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Control Strategies for Vertically Wiggling Snake Robots

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Abastract
Most of the terrestrial mobile robotic systems developed use wheels or limbs as their propulsion elements. Biological snakes' locomotion is very interesting because it allows moving through narrow paths, uneven surfaces, or overcome obstacles. The physical serpent structure and their locomotion capabilities era reproduce in the articulated chain robots. The paper presents a project on snake-like robots developed at the Universidad Javeriana, and discusses the design aspects and experiment results of ANA-II and 4N: vertically wiggling Snake Robots. A comparison of two control strategies is done: In ANA-II a master – slave control has been developed, and in 4N a distributed control was implemented.

Keywords
Articulated chain, mobile robots, modularity, master–slave architecture, distributed control.

1. Introduction

Serpentine locomotion and snake-robots are a new study area which researchers are beginning to explore. This paper presents two snake-like platforms developed at the Universidad Javeriana in 2005. The advantage of working with bio-mimetic articulated chains and implementing serpentine locomotion is the ability to move through narrow paths, uneven surfaces and overcome obstacles. Wheeled or legged platforms, which have been use to perform these tasks, have develop some problems, opening applications on mobile robotics that have not been explored yet. The physical serpent structure and its locomotion capabilities are reproduced in articulated chain robots.

Natural disasters, such as earthquakes, provide evidence of the technical failure of the tools used to attend to these catastrophes. In the future, a bio-inspired robotic platform could work in these circumstances. In these situations, human loss and endangerment of lives are inevitable. One of the most important applications of articulated chains is the victim's rescue, where the process can be accelerated and the number of people at risk can be diminished. Another application for a snake robot is the exploration of pipelines for maintenance or reparation. Pipelines are narrow paths where a wheeled or legged platform would fail while trying to move through whereas an articulated chain will succeed.

The work on articulated chains at the Universidad Javeriana started five years ago when the snakelike robot ANA-II was developed. ANA-II is a fully functional robot with master-slave architecture. This was a first approximation, which helped to understand the reproduction of the simplest snake locomotion method, the rectilinear gait. While developing the project some limitations where found; the platform has some restrains in terms of motion sequence execution, due to the lack of information that is needed by the platform to generate these movements. It was concluded that in order to increase the complexity of the movements executed by the articulated chain, it was necessary for each segment to have information about its surroundings, about the structure, and about itself. Also, it was very important that each segment had the ability to make decisions about what action to take for a given input.

From these concerns a new project arises. The next step was to replace the master-slave architecture, for a distributed control one. By doing this each segment would have the ability to make decisions from the information gathered about the state of each of the other segments and the executed movements. The development of the new control strategy was implemented in the new snake robot 4N.

This paper presents a brief state of the art, the description for both snake robots ANA-II and 4N and their control strategies, followed by a discussion comparing both architectures, master-slave and distributed control, and the conclusions drawn from this work.

2. State of the Art

In this section, some of the developments found on the field of snakelike robots are briefly presented. These projects were taken into consideration when developing ANA-II and 4N.

The work in articulated chains with serpentine locomotion began in the early 70's. In 1972, Hirose (Hirose and Morishiman,1997) focused his work on platforms that could perform lateral undulation, and later he developed a series of wheeled coupled-mobility devices to improve the movement of the articulated chain. He termed the devices Active Cord Mechanisms or ACM's.

Shan (Shan et al., 1997) also worked with articulated chains. He focused his work mainly in obstacle accommodation: he used obstacles to help propel the structure and not just to avoid them. He accomplished this by using concertina mode that required a great deal of space.

In 1995, the Japanese company, NEC, developed an articulated chain called Orochi. This work was designed mainly to search for survivals after earthquakes and explosions making this process safer. The device used an active universal joint, which was derived from a Hooke's joint and developed by Ikeda and Takanashi (Ikeda and Takanashi, 1997).

Martin Nilsson (Nilsson and Ojala, 1997) of the Swedish Institute for Computer Science in Sweden, as part of the PIRAIA project, developed a new serpentine universal link. This gives the robot the ability to perform some non-snakelike locomotion modes that incorporate rolling movements. The platform would have the possibility to "hug" a tree and then roll up the tree.

Karl Paap (Paap, et al., 1997) and his group at GMD (GMD-SNAKE) in Germany developed a snakelike device, which develops real time control. The structure uses tensors combined with a short section of cable winding to give the curvature the device required.

LS Robotics built a snakelike machine called Kaa (Desai, et al., 1997). It was designed to move through network of pipes and support structures. This was one of the first prototypes to be a self-contained unit. It uses RC-servos as actuators; Kaa has a straight-line motion on flat surfaces.

3. Description

At the Universidad Javeriana, two projects had been developed in articulated chains, ANA-II and 4N. In this section of the paper the description of both snake robots is presented. A brief physical description and the development of the control strategy for ANA-II and 4N are found below.

3.1 ANA-II Project

ANA-II (Figure 1) is a five interconnected modular segments articulated chain. Each segment has two degrees of freedom; one on the vertical axis and one on the horizontal axis (see Figure 2). A micro-controlled Master circuit does the platform's control. The master unit has a serial communication (I2C) with the micro-controlled circuits in each of the segments. These segments are called Slaves. These modules are in charge of generating movement sequence and controlling the actuators positions that propel each segment of the chain. The Master indicates each Slave which sequences it must perform to generate the serpentine locomotion.

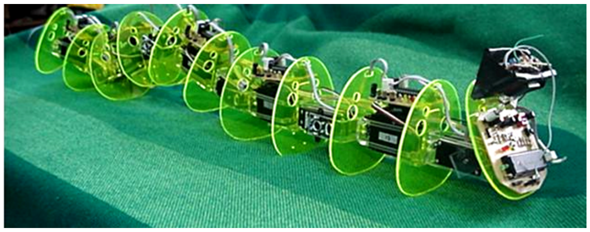


Figure 1. Mechanical structure ANA-II

The serpentine locomotion implemented in ANA-II is the rectilinear mode (Lissman, 1997) with the capability to make turns and manipulate the direction of the platform (forward or backward).

ANA-II is a well-built platform that allows controlling the position of each segment in its vertical and horizontal axis. This is possible due to the mechanical structure of each segment built with two actuators (servomotors). The development has given the platform freedom that enables it to control and supervise the motion from micro-controlled modules in each segment of the chain. To achieve this goal, the modules were built so that the execution of the motion sequence does not depend on an external computer, but depends on the communication and the information shared between links. A general description of the master/slave modular implementation followed by the sequences description is found below (see Figure 3).

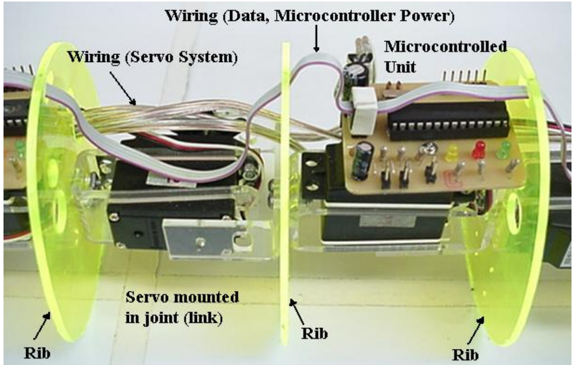
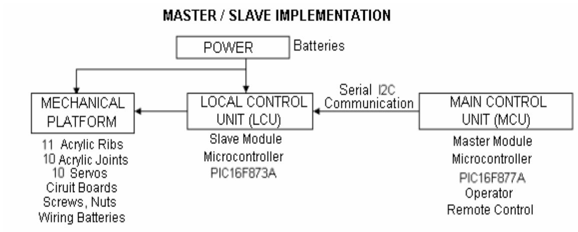


Figure 2. Lateral view of ANA-II's segment

ANA-II was conceived and constructed based on the modular concept. It has the advantages of any modular design, easy reproduction, assembly, and maintenance. The platform's modular design allows modifying the control system of each segment, giving the robot the flexibility to expand its capabilities without any changes in hardware. Also, the platform can increase or reduce its size without substantial changes in architecture.



A master unit and five slaves units constitutes the system. Each slave unit is in charge of the position control of the segment's servomotors. The operation of the slaves units is independent from each other, and the master unit is in charge of conducting the chain's performance.

The master and slaves flowcharts are described below.

Figure 3. Block diagram of the master-slave implementation

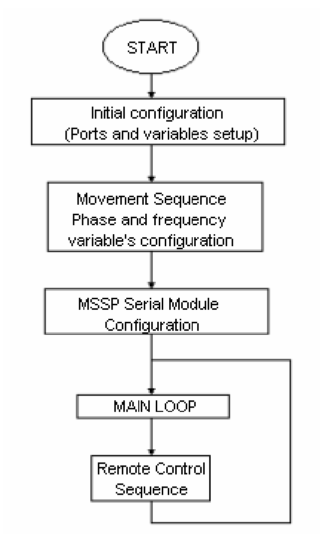


Figure 4. Master module principle flowchart

Fig. 4 shows the master module principle flowchart. First the initial configuration is done. Afterwards, it enters a loop where it waits for the signal coming from the transmission module. When the information is received, the master sends the sequence to the slaves.

Figure 5(a) shows the subroutine in charge of analyzing the action sent by the operator while figure 5(b) shows the subroutine in charge of sending the information to the slaves.

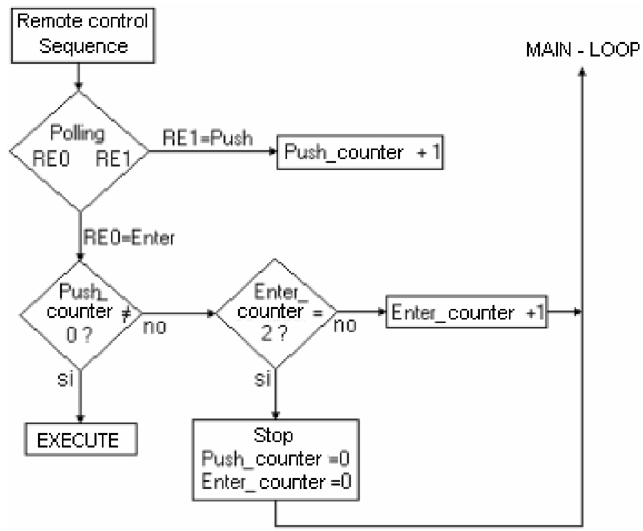


Figure 5(a). The subroutine in charge of analyzing the action sent by the operator

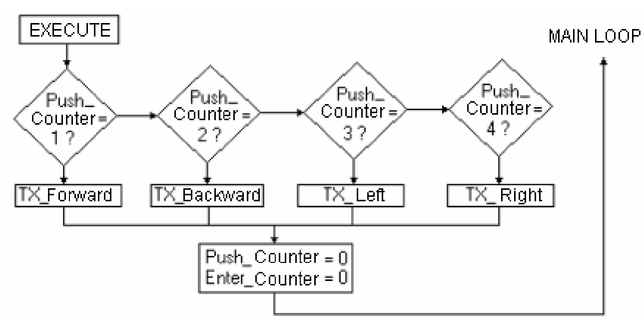


Figure 5(b). The subroutine in charge of sending the information to the slaves

The serial communication is done by interruption. The master unit indicates when the movement should start, and it does this by interrupting the slave operation so that it could be attended.

Figure 6 shows that the slave unit is always reviewing the command that it is executing at any given time. It allows the necessary changes in each segment when the master unit issues the command.

When the master unit receives the signal from the remote control it evaluates the action to take which is translated into a forward or backward movement. The master unit will then send the information to each of the slaves' modules and the slaves' modules will execute the given command. The slaves' modules do not make any kind of decisions, they just execute the commands.

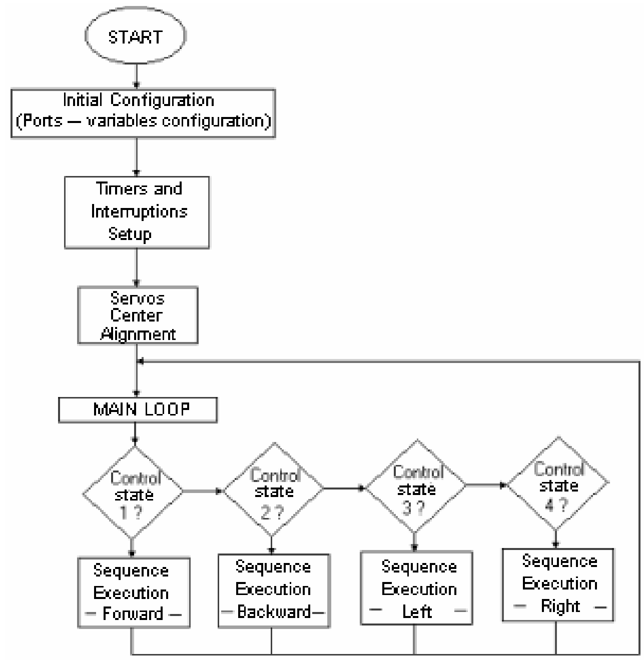


Figure 6. Flowchart that shows the slave unit always reviews the command that it is executing

3.2 4N Project

The snakelike robot 4N is a four interconnected segments articulated chain (see Figure 7). Each segment has two degrees of freedom; one on the vertical axis and one on the horizontal axis. A distributed control strategy was developed and implemented in the platform 4N (see Figure 8). Each segment has a micro-control unit which is in charge of controlling the motion sequence of the segment and communicating with all other segments. There is an extra module which is in charge of giving the different commands to the structure and is called COMMAND UNIT. These five units have serial communication (USART) with each other.

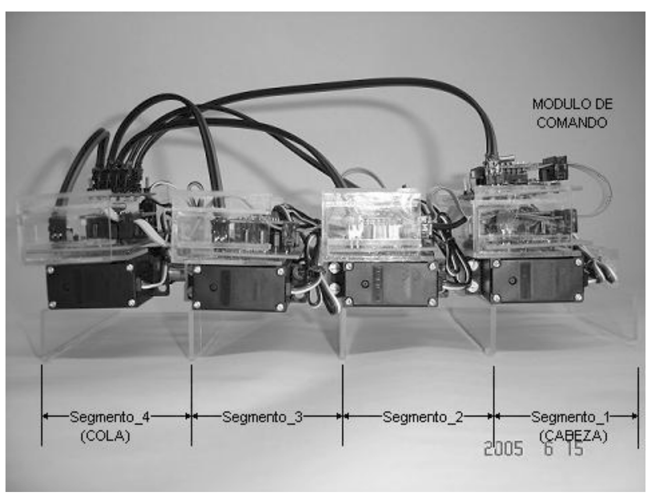


Figure 7. Mechanical structure 4N

4N was conceived and constructed based on the modular concept. It has the advantages of any modular design, easy reproduction, assembly, and maintenance. The platform's modular design allows modifying the control system of each segment, giving the robot the flexibility to expand its capabilities without any changes in hardware. Also, the platform can increase or reduce its size without substantial changes in architecture.

Figure 8. Lateral view of 4N's segment

Each control unit has a microcontroller which is in charge of controlling the position of the servomotors belonging to its link. Each control unit is completely independent of the rest and of the COMMAND UNIT. The control unit is in charge of communicating with the others control units to share information about the motion they are executing. The COMMAND UNIT gives the commands for the different sequences: FORWARD, BACKWARD, and STOP.

To develop the control strategy, it was necessary to understand the motion sequence which was to be implemented. The implemented sequence was chosen after the evaluation of the previous work done in ANA-II. This motion sequence has already been validated, and it is known to work.

The control strategy is based on the communication protocol, and this has been inspired in token passing protocols. In the communication net, the information is available to all of the segments. All of the control units receive what each of them transmits, but not all of them respond. Only after the one immediately before has spoken, it transmits. They all share information about the sequences they are executing, and about the state of the segments i.e. whether they are working properly or they are malfunctioning.

The flowchart for each control unit is shown in figure 9. After initializing and performing the motor alignment, the control unit enters an infinite loop. In this main loop, the control unit checks first if there is a malfunction in any of the segments of the structure. If there is not a malfunction flag, the control unit looks at the new instruction register. If there is a new instruction it goes and executes it. If there is not a new instruction, it will keep executing the previous command given by the COMMAND UNIT. If there is a malfunction in any part of the structure, the command unit will check where the malfunction was presented. If the malfunction was in any other segment, it will execute the BACKWARD command in order to return to its origin. If this segment was the one which malfunctioned, it will automatically shut down. By doing this, it has ensured that the malfunctioning segment will not cause any more conflict in the structure and that it can return to the origin to be repaired.

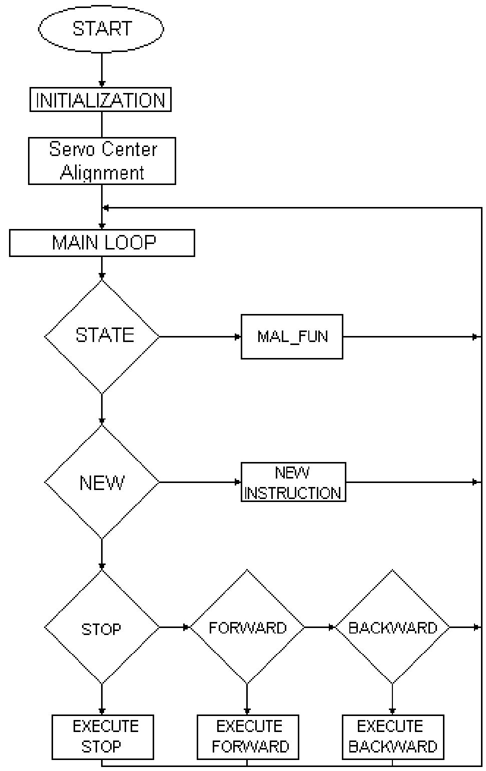


Figure 9. The flowchart for each of the control units

With the distributed control strategy the platform has more freedom to perform different tasks. Each segment can make decisions on what sequence to execute with the information it gathers from the others control units and from itself.

The malfunction sequence is just a trial sequence to ensure that the platform is able to recognize that there is a malfunction in the structure and which is the malfunctioning segment. In future development this malfunction sequence can be improve to perfume a different task when the malfunction has been detected.

4. Summary

The project gives an experimental mechanical foundation (modular structure) for well-documented robots to develop a complete robotic system capable of performing advanced operations in the articulated chain field. The platforms' modular design allows modifying the control system of each segment, giving the robot the flexibility to expand its capabilities without any changes in hardware. Besides, it has the advantages of any modular design, easy reproduction, assembly, and maintenance.

The developed done from ANA–II to 4N is evident. The distributed control strategy brings more freedom to perform different tasks. Each segment is now able to communicate with each other and make decision about which sequence to execute. This was a great improvement, and now more locomotion sequences can be developed, executed, and implemented.

This project opens an endless list of applications where humans are incapable of operating or are too dangerous to perform. Thus, a small step has been taken to research and improve articulated chain robot's development. In a short-term period the platform can be adapted to implement more efficient locomotion methods. A video camera system can be installed on the robot for visual feedback for exploration purposes. Also, the system can be upgraded with a sensor array to control servo current, obstacles, and different surfaces. The battery system can also be upgraded with the latest technology. The servos can be lighter and with low current high torque specifications. Some research in shields or skins to cover the platform can be done, in order to provide the platform with heat resistant, water resistant, or corrosive-agents resistant capabilities. In the future, the project can reach the stage of a fully functional exploration and recognition system, pipe maintenance, search and rescue system for disasters, and military intelligence system.

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