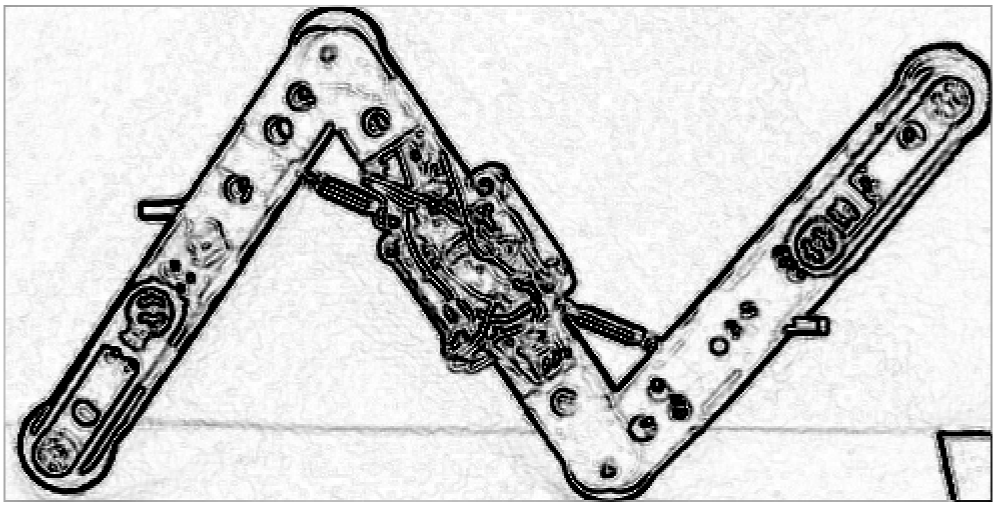
**EEL 5666: Intelligent Machines Design Laboratory**

# SLINKY



**An Autonomous Pipe Exploration Robot**

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## Abstract

An autonomous robotic vehicle that will explore the inside of a six to eight inch pipe will be designed, built and tested. The robot will change its configuration "on the fly" when travelling between pipes of varying diameters. The robot will be able to travel back and forth inside the pipe. The robot will feature infrared emitters and detectors for obstacle avoidance.

## Executive Summary

A robot was created that would travel inside a pipe of varying diameters. The robot was built using segment of equal length. The robot adapts itself to different pipe diameters through the use of springs mounted on the outside of the segments. The robot uses infrared detectors and emitters for collision avoidance. The robot also uses a single chip Microcontroller board purchased from Novasoft™. The robot also employs two servos hacked as servomotors. The robot was programmed to exhibit collision avoidance behavior as well as pipe diameter adaptability.

## INTRODUCTION

American industry is faced every day with problems in fluid systems. These systems vary from simple, low-pressure air control systems to high energy, high-temperature main steam systems usually found in electrical generation plants. The pipes servicing these systems could face problems such as blockages, internal wall erosion, and even cracks. Current investigative methods are bulky, not easy to use and expensive. Slinky, the autonomous pipe exploration robot, is the answer to these problems.

Slinky is a small, completely autonomous, and cheap robotic platform. The Slinky design project will construct a small robot that will travel in a six to eight inch pipe. The robot will be completely autonomous. Slinky will be able to change "on the fly" from six to eight inch pipe diameters. Slinky will also exhibit simple collision avoidance. This paper will introduce the Slinky system, this will include the mobile platform, robot actuation, mechanical and electrical sensors, and programmed behaviors.

## MOBILE PLATFORM

The Slinky system consists of several separate components pieced together to form a complete autonomous pipe exploration system. The most important of these is the robot platform. Slinky's mobile platform is designed to fit in a six or eight inch pipe. The robot will be able to travel back and forth inside the pipe. Slinky's design allows it to expand or contract to fit either a six or eight inch pipe. The Slinky project went through two different design iterations.

**First Design Iteration**

Slinky’s first platform design was generated to test the feasibility of using spring-loaded segments. In the first design the springs were located between the outer and inner segments, in a sandwich arrangement. Slinky’s first design only employed a single thickness of aircraft plywood.

Figure 1 shows the general arrangement of Slinky’s first design. The single chip computer board is located in the center segment. The batteries are also located on this segment but on the underside of the board. The two outer segments contain the servos. The servos are attached to the tires via a gear, which is attached to the servo and the tire. A plastic Lego chain connects the servo gear and the tire gear. The body was designed using AutoCAD. The ensuing design was then imported to the T-Tech milling machine as a HPGL drawing.

**Lessons Learned from Design 1**

Testing of the first design pointed out some of the limitations of the proposed design. The joints were not strong enough. They tended to wobble and therefore caused the robot to rotate and flex inside the pipe. Also the battery pack, which was an unmodified six pack, projected to far from the underside of the robot.

The servos where only mounted on one thickness of plywood. This caused the servo to flex. This flexing would cause the plastic chain to skip or jump the gear.

**Second Design Iteration**

The second design was generated to address some of the problems encountered in the first design. Figure 2 shows what the second design looks like.

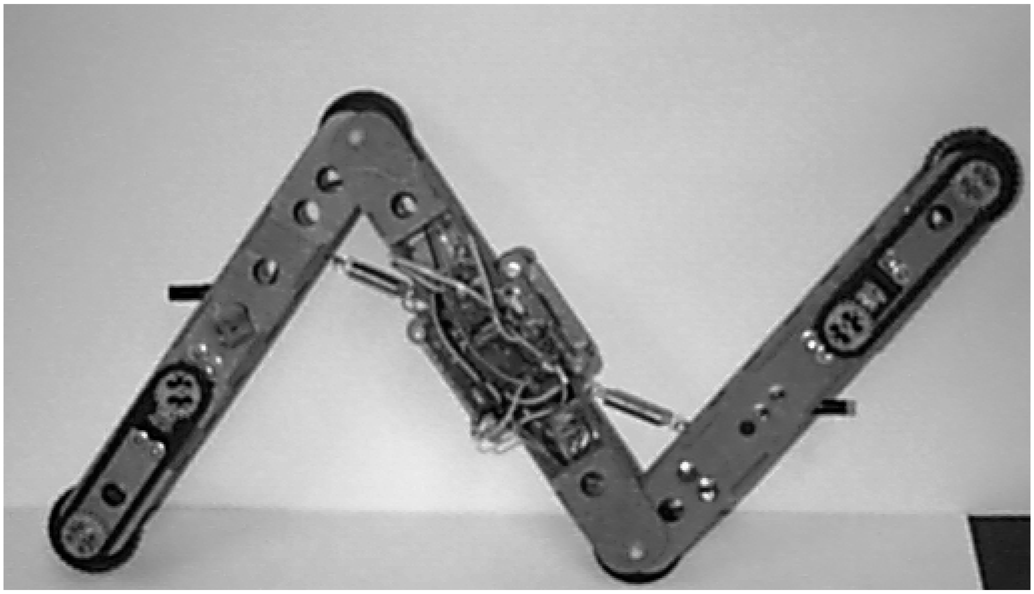

**Figure 2**

As can be seen in the above figure, the second design kept the same configuration as the first design. The body was redesigned in an effort to strengthen it. A box like shape was used to add stiffness. This shape was then filled with holes to lighten the entire structure.

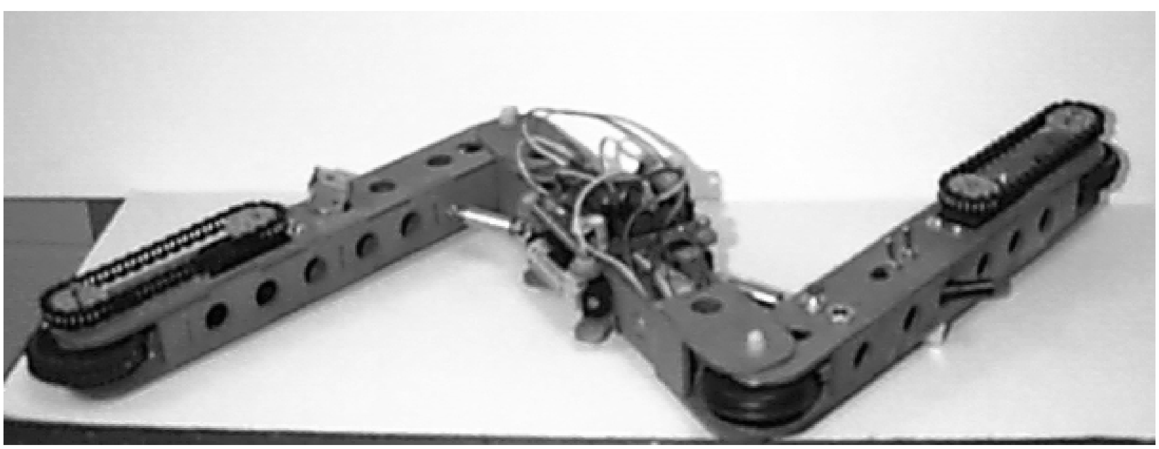

**Figure 3**

Figure 3 shows a side view of the second design iteration. The lightening holes can be seen on the segment sides. This box like shape also allowed the routing of all wires on the inside of the robot.  This prevents the robot from being snagged by any protrusions inside the pipe.  The battery pack on the second design has been set inside the middle segment, with only two single cells being located on the outside.  This arrangement can be seen in Figure 4.

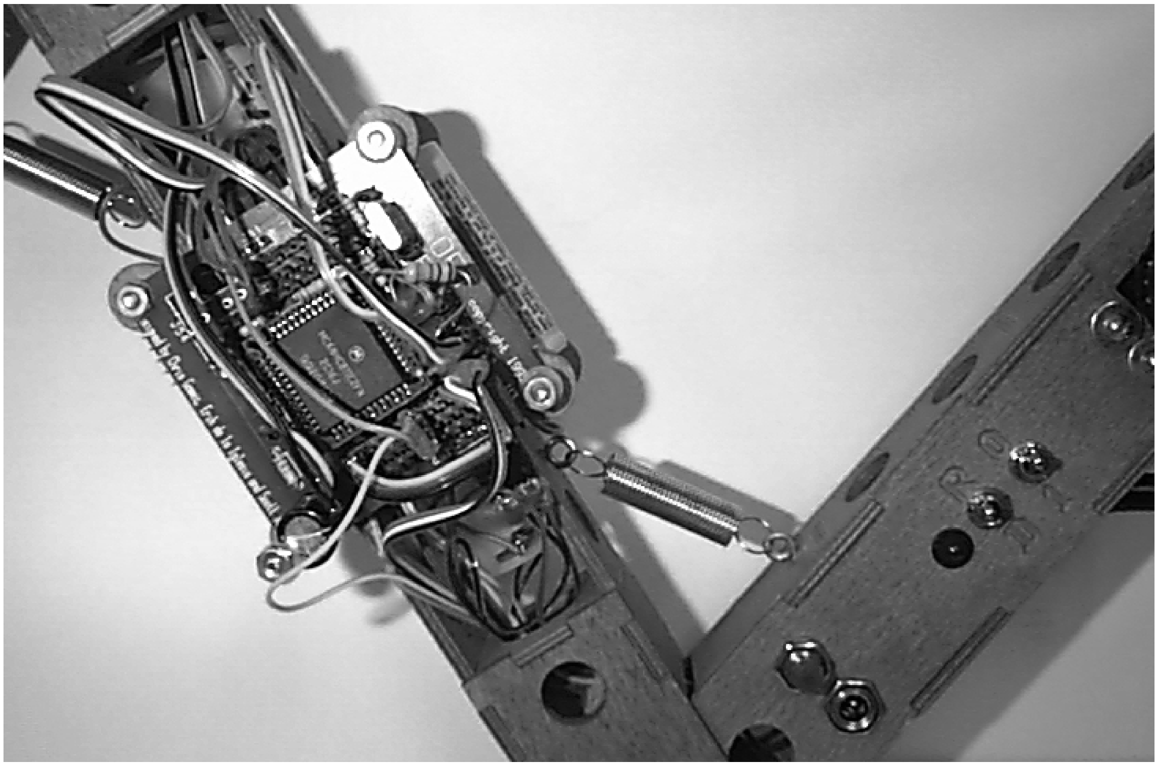

**Figure 4**

The above figure also shows the new placement of the springs.  In the first design, the springs were modified heavy-duty safety clips.  The second design incorporates utility springs.  The amount of tension is controlled by the diameter of spring utilized.  For six to eight inch pipe a spring diameter of 0.30 inches and one inch in length was used.  The use of tabs in generating the new design allowed assembly with out any adhesive of any kind.  Epoxy was used to impart more strength to the design

**Lessons Learned From Design 2**

During the testing phase of the second design, it was noticed that the robot did not have enough traction to move down the pipe. The pipe used was a six-inch sewer pipe. Different tire types were tried and different springs were employed. It was determined that stiffer springs with a "tackier" tire were the best combination for successful pipe navigation. A deep "tank" tread was attached to the tire to enhance its gripping power.

It was also determined during the testing phase, that the robot was still too big for its intend job. The robot electronics and propulsion system need to be smaller. The robot as designed fits snuggly inside the six-inch pipe.

**Robot Actuation**

Slinky's main job is to travel back and forth inside a pipe. Slinky accomplishes this task with the help of two servos, which have been "hacked" as servomotors. This is the same hack featured in the TJ© robots from Novasoft™. The servos are attached to the two outer robot segments. They are firmly attached to the robot with fasteners and by the encapsulating nature of the box-like design. The servos each drive a chain sprocket attached to the servo and to the handmade shaft. The two sprockets are then connected together via a plastic Lego™ chain. The shaft drives a 1.75" Dubro™ plastic tire obtained from a local hobby store. The wheel is firmly attached to a steel shaft using a two-component epoxy.

The inner wheels are mounted in a free-wheel configuration. The wheels spin normally in either direction of travel. This method of actuation proved to be successful. The only problems noted occurred during the testing of the second design iteration. Lack of traction forced the search of different tire designs. Deep-treaded tires were looked at. Once design that was looked at was the attachment of rough grit sandpaper to the tire.

**Mechanical and Electrical Sensors**

The Slinky robot is supposed to travel up and down a pipe without hitting any obstacles and pipe caps that lie in the path of the robot. To accomplish this, Slinky will be outfitted with an array of infrared emitters and detectors. Computer code was generated to allow Slinky to use the information obtained by these sensors.

The final version of Slinky has a pair of infrared emitters and detectors. The emitters are mounted next to the Sharps detectors. The Sharps detectors have been hacked in the project. The reason for this is that the Sharps detectors provide a digital signal. The hack essentially turned the output from digital to analog, for subsequent input into the analog ports of the Single Chip MC68HC11 Microcontroller Board.

The sensors were mounted facing the “front” and “rear” of the robot. In the first design, the emitters were not collimated. Due to the enclosed environment, IR transmitters generated a lot of splash against the pipe walls. This problem was fixed by collimating the IR beams.

A mechanical sensor in the shape of a spring was also utilized. This spring allowed the robot to expand or contract to fit the pipe walls. The springs in a sense allowed the robot to sense and detect the pipe walls.

**Programmed Behaviors**

The final design of Slinky exhibits only two behaviors. One of the behaviors is that of obstacle avoidance. This is accomplished with the input of the IR detectors mounted at the front and rear of the robot. The behavior is set up so that the robot will stop rather close to the pipe wall/cap or obstacle and then go backwards in the other direction. A speed table was setup in memory so that as the robot approached the end, the IR detectors would return an ever-increasing value. Depending on the value returned, a value from the speed table would be inputted to the servos. This would cause the robot to slow down as it nears the obstacle, and therefore prevent it from quite possibly crashing into the obstacle.

The second behavior is that of size adaptability. This is accomplished using the springs mentioned in the previous section. The springs allow the robot to flex and adapt it self to varying pipe sizes.

**CONCLUSION**

This project has been a very good learning experience. Several issues still remain to be addressed. Primarily, the issue of traction needs to be solved. Machining the wheels out of aluminum and covering them with a sticky rubber compound is currently being investigated. The second design proved to be very successful in nature. The added stiffness and strength where needed to ensure the robot would be able to accept the mounting of a remote video camera and diagnostic equipment, which are to be added in future work.

## APPENDIX

Slinky Avoid Program Code Attachment 1