

XANTHUS: ALL-TERRAIN NAVIGATION ROBOT

Adrian Arbide, Vishnu V Madadi, and Sabri Tosunoglu
Florida International University
Department of Mechanical Engineering
10555 West Flagler Street
Miami, Florida 33174

ABSTRACT

The use of mobile robotic platforms in increasingly broader application areas makes it necessary to develop new navigation mechanisms that are adaptable to a variety of topologies. Driven by this need, a new design of the previously developed modular reconfigurable robot has been presented in this work. Named Xanthus, this new modular robot integrates crawling, walking and rolling modes of transportation into one design. Transition from one mode to another does not require any human intervention and is accomplished by the built-in software as required by the terrain conditions. For instance, while rolling may be the fastest mode of navigation in a particular terrain, walking on four legs or crawling may be more suitable in other settings. This work reviews mechanical design, hardware requirements, control, and software development for the Xanthus all-terrain navigation robot. Gait development is addressed for quadruped walking, crawling and rolling modes. Experimental test results on the prototype are also presented.

INTRODUCTION

There is an increasing demand for researchers to develop mobile robots that yield results to real world problems for a wide range of application domains. The principal rationale for the development of these systems is to deploy these robots to perform tasks at remote destinations or terrains that are considered hazardous or inaccessible for humans. Among the many diverse features that these systems are demanded to possess, the fundamental aspect that governs their functional competence is the system's navigation capability.

Development of an all-terrain mobile system involves complexity in various levels of design and control. Other factors that play a role in the development of these systems are reliability, cost, development time and degree of mobility. Previous version of a modular robot that was developed at the Florida International University Robotics an Automation lab investigated the design and control for crawling gaits of the modular robot. The developed system consisted of several one degree-of-freedom modules

providing a fault-tolerant mechanism. Crawling gaits developed were optimized for velocity based on the distance traveled per cycle.

Most mobile robots are built for navigating specific terrains using legs, wheels or tracks. The work presented in this paper counters the fore mentioned concept by developing a system capable of executing three different modes of navigation by reconfiguring its structure depending upon the desired task. Xanthus is capable of crawling, walking and rolling, and changing its mode of navigation autonomously. The developed system incorporates advantages established by different methods of mobile system navigation thereby overcoming drawbacks of each individual system [1].

The present version of the all-terrain navigation system is designed to adapt to the navigating terrain and execute motion which is best suitable for the particular terrain. A modular design is adopted for the system as it presents several advantages. The designed system has homogeneous modules which decrease system developmental costs. The innate fault tolerant capabilities of modular systems assist in unhindered navigation in complex unstructured environments.

The modular self-reconfigurable robot Xanthus presents several kinematic configurations for gait development of the system. Gait development for system is based on controlling and coordinating modules to avoid singular position when changing modes of navigation

This paper presents the design and development of an all-terrain navigation robot. The system design of the modular self-reconfigurable robot is presented prior to the fabrication of the system. All components utilized to develop a prototype for experimental testing is detailed. The gait development for the three different modes of navigation envisioned for the designed system is then addressed.

SYSTEM DESIGN

The modular design of Xanthus provides several advantages for self-reconfiguration of the system to adapt to and navigate based on the desired task. A modular

robotic system consists of a set of independent modules, such as actuators, passive joints, rigid links, mobile platforms, and end-effectors that can be rapidly assembled into a complete robot with various configurations [2-5].

The design of the system consisted of developing single degree-of-freedom modules that allow easy modifications when design alterations are required. A linkage mechanism was designed for the developed modules to be serially linked providing a track or chain mechanism that can be manipulated to navigate different terrains.

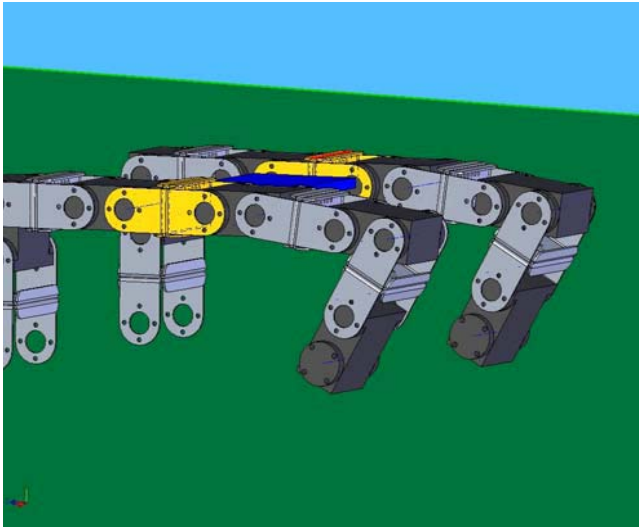


Figure 1. CAD model of Xanthus

System design for Xanthus was accomplished by taking into account factors concerning crawling, quadruped walking and rolling. A bipartite system consists of a passive element connecting two serial chains made of several modules linked to each other. This design was chosen over a single chain of modules serially linked although it involved increased costs and complexity of control. A bipartite system increases the amount of traction the system develops when navigating in the crawling mode. Crawling and rolling are two features that are capable of being developed using single chain mechanisms. However, the adopted bipartite system design provides an advantage by augmenting the systems capability for quadruped walking.

The number of modules on each serial chain has a direct bearing on the system’s stability, mobility and complexity of control. Several conceptual models were designed by varying the number of modules on each serial chain. These models were analyzed prior to adopting the final design for the system.

The crawling motion has the least impact on the number of modules to be implemented on the system. This is however based on the assumption that the developed

system will be capable of generating sufficient system-terrain interaction for system propagation.

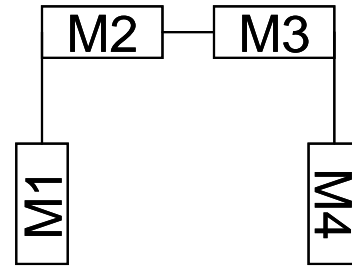


Figure 2. Quadruped walking mode configuration for a chain consisting of four modules

A sagittal plane view of a chain consisting of four modules is shown in figure 2 with M1, M2 M3 and M4 representing the four modules. Based on the above figure, geometric analysis would reveal that a minimum of four modules is required on each serial chain for the system to be capable of quadruped walking. In order for the system to be capable of navigating based on rolling motion, each chain should consist of a minimum number of modules to form a closed loop to enable smooth motion. Hence, the above mechanism is termed under actuated for the system to be capable of rolling.

Based on mathematical models developed for stable static positions, the known module lengths are plotted to form a closed loop mechanism to enable system rolling.

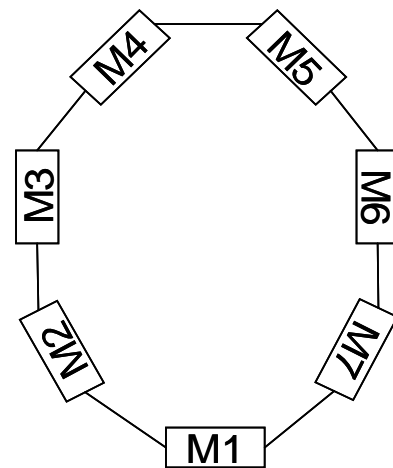


Figure 3. Sagittal plane view of a seven modules on a single chain

A serial chain containing seven modules shown in Figure 3 is selected, as the closed structure forms a smoother outer boundary compared to other systems designed. An increase in the number of modules provides more configuration options for the system, and at the same time increases the cost and complexity of control of the system. A novel rigid linking mechanism designed is used

for inter-module attachment and detachment to perform various tasks.

SYSTEM HARDWARE

The designed modular self-reconfigurable robot has a total of 14 modules each possessing a single degree-of-freedom. System fabrication mainly consists of linkages and actuators designed for the system. Each module consists of two brackets and an actuator.

Hitec “U” Universal brackets are employed which serve as linkages for the mechanism. A servomotor is employed in each module to actuate and govern the motion generated by the particular module. Hitec HSR-8498HB servomotors are used to serve as actuators for the system. The Hitec HSR-8498HB servomotors are capable of a 180° motion. They come along with Karbonite gears which are capable of withstanding large amounts of torque for long periods of time. The universal brackets are connected directly to the hub of the servomotor which is configured to provide a revolute joint. These links are connected back to back to provide a very sturdy and rigid connecting mechanism between two modules on the robot.

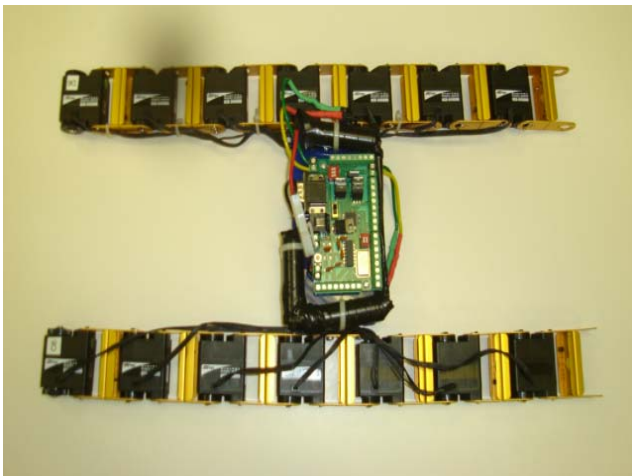


Figure 4. Fabricated model of Xanthus

The Hitec universal brackets are light in weight thereby decreasing the stress generated on the actuators for self-reconfiguration of the system. The weights of the servomotors contribute a significant sum to the total weight of the system. This generates sufficient amount of traction for system propagation in the crawling mode. These light-weight links along with the powerful torque capabilities of the servos decrease power consumption and enhance effective navigation of the system.

The microcontroller used for the developed platform is a PIC16F877A microchip on a custom board with built-in power regulators. It includes a MAX232 chip and an ICD

(In Circuit Programming / Debugging) for software control of the system. The PIC16F877a was chosen as the processor as it allows for compact packaging and possesses high speed capabilities. Multiple power regulation options were provided for long-term development of the system. The microcontroller is designed to distribute and regulate power requirements in addition of other peripherals in the range of 5W to 30W. The control system is designed for future addition of various sensors and peripherals depending on the task to be accomplished. Each module will include a multi-sensor system [1].

The inclusion of a sensor system will enhance the system’s navigation capabilities. The robot then will be able to estimate its position and orientation to assess its actions accordingly to unstructured environments.

GAIT DEVELOPMENT

Crawling Gaits

The system is most stable in this mode of navigation as problems concerning stability control and tipping over is minimal. Crawling motion for Xanthus is developed based on the traction developed by the system with the navigating terrain. Forward motion is achieved by the propagation of a lateral undulatory wave from the rear to the front of the robot which deforms the shape of the system periodically [6].

The system is initially actuated to lay parallel to the navigating terrain when activated into the crawling mode. The modules at the head of the system are raised causing initial displacements. Adjacent modules are then actuated while the initial modules are brought back to the ground. When the module is lowered, it reaches the ground in a position past its initial point of contact with the ground. The above process is repeated periodically propagating an undulatory wave from the tail to head of the system.

The speed of the crawling gait is modified based on the actuation times between adjacent modules. The modules adjacent to the passive connector experience higher stresses in comparison with the other modules in the system. Limbless motion adopted by the system experiences slippage when navigating smooth surfaces. This is avoided by a padding place beneath the modules, which increases tracking by improving system-terrain interaction.

Walking Gaits

Walking gaits for Xanthus is based on the static stability principle. It follows the principle of maintaining the center of gravity of the system within the support area of the feet. A larger support area is formed by the feet of the system in comparison to biped robots providing superior system stability.

The modular design of Xanthus allows several walking gait configurations. Based on the desired objective, the walking gait is configured to the particular initial configuration.

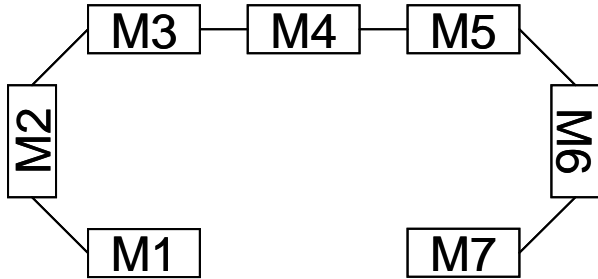


Figure 5. General walking mode initial configuration

In the initial walking configuration shown in Figure 5, the inner three modules act as passive joints with the outer two modules enabling walking mode navigation for the system. This method of walking provides maximum system stability as the system is configured to a kinematic position forming a larger support area. It however decreases the speed of the system owing to the sizes of the outer two modules on either ends. System speed is lowered owing to larger ground clearances required and interferences experienced.

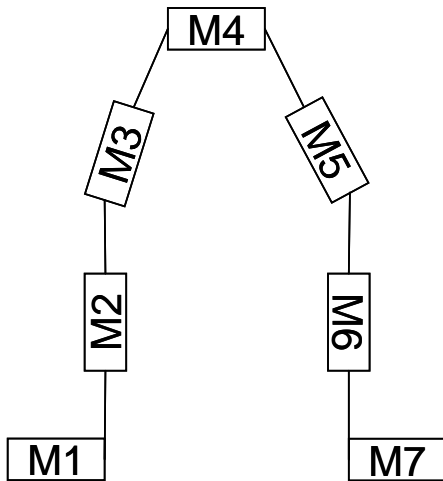


Figure 6. Schematic of fast walking mode initial configuration

The initial walking mode configuration for Xanthus shown in Figure 6 is employed for faster modes of walking. The center module on either chain acts as the passive element in this walking gait. The remaining three modules on each leg are utilized to generate walking patterns enabling similar functions as the hip, knee and ankle joints in a human leg. Control of system stability is more complicated in this mode of walking owing to smaller support area of the system.

There are several methods of propelling forward motion in quadruped walking as experienced while developing motion sequences for the system. The system is able to move forward based on body centered forward propulsion, leg centered forward propulsion or a combination of both [6].

In body centered gait development, the body mass of the system is moved forward initially which is compensated by the legs for forward motion. Leg centered gait development consists of actuating legs for initial forward displacement which is compensated by the body by the forward propulsion induced into the system. The combination of both of the above methods is executed by moving the body forward during intermediate stages of leg displacement. At this point some legs reach their final state while the rest are at their initial stage [1].

Rolling Gait

The rolling navigation mode for Xanthus is initially configured into a spherically symmetric heptagon. A single module provides a platform for a stable initial configuration. Rolling motion for Xanthus is achieved by configuring modules to shift the center of gravity forward until the system tends to tip over. The system moves into the next stage of transition when the center of gravity falls outside the pivot point of the system. Adjacent modules are similarly actuated for the repetition of the above process to obtain a continuous motion pattern. This generates moment in the direction of motion allowing the robot to accelerate [7].

The speed of the rolling gait can be altered by varying the time lag associated in actuation of adjacent modules. A uniform system speed is maintained by periodic actuation of the modules. The system configurations after the first loop are kept the same as the initial rolling configuration for a constant speed rolling gait. The robot can be accelerated by manipulating the robot configuration to displace the center of mass of the system to the farthest point with respect to the module in ground contact. The moment gained by the weight of the system displaces the robot forward providing continuous acceleration and a smoother motion [8].

Alternative means of rolling have been developed to reduce the energy requirements of the system. The momentum generated by the initial few cycles and inter-module arrangement is utilized to provide continuous rolling.

CONCLUSIONS AND FUTURE WORK

The development of an all-terrain navigation system has been presented in this paper. The developed system is designed and fabricated for crawling, walking and rolling modes of traversing terrains. The fabricated prototype of Xanthus was experimentally tested for the developed gait

algorithms. Experimental results validate the developed gaits based on successful navigation. The system has been successfully programmed to operate autonomously during changing modes of navigation. Singular positions have been avoided during self-reconfiguration of the system.

Current work involves optimization of gaits for minimal module movements, reducing time for reconfiguration and minimizing energy requirements for the system during reconfiguration. A perpetual rolling motion is being designed for the system for high speed traversing and minimizing energy at the same time. System capabilities will be further augmented in addition to adding a sensor system for autonomous terrain detection.

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