Self-Reconfigurable Moon Rover System With Embedded Swarm Intelligence

Karthik Thiyagarajan D.Prabhu Hari
Karthik.thrn@yahoo.com prabhuhari@yahoo.com
Department of Information Technology, St.Joseph's College of Engineering,Chennai,India

Abstract :

Moon rovers have come a long way embedding new degrees of robustness, self organization and decentralization. The exploration of the moon demands high parallelism and intelligence due to understandable constraints of energy and terrain. In this paper, we propose the integration of Self Reconfigurability and Swarm Intelligence for enhanced functional response in dynamic operational scenarios. However these varied concepts exist independently and have never been used in conjunction. The proposed rover has these two radical concepts integrated on a design level.These rovers work in swarms or intelligently reconfigure themselves to form a new functional unit suiting various application requirements. In the absence of locomotors, the polymorphic robots are limited to few forms of locomotion. They might be worm-like movement, loop structure, T and H walking styles. Although these movements are highly capable of traversing any terrain, there is a lack of fast mobility for individual modules. This architecture provides the mobility for individual modules and thus the design reflects characteristics of robustness, flexibility and graceful degradation.

Keywords: Swarm Intelligence, Self Reconfigurable Robots,ISIS ROVER, Agents

1. INTRODUCTION

Self Reconfigurable Robots are special type of robots which have the ability to mutate to different forms and shapes. These robots are made up of smaller discrete units referred to as modules. These modules are identical and consist of reconnectable joints (connectors). The Connectors facilitate the assembly and disassembly of the modules. This connecting mechanism may be mechanical, electro-magnetic or others. Apart from these joints, each module may also consist of gearboxes, motors, processors and shafts to enable reconfiguration. The hardware of the module controls the sensors, actuators, communication with neighboring modules, and other functionalities. The software is responsible for bringing about global coordination of modules and distributed control of the polymorphic robot. These robots can be applied in warfield reconnaissance, fire accident, in events of disaster and space applications. Swarm Robots are simple autonomous agents which collectively work towards a common goal. They interact with each other and the environment but remain independent of one another. They do not adhere to commands from a central source but can vary according to needs of the task. A single robot of the swarm would consist of the following- wheels or belts for locomotion, since mobility is highly important for agents in a swarm. Wireless antennas for communication between agents and sensor arrays for obstacle detection etc., Apart from these, it consist of circuitry to control movement , store data and transmission of data to peers. Swarm Robots are employed in resource discovery, space craft inspection and agriculture. The concepts of Swarm robots and Self reconfigurability however have not yet been explored in totality on a common design platform and share a different set of communication protocols, software algorithms and hardware components. ISIS(**I**ntegration of **S**warm **I**ntelligence into **S**elf Reconfigurability) ROVER is a robot which has these two radical concepts integrated on a design level. Problems such as interoperability of architectures, resolving communication protocols, hardware issues and optimizing software algorithms have been addressed. The main issue concerning ISIS ROVER is integrating the decentralized intelligence aspects of the robot into the event driven synchronization paradigm used after the robot has reconfigured itself to a new physical state.

The design used in ISIS ROVER can be adapted in other robotic architectures to enhance their performance in various applications such as Search and Rescue, Surveillance, agriculture and mining. The design would also aid in optimizing robots for greater degrees of robustness, distributed co-ordination, synchronization and maximum effectiveness.

2. RELATED WORKS

Self-reconfigurable robots are of two different types. They are either lattice-based or chain-based. In Lattice-based systems, the modules are fixed into geometric relationships with their neighbors and occupy discrete positions in a lattice structure. Crystal , Molecule , and ATRON are examples. On the other hand, Chain-based systems are robots in loop structures with continuous motor positions. Examples of such systems include Polybot , CONRO , M-TRAN , and Superbot [15]. A number of robotic scientists have researched on Polymorphic robots .Fukuda and Kawauchi [1] proposed a cellular robotic system which could reconfigure. Yim [2, 3] studied how to achieve multiple locomotion modes using robots composed of basic modules. Murata et al. [4, 5, 6] and Yoshida et al.[7] separately, designed and constructed systems that can achieve planar motion by arranging modules.Pamecha, et al. described metamorphic robots that can aggregate as stationary 2-D structures with varying geometry and that implement planar locomotion. “Robotic molecules” were used by Kotay, et al. to implemented metamorphic robots. Fujita, et al. built a biologically inspired reconfigurable robot. Paredis and Khosla proposed modular components for building reconfigurable robots. Crespi et al [9, 10]. designed an amphibious snake robot capable of swimming and crawling.Nilsson [8] designed and implemented a torsion-free joint for modular snake-like robots. Khoshnevis et al built the CONRO robots using reconnectable joints. Kasper Stoy [11] built the Deformatron Robot, a biologically inspired polymorphic robot whose individual modules can act as bone, tendon or muscle.

3.DESIGN OF ISIS ROVER MODULE

The body of each module in the robot consists of two linked cubes. They consist of three distinct units, a central unit capable of rotating and two units on either side with latching mechanisms on them to enable reconfiguration. Apart from this, the modules are also fitted with belts on four sides . These beltss enable faster locomotion of the modules when it is in isolation and on relatively a flat surface. The belts do not play a role when the modules reconfigure themselves into a larger robot. In such cases the belts would retract into the module and facilitate reconfiguration. Apart from this, the modules are also provided with an antenna for communication within a certain range. The antennas are used exchange information when the modules are completely disintegrated and are working as a swarm. Each module is powered by its own battery. Small motors are used to generate the power for locomotion. They are used to render the yaw, turn and pitch required for reconfiguration.

3.1 HARDWARE ASPECTS

Figure 2 shows the hardware architecture of an individual module in ISIS ROVER. As it is depicted in the figure, each module of ISIS ROVER consists of a dedicated micro controller that manages the overall functioning of the module. It is also equipped with a pair of DC motors to perform operations pertaining to locomotion and latching. A total of six latches are present in each module which permits connecting to the neighboring modules. The modules may connect to the front, rear,top, bottom, left or to the right of other modules. The power source to the module is a Dry Battery that forms the replaceable part of the module. Apart from these, the hardware also consists of the actuators, sensors and other components. The “Intelligence Engine” is the software component of the module's architecture which has two varied algorithms embedded in it, namely the Swarm Optimization Algorithm used for the individual mode of operation and the Recon Event Driven Algorithm used in the reconfigured mode of operation. These algorithms can either be used separately or in conjuncture.

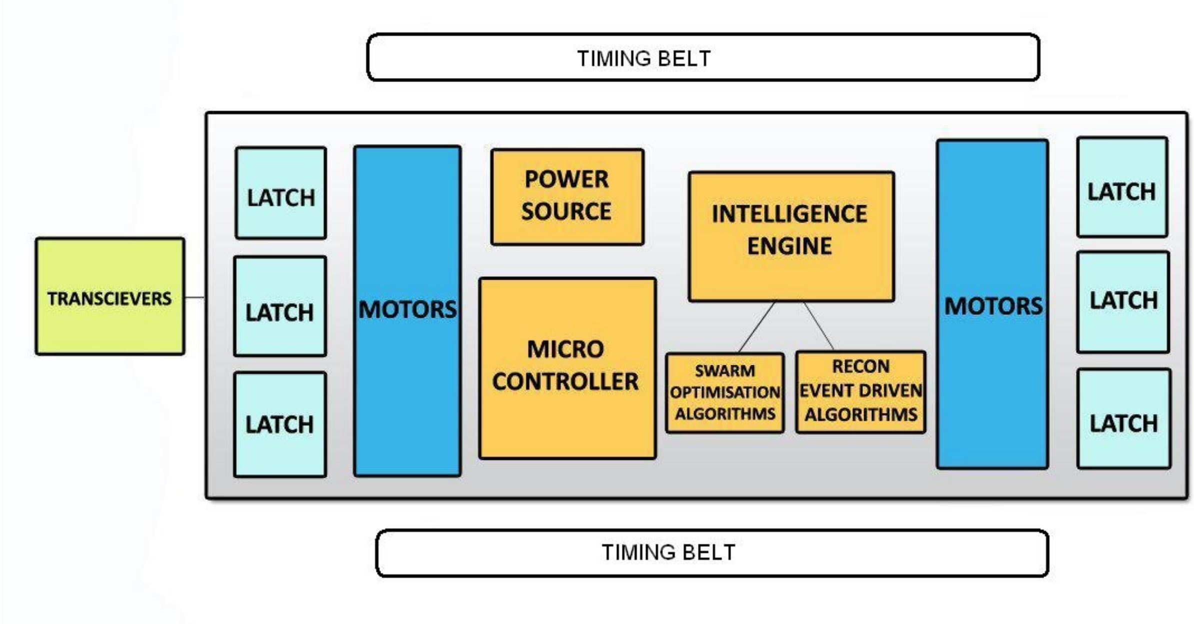


Figure 2 : Design of a Single Module

3.2 SOFTWARE ASPECTS

Software designed to control ISIS ROVER would address the following factors.Objectives of softwares written for reconfigurable robots and swarm robots are completely different and share no common goals. The Software controlling a reconfigurable robot performs Processes pertaining to reconfigurability alone and the embedded software to co-ordinate swarm robots carries out restricted actions concerning collective intelligence. But the software for ISIS ROVER must use both the above logics in conjecture. Software designed to control ISIS ROVER would address the following factors with respect to reconfigurability.

Decentralized approach: The software would be built based on concepts of distributed systems so that failure of a module doesn't create a communication bottleneck.In case of a failure or malfunctioning, the corresponding module would be disconnected and they wouldreconfigure into a new structure.

Networked: All modules would communicate with one another to result in the final action of the robot. They can exchange information to derive the best possible output.

Scalability: The addition of large number of modules to form a larger robot results in challenges of maintaining the centre of gravity, communication of the module's status to other units etc.

Swarm robotics emphasizes large number of agents and promotes scalability.

Data sharing: In swarm Intelligence, the robots will have to constantly exchange data to maintain the Stability of the swarm. The software would require a certain amount of memory to maintain the data.

4. MODES OF OPERATION

There are three modes of operation in the proposed system.

4.1 RECONFIGURABLE MODE

In this mode, the modules combine to form a polymorphic robot. They may re-organize themselves to form new shapes and sizes etc. The locomotors and antennas are not put to use. The software deals with global coordination of modules and distributed control of the polymorphic robot. The part of the software that deals with reconfiguration is alone executed in the memory. Though it is possible to have both the programs simultaneously running, this approach reduces the load on the memory of the modules.

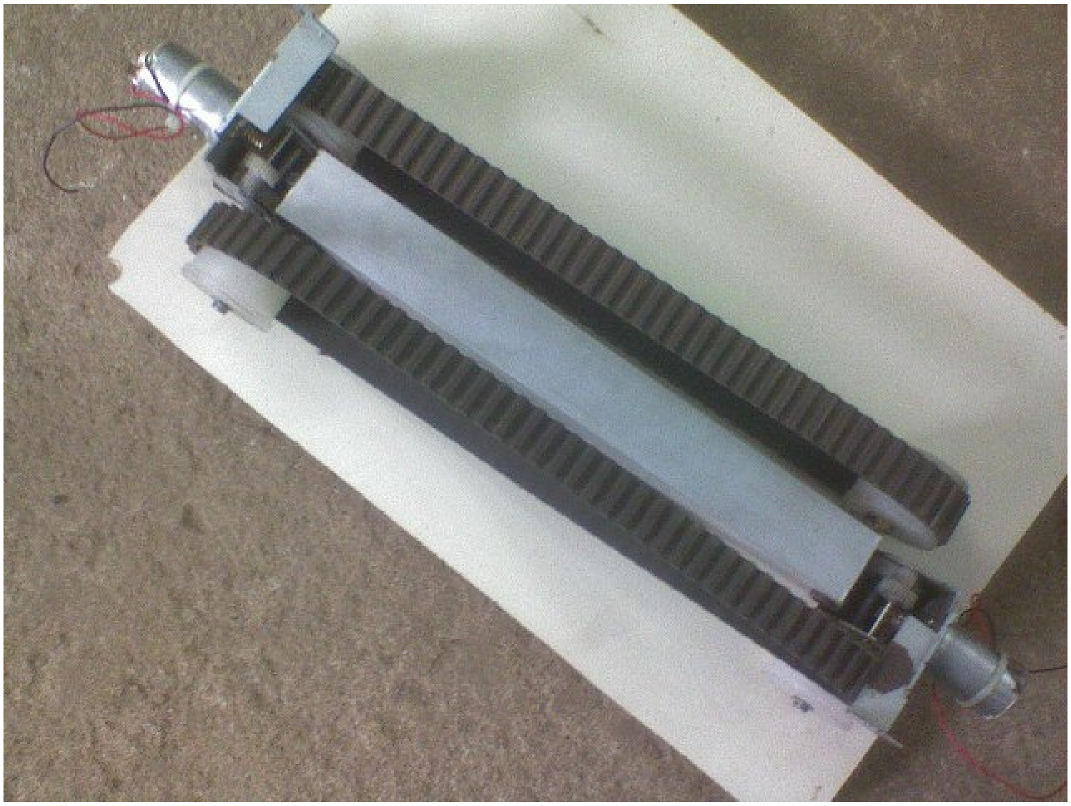
4.2 SWARM MODE

In this mode, the robot is completely disintegrated into modules, and these modules would behave as agents. The agents can now use their locomotory devices and antennas to exchange information. This might need considerable computational resources. Specific algorithms are used to behave as a swarm. One of the major advantages of this mode is Co-coordinated search. All the robots can communicate with one another and search for a common resource by updating information collected by them. In this mode, the program required to perform swarm activities is alone executed and the other is blocked.The antennas used for communication are of limited range.The Swarm mode does not limit the Agents to a single module. A collection of modules can also act as a module, which is explained in Mode 3.

4.3 RECON SWARM MODE

This is the most interesting mode of ISIS ROVER architecture. Here both the programs are simultaneously put to use. A certain set of modules reconfigure themselves into a new structure and all other modules are independent. The new structure exists in both Recon Mode as well as in Swarm Mode. All other modules exist in Swarm mode alone. In the reconfigured structure, one module is arbitrarily elected as the Master Module. This module is responsible for performing “abstraction”. It abstracts the entire structure as a single agent to the rest of the swarm; however the swarm may possess the knowledge of the new structure and its capabilities. The Master Module also participates in reconfiguration as it is a decentralized process and all the modules are involved in altering the structure of the robot.Although the reconfigured structure is abstracted as a single agent to the swarm, its structural details are disclosed to the swarm. When a new module needs to be attached to the existing structure, the system may choose the most optimum module to get attached by surveying the environment. In such situations, the new module to get attached to the larger structure exits the swarm mode and shifts to the Recon Mode.

PRELIMNARY DESIGN ATTEMPTS:



These our prelimnary attempts in constructing the envisioned moon rover. It represents one fourth of the model to be constructed. Four of these units would be used to form a rectangular box. The latches would be present beyond the ‘rectangular portion’ without hindering the timing belts to facilitate reconfiguration.

5. NEED OF THIS ARCHITECTURE

In the absence of locomotory device, the polymorphic robots are limited to few forms of locomotion. They might be worm-like movement, loop structure, T and H walking styles. Although these movements are highly capable of traversing any terrain, there is a lack of fastmobility for individual modules. This architecture provides the mobility for individual modules, addition of required software and hardware components can mutate the modules into intelligent agents.

6. CONCLUSION

In this paper, we have put forth our theory of integrating swarm intelligence concepts and self – reconfigurability in robotic systems through the design of ISIS ROVER. The system in theory appears to have great promise in acting as an efficient and optimal architecture aid in dynamic operational scenarios. The use of swarm concepts embeds overall intelligence into the system and the reconfigurability provides adaptability. This design thus reflects characteristics of robustness, flexibility and graceful degradation.

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