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THE CLIMBING CRAWLING ROBOT
(A UNIQUE CABLE ROBOT FOR SPACE AND EARTH)

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ABSTRACT

Some of the greatest concerns in robotic designs have been the high center of gravity of the robot, the irregular or flat surface that the robot has to work on, the weight of the robot that has to handle heavy weights or use heavy forces and the ability of the robot to climb straight up in the air. This climbing crawling robot handles these problems well with magnets, suction cups or actuators. The cables give body to the robot and it performs very similar to a caterpillar. The computer program is simple and inexpensive as is the robot. One of the important features of this system is that the robots can work in pairs or triplets to handle jobs that would be extremely difficult for single robots. The light weight of the robot allows it to handle quite heavy weights. The number of feet give the robot many roots where a simple set of feet would give it trouble.

INTRODUCTION

Through the years it has been difficult for robots to maneuver because the robot has a high center of gravity and the precision of its accuracy depends upon the angular rotation and the necessity of the grippers to precisely mate with and grab a target. This concept was developed first as a method for climbing, stripping and painting towers that were many feet off the ground.

An individual element is shown in Figure 1. It consists in two "U" structures held together by two circular cables. It is mounted on a magnet shown at the far left. The mounts for individual elements could be magnets, suction cups, grippers or wheels. The electronics are not shown but it will be discussed later.

FORWARD MOTION

The individual elements described in the introduction are attached by circular elements with a hole down the center to carry the air and the DC current. Eventually these elements will index left and right so that the robot can reach any structure in space with the proper orientation to move on.

The forward motion is shown in Figure 2. Step 1 shows the actuators in neutral while the magnets are all firmly attached to the structure. In step 2 the Number 1 magnet is released while its actuators are extended. Then the number 1 magnet is firmly attached. In step 3 the No. 1 and number 3 magnets are held while the number 2 actuators are extended. The number 1 actuators are limber. The number 3 actuators are held. In Step 4 the no.1 and no. 2 magnets are held while the no. 2 actuators pull no 3 along. This is just one sequence of motions. There are many more.

Figure 3 shows the robot going over an obstacle. This maneuver is accomplished by taking the first element and lifting it off the ground while the no. 2 element is held firm. Then the no 3 element lifts the no. 1 and no. 2 elements off the ground. This is continued until the first element goes over the obstacle. When the no. 3 and no. 4 elements go forward the number 1 elements has their actuators go into neutral. As it goes further the no. 1 element bends the other way until it strikes the structure. Then the forward part of the robot lifts the back parts over the obstacle.

There are many other maneuvers not discussed here. such as a climbing turn and lift. These get more complex. The feature that makes all of these maneuvers perform so well is that all of the robot is not standing on two or three grippers to perform a function.

CABLE ROBOT CONTROL ARCHITECTURE

This prototypes a standard off the shelf controlled which is generally used for the automated machine industry. The controller allows up to 16 outputs (on/off) and 8 inputs. A personal computer acts as a 'dumb' terminal, communicating to the interface controller in Figure 4. The programmer sends programs to the controller from the personal computer via serial links. The interface controller then executes the programs by simply stepping through the instructions. The instructions consist of 'states' that the outputs can be in during each step of the program, and its duration. Since the prototype will have a given number of known states, it is a simple matter to organize these states into coherent programs which will allow the Cable Robot to walk forward, grasping with the electromagnets at the appropriate times, and extending or retracting the segments in turn.

As example of a program to move the forward two magnets forward is as follows: (1 = actuator extended or magnet on)

STATE:	1a	1b	2a	2b	3a	3b	4a	4b	4c
Module 1:									
Act 1	0	1	1	1	0	0	0	0	
Act 2	0	1	1	1	0	0	0	0	
Act 3	0	1	1	1	0	0	0	0	
Act 4	0	1	1	1	0	0	0	0	
Magnet 1	0	0	1	1	1	1	1	1	
Module 2:									
Act 5	0	0	0	0	1	1	1	0	
Act 6	0	0	0	0	1	1	1	0	
Act 7	0	0	0	0	1	1	1	0	
Act 8	0	0	0	0	1	1	1	0	
Magnet 2	1	1	1	0	0	1	1	1	
Module 3:									
Act 9	0	0	0	0	0	0	0	0	
Act 10	0	0	0	0	0	0	0	0	
Act 11	0	0	0	0	0	0	0	0	
Act 12	0	0	0	0	0	0	0	0	
Magnet 3	1	1	1	1	1	1	0	0	

Note: This would be a "2/3" step forward, since the actuators in the third module never extend. Other sequences would allow larger steps to be taken, but for demonstration purposes, this will serve.

The prototype controller will allow the states to be changed as often as ten times a second, so that the above steps would take about a second. If we allowed the electromagnets to 'trade' in one program step, then steps 2b and 4a could be eliminated. This would allow the prototype to walk about 5 feet per minute.

Additional prototpype experiments would include inclined walk programs and turning walk programs in which two of the four actuators in a module would be extended while the other two are retracted. This allows an angle to be developed in any of four planes in the module: up, down, right, or left. The actual angle developed depends on the stroke of the actuator and the construction ratios of the module cable joint.

Connected to the computer outputs are circuits which convert the digital logic signals to coil drivers which actuate the miniature air valves for the cylinders. The same coil drivers will drive relays to turn on or off the electromagnets. The digital side is protected by opto-isolators, and the relays are protected by snubber circuits.

The computer program in the prototype will have several demonstration modes:

- Walk forward
- Walk backward
- Make right turn
- Make left turn

The modules can be outfitted with any one of a number of capabilities. Just a few are listed:

- Gripper actuation (as alternative to electromagnets)
- Vacuum cup (As alternative to electromagnets)
- Camera control (pan, tilt, focus, etc.)
- Sand blast
- Paint chipper
- Air blast cleaner
- Brush clean
- Vacuum cleaner head
- Paint (spray, roller, brush applicators)
- Sensor mount (metal detector, Distance measurement, etc.)
- Energy storage (battery, air cylinder)
- Radio communications
- Cable payout/retrieval

The modules can be made to operate under water with appropriate sealing of the electronics and using water or hydraulic actuation fluids. Bellows type covers can be fitted to protect from paint spray or sand blast damage.

Applications for this robot include:

- High tension wire tower (inspect, dye penetrant, weld, paint and repair)
- Drill rig inspection and repair
- Building air duct inspection/cleaning
- Overhead crane inspection
- Piping inspection (dry or wet)
- Hazardous waste container inspection and clean out
- Surveillance camera positioning
- Bridge girder inspection, repair and paint
- Radio tower inspection, repair and paint
- Ship's tanks inspection, repair and paint
- Boiler inspection, repair and paint or clean.

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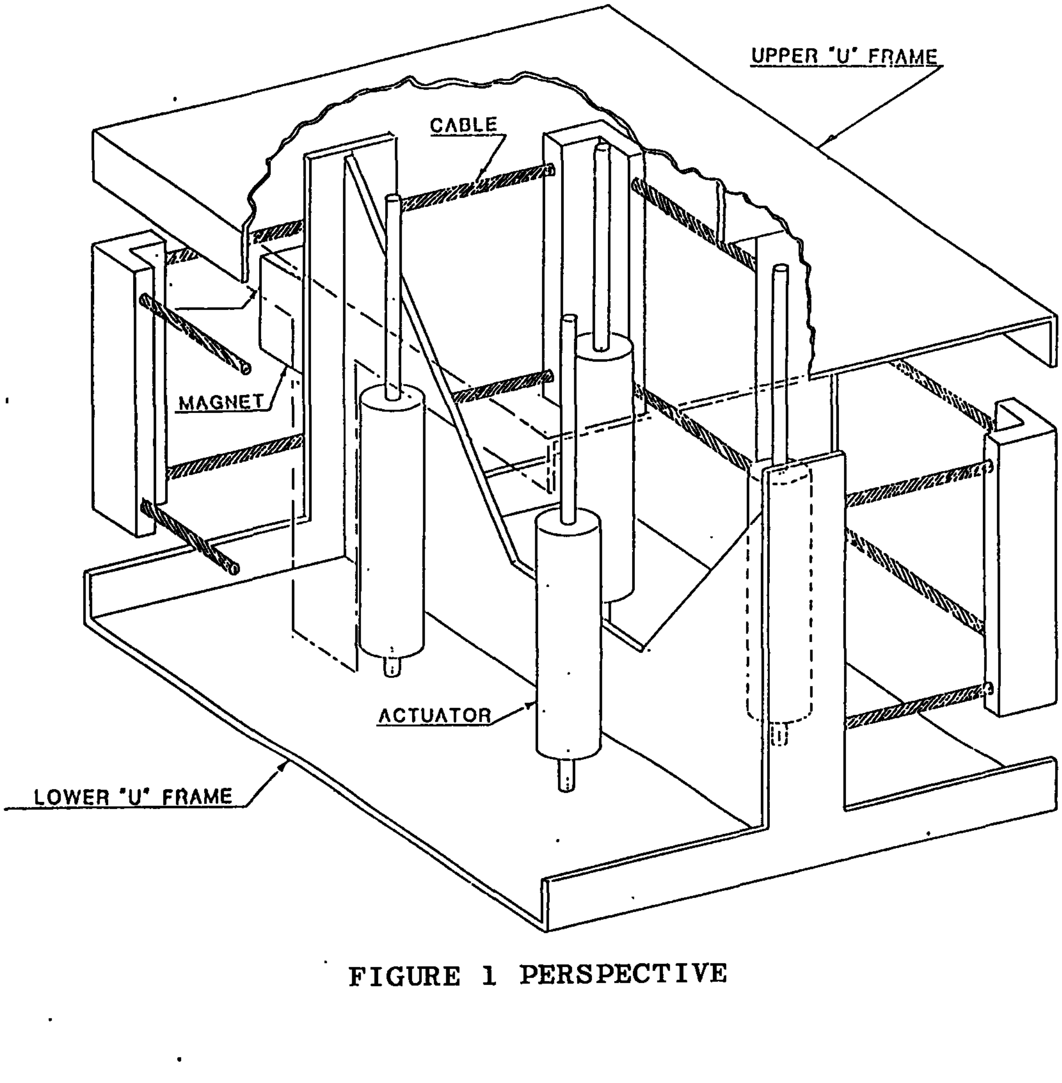

FIGURE 1 PERSPECTIVE

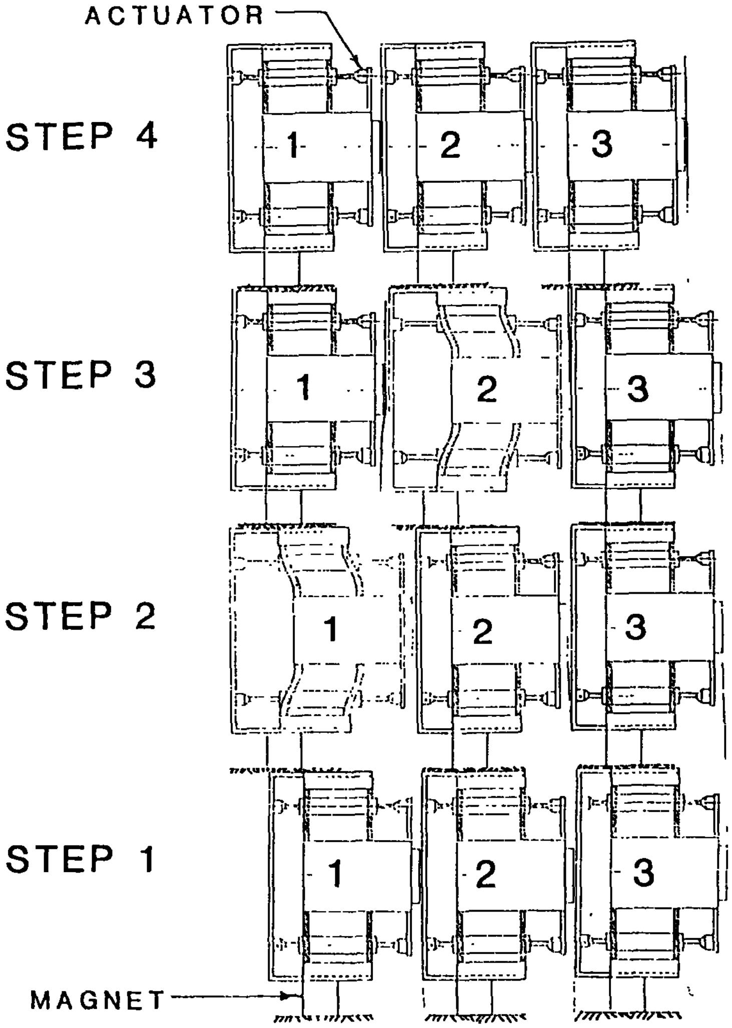

FIGURE 2 MOTION

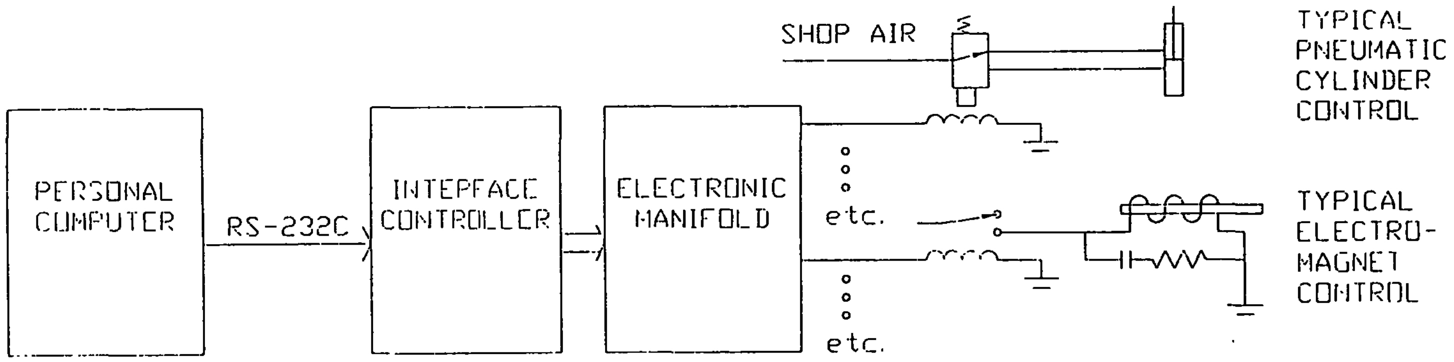

FIGURE 4 ELECTRONICS

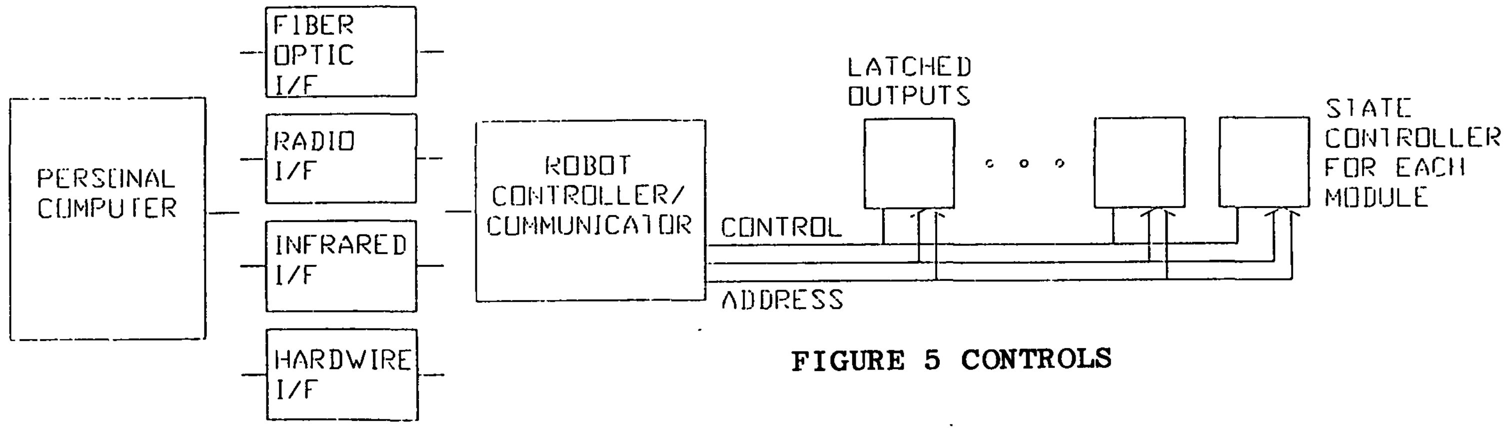

FIGURE 5 CONTROLS

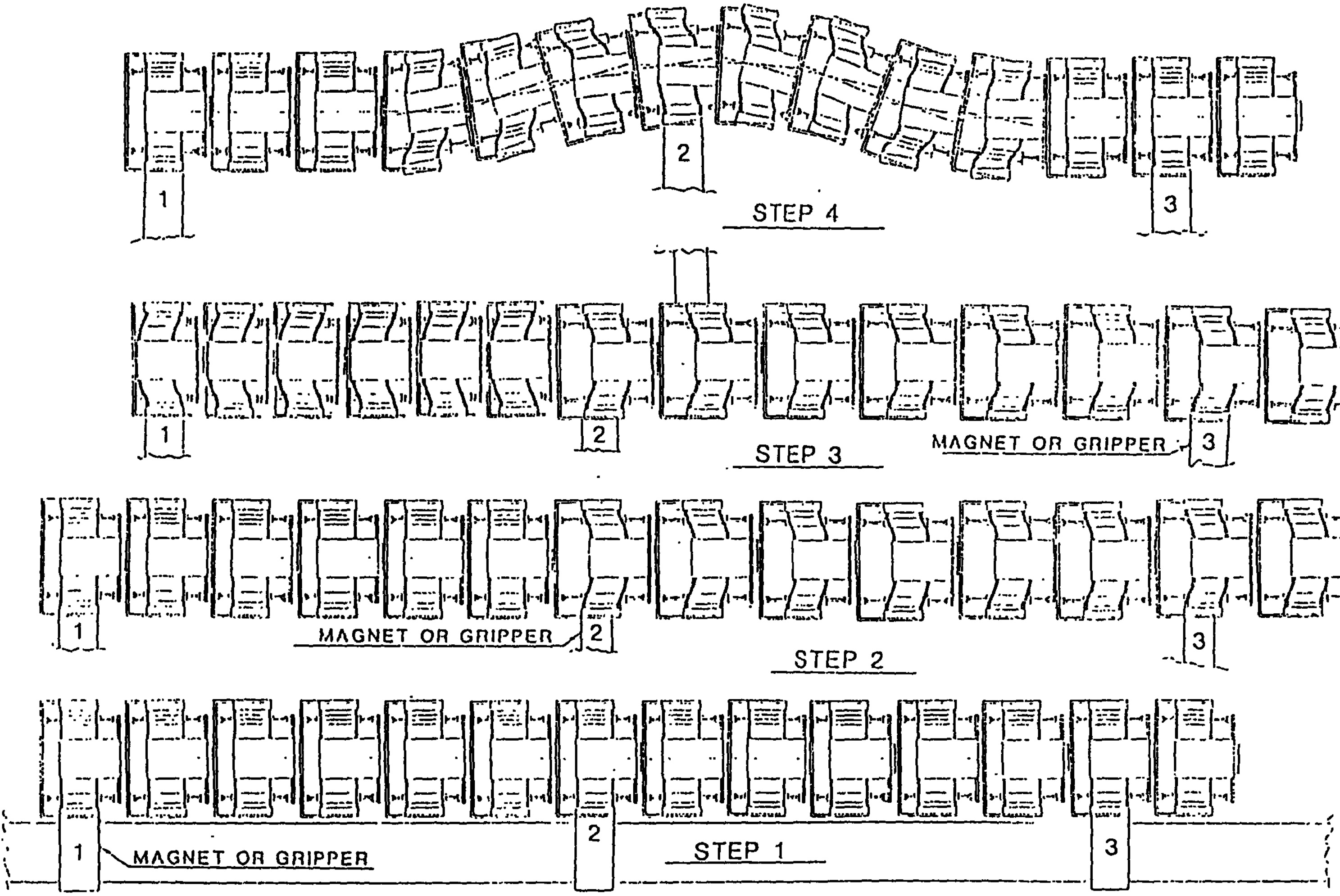

FIGURE 3 OVER AN OBSTACLE