Balancing and Locomotion of a Hexapod Robot Traversing Uneven Terrain

Jonatan Ekelund

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Today robots are an integral part of our society. Not only do we find robots in factories and warehouses, but robots also go to previously unreachable and dangerous places. Drones fly over volcanoes and radioactive hazard zones and the rover Curiosity is still working its way across the surface of Mars. This master thesis project has developed a method for a six-legged robot to traverse uneven terrain.

The Hexapod

This project has developed a adaptive way for a six-legged robot (also called a hexapod) to traverse obstacles and uneven ground. The hexapod robot used in this project has been the platform for several different projects before. When this project began the hexapod was only able to move across flat ground. It did not try to keep it's balance while walking, nor could it discern if it's feet were on the ground or in the air. The hexapod could however balance while standing still, keeping its body horizontal. This is shown in figure 1.

A camera had been installed on top of the hexapod. The camera could measure distance and was used to map the hexapod's surroundings. The hexapod used a path-planning algorithm to plan its movements, avoiding obstacles by walking around them. This camera has not been used in this project, however it has been taken into consideration when making design decisions so that it could be used in future projects.

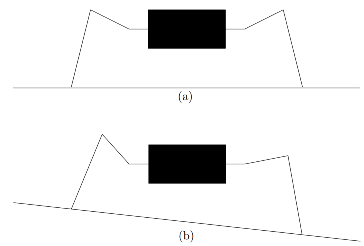

Figure 1: (a)Hexapod standing on level ground keeping the main body leveled. (b) Hexapod standing on a slope keeping the main body level by altering the heights of the leg positions. [1]

Traversing Terrain

There is three parts to moving across uneven terrain. Imagine yourself standing up with your eyes closed, when you take a step forward you do three things. First of all, you are keeping your balance, you are standing straight up and not leaning to one side or the other. Secondly, you feel your feet, you know when they are on the ground and you know when you lift them. The third thing you are doing is moving with the angle of the ground, if you are walking walking up a hill you move up the hill and not straight forward.

These are the three parts that make it possible for the hexapod to move across uneven terrain. The hexapod needs to be able to keep its balance, feel when its legs touch down on the ground and it needs to estimate if it should be moving up or down with the terrain. These features will be referred to as balance control, step impact detection and floor angle estimation throughout this article.

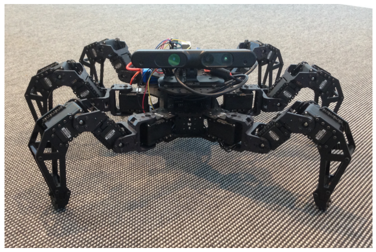

Figure 2: An image of the real Hexapod. [2]

Balance Control

Installed on the hexapod robot's body is an Inertial Measurement Unit, an IMU, which uses several different sensors to estimate the angle of the hexapod. Since the position of the feet of the hexapod are known it is possible to calculate how the feet should move to compensate for the angle measured by the IMU. By moving the legs up or down it is possible for the robot to keep it's balance, just like a human does when standing on a slope.

The system gets the angle from the IMU, calculating the movements needed to compensate for the angle and then sending the movements to the hexapod's motors. However, the hexapod can't move too fast, lest it might overcompensate and lose its balance. The compensation movements need to be dampened somehow. To do this a controller was installed, dividing the angle by a constant, so that we only compensate for a fraction of the angle at a time. This way the robot would move slower but still compensate quickly for large angles.

However, using a fraction of the angle to calculate the angle compensation movements is an very indirect way of slowing down the movements. To design a more direct control system this project also developed a controller that instead divided the distance of the compensation movements with a constant. The two controllers worked equally well since the hexapod usually is only compensating for small angles. For larger angles and for future development the more direct movement controller is the best option.

Experiments using several different methods were done to find a faster and more robust balance control, adding integration, derivation and maximum change constraints to the controllers. However, none of these new controllers worked as well as the less complicated division controller.

Step Impact Detection

To detect when the hexapod's legs would hit the ground this project first tried to install small force sensitive resistors on the hexapod's feet. These resistors have a tiny pocket filled with air, if the resistor is compressed the air is let out through a small hole. This way the resistance of the resistor changes depending on how compressed the pocket of air is. By measuring the voltage over the resistors it is possible to know if the resistor is compressed, thus knowing if a foot is pushing against the ground. The resistors worked well when tested by themselves, but when put on the hexapod's feet they either got worn out very quickly or simply did not react when a leg would push against the ground.

After experimenting with different movement patterns to make the force sensitive resistors work, the project went on to instead use mechanical buttons. The buttons did not work very well either, as they were not sensitive enough to quickly stop the legs from pushing into the ground.

After moving the development over to a simulation environment and improving the floor angle estimation, it was possible to design a system that detected when a leg hit the ground by how the angle of the hexapod changed. This concept worked very well in the simulation and when comparing data gathered from the real hexapod and the simulation hexapod, it points toward this new method of step impact detection to be a solution for the real hexapod too.

Floor Angle Estimation

Since the hexapod needs to move along the ground it needs to estimate what kind of slope it is moving across. Since the hexapod always starts parallel to the ground, it is possible to estimate the angle of the ground by adding up all the angles the balance control system adjusts for. However,after a lot of experiments and testing it was clear that this method was too prone to errors, since every little miscalculation or vibration gets added to the estimate, making the hexapod think the ground to be tilting more or less than it actually was.

Instead, a new method was designed, using distance measuring sensors to measure the distance between the hexapod's body and the ground. This way the slope of the ground could be calculated by comparing the distance of several different sensors, installed on different places on the hexapod's body. As there were hardware restrictions that stopped the hexapod to have more than one distance measuring sensor installed at a time it was instead decided to prove the concept using a simulation of the hexapod.

The simulation worked very well and the new floor angle estimation made it possible to further develop the hexapod by improving the step impact detection and designing new systems such as a height controller.

Results

The final part of the project was done using a very precise simulation environment. When working in a simulation it is important to not design a system that won't be possible in reality. To make sure that the work done in the simulation could be used in reality a lot of work has gone into comparing the simulation and reality and everything points to there not being any discrepancies.

The final product of this project is a hexapod robot that is able to traverse uneven terrain. It balances itself by measuring the angle of the hexapod's body. By using distance sensors to measure the ground beneath it it can move up and down hills and obstacles without problem. It detects when its legs hit the ground using the angle of the body, which makes it possible to move over obstacles.

References

[1] Thilderkvist, D. and Svensson, S., Motion Control of Hexapod Robot Using Model-Based Design, Department of Automatic Control, Lund University, Sweden, Master's Thesis ISRN LUTFD2/TFRT- -5971- -SE, 2015.

[2] Malmros, M. and Eriksson, A., Artificial Intelligence and Terrain Handling of a Hexapod Robot Department of Automatic Control, Lund University, Sweden, Master's Thesis ISRN LUTFD2/TFRT–9999–SE, 2016.