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# Interconnection of Modules of Reconfigurable Modular Robots: A Review

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**Abstract - Robots normally perform pre-specified tasks in a predictable environment, like that on shop floor. Normally, assembly-line like operations are performed by robots due to geometrical and programming constraints. Rapidly changing requirments at customer level has greatly influenced the manufacturing technology, due to the risk of obsolescence. Multiple small robots called modules, interconnect with each other its own, to make a great structure are called self-reconfigurable modular robots. For few modules, a large number of configurations are possible. As per the level of difficulty of the task, it can take any shape, to complete the work. Each module of the modular robot has its built-in intelligence with separate memory, connection assemblies, detectors and actuators to operate it. Such robots are highly useful in remote operations, especially in hostile environments.**

**For physical docking of the connection plates of the modules, the connection plates should be properly aligned towards each other. This review paper enlightens the capabilities of the modular reconfigurable robots and the techniques explored by some researchers in this field, for proper alignment of the connection plates, for physical docking of modules. Position sensors like hall-effect sensors; and proximity sensors like infrared (IR) detectors and emitters have been used for docking of connection plates of the modules. Controlling and coordinating modules to work together effectively and not collide or otherwise interfere with each other is a bottleneck in this concept. Some work using IR intensity to guide the alignment of the modular robots have already been undertaken. Possibility for the use of MatLab by Mathworks is explored to simulate the alignment for interconnection of Modules of Reconfigurable Modular Robot using data captured by the CCD camera through image recognition.**

**Keywords: Self-reconfigurable Modular Robots, Simulation, Image Recognition, Module Docking, MatLab**

## I. Introduction

A robot is a programmable machine that can perform variety of tasks depending upon the requirements and the programming. Robots normally perform pre-specified tasks in a predictable environment. Initially, the robots were extensively used for material handling in the manufacturing systems, especially in assembly operations. Due to high load carrying capacities and the wide working range, the robots are highly preferred for material handling in the industry. In addition to this, machine loading, un-loading, spray painting, thermal spray coatings or assembly like operations are also performed by the robots. With the advancement of technology, the capabilities of the robotic systems are getting improved. The selection of a robot is made according to the requirements of the procedure as shown in figure 1 [1].

Rapidly changing requirments at customer level has greatly influenced the manufacturing technology due to the risk of obsolescence.

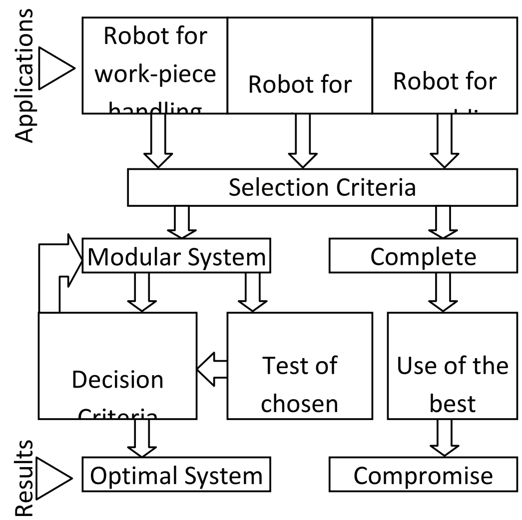


Fig.1 Applications Engineering of Robots [1]

With the increase in the complexities in the system requirements, the special purpose robots came into picture but it increased the cost of design, manufacturing and that of maintenance and further reduced the flexibility in use for different purposes. Use of modular approach in the construction of the industrial robots has proved to be an effective way-out to reduce the cost and to make it maintenance friendly. In addition to the modular approach, the concept of emergence systems has also played an important role in the field of robotics. The emergent systems are capable of adjusting the system itself with respect to any change in the environment, without any external help. [2].

Efforts have been made [2] to embed such functionalities into the systems by new theories and algorithms. Another approach is to change hardware structure to realize the emergent functionality.

In recent years, many modular robots for self-assembly, self reconfiguration, and self-repairing have been developed because these systems possess the potential advantage of versatility through reusability of modules, low cost through mass fabrication of modules, fault tolerance, and ease of repair by replacing not functioning modules [3].

Modular Robot can be made by interconnecting multiple, simple, similar units. Each comprising module having separate detectors, connection assemblies and motor housings to operate its arm with built in intelligence and memory. Such a modular robot can shape itself into a loop and move by rolling like a self propelled tank tread; then break open the loop to form serpentine configuration to slither under or over obstacles; then re-arrange its modules to "morph" into a multi-legged spider, able to stride over rocks and bumpy terrain (fig. 2). Systems of this kind would be useful for remote autonomous operations, particularly in hostile environments such as under sea, on other planets, or at the scene of natural disaster [4].

Modular approach in robots has got World wide attraction due to greater versatility and robustness. Like children block games, a number of same set of modules can take any shape to perform wide variety of tasks. For a typical system with limited number of modules, a large number of configurations are possible, which can be applied to many diverse tasks. It is born out of redundancy and small number of module types. The units diagnose themselves and each other and compensate for, replace, or reconfigure themselves around any that are malfunctioning. The main advantage of redundancy is that when one or more modules malfunction, overall function degrades gracefully, instead of failing catastrophically [4].

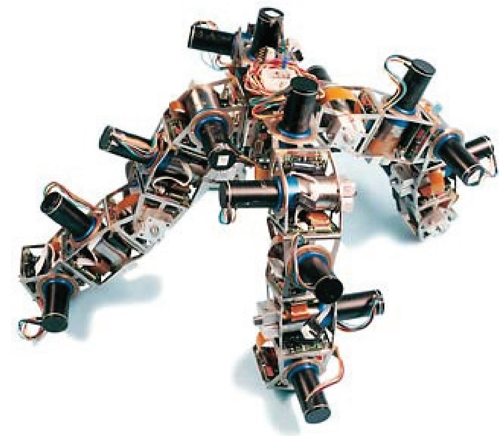

Fig. 2 Different Chain / Linear Configurations of Modular Robots [4]

Moreover, being few in type these modules can be mass produced and as economies of scale come into play, the cost of each one can be reduced. The drive units of have the biggest share in the costs of industrial robots. Therefore, in modular concept, the derive units play an important role in the modularity and re-utilisation [1].

CEBOT [5] is one of the first self-reconfigurable modular systems, where the modules in the system were heterogeneous, such as mobile module with wheels, blending module for a part of an arm and a hand unit as an end effector. The modules could be connected automatically to create combined structure to form a manipulator. The fracta system and the self-reconfigurable robot are two dimensional modular type sytem [5]. These systems are composed of homogeneous units, which do not have any specific functionality. However, the group of units is supposed to have some useful function such as handling object or moving on the terrain. Homogeneity of the system is specially advantageous in self-repair operation, because any unit can be replaced by any other unit. Several algorithms of self-assembly and self-repair have been developed for these systems [5].

Modular robotic system having self reconfigurable capabilities are generally classified on the basis of their architectural topologies [6], which includes mobile, lattice, chain, and hybrid, as shown in fig. 3.

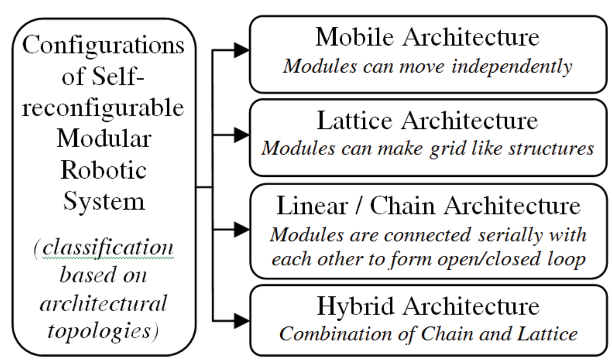


Fig. 3 Configurations of self-reconfigurable modular robotic systems

In mobile architecture, the modules can move indpendent to each other. As per the name, in lattice structure, the modules are connected to each other in such a manner that a matrix is generated to form grid a grid like structure. In linear / chain architecture, a number of modules can be connected serially by making joints between each other to take the required shape, to perform the specified task. The configuration of such modular structure can be changed by changing number and order of modules. It can take different shapes by connecting in different manner, creating the tree structure or closed loop to roll like a circular ring. In hybrid architecture, the benefits of both the architectural configurations i.e. lattice and chain are combined together, by eliminating the drawbacks of individual. Hybrid configurations therefore can make wide variety of configurations to perform variety of tasks [7].

## II. Interconnection Of Modules

For self-reconfiguration of the modules of modular robots, a very precise control on the coordination and on the movement of connecting modules is required. Interconnection between the modules depends upon the two main factors i.e. the proper alignment between the connection plates of the modules and the latch / connection mechanism. The level of precision required for docking actually depends upon the latch / connection mechanism. The latch mechanism that reduces the level of precision required for docking is preferred, while designing it. Some geometrical and other important issues were presented by Nilson to minimize the level of precision in docking system [8].

In this paper, the study is focussed at the different dock and latch systems available, with relative merits and demerits of each. The possibility of use of alternative techniques for docking and latching is also explored for future work.

Many authors presented the different dock and latch mechanism, in order to reduce the level of precision required for docking. Yanqiong and Xifang presented a dock analysis of a lattice base self-reconfigurable modular robotic system. In the design considered, the modules were of cubic geometry with each face having rotary sides as shown in figure 4. For docking, two extension pegs were provided at each rotary face of cubic module, which can move in the two corresponding holes on the either rotary face of the another cubic module. More number of modules can be connected to take the desired shape [9].

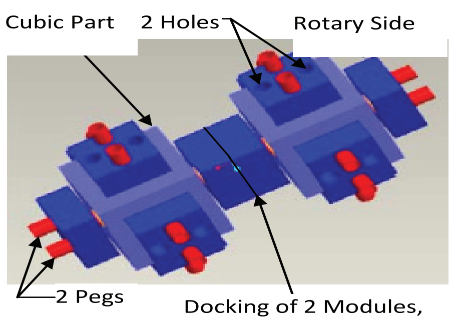


Fig. 4 Docking of Modules [9]

In this paper [9], the states of docking and constraints between modules were analyzed with the geometric method and the contact force of docking was described.

PolyBot a self reconfigurable modular robot was developed at PARC were of two different types viz. G2 and G1v4 [10]. The more powerful one, G2, is made of just two types of cube-shaped modules: a segment that has a hinge-joint between two hermaphroditic connection plates and a node, which doesn't move but has six connections. The two connection plates on either side of the hinge join it to other modules, electrically as well as physically. On every connection plate there are four electrical connectors, each with four contacts; and through the connectors electric power and communications pass from module to module (fig. 5). The communications network uses the CAN protocol (for Controller Area Network), which is a popular automotive serial network standard [10].

For physically docking and undocking, every connection plate also houses a latch. At its heart the latch is a wire made of a shape memory alloy, a nickel-titanium combination that alternates between two shapes when alternated between two temperatures. In this case, resistive heating is used. When current is run through the wire, the latch opens and releases its hold on a neighboring module. Stopping the current allows the latch to close by a return spring [10].

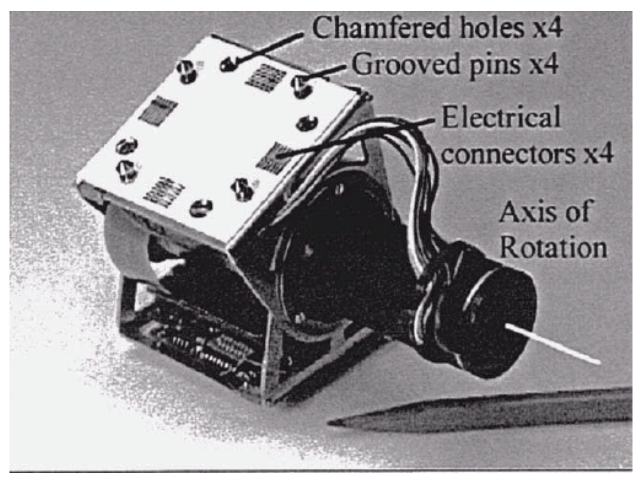


Fig. 5 One G1 showing the connection plate with 4 pins, 4 mating chamfered holes & 4 hermaphroditic electrical connector sets

In PolyBot G2, to determine the angle between the connection plates, position sensors were used. Infrared emitters and detectors were mounted on the connection plates to serve as the proximity sensors to aid the docking between two modules. A lower version of PolyBot G1v4 was not capable to automatic docking and un-docking of modules [10]

"Telecubes" [11] is a cubic module that has six prismatic degrees of freedom whose sides can expand more than twice its original length and has the ability to magnetically (de)attach to other modules. Many of these modules can be connected together to form a modular self-reconfigurable robot.

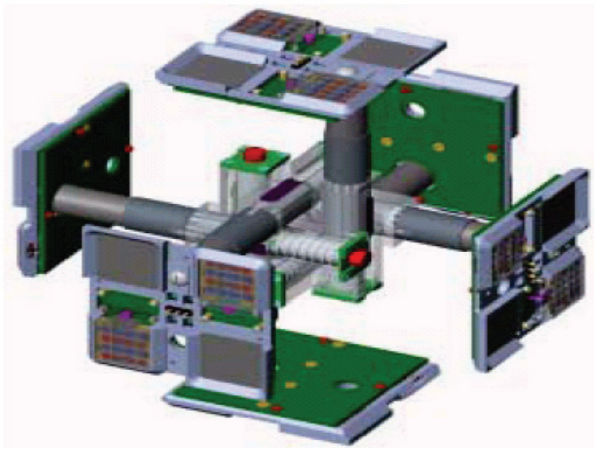

Fig. 6 CAD solid model of a Telecube module in full extension [11]

The paper [11] presents the intended functions, discusses the physical requirements of the modules and describes two key mechanical components: a compact telescoping linear actuator and a switching permanent magnet device.

Chain modular robots [8] form systems with many degrees of freedom which are capable of being reconfigured to form arbitrary chain-based topologies. This reconfiguration requires the detaching of modules from one point in the system and re-attaching at another. The internal errors in the system (especially with large numbers of modules) are such that accurate movement of chain ends, required for the attaching of modules, can be extremely difficult. A three phase docking process is described that utilizes both open and closed-loop techniques.

One paper [A. Casal, 1999] examines the self-reconfiguration problem and presents a divide-and-conquer strategy to solve reconfiguration for a class of problems referred to as closed-chain reconfiguration. This class includes reconfigurable robots whose topologies are described by one-dimensional combinatorial topology. A robot topology was first decomposed into a hierarchy of small "substructures" (sub-graphs of modules) belonging to a finite set. Basic reconfiguration operations between the substructures in the set were pre-computed, optimized and stored in a lookup table. The entire reconfiguration then consisted of an ordered series of simple, pre-computed sub-reconfigurations happening locally among the substructures. [12]

Six DOF offset sensing between two plates is important for Automatic Docking Mechanisms. The paper [13] presents an easy and inexpensive implementation of such a system using four commercial-off-the-shelf (COTS) infrared (IR) light emitting diode (LED) emitters and two COTS IR receivers on each of two docking plates. The angular intensity distribution of an emitter and the sensitivity distribution of a receiver allow for estimation of the angle and distance between them. In this paper, theoretical framework was also established using least squares minimization. The theoretical framework was general and applied to other configurations of emitter and receiver parts and positioning. [13]

However, one main concern in the modular robot system is the positioning accuracy of the end-effector. The machining tolerance, compliance, and wear of the connecting mechanism and misalignment of the connected module components may introduce errors in positioning the end-effector or the tool [14]. The purpose of calibrating the kinematic parameters of a modular robot is to identify the parameters of the robot, which describe the actual (or measured) position of the end-effector.

## III. Scope Of Using Matlab In Module Alignment

Robotic Vision Systems, Inc. (RVSI) has conceptually designed an innovative laser-based ranging system capable of acquiring three-dimensional image data for an entire scene without scanning [15].

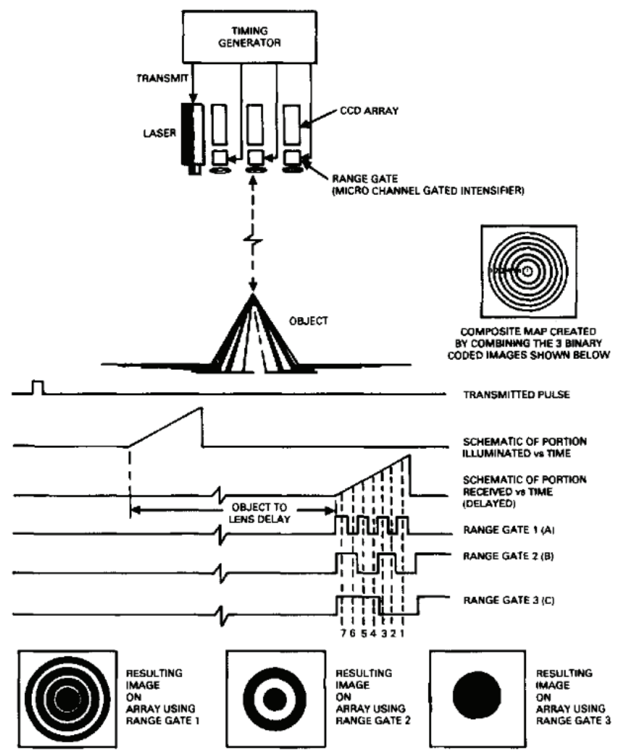


Fig. 7 Block Diagram of RVSI LORDS Ranging Concept (Courtesy: RVSI)

The Long Optical Ranging and Detection System (LORDS) is a patented concept incorporating an optical encoding technique with ordinary solid state camera(s) (fig. , resulting in precise distance measurement to multiple targets in a scene from a single laser light pulse [15].

MatLab is a very powerful software tool [16-18] that works on mathematical environment. It has gained a huge popularity in the area of Automation and Robotics due to its number of toolboxes that extend its functionality. Brandao presented a toolbox that enable access to real Robotics and

Automation equipment from the Matlab shell. The developed robotic toolbox extended the applications of MatLab for its use in robotic simulations and data analysis, with the help of which the user can interact online with the system. This tool shows its usefulness for research applications, but also for teaching projects. With students, using Matlab means taking advantage of the less training required to start using it, if we compare with other programming environments and languages we also use (Microsoft Visual C++ or Visual Basic). [19]

Controlling and coordinating modules to work together effectively and not collide or otherwise interfere with each other is a bottleneck in this concept. As discussed in this paper, some work using IR intensity to guide the alignment of the modular robots has already been undertaken [13].

MatLab by Mathworks can be used to simulate the alignment for interconnection of modules of reconfigurable modular robots, using image data captured by CCD camera, to control the motion of the modules for proper docking by avoiding any collision or interference.

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