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Evaluation of a Locomotion Algorithm for Worm-like Robots on FPGA-embedded processors

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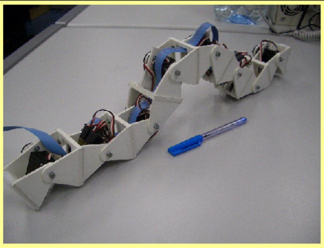
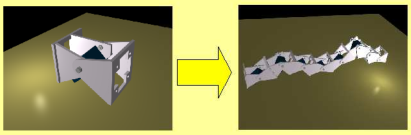
1 Abstract

In this paper, a locomotion algorithm designed for an eight modules worm-like robot has been successfully tested on three different FPGA-embedded processors: MicroBlaze, PowerPC and LEON2. The locomotion of worm-like robots, composed of a chain of equal linked modules, is achieved by means of wave propagation that traverse the body of the worm. The time the robot needs to generate a new motion wave, also known as the gait recalculation time, is the key to achieve an autonomous robot with real-time reactions. Algorithm execution time for four different architectures, as a function of the total number of articulations of the robot, are presented. The results show that a huge improvement of the gait recalculation time can be achieved by using a float point unit. The performance achieved using the LEON2 with FPU is 40 times better than LEON2 without FPU, using only 6% of additional resources.

2 "Cube Revolutions": the worm-like robot

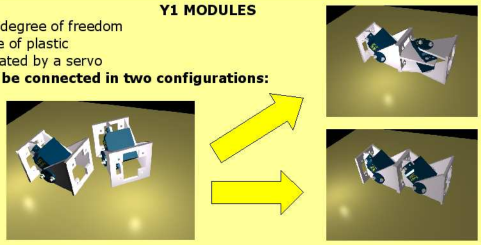


- It is composed of 8 similar linked Y1 modules
- The modules are connected in the same orientation
- The robot only can move forward or backward
- The electronic and power supply are located off-board

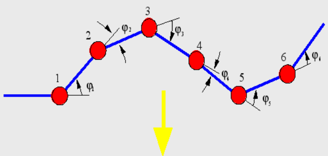


Y1 MODULES

- One degree of freedom
- Made of plastic
- Actuated by a servo
- **Can be connected in two configurations:**



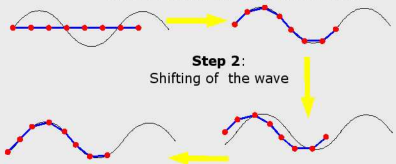
3 Locomotion Algorithm



$\overline{\varphi(t_i)} = [\varphi_1\ \varphi_2\ \varphi_3\ \varphi_4\ \varphi_5\ \varphi_6]$

Angular position vector

- The problem to solve is the generation of a sequence that allows the robot to move forward or backward
- The shape of the robot at instant *ti* is described by the *angular position vector*
- The sequence of movement is characterized by a Matrix, which rows are the angular position vectors at different instants.
- The locomotion algorithm calculates this matrix, based on the propagation of waves along the body of the robot



- **The algorithm operates as follows**:
  - **Step 1**: The articulation's angles are calculated so that the worm fits the wave.
  - **Step 2**: The wave is shifted
  - **Step 3**: The worm is fitted to the wave again
  - Steps 2 and 3 are repeated until the wave has moved a distance equal to the wavelength

4 Implementation on FPGA

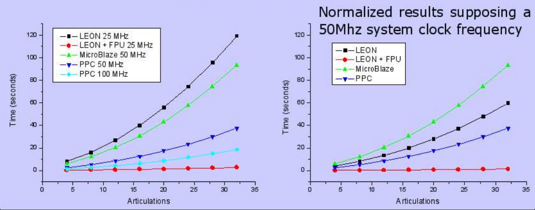
Architectures used for the evaluation of the algorithm

Target architectures	Processor	Frequency	FPGA
1	LEON	25Mhz	Virtex XC2000E
2	LEON + FPU		
3	MicroBlaze	50Mhz	
4a	PowerPC		Virtex II Pro
4b		100Mhz	

Synthesis results:

Processor	Slices	BRAM
MicroBlaze	1321 (6%)	74 (46%)
LEON	4883 (25%)	43 (26%)
LEON + Meiko FPU	6064 (31%)	40 (25%)

Algorithm execution time



5 Conclusions and future work

- The locomotion algorithm for worm-like robots locomotion has been tested on four different architectures
- The gait reconfiguration time (GRT) can be drastically improved by means of the use of and FPU unit
- A 25 Mhz LEON2 with an Meiko FPU is almost one order of magnitude faster than a PowerPC working at 100Mhz
- When not low GRT is required, the use of the MicroBlaze is a good solution.
- It saves about the 75% of the area, leaving this percentage free for the implementation of new hardware cores
- For further work, the architecture chosen is the LEON2 + FPU.

- The locomotion on 2D problem (2D) has to be solved.
- The same algorithm will be used but using two waves: one for the joints in the plane parallel to the ground and the other for the joints in the perpendicular plane.
- The final locomotion will be generated as a composition of the two waves