First semester report

First semester report	July 2017	Note:

Student to complete this section			
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Design of a holonomic five legged robot			Study leader: Dr D le Roux

Degree programme enrolled for: Electronic Engineering	Project number:	DLR5	Revision number:	0

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1. Literature study

In this section of the report, a brief overview of the existing research that is relevant to this project will be given, as well as a short discussion on how this existing research will be used to aid in the design of a five legged holonomic robot during the course of this project.

Legged vehicles are preferred to wheeled vehicles for exploration and rescue in remote areas because of their ability to cross rough terrain quickly with a severely reduced risk of getting stuck. The price to pay for this superior drive-train is far more complex electronics and movement algorithms [1]. Instead of just driving the wheel motors and steering, each limb actuator of each leg has to be controlled to move to a calculated position.

Inverse kinematics is the mathematical process used to calculate the required angles of the limbs of a structure to reach a specific set of coordinates. This is used extensively in this project because of its ability to easily transform desired Cartesian coordinates into the required actuator angles. In the paper [2], a method is discussed for solving the inverse kinematic equations involved in a seven degrees of freedom robotic arm. This method takes into account specified minimum and maximum values for each actuator and degree of freedom in order to avoid self-collision. This method can be applied to any system with a specified degrees of freedom and can therefore be simplified to solve the inverse kinematic equations for the system designed in this project.

To obtain the Cartesian coordinates desired at any given time, the method described in [1], namely Sine pattern methods is used. In [1], the method was applied to a quadruped robot. In the case of this project, the method is expanded to make it suitable for use on a robot with five legs. Adaptation is required because the method relies on the symmetry of a quadruped robot to schedule the lifting of the legs. Since the same symmetry does not exist in a robot with five legs, a different scheduling technique is investigated. This method will rely on information from the current position of the legs, the limits of leg movement, as well as the current horizontal tilt of the robot.

In the conference paper, [3] motion planning of omnidirectional robots is discussed and a sophisticated yet simple and efficient method of route planning is proposed. This method is based on vehicles that use three omnidirectional wheels in combination to form a resultant force vector in the desired direction. This type of vehicles differ largely in terms of locomotion when compared to a holonomic legged design used in this project, but there are a few key similarities. Both these designs can move holonomically, therefore has the ability to move in a straight line while rotating, move in an arc without rotating, or any combination of the two. These similarities mean that some of the methods discussed and applied in [3] can be used to aid in the design of the algorithm used in this project.

A team from Instituto Tecnologico de la Laguna in Mexico designed a hexapod robot [4] similar to the robot designed in this project. The purpose of the hexapod was to investigate its potential for use in exploration of areas that are hard to reach by any commonly used means of transportation. Legged vehicles are more suited to cross rough terrain, but this rough terrain complicates the design of the drive-train. In application where the surface is smooth or close to smooth, open loop control can be applied where the leg is simply moved to the desired position and it is assumed by the designer that the robot foot is making contact with the ground at this point, and therefore supporting part of the distributed robot weight. When the robot is crossing rough terrain where the surface consists of mainly bumps and holes, this assumption could be false. In such a scenario, the robot could lift another leg while under the impression that its weight is being supported by the other legs. If this is not the case, the robot could fall over and possibly damage itself or be unable to rectify itself. To avoid this problem, closed loop control should be used in the height positioning of the legs. This involves having a sensor in the system that could provide feedback on the state of the foot. The hexapod in [4] used miniature resistive force sensors attached to the bottom of each foot of the robot. The robot therefore has the ability to take analogue measurements from these sensors and determine the weight distribution of the individual feet of the robot. This data is used to confirm that all robot feet are making contact with the surface and correct the situation if this is not the case. This type of feedback is also useful when the robot is operated on slanted surfaces because of the effect that the center of gravity has on a slanted surface. A feedback sensor will be included in the design of the five legged holonomic robot in this project.

If the robot is operating on a slanted surface without it being aware of this and the center of gravity shifts over the lowest foot making contact, the robot could fall over even with all of its legs making contact with the surface. In a paper on reactive robot navigation [5], it is proposed that the use of a digital inclinometer can aid in solving this problem. The sensor provides information on the current tilt of the robot in two dimensions. This sensor in combination with the feedback sensors on the robot feet can be used to ensure that the robot levels itself automatically to avoid tipping over. The data collected from this sensor can also be used to collect information on the terrain. In the journal article [5], this data is used for hill climbing as well as finding valleys in unexplored areas. In order to enable the robot designed in this project to walk on slanted surfaces, a digital inclinometer will be used. Some of the reactive navigation techniques discussed in [5] will also be implemented to aid the robot in navigating on slanted planes.

In a paper on the effects of slippery surfaces on biped robots [6], methods on avoiding falling over of a biped robot is investigated. Since these robots have to balance themselves to stay upright, an unforeseen slippery patch on a surface could be fatal for the robot. If it were possible to foresee a slippery surface, slowing down the walking gait and increasing foot surface would help increase the traction of the robot, and therefore lower the risk of slipping. Since a five legged robot is inherently stable and there is no balancing required, slippery surfaces influences the traction of the robot but there is very low risk of falling over on level surfaces that are slippery. It is therefore suitable to just slow down movements on slippery surfaces and increasing the traction where possible.

2. Approach

In order to fully constrain the system, one actuator is required for every degree of freedom in the system. The robot uses 5 identical legs spaced 72 degrees apart around a circular chassis in order to make the system holonomic. If every leg has N degrees of freedom, the robot will require $5 \times N$ actuators for it to be fully constrained.

The robot can be designed with either two or three degrees of freedom per leg. Figure 1 below shows an illustration of a leg with two degrees of freedom. The first hinge can move in the horizontal plane to pivot both segments A and B sideways. The second hinge pivots segment B up and down. The dashed line shows the pivot axes.

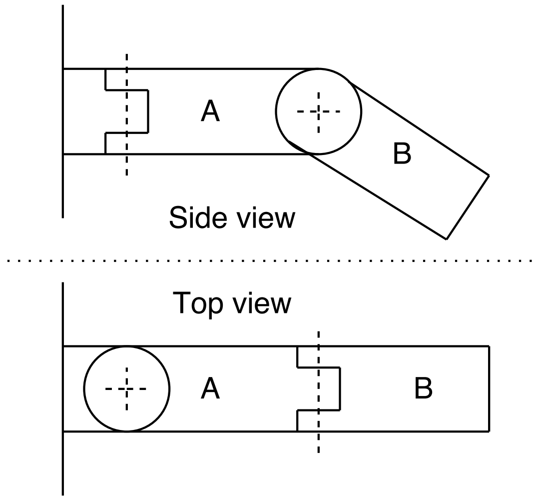

Figure 1. Diagram showing a robot leg with two degrees of freedom

Figure 2 below shows an illustration of a robot leg with three degrees of freedom. The first two hinges work the same as in the case of figure 1 above. The difference is the additional hinge at the end of segment B and the Additional segment C attached to it. The third hinge between segments B and C functions exactly the same as the hinge between segments A and B.

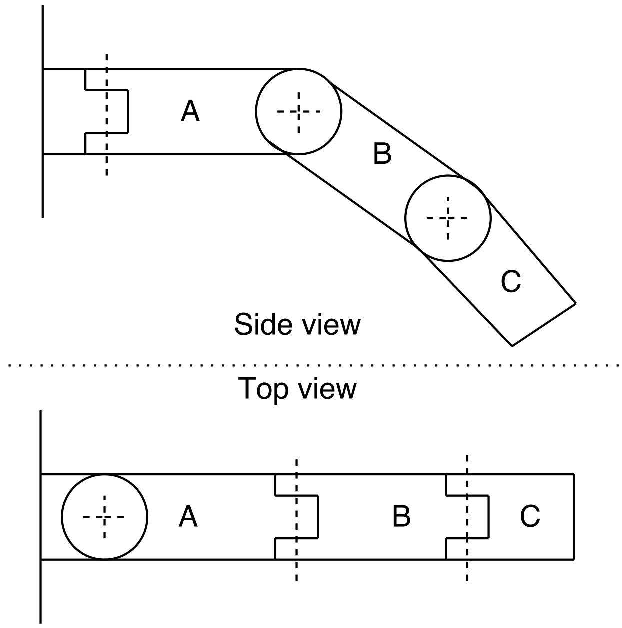

Figure 2. Diagram showing a robot leg with three degrees of freedom

If a point with coordinates (x;y;z) is desired, the leg with two degrees of freedom in figure 1 above will be able to move to a point that satisfies two of the three coordinates. The third is a function of the other two and can therefore not be satisfied without violating one of the other two conditions. The leg in figure 2 will be able to satisfy all three of these parameters for every set of coordinates within reach of the leg. This leg can move in the X, Y or Z axis without violating the other two parameters.

The robot developed in this project should be able to walk on slanted surfaces and rough terrain that includes small obstacles. Control of the Z height of individual legs is therefore important and as a result, the legs should have 3 degrees of freedom each. The robot will therefore require 15 independent actuators to be fully constrained.

In section 1. above, the importance of having feedback on whether a specific leg is touching the surface was discussed. The team in [4] made use of resistive force sensors to determine the exact weight lifting contributed by each leg and therefore the weight distribution of the whole robot. This amount of information is not required in this project. The sole purpose of these sensors in this case is simply to confirm that the leg is touching in order to prevent the robot falling over. Due to the cost of these resistive force sensors, these will be substituted with simple tactile switches at the bottom of each foot to provide binary information on the feet touching the surface. This will provide all the information necessary to prevent falling over.

The importance of having feedback on the current tilt of the robot chassis was also discussed. There is mainly two methods of measuring this digitally. The first method is to use an accelerometer. The earth's gravitational pull will register on the sensor and the tilt of the sensor can be calculated from this. The benefit of using this method is that data on acceleration can be obtained as well. The second method is using a digital inclinometer. This measures the same as the accelerometer but does the conversion calculations on-chip and provides the user with information on tilt in two axes. Since the inclinometer is less expensive and provides the necessary information directly, this will be used in the project.

3. Project plan

This section includes the planning for the complete project period which spans over the period 1 February 2017 to 30 November 2017. The planning is in the form of a Gantt chart with a one week resolution. Figure 3 below shows the planning for the project up to the date of handing in this report. The blocks coloured in blue therefore represent work that is already completed.

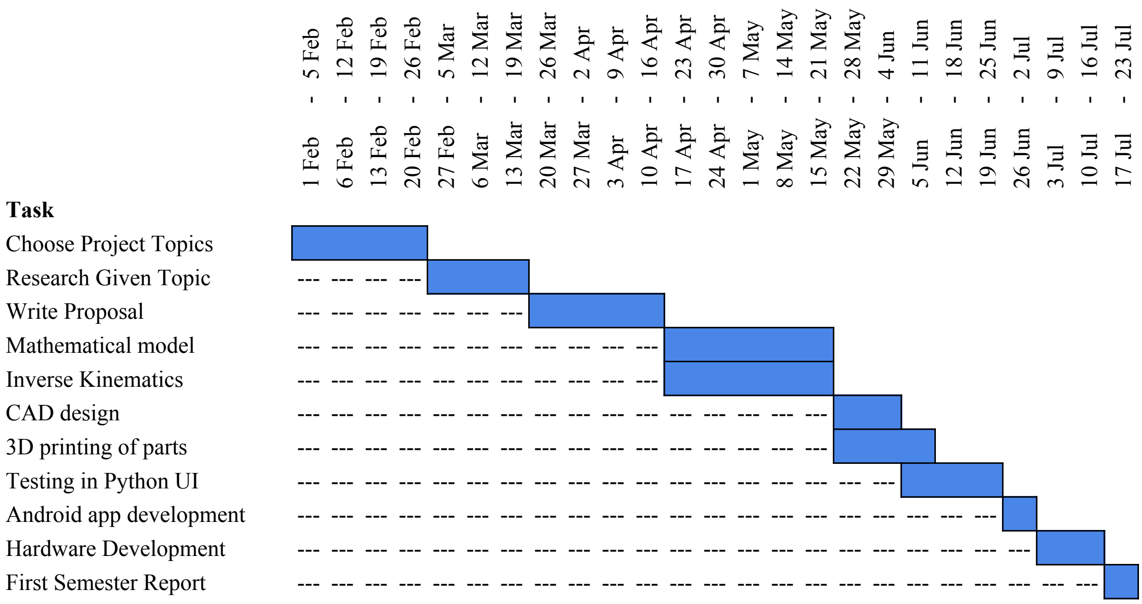

Figure 3. Gantt diagram for work already completed

Figure 4 below shows the remaining time in the project period. The blocks coloured in purple therefore represent work that still has to be completed.

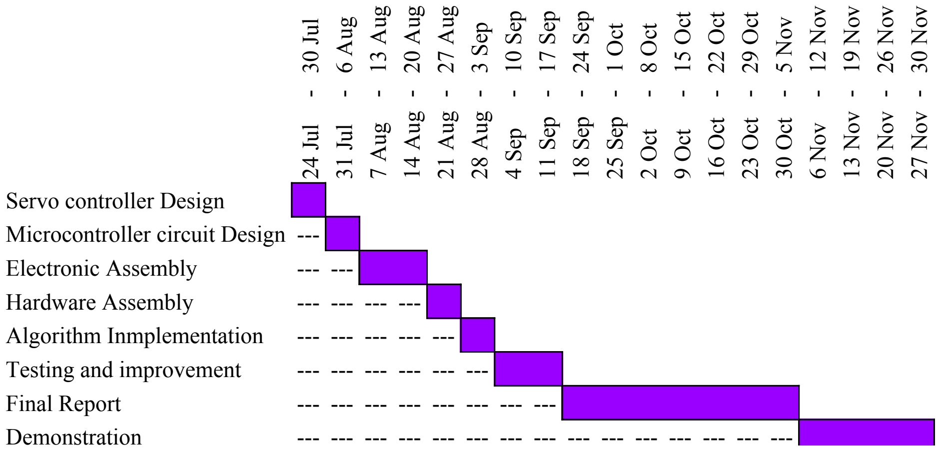

Figure 4. Gantt diagram for work to be completed

4. Progress

In semester 1, the mathematical analysis of the robot structure was completed and this was used to develop the formulae that is used to perform the inverse kinematics required during normal operation. The inverse kinematic equations was developed from first principles using the mathematical structure analysis and trigonometry.

The parts required to build the robot was designed in a CAD package to be as strong and light as possible without compromising on functionality. It is important for these parts to be light as this results in less torque required by the stepper motors. It is also important because the parts are 3D printed and lighter parts result in lower cost. The parts were all sanded and filed after printing to make the parts smoother and make the fit between parts better with less friction between joints.

In order to test the inverse kinematic equations and preliminary algorithms, a GUI was developed in Python. The program takes inputs from a cluster of buttons similar to that of a remote control. The programs plot a diagram in 3D that represents the actual robot. This will be used to tune the final walking algorithm as well.

An Android application was developed to communicate instructions to the robot via Bluetooth. The user interface consists of two on-screen joysticks as well as a few buttons that is used to control the movements of the robot.

5. References

[1] A. Hidayat, A. N. Jati, and R. E. Saputra, “Autonomous quadruped robot locomotion control using inverse kinematics and sine pattern method,” *IEEE*, 2017.

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[3] P. Jain, “Odometry and motion planning for omni drive robots,” *IEEE*, November 2014.

[4] J. Ollervides, J. Orrante-Sakanassi, V. Santibanez, and A. Dzul, “Navigation control system of walking hexapod robot,” *IEEE*, 2012.

[5] R. C. Arkin and W. F. Gardner, “Reactive inclinometer-based mobile robot navigation,” *IEEE*, vol. 2, 1990.

[6] J. H. Park and O. Kwon, “Reflex control of biped robot locomotion on a slippery surface,” *IEEE*, May 2001.