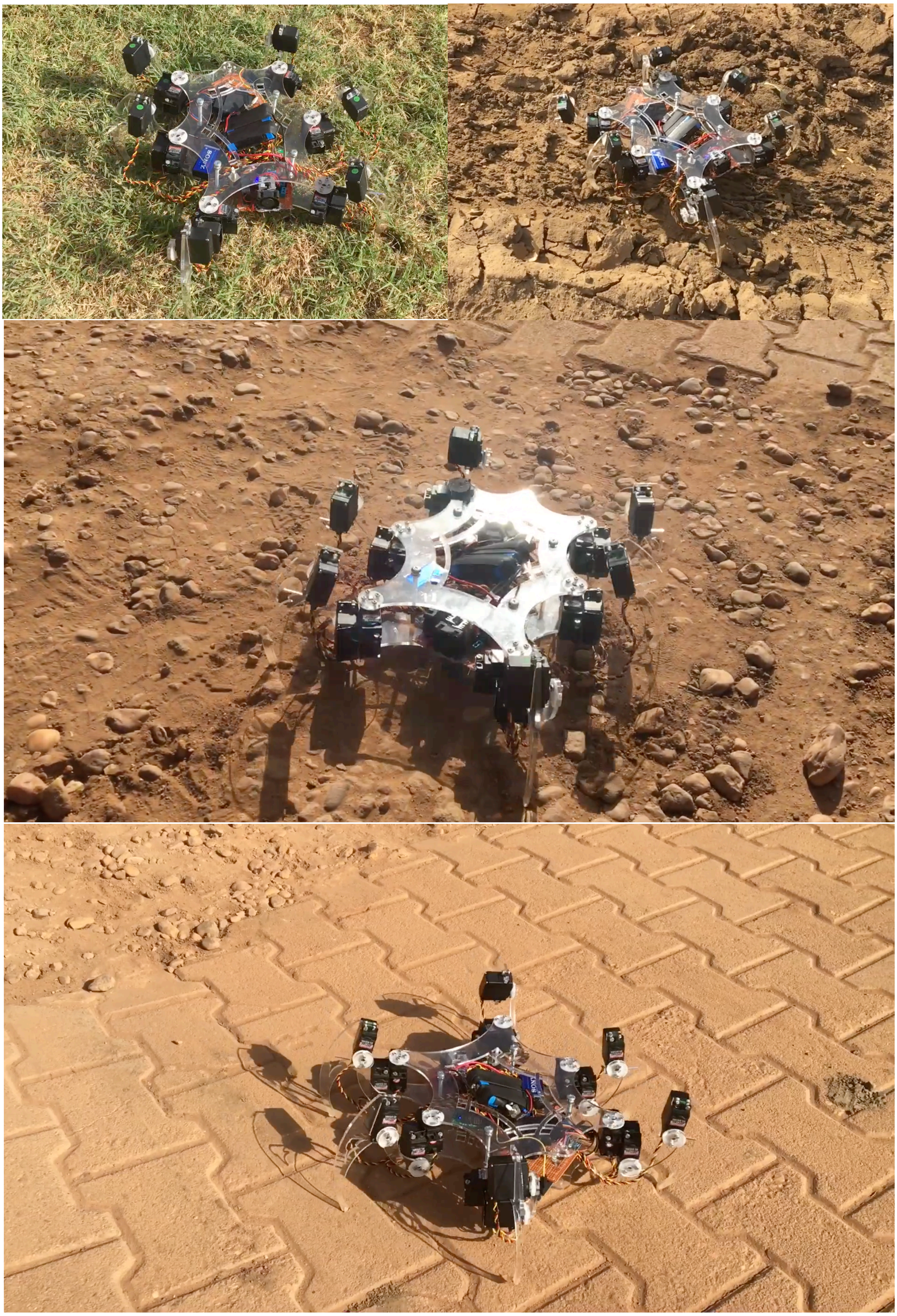

Figure 4.19: Hexapod maneuvering over various types of terrain

CHAPTER FIVE

CONCLUSION AND RECOMMENEDATIONS

5.1 Conclusion

Despite the encountered difficulties. A hexapod robot was designed and implemented successfully. The development of this robot had almost achieved its objectives that is to build a hexapod robot capable of handling all terrain and obstacles. However, certain problems encountered that caused the robot to perform less effectively. The robot components need to meet certain specifications for it to operate in its optimum performance. The robot parts manufacturing did not meet the desired tolerance resulting in an inaccurate structure resulting in an overall reduced performance. Further research needs to be done to make the robot reach its full potential. And more accurate manufacturing needed to build the robot to meet its desired specifications. It is hoped that the development of this robot can later help to provide all terrain maneuvering with the application that requires moving through difficult terrain with ease.

5.2 Recommendations

- To use a stronger and lighter materials like aluminum.
- To use a wider range remote controller.
- To use a wireless camera to allow the robot to be sent to places out of visibility.
- To use a gyroscope sensor and a GPS receiver to give the ability of location based navigation.
- To use an accelerometer to provide active suspension.
- To use force sensors to show when a step is made.
- To program other gaits like ripple and wave to increase robot capability of handling all difficult terrains.
- To manufacture the body parts with more accurate machines.

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