An Inchworm-like Robot Prototype for Robust Exploration

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Abstract

This research focuses on the development of flexible robot prototypes capable of robust terrestrial exploration. The development of such mechanisms is important, on the one hand, to enhance remote sensing capabilities during emergency situations, and on the other hand, to investigate new forms of mobility.

In this paper, the design and implementation of an inchworm-like modular robot prototype are described. This prototype was developed to perform exploration tasks of unknown environments with obstacles and walls.

1. Introduction

This research focuses on the development of flexible robot prototypes capable of robust terrestrial exploration, i.e. exploration of non-structured environments with uneven, variable or rough surfaces.

From a practical point of view, these robots are needed to enhance remote sensing capabilities, such as rescue and inspection in areas where motion is constrained, e.g. in situations involving disasters such as earthquakes, fires, and acts of terrorism. From a scientific point of view, the development of these systems involves many challenges about the understanding and design of various forms of mobility.

Nature has been for engineers and roboticists a rich source of metaphors providing uncountable examples of locomotion systems. Therefore, the design of robot prototypes for robust exploration may start in nature by studying animals with extreme functional demands. Indeed, artificial models cannot be reduced to simple copies of their natural counterparts. The former are based on assumptions about the properties and parameters that are consistent with the observed behavior of the latter [2].

Worms are good examples of animals that developed remarkable functional locomotion systems. For instance terrestrial inchworms, the larvae of lepidoptera, are equipped with one clasper at each end of their bodies and move by contracting and expanding their bodies. These movements provide undulatory locomotion [5]. This kind of locomotion enables inchworms to move over propulsive surfaces with various properties.

In this paper, the design and implementation of an inchworm-like modular robot prototype are described. This robot prototype was developed to perform exploration tasks of environments with obstacles and walls.

The rest of this paper is organized as follows: Section 2 briefly summarizes related work. Section 3 describes general design issues, and operating and control principles of our robot prototype. Section 4 presents and discusses results of experiments concerning exploration using our robot prototype. Finally, Section 5 gives conclusions and perspectives of our work.

2. Related work

Shigeo Hirose presented the first known serpentine robot prototype in 1993 [8]. Since that year, he has conducted research on articulated robots at the Hirose Lab that result...
in several prototypes, such as Koryu and Souryu.

Hirose’s first robots were based on hybrid configurations consisting of a number of modules equipped with passive wheels or crawlers. Similar prototypes include the Hyper-Redundant Robot developed at the California Institute of Technology [3] and the Super Mechano Anaconda project developed at the Tokyo Institute of Technology [9].

Mark Yim, one of the founders of modular robotics, developed various worm and snake-like robot prototypes at the Palo Alto Research Center. Yim argued that the best way to design a modular robot, and in fact any robot, is to build it from atoms or modules. Yim’s sense of module is a small robot able to perform specific and simple tasks. Various modules are then integrated into a supra robot whose capabilities result from the individual capabilities of its modules [10].

Howie Choset and his team have also developed a family of serpentine robots during the last 12 years at Carnegie Mellon University. They have worked on different planners to control the motion of these robots in convoluted environments [4].

González Gómez et al. [6] designed and built a generic module that can be connected to other modules providing 1-DOF joints, or that can be alternated in orientation providing 2-DOF joints. These modules were integrated into a worm-like robot able to perform linear movements.

Finally, OmniTread is one of the most remarkable snake-like robot prototypes. It has been recently developed by Granosik et al. [7] at the University of Michigan. This prototype comprises five modules linked by 2-DOF joints. Modules are covered with moving threads that enable the robot to cope with extremely difficult environments.

In this paper, Ocuillin\(^1\), an inchworm-like robot prototype is presented. The hardware and the electronics of this prototype were completely designed and built at the National Institute of Astrophysics, Optics and Electronics and at the Autonomous University of Puebla. In contrast with previous works, Ocuillin was designed to operate autonomously based on local perception and simple sensors and was also constrained to be as simple as possible in the number of its actuators. As far as we know, Ocuillin is the first inchworm-like robot built in Mexico.

3. Robot prototype

In this section, the electronics and composition of Ocuillin are described. The operating and control principles of the robot are also summarized.

\(^1\)Ocuillin is a Nahuatl word which means worm.

3.1. Control board

A homemade electronic control board was developed to control our robot prototype\(^2\). This control board is based on the Microchip’s PIC16F877 micro-controller with 8 Kb of flash program memory. Even though this board was mainly oriented to control Ocuillin, it was developed as a general-purpose board able to control mobile robots.

This board is equipped with three 8-bit digital inputs, three 8-bit digital outputs, one 16-bit digital power output, one port to control up to eight servomotors, one voice synthesis module, five input channels with 10-bit multichannel analog digital converter module, and 1 Mb of additional memory. The board is connected to a 12-volt battery and consumes about 380 mA (see Figure 1). For a detailed description of this control board, see [1].

![Figure 1. Control board.](image)

3.2. Hardware

Inchworms lack legs or extremities, but have nevertheless an extremely functional locomotion that enables them to creep on a variety of surfaces. The mobility of an inchworm is generated by its muscles in expansion and contraction that provide rectilinear progression. The maximum distance that an expanded inchworm can reach is less than or equal to the vertical loop of its previous contraction (see Figure 2).

Because real inchworms have many joints, their locomotion is difficult to reproduce. A real inchworm is not only able to make rectilinear movements, but it is also able to raise a large proportion of its body off the ground.

Technical specifications. Below is a list of the minimum technical specifications which, according to us, should be satisfied by an inchworm-like robot capable of robust exploration.

\(^2\)Patent pending.
Modular structure, ability to perform rectilinear movements forward and backwards, ability to turn, ability to raise at least a third of its body, and stability of its moving base.

A robot that covers these specifications should be able to move forward, cross obstacles by raising its body and moving forward, and avoid obstacles by moving backwards, turning and moving forward.

Modules, joints and actuators. As we mentioned previously, Ocuillin was constrained to use the fewest number of actuators. The minimum number of modules for an inchworm-like robot is four: two modules to clasp the robot’s body to the ground and two internal modules to make a loop. One 1-DOF joint among these modules provides rectilinear movements, whereas one 2-DOF joint among these modules provides left and right turn movements in addition to rectilinear movements. Therefore, to cover technical specifications, a traditional inchworm-like robot requires at least eight actuators.

In order to reduce the number of actuators for Ocuillin, an innovative and unnatural morphology was designed. Ocuillin comprises four modules connected by 1-DOF joints and one central module alternated in orientation providing one 2-DOF joint. In total, Ocuillin uses five DC motors. A schema of the robot prototype is illustrated in Figure 3. Modules 1, 2, 3 and 4 move on the ground plane, whereas module 5 moves perpendicularly to the ground plane.

The modules of Ocuillin are made of acrylic and metallic gears while its joints are made of plastic gears. These materials were chosen because of their commercial availability, light weight and resistance. For a comparison of the materials considered to build Ocuillin, see [1].

Sensors. Ocuillin is intended to operate autonomously in dynamic environments. For that, a number of sensors distributed around the robot’s body are necessary to enable effective local perception.

Ocuillin is equipped with 19 sensors to detect the position of its modules, obstacles, and a goal located within its environment. The distribution of these sensors is illustrated in Figure 3: sensors 1 to 10 are bumpers that detect if a movement threshold has been reached. Sensors 11 to 15 detect if modules are aligned in the middle, vertically, or horizontally with respect to each module. Sensor 16 detects a goal consisting of a group of light-emitting diodes that work at a particularly frequency of light (see Figure 4). Sensors 17, 18, and 19 detect, respectively, frontal, right lateral, and left lateral obstacles.

Bumpers and IR sensors were chosen to equip our robot
for simplicity in order to save processing time required to manage sensors involved in its basic operation. More complex sensors such as sonars and cameras are considered to extend, in the near future, the capabilities of the robot.

In Figure 5, an image of our robot prototype is shown.

3.3. Control

Control for articulated robots concerns a description of the robot’s actuators in order to generate movement patterns. In the first serpentine and inchworm-like robots [10], a gait control vector containing the kinematics of the gaits of the robot’s modules is calculated a priori and downloaded to the robot. In more recent prototypes [6], these values are generated on-line.

The coordination of the modules of Ocuillin is achieved on-line, supported by its sensors. When an obstacle is detected, the robot goes forward generating a half-sinusoidal wave with its modules 3 and 4 (see Figure 6). When a frontal obstacle is detected, the robot tries to cross this obstacle keeping raised its modules 1 and 2, while its modules 3 and 4 generate a half-sinusoidal wave to go forward. Module 5 is concerned when a frontal obstacle is avoided instead of being crossed. Ocuillin decides that he has to go backwards and turn after three unsuccessful attempts to cross an obstacle. In that case, modules 3 and 4 generate an inverted half-sinusoidal wave to go backwards, while always keeping raised modules 1 and 2. After a while, module 5 turns until its threshold movement is reached. Then, the robot is ready to continue.

In goal-oriented exploration, if the goal is detected by the robot, it stops its motors and finishes the task.

The generation of movement patterns was encapsulated in simple functions called actions. Common actions for Ocuillin are Go forward, Turn to left and Jump obstacle. These actions are tested in the experiments described below.

4. Experimental results

In this section, two experiments of exploration of unknown environments using Ocuillin are summarized. Both experiments were conducted in an enclosed environment of $2.4 \times 1.2 \text{ m}^2$.

The first experiment concerns wandering in an environment without obstacles. Ocuillin was oriented towards a wall in order to test its ability to cope with this situation (see Figure 7).

The second experiment concerns a goal-oriented exploration in an environment with one obstacle. Neither information about the obstacle within the environment nor information about the goal location were provided to the robot. Ocuillin was located in such a way that the goal was in front of him in the opposite side of the environment. An obstacle was located between the robot and the goal (see Figure 8).

Figures 9 and 10 plot the actions that were executed by Ocuillin during these experiments. These images illustrate how the robot modifies its behavior according to its local perceptions.

The first experiment lasted $5 \text{ min } 50 \text{ sec}$, while the second experiment lasted $3 \text{ min } 28 \text{ sec}$. Both experiments can be considered successful because the robot detected an obstacle, raised its body, and avoided or crossed the obstacle detected in front of him. The robot then continued its exploration.

For a more detailed description of Ocuillin’s performance see [1].
5. Concluding remarks

In this paper, the development of Ocuillin, a homemade inchworm-like robot prototype, is described. The study and implementation of this kind of robots are important for a number of applications, such as rescue and inspection in areas where motion is constrained for common robots, e.g. in situations involving disasters and emergencies.

Our robot was initially inspired by a natural locomotion system, but in order to reduce the number of its actuators, an innovative simple, although unnatural, morphology was finally implemented. Even though the robot was equipped with simple sensors and actuators, its performance covered the established technical specifications.

In the near future, we will extend the equipment of the robot in order to enable remote visual sensing. The implementation of a second prototype is also considered for experiments involving two interacting inchworm-like robots.

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References


Figure 9. Actions executed by the robot during the first experiment.

Figure 10. Actions executed by the robot during the second experiment.