ALiCE II:
Advanced Locomotion of a Line-Crawling Robot Designed for Manitoba Hydro

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Abstract

The is the fourth in a series of research reports from the first phase of the ALiCE II project. This report focuses on an approach to advanced locomotion in the design of the line-crawling robot affectionately named ALiCE II. ALiCE II is an acronym for Autonomous Line-Crawling Equipment II, a second generation version of a new family of autonomous line-crawling robotic devices using swarm intelligence system engineering design principles introduced during the past 3 years. ALiCE II represents the combined efforts of Maciej Borkowski, Christopher Henry and Dan Lockery. The main architect of ALiCE II has been Dan Lockery. ALiCE I was a single line-crawling robot designed by Vitaliy Degetyarov in 1999 as part of his M.Sc. project, which was also funded by Manitoba Hydro. ALiCE II is the focus of Dan Lockery's M.Sc. research project.

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1 Introduction

This research report covers the discoveries and changes currently being made to the line crawler robot's locomotion drive. From the last set of notes, we have changed our dc motor drive based on the estimated torque and rpm's necessary for driving an increased payload. Each of the necessary steps has been researched, built (as required) and gone through a verification procedure to ensure proper operation. There is also a brief discussion towards the end of the report consisting of the currently active problems with the new drive motor along with our plans for future expansion of the work once they are solved.

2 Starting Point: Locomotion Drive

The first area discussed in this report is to address the previous setup for the dc motor drive. The initial specification underestimated the necessary torque and efficiency required to provide locomotion for the line crawler. There were several contributing factors to this problem. First, the weight of the robot kept changing as the systems evolved. In addition to that, the efficiency of the gearhead motors were mistakenly overestimated. After going through a couple of revisions we were able to arrive at a more plausible solution.

The first locomotion drive that was setup for driving the line grip was a standard dc motor (of the non-gearhead variety). This was effective for the initial design with very low payload weight, however the rpm's were much too high for satisfactory control and the torque provided by the motor was too weak to push any sort of moderate payload. This forced us to move into a second generation of dc motor drive.

With the increased weight of our payload due to adding control boards, power supplies and wireless communication devices, a new, stronger motor drive was necessary to meet the demands placed upon the line crawler grip. When specifying the locomotion drive, we looked at slower rated output shaft speed (rpm's), higher torque and the introduction of a gear-head motor. Fig. 1 shows the second generation Sanyo GM-14 gear motor (gear ratio of 297.1:1).

Once the modifications were made to allow for mounting the Sanyo motor on the line grip, we discovered that when greater payloads were added that the torque was insufficient to drive the line crawler. This was as a result of two factors, newly added weight in the payload was not compensated for in the torque calculations, and the efficiency lost in the gear train was mistakenly not included. Both of these factors were corrected and compensated for in the third specification (see August 10th report for further detail of new specifications). The efficiency of the gearhead can be estimated reasonably well via Table 1 [1].

Table 1: Gearbox Efficiency vs Gear Ratio

$GearRatio$	$GearboxEfficiency$
6:1	81%
30:1	73%
75:1	66%
100:1	66%
180:1	59%
300:1	59%
500:1	59%
800:1	53%
1000:1	53%
3000:1	48%

Figure 1: 2nd Generation Locomotion Drive

Keeping in mind the new efficiency and the torque calculations from the previous set of notes, a new group of motor drives were specified. Unfortunately, our requirements were fairly unique and in most cases companies were unwilling to supply a solution to meet our needs based on the low quantity we required. However, we did come across one provider that came close enough to meeting our constraints that we would be able to make use of the motor with several modifications instead of a complete re-design.

3 New Locomotion Drive

From the specifications provided in the November 12, 2005 report, the first motor option (the parallel shaft) was the solution that we were able to order successfully. This left us with the problem of integrating the new motor into the line crawler robot. Fig. 2 shows the size difference in motors from the previous model to the current edition. The dimensions of the new motor warrant a few changes to the upper grip chassis. The problems addressed when integrating the new drive into the existing grip are as follows. First, the shaft location is higher on the motor frame than the previous drive and its width is double that of the previous motor. Next, the length of the motor is greater than the compartment space available by several centimetres and finally, the diameter of the overall motor is far greater in size and required a new method to fasten it into the drive train.

3.1 Drive Shaft Integration

There were two main compatibility issues with the drive shaft of the new motor when integrating it into the current setup for the line crawler robot. First, the shaft thickness is double that of the previous motor. This warranted a new drive gear as the alternate solution for mating the two would have required more space

Figure 2: Comparison of New Locomotion Drive with Previous Version

than is available. Fig. 3 shows a comparison of the two driver gears. Since we were ordering new parts, we made a decision to reduce some more of the weight by selecting an aluminum composition over the original stainless steel variety (weight savings of approximately 40%).

As can be seen in Fig. 2, not only the size of the drive shafts are different, also the distance from the base of the motor to the centre of the shaft is different. The previous drive had been mounted on a shim to make up for the extra space allowed in the design for larger motors. It was hoped that the space available would be sufficient for integrating the motor simply by removing the shim. Unfortunately, we were short by 0.1cm, which was significant enough that the bottom of the chassis needed to be lowered by that amount. Since the holes had already been drilled in the upper chassis for the current format, it would be next to impossible to drill new holes. The best alternative to ordering new parts was to drill out the holes in the chassis and use nuts and lock washers to secure the screws in the upper chassis. After several attempts to widen the holes, the motor fit in reasonably well and the screws were secured with lock washers and nuts. Fig. 4 shows the two nuts at the back of the chassis where it is secured.

3.2 New Motor Length

Looking at Fig. 2 it is obvious to see that the new motor is much longer than the previous one. The length actually extends beyond the allowed space in the upper grip chassis. This warranted a simple change at the back of the upper grip chassis.

Fig. 5 shows the view at the back of the line grip where the motor protrudes from the chassis. Note that the chassis has a whole cut out for the motor to fit. This was the fastest method for integration into the upper chassis. Now that space was created for the motor to fit into the upper grip, the final problem was to fasten it into the drive train for powering the line crawler.

Figure 3: Comparison of Driver Gears, New vs Old (LtoR)

Figure 4: Lowered Chassis and Secured With Lock Washers and Nuts

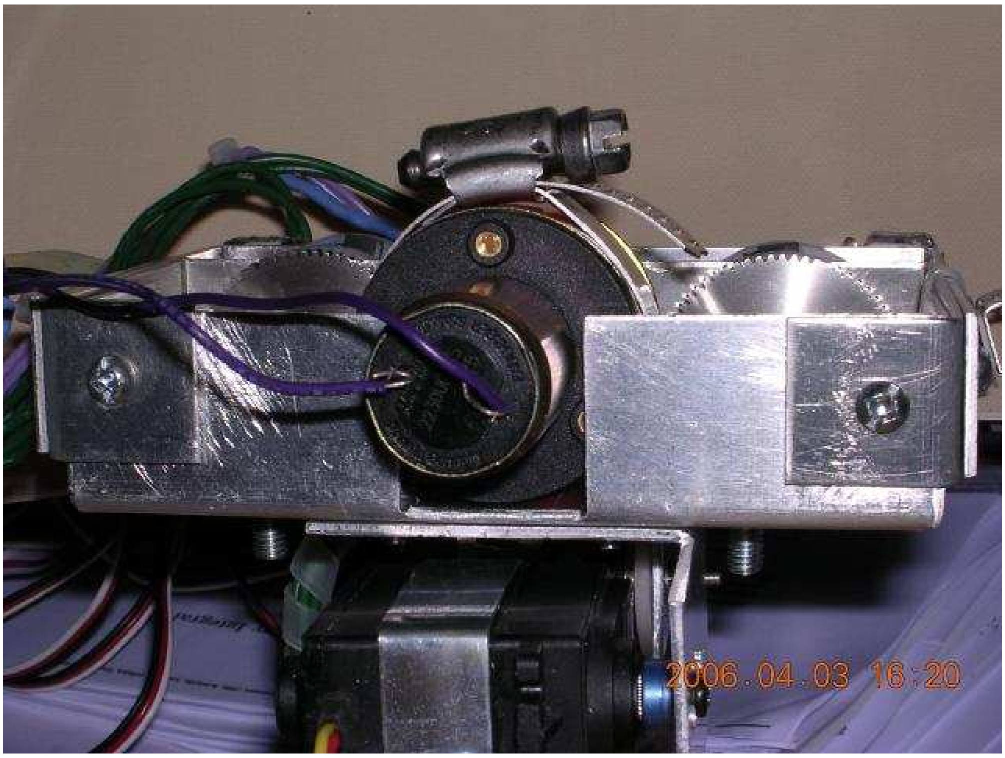

Figure 5: Upper Grip Chassis Rear View of Locomotion Drive

3.3 Securing The New Drive

Fig. 4 shows how the new motor drive looks when it is installed and ready to run. Instead of using the previous method of shaped metal to secure the drive to the chassis, we made use of a similar approach but with a variable size. The metal is a 2-inch diameter hose clamp that was cut in half. The ends of the clamp were trimmed and then drilled out for 10-32 machine screws for fastening to the line grip chassis. Once the machine screws were tightened, the motor was positioned properly and then secured by tightening the hose clamp screw on top of the motor.

At this point, the locomotion system had been completed and prepared for running preliminary trials on the sky-wire test setup.

4 Verification Experiments

With the new drive in place, the line crawler was ready for basic movement tests back and forth on the sky wire. Testing the new drive occurred over the course of a day of simple experiments. We recorded our findings and while the overall results were promising, there are still a few areas that need attention before moving to the next stage of development.

4.1 Locomotion Tests

The first few tests for the line crawler involved moving along the sky wire on a continuous path. The new motor has a much higher gear reduction ratio than the previous one (689:1) and as a result the output shaft speed is proportionally reduced. This makes for a much slower (approximately 11 rpm), more controlled traveling speed along the wire. Fig. 6 shows one of the experiments where the line crawler was rolling past an insulator on the floor (simulating where it would generally want to point the camera when examining insulators).

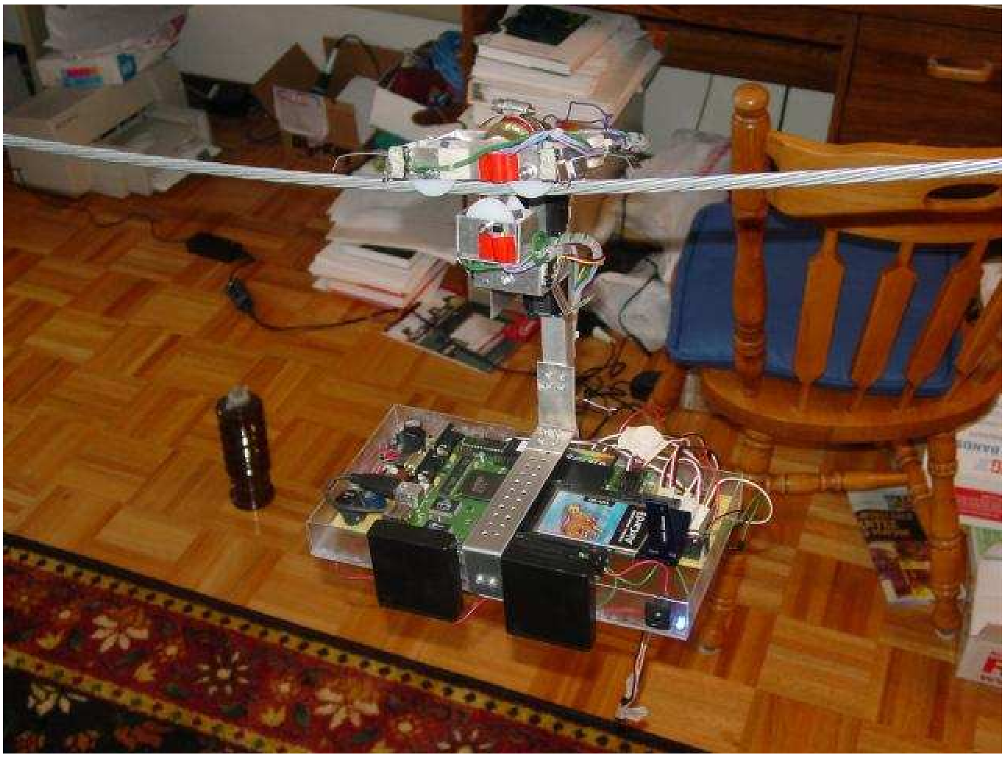

Figure 6: Preliminary Sky Wire Experiment

The same experiment was repeated several times to ensure that the locomotion drive would be able to handle any type of line section it encounters. With the improved grip due to the treads on the insides of the wheels we were able to handle moderate inclines (we tested up to approximately 25 degrees). Steeper inclines were left for a subsequent experimenting session. We included the camera operation in the preliminary experiments as well and took some pictures with the robot vision system. Fig. 7 shows an image of the insulator taken by the onboard camera. After completing the preliminary experiments and proving that the current design is capable of simple locomotion and gathering image data of its surroundings, we set about addressing the areas that needed improvement.

4.2 Locomotion: Room for Improvement

Although the preliminary experiments were successful, there are still a few areas related to the locomotion drive that need to be improved before more extensive testing can occur. First, there is a point in the rotation of the drive where the resistance in the power train is such that the wheels stop turning even though the main drive shaft continues to move. Next, one of the follower gears ended up coming loose after an afternoon of testing (about 5 hours) and this should not have occurred as it was initially secured tightly. Finally, the new motor appears to drive well in one direction but reversing the polarity and direction of travel tends to provide a much weaker performance. Each of these problems will be discussed in the subsections that follow.

Figure 7: View of Insulator From Line Crawler Camera

4.2.1 Resistance in the Power Train

This is a problem that can be seen easily once the locomotion drive is powered up. Every time it completes one rotation, there is a spot where the wheels cease to rotate but the gears keep turning. This indicates that the torque is strong enough to keep the wheels moving, but there is too much force holding the wheels in place and the set screws have insufficient strength to allow them to turn properly. Although this problem hasn't been solved yet, my initial instincts suggest that there may be a bend somewhere in the upper chassis framework near the central drive shaft.

During the next stages of the experimental verification we will be testing the framework to make sure that the holes line up and that there are no small bends in the metal that are difficult to spot. The chassis material is made from aluminum (for reduced weight purposes) so it is fairly malleable and prone to bending. We expect that once the source of the increased friction on the shafts during rotation is found, the locomotion drive will operate smoothly.

4.2.2 Loose Follower Gear

The loose follower gear problem may be linked together with the previous problem. This is likely the case since there is potentially a bit of a bend or a mis-alignment problem in the chassis framework and this could easily cause misalignment problems. The reason why these two problems appear that they might be related is since the follower gear took an entire afternoon of experimenting to work its way loose. Fig. 8 shows that the follower gear only worked its way partially loose. Even though the line crawler was still able to operate with this much distance between the meshing of the gears it is still a serious problem that needs to be addressed and monitored.

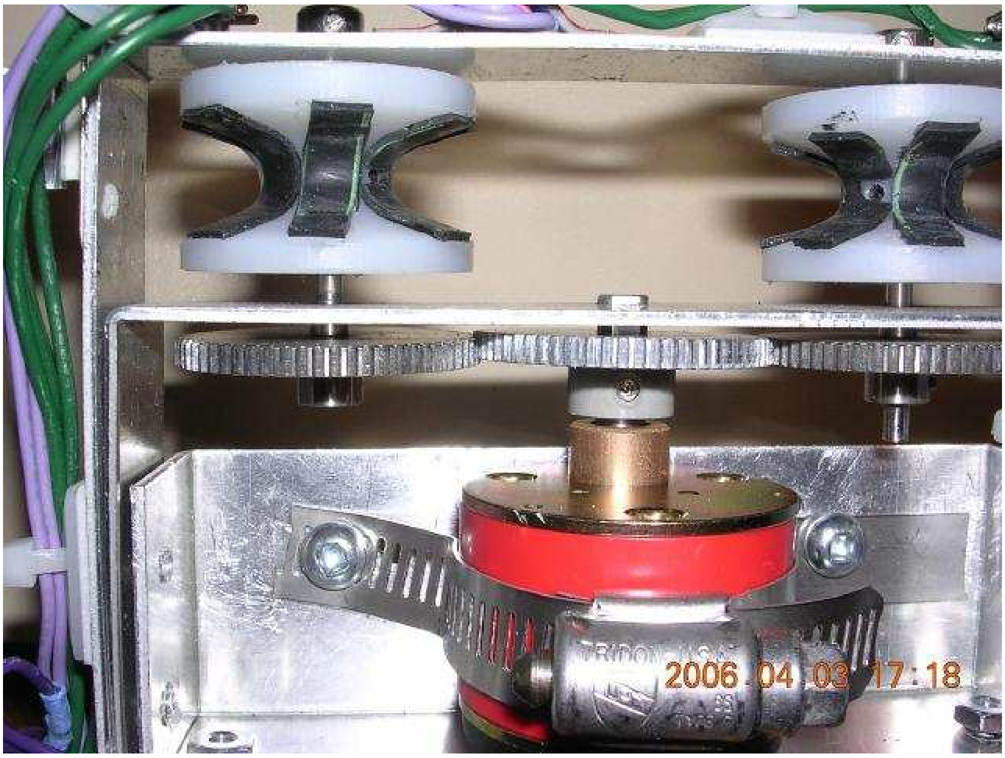

Figure 8: Follower Gear Working Loose

4.2.3 Uneven Drive Characteristics

The last problem relates directly to the dc motor as it occurs when the motor is connected to the drive train as well as when disconnected. Driving in the forward direction, the output torque provides a strong enough drive to move the line crawler. However, switching directions and moving in reverse yields substantially less torque.

This problem has not been explored in its entirety yet. There are two possibilities that we are currently exploring. The first possible cause of this problem might be related to an un-even driver in the H-bridge circuit. Our initial reason for thinking the H-bridge might be at fault is that we saw a similar problem with the previous motor as well. The second possibility which is looking more likely to be correct is that the gearmotors (planetary, high reduction ratio) in general may not move smoothly in both directions. This would explain why both motors exhibit the same problem although further testing needs to be done to prove this as of yet.

4.3 Locomotion Tests: Conclusion

Although there are still a few outstanding problems, the initial tests were a success. We have both still images and video footage that was gathered whilst performing some basic operations with the line crawling robot. Once the current set of problems with the locomotion drive have been addressed, more extensive testing will continue. This will lead into the expansion of the line crawler robot into the next stage of development.

5 Next Stage of Development

Once the current issues with the locomotion drive are sorted out, we are planning on building upon the idea of the individual line crawler robot. There are two ideas that we are currently planning on including. First, adding a second contact point to an individual robot with the sky wire will make the weight distribution a little more even. Secondly, the idea of having a multiple robot environment where there are several robots on the sky wire, able to communicate and help one another.

5.1 Multiple Contact Points

This is a natural extension to the line crawler based on the prototype experiments done using Lego Mindstorms during the early stages of the project. The initial design of the robot was top-heavy and difficult to control or demonstrate as it maneuvered on a clothes-line (simulated sky-wire!). Fig. 9 shows the Lego version of the original line crawler. When more contact points were added, this robot was far easier to control when investigating the possibility of moving around simple obstacles on the wire. Keeping this in mind, we

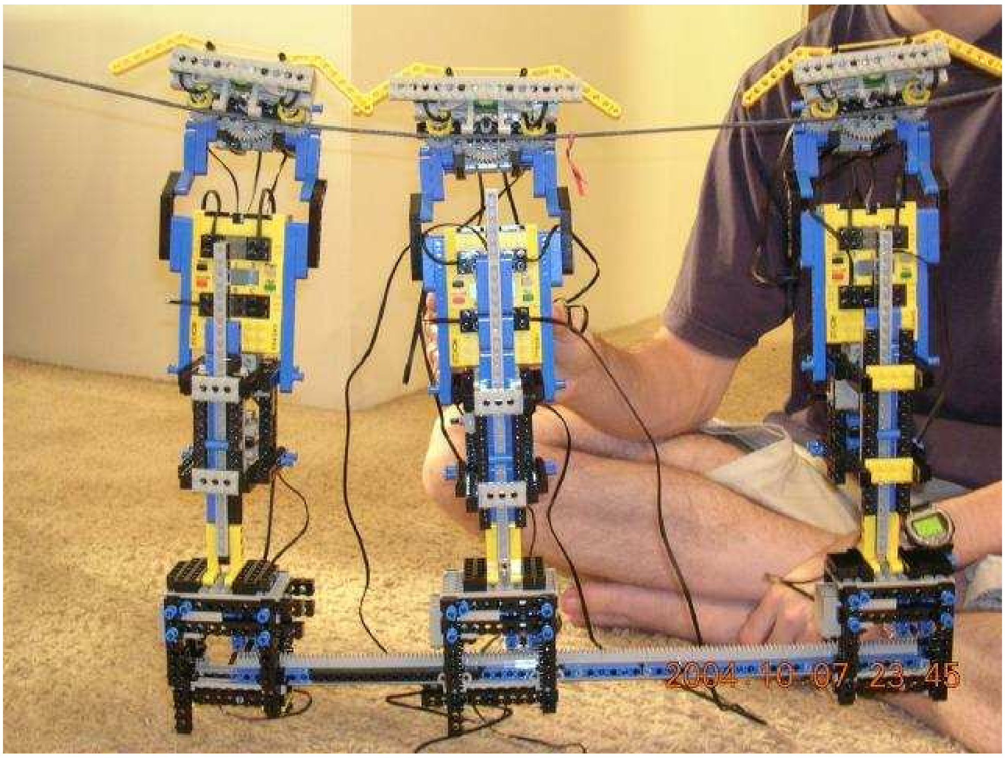

Figure 9: Original Prototype Lego Line Crawler With Multiple Contact Points

are interested in the possibility of expanding the current line crawler design to also have multiple contact points. Parts have been ordered to implement this idea as seen in the conceptual sketch, Fig. 10. The intent of moving into multiple contacts for the existing line crawler is to gain some of benefits that were discovered when working with the original Lego prototype from Fig. 9. The robot with added contact points was more sturdy and presented a safer environment for testing and working on the sky-wire. In addition to this, there is the possibility of adding an increased payload which would be more readily handled with an extra contact point and motor drive. The drawback to this approach is that more parts are required, which implies more weight gain and more power will be needed to drive the robot. This will reduce the survival time of the line

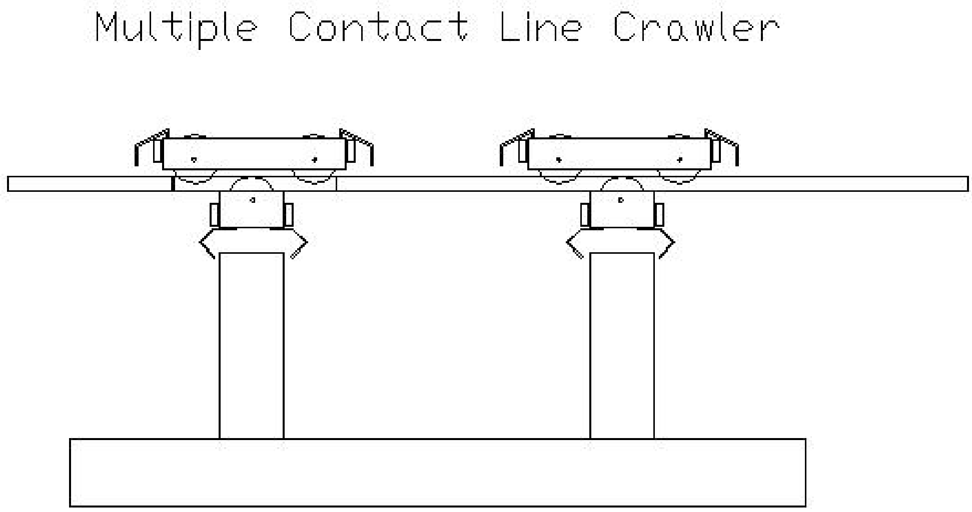

Figure 10: Conceptual Drawing of Line Crawler With Multiple Contact Points

crawler on the sky wire. This idea leads into to the next section which introduces cooperative robotics where multiple line crawlers work together to achieve things that the individual robots may not be able to achieve.

5.2 Multiple Line Crawlers

The concept of having multiple individual robots on the sky wire lends itself nicely to the idea of having them collaborate to achieve more than they could possibly do alone. This opens up a wider range of possible tasks since there are multiple sets of cameras, contact points, processing capabilities and communication links. Fig. 11 shows two robots already constructed.

Using the idea of multiple line crawlers there are several improvements in the capabilities that will occur. To begin with, we will have access to multiple cameras and this will provide us with an improved view of the surroundings during the line crawler's travels. In addition to this, having multiple robots with extra contact points with the sky wire will facilitate moving around obstacles. There are two main types of obstacles that were considered during the design and construction of the line crawler, vibration dampers and line clamps. Each obstacle has its own size parameters and respective pattern that would be necessary to circumnavigate it.

With the addition of multiple line crawlers and through cooperative robotics, obstacle avoidance can be achieved with the idea of linking a pair of robots, providing more contact points over a larger surface area of the sky wire. The result is a more stable unit that is capable of a much wider range of travel instead of being restricted to an individual section of wire.

The linking of robots will take place in stages, beginning with a hard-fastened connection that will not come apart to begin with and then moving into separate agents with connecting components. Both support the idea of separate entities working on the sky wire and collaborating to achieve a common goal. With this approach, more sections of sky wire and the associated power grid can be examined.

The sketch shown in Fig. 12 demonstrates how the line crawlers will connect together, initially. The plate underneath the platforms corresponds to separate aluminum beams that run the length of both platforms. Initially these will be connected with hardware, implying that the two robots will in fact be one connected

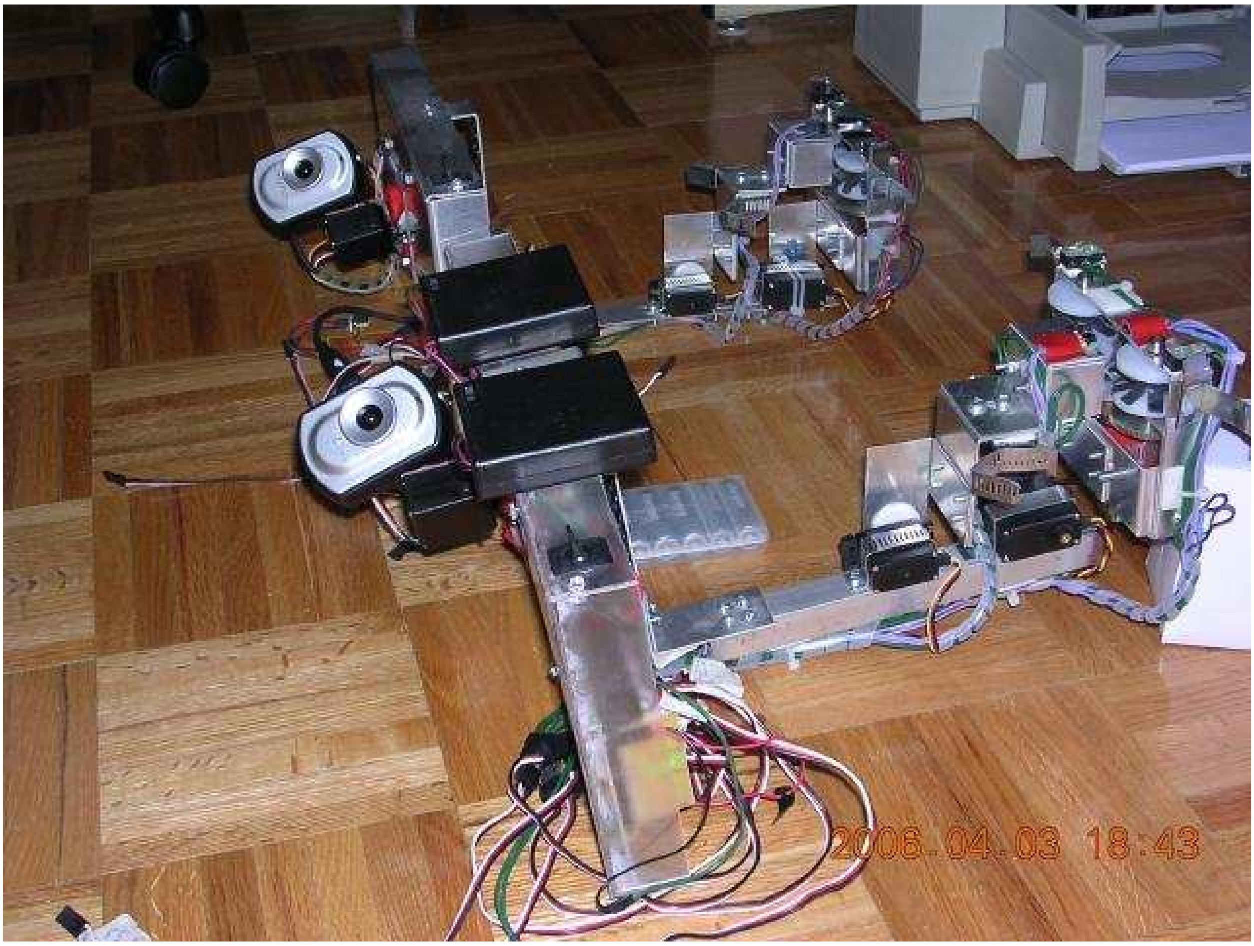

Figure 11: Two Line Crawler Robots

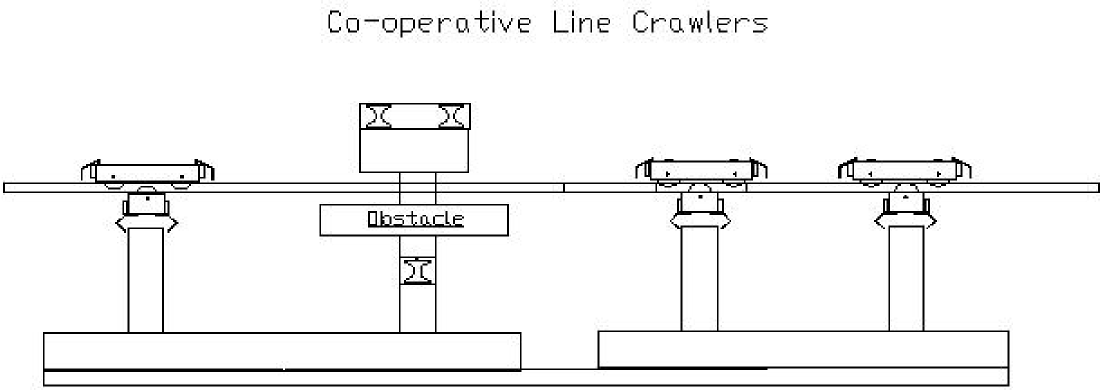

Figure 12: Co-operative Line Crawler Robots

unit. The plan is to start with fastened connections but eventually move to individual robots that are capable of docking with one another to achieve the same feat, thus leaving individual line crawlers on the sky wire.

6 Summary

This report focuses on the latest developments in advanced locomotion studies associated with the design of a line crawler robot. We have begun experimental work on the sky wire using a prototype, shoulder-high wooden tower tower setup. Before moving onto the next set of experiments, there are still several areas that need to be addressed with the locomotion drive first. Additional parts are on order to build multiple contact line crawlers in preparation for the next stages of ALiCE II navigation along a sky wire. In the meantime, work will progress on enhancing the behaviour and capabilities of an individual robot now that the structure has taken shape.

References

[1] D.Clark and M. Owings: *Building Robot Drive Trains*
McGraw-Hill Publishing, New York, NY, 2003