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A CASCADED WORM-LIKE LOCOMOTION SYSTEM – CONSTRUCTIVE DESIGN, SOFTWARE AND EXPERIMENTAL ENVIRONMENT

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ABSTRACT

The earthworm utilizes a special type of locomotion. Robots which reproduce this way of movement could have very versatile applications in the future. The Ilmenau University of Technology is actively researching in this field. Now a robot has been developed to apply the theoretical results. This paper describes shortly the basic principle and the development of the robot. Furthermore, a platform is presented, which was created to demonstrate and test the abilities of this robot. The platform allows the altering of some environmental parameters to display the effect on the motion. On a laboratory computer runs a software which generates the gait and transmits it to the control system of the robot. This software can also the visualization the generated gait, so the user has a direct feedback.

Index Terms - biomimetic robot, apedal, locomotion, gait generation, gait visualization

1. INTRODUCTION

The earthworm is very well adapted to its underground environment. Its body and way of moving are closely linked, to enable the worm to move in the limited underground space.

The body of the worm is separated into many segments. Each segment holds four pairs of bristles (*setae*) and can be stretched or contracted. When stretched, the diameter of a segment decreases and the bristles are retracted. While contracting, its diameter increases and the bristles are set out. Thereby the worm supports the segment to the soil. A part of the worm is stretched, while the rest is contracted. The region of stretched segments moves backwards through the worm, which results in the worm moving forward. If the region reaches the tail of the worm, it starts to stretch the leading segments over again. A contraction wave moves backwards from the "head" of the worm. This periodical process is called *peristalsis* and is displayed in fig. 1. [1]

The papers [2, 3, 4, 5, 6, 7, 8, 9] describe how many types of robots have been build, to recreate the worm-like locomotion.

This form of locomotion has the potential to give robots in the future new abilities. They could be capable of moving underground or on very rough terrains. Thereby a worm-like robot could support search and rescue teams in a disaster scenario. Or it could be send out to discover the surfaces of distant planets. The segmented structure makes these robots very well scalable which results in potential economic benefits. Also, the structure gives the robot a certain redundancy, thereby it is less vulnerable to damage.

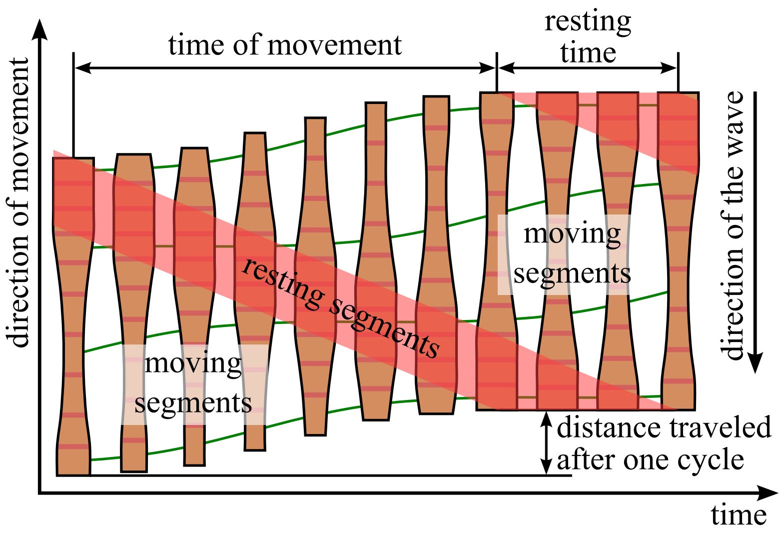

Figure 1: One sequence of the periodical worm-motion of a worm with 10 segments

2. A NEW APPROACH TO WORM-LIKE LOCOMOTION

In [10] and [11] are the theoretical basis of the worm-like locomotion layed out. The presented model simplifies the segments to bodies with their mass concentrated in a point. Each mass m_i has a coordinate x_i, where i ranges from 0 (head segment) to n (number of segments $-$ 1). The bodies are connected by links of which the length can be controlled. The link length is given by l_j with $j = 1 \dots n$. On the underside of the bodies are bristle-like structures. These interface with the ground and allow a segment to move only in one direction (here $+x$), while they lock the body to the ground, when a force is applied in the opposite ($-x$) direction. An example of this model with 4 segments ($n = 3$) can be seen in fig. 2.

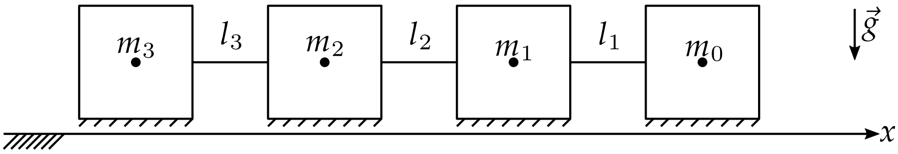

Figure 2: The model from [10, 11] for worm-like systems

To evaluate the theoretical achievements in practice the task for the masters' thesis [12] was to develop a worm-like robot. The idea was to create a robot with which a broad band of movement patterns (gaits) can be tested. Therefore, the main requirements were:

- simple addition and removal of segments to the robot
- high dynamic drives
- very high stretching factor $\left(\frac{\text{length of stretched segment}}{\text{length of retracted segment}}\right)$

The development of this new robot is described in [12]. To extend and contract the links between two segments, the robot uses an energy chain as a push-pull chain to transform the rotatory motion of a high dynamic electrical drive into a linear motion. Therefore, the robot was named *Chainbot*. This mechanism is seen in fig. 3. The assembled robot can be seen in fig. 4. It has a segment length of 61 mm and can stretch the links from 0 mm to 93 mm. Thereby it reaches a stretching factor of over 2.5.

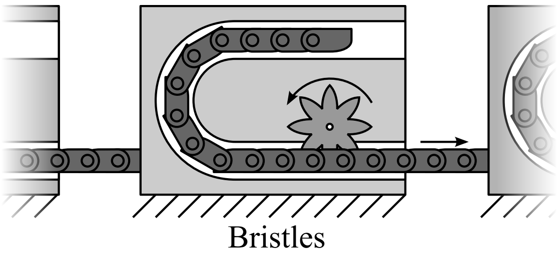

Figure 3: Mechanical principle used in the developed robot [12]

On the bottom of the robot a bristle-like structure with angled spikes is mounted (as seen in the bottom picture in fig. 4). Paired with for example a textile underground these spikes will create a anisotropic friction. When a segment moves forward the friction force is minimal. When a backwards facing force is applied, the bristles will lock into the fabric and block a backward motion of the segment. These properties are used to move a segment forward and then pull the trailing segment with only one actuator.

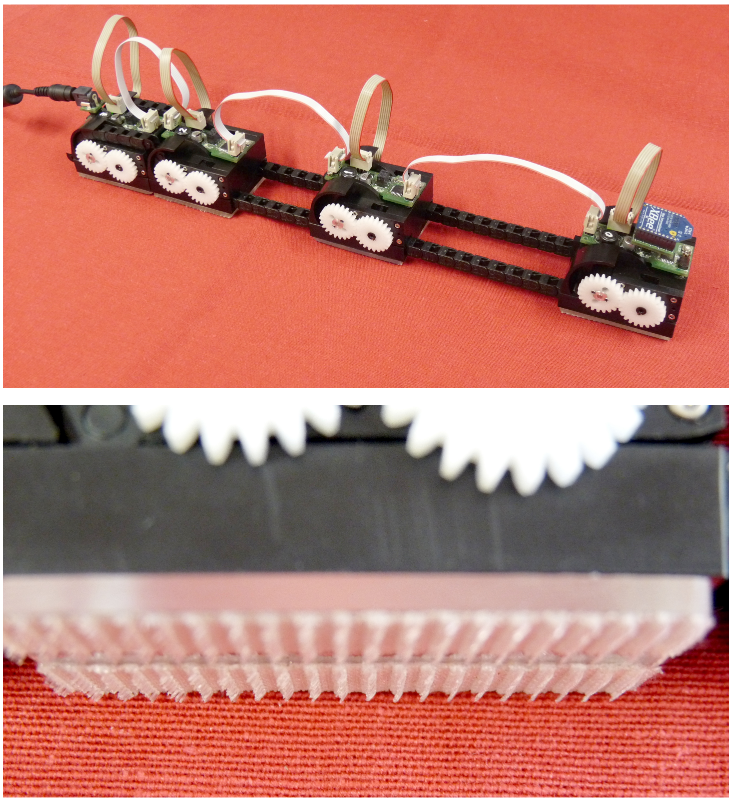

Figure 4: Top picture: photo of the Chainbot with four segments; bottom picture: bristle-like structure on the underside of one segment

Every segment is equipped with an electronic processing unit whose major task is to control the distance between its segment and the one in front of it (length of the link). Additionally, it needs to process the data of the measuring device and receive and transmit control information. Each segment controls the drive independent from the other segments. Self adjusting control algorithms have been developed in [13] and implemented into the control program of the microcontroller.

The segments communicate with the master-controller via a I²C-bus. This master-controller is mounted on the first segment of the robot, which does not need to do any motion control, since it has no segment in front of it. It communicates wireless with the laboratory computer, which sends it the desired values for the link-lengths. The master-controller forwards the received values then to the corresponding controllers.

Reduced to two segments, this robot can be used for another type of locomotion as described in [14].

3. EXPERIMENTAL SETUP FOR WORM-LIKE ROBOTS

To test the abilities of the robot and to experiment on different gaits the testing-platform shown in fig. 5 has been developed in [15]. An industrial conveyor belt system is used as a treadmill to give the robot theoretically unlimited space to move. The gradient of the conveyor can be adjusted to up to 60° to simulate ascending. The frame is made up of aluminum profiles to make the structure light (transportable), stiff and simple to modify. Via Velcro the surface of the belt can be interchanged. Thereby different friction coefficients can be experimented with. To control the belt speed, the control unit of the conveyor is also connected to the laboratory computer. To keep the robot from running of the track, acrylic glass panels have been mounted to the sides of the conveyor.

Figure 5: Experimental environment for worm-like locomotion systems [15]

Basic experiments have been executed to ensure the operation of the robot and the conveyor.

4. CONTROL SOFTWARE

In [15] a control software was developed, to control the Chainbot and the testing platform simultaneously. The technical communication channels are shown in the signal flowchart in fig. 6.

Initially the user puts a set of gait parameters with the help of a graphical user interface into the program. The gait generator (based on [16, 10]) takes these parameters to create a gait and displays the result as a video preview. The user can further adjust the parameters or continue to start the robot motion. The motion information (link lengths $l_j(t)$) is then handed over to the *Chainbot*-class. This class includes all communication with the robot. Thereby it is easily reusable for future projects and also directly accessible from the command line for direct control commands.

The gait generator also calculates the average speed of the robot, which is sent to the conveyor controller to synchronize the belt speed.

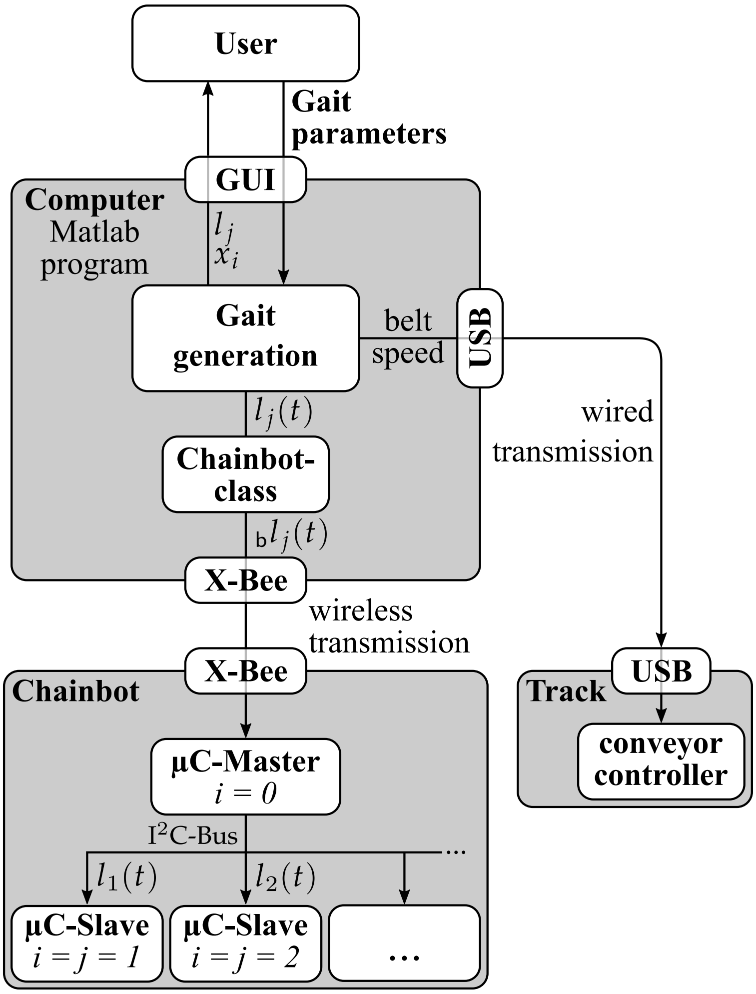

Figure 6: Flowchart of the signals transmitted between laboratory computer, Chainbot and conveyor test environment

In the class, the data is transformed into a simpler binary representation for the wireless transmission. The master controller on the robot collects the information and forwards it onto the $\mathrm{I^2C}$-bus. The slave controllers of each segment reads their associated data packages. These include the desired link length $l_j(t)$ which is the set-point for the motion controller. If the measured link length is different from the set-point, the controller powers the drive to minimize the deviation. The Chainbot-class sends every 10 ms new set-points, until the preset time is over or the user cancels the process.

As a programming environment MATLAB was used, because of its big library of predefined functions and good capabilities of displaying the gait (video preview and graphs).

5. CONCLUSION & OUTLOOK

A new robot has been constructed, which is capable of peristaltic locomotion. It features a large stretching factor and very high dynamics. Additionally, a testing environment has been created, on which the capabilities of the robot can be examined. Furthermore, a control software has been programmed to simplify the process of creating a gait and executing it with the robot on the testing environment.

Currently the electronics of the robot get reworked, to allow the addition of sensors. With an accelerometer the robot could measure the gradient of the slope it is climbing. Furthermore, a sensor could be utilized to measure, whether a segment is sliding backwards. With this information, the robot could be capable to choose for itself, which gait is the optimal, to climb a certain gradient with a certain friction coefficient. Also the testing environment will be automatized to simulate a course with different gradients for the robot.

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