Research Journal of Applied Sciences 13 (10): 603-609, 2018
ISSN: 1815-932X

Simulation and Implementation of a Hexapod Configuration Using Modular Robotics

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Abstract: This study details development of a functional hexapod configuration by means of MECABOT robotic modules, previously designed and built at Universidad Militar Nueva Granada. For this configuration, the modules received a series of upgrades which allowed reduction of size and weight as well as an increase in torque. In order to develop control software, Webots IDE was used to simulate workspace characteristics in a virtual environment. Once the configuration was assembled using the improved modules, locomotion tests were carried out for forward and lateral motions for which robot speed was measured and compared with simulation results. Analysis of the divergence between simulated and practical speeds led to a series of design considerations that will require further evaluation in future research.

Key words: Modular robotics, hexapod configuration, Webots, MECABOT, Webots IDE, locomotion tests

INTRODUCTION

At the core of current robotics research lies deep interest in increasing robustness (Brooks, 1985) and adaptability (Levi and Kernbach, 2010) given that a common characteristic in more recent robotics applications is the occurrence of dynamic workspace conditions (Fraichard, 1998). Modular robotics has been proposed as a viable solution: use of small independent modules which can be coupled when necessary as building blocks for more complex system architectures (Alonso-Puig, 2006).

In modular robotics, design is more focused on the module rather than the complete configuration which requires further consideration of how locomotion is achieved (Arredondo, 2006). This extends to the module's embedded communications and control systems (Kurokawa *et al*., 2007) which factor in criteria such as the number and shape of modules to be used (Rubenstein *et al*., 2012).

A widely accepted classification for modular robots discriminates whether the modules are capable or not of self-reconfiguration when necessary (Rai *et al*., 2011) by use of geometric algorithms (Bares and Wettergreen, 1999). This capability is closely tied to the availability of actuators enabling independent movement of each module in two or three-dimensional space (Borenstein *et al*., 2006). MECABOT modules have been successfully used in caterpillar, snake, wheel and hexapod configurations.

MATERIALS AND METHODS

Design considerations: An important distinction to note in modular robotics is that regardless of the module's degrees of freedom, a configuration is said to be two-dimensional if it can only move in a single plane (Ostergaard *et al*., 2006) as is the case with ground-based robots such as the hexapod configuration. Its design, biologically inspired by insect's morphology, ensures that regardless of terrain ruggedness the robot can maintain static equilibrium given the number of points in contact with the surface (Bessonov and Umnov, 1974).

Experimental NASA concepts such as the quadruped aimed towards space exploration shown in Fig. 1, make use of several modules (each of which is self-contained in terms of energy source) to form the robot's legs, greatly simplifying design and reducing both manufacture and operation costs. Analysis of tests is aimed at increasing locomotion distance and energy efficiency according to gait patterns described as actuator movement sequences (Hancher and Hornby, 2006).

The highest degree of module independence requires decentralized control algorithms (Takahashi *et al*., 2004) running locally on each module to deal with disturbances generated by uneven workspace terrain (Munteanu *et al*., 2010). Figure 2 shows a self-balancing table created by Harvard scientists, capable of maintaining constant stability by adaptive modules which emulate a quadruped's gait (Arredondo, 2006).

Improvement of the MECABOT modules: A key principle in MECABOT's conception is that the smallest independent unit is the semi-module illustrated in

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Fig. 1: Quadruped robot prototype for space exploration (Hancher and Hornby, 2006)

Fig. 2: Self-balancing table based on a quadruped's gait (Arredondo, 2006)

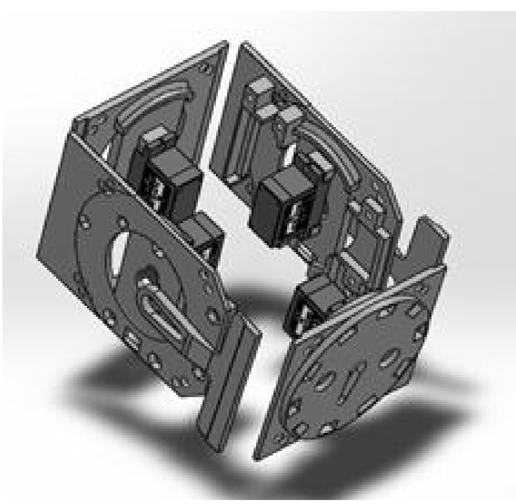

Fig. 3: Exploded view of a semi-module

Fig. 3. In other words, each MECABOT module is formed by two semi-modules which allow the module to operate akin to joints in traditional manipulators.

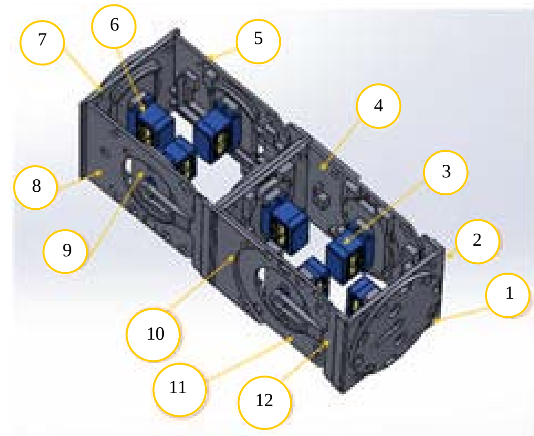

Fig. 4: CAD Model of a complete MECABOT module

Table 1: List of MECABOT components

Elements	Description	Quantity
1	Magnet wheel	2
2	Frontal flat face	2
3	Pivot servomotor	4
4	Left flat face	1
5	(Battery-housing variant) left flat face	1
6	Face rotation servomotor	3
7	Rear flat face	2
8	(Battery-housing variant) right flat face	1
9	Servomotor support	7
10	Wheel support	4
11	Right flat face	1
12	Pivot	2

A semi-module resembles a compact rectangular prism and uses 4 servomotors to enable pivoting (locomotion) and rotation (repositioning) movements. The complete module presented in Fig. 4 is obtained when two semi-modules latch using magnets embedded in their frontal/rear faces. Table 1 indicates the list of contained components in a module. It is important to note that the inside of the prism's faces varies to accommodate the battery within the rear semi-module.

RESULTS AND DISCUSSION

Hexapod configuration simulation: Once CAD designs for the semi-modules have been developed, the robots can easily be imported into Webots as VRML files. The hexapod configuration is created by assigning position and rotation relationships between modules, thus, obtaining the architecture displayed in Fig. 5. It is important to note that the CAD designs possess a series of geometry simplifications to ease computational workload (Thakur *et al*., 2009).

Due to its bio-inspired design, the hexapod configuration is capable of omnidirectional movement (Bessonov and Umnov, 1974). Consequently,

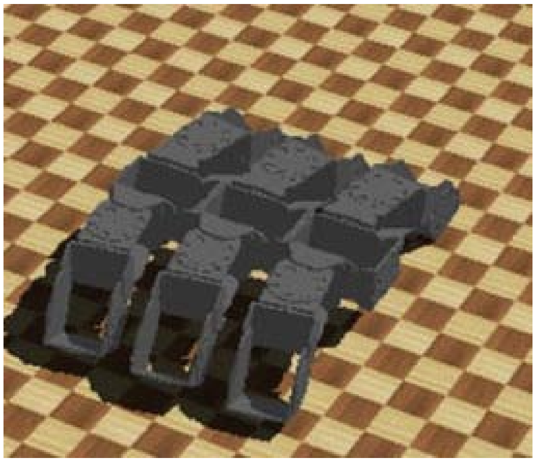

Fig. 5: 3D Model of the hexapod configuration in Webots

a streamlined control interface is developed for execution of 6 basic motion primitives: forward/reverse motion, left/right lateral motion and clockwise/counter clockwise in-place rotation. Said primitives suffice for common mobile robot tasks such as obstacle evasion, path execution and robot repositioning. The base algorithm for the forward/reverse and left/right motion pairs is now described, noting that the opposite movement heading is achieved by inverting the sequence of steps.

Forward motion: To maintain static stability, movement of the hexapod's legs follows an alternating sequence in which 3 legs move while the other 3 maintain ground contact. The corresponding algorithm's flow diagram is presented in Fig. 6 and a series of screen captures from the motion's simulation are displayed in Fig. 7. Given that the square tiles in the virtual workspace are assigned 5 cm edges, it is possible to evaluate the robot's overall speed during a fixed-length movement segment by logging simulation runtime.

A series of tests were performed modifying the speed and acceleration limits of the servomotors channel's output to determine the best combination for overall robot speed. As can be observed in Fig. 8, unbounded acceleration and a high-speed limit provided best results, since, the hexapod was less prone to slippage when its legs established ground contact.

Lateral motion: Locomotion of crustaceans is mimicked for lateral motion, sequentially stretching and contracting the hexapod's legs as detailed in Fig. 9 algorithm and Fig. 10 series of screen captures.

Once again, overall robot speed is evaluated as a function of the servomotor's angular velocity and acceleration. As seen in Fig. 11 for this motion pattern, unbounded acceleration and a low speed limit reduced leg slippage and increased movement speed. More interestingly, the hexapod configuration presents a more than five-fold increase in overall speed for lateral motions in comparison with forward/reverse motions.

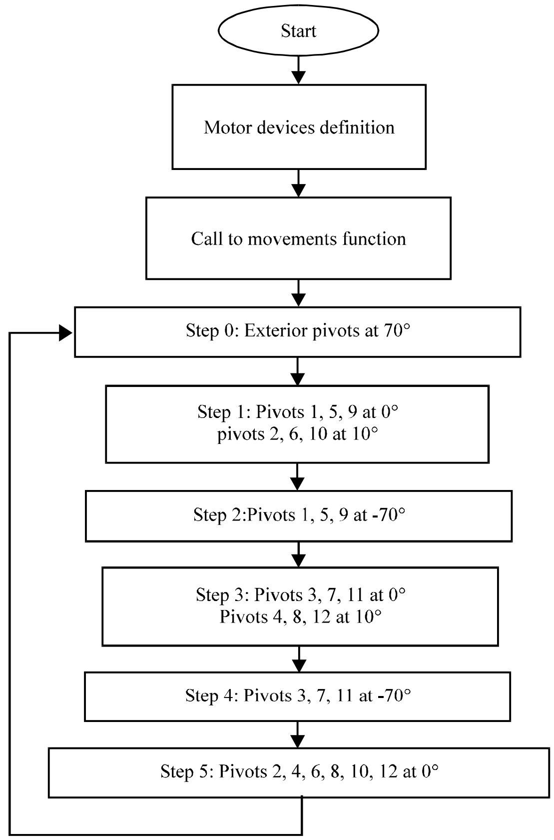

Fig. 6: Algorithm for forward motion

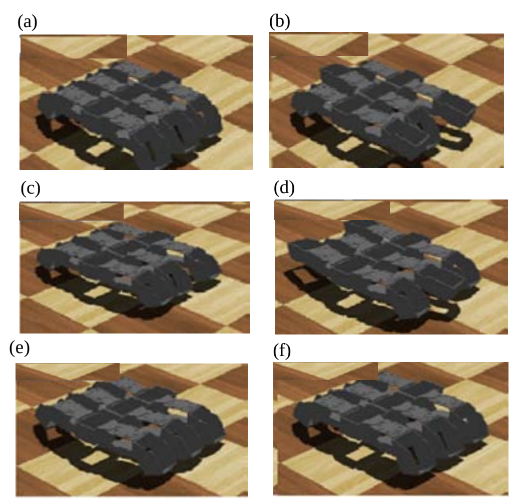

Fig. 7: Screen captures for the individual phases in the forward motion sequence: a) Step 0; b) Step 1; c) Step 2; d) Step 3; e) Step 4 and f) Step 5

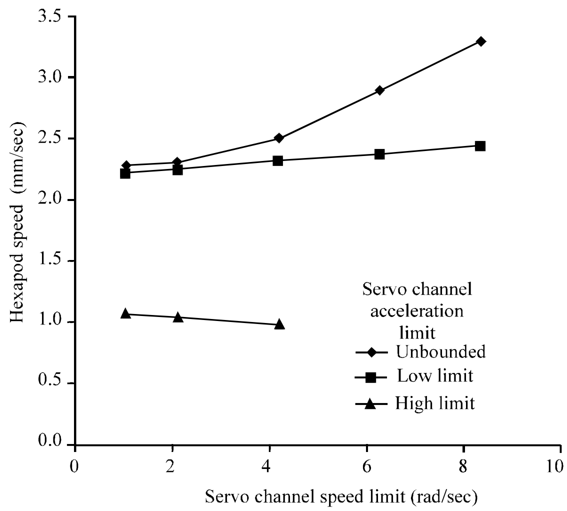

Fig. 8: Overall hexapod forward speed according to servomotor parameters

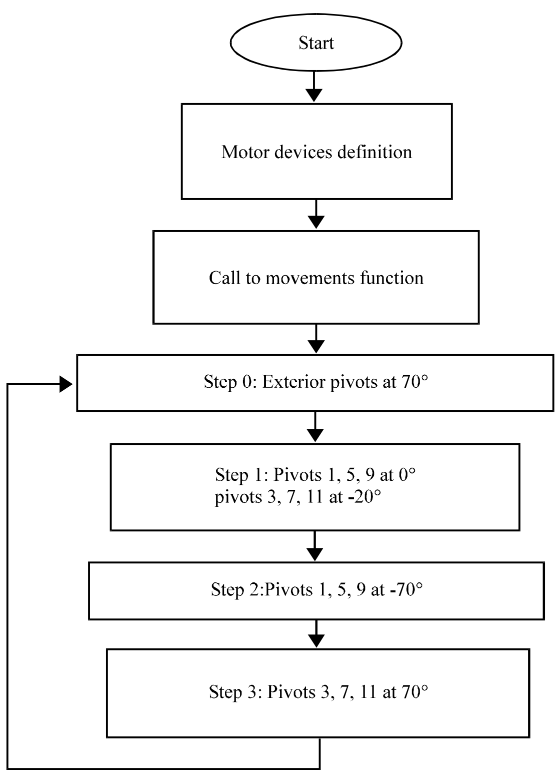

Fig. 9: Algorithm for lateral motion

Physical implementation: The chassis pieces of MECABOT modules are fabricated in ABS plastic while any electromechanical component is easily disassembled from a module with a hex tip screwdriver, the majority of chassis pieces are welded with methylene chloride for structural rigidity. A module is shown in Fig. 12 and the complete hexapod configuration is shown in Fig. 13.

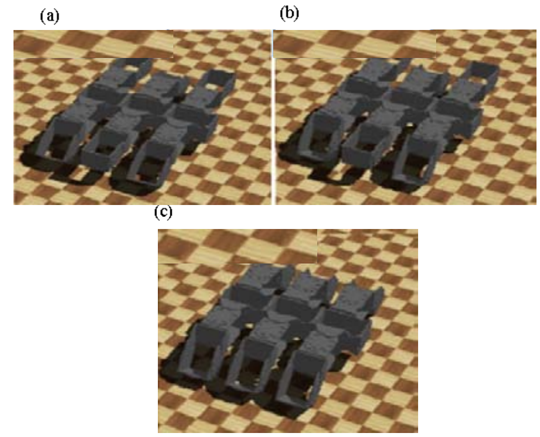

Fig. 10: Screen captures for the individual phases in the lateral motion sequence: a) Step 1; b) Step 2 and c) Step 3

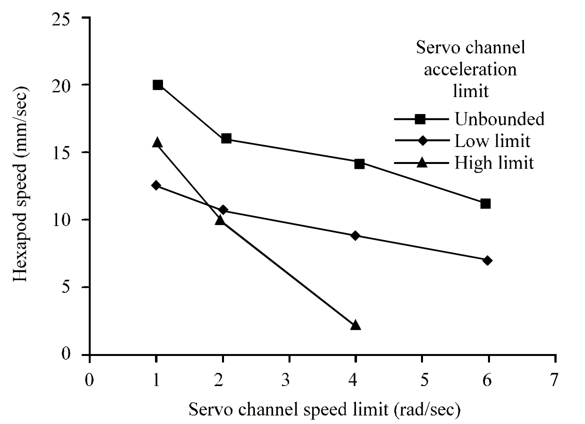

Fig. 11: Overall hexapod lateral speed according to servomotor parameters

Fig. 12: MECABOT module

The motion controller previously developed and tested in Webots was easily ported to MATLAB where an additional communications interface is built to send synchronized movement commands using an open-source 3D printer and then assembled manually.

Fig. 13: Hexapod configuration

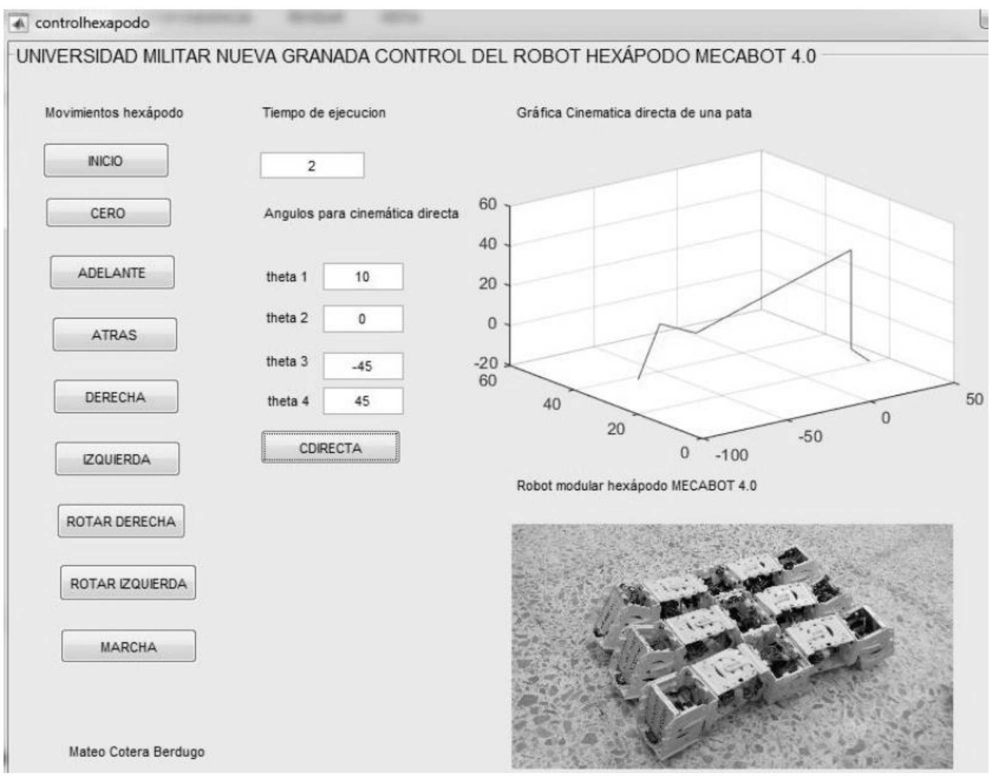

Fig. 14: MATLAB control and communications interface

For all modules using a Zigbee communications protocol. Said interface is presented in presented in Fig. 14.

Both forward and lateral overall robot speeds in practice were notably lower than their simulated counterparts. This can be attributed to the complexity of contact interactions between the hexapod's legs and the workspace's surface which cannot be accurately represented in simulation software.

CONCLUSION

Though a proper approximation of a 6-legged insect's gait was achieved with the designed hexapod configuration and software, leg slippage remains a key bottleneck limiting the configuration's movement capabilities. Further testing with other materials is required to determine an optimal material which maximizes friction (and consequently, grip) with the works pace's surface without compromising module integrity due to wear which will be a critical parameter when the hexapod operates in various types of uneven terrain such as grass or gravel.

A second divergence between simulation and practice is structural rigidity in all joints that interconnect the robot's "Torso" with each leg. Given that the associated actuators are under constant load, current spikes can cause the drivers to briefly de-energize the servomotors and disturb the gait pattern. Consequently, higher range current regulators and metal gear servos should be considered to address this issue.

Whilst greater range of leg motion (and implicitly, higher overall robot speed) is possible by using more semi-modules to increase the length of the robot's "Torso", the increase in weight requires modifying the current magnet-based coupling mechanism between modules to avoid the configuration's disassembly during movement.

ACKNOWLEDGEMENTS

This study is a result of the ongoing ING-2381 research Project, titled "Design, implementation and coordination of a heterogeneous multi-agent system composed by robotic modules for collaborative tasks", funded by the Vice Deanery for Research of Universidad Militar Nueva Granada.

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