1. INTRODUCTION

1.1 ROBOTS

A robot is a mechanical or virtual, artificial agent. It is usually an electromechanical system, which, by its appearance or movements, conveys a sense that it has intent or agency of its own.

A typical robot will have several, though not necessarily all of the following
properties:

- Is not 'natural' i.e. has been artificially created.
- Can sense its environment.
- Can manipulate things in its environment.
- Has some degree of intelligence or ability to make choices based on the environment or automatic control / pre-programmed sequence.
- Is programmable.
- Can move with one or more axes of rotation or translation.
- Can make dexterous coordinated movements.
- Appears to have intent or agency (reification, anthropomorphisation or Pathetic fallacy).

Robotic systems are of growing interest because of their many practical applications as well as their ability to help understand human and animal behavior, cognition, and physical performance. Although industrial robots have long been used for repetitive tasks in structured environments, one of the long-standing challenges is achieving robust performance under uncertainty. Most robotic systems use a manually constructed mathematical model that captures the robot’s dynamics and is then used to plan actions. Although some parametric identification methods exist for automatically improving these models, making accurate models is difficult for complex machines, especially when trying to account for possible topological changes to the body, such as changes resulting from damage.

1.2 ERROR RECOVERY

Recovery from error, failure or damage is a major concern in robotics. A majority of effort in programming automated systems is dedicated to error recovery.The need for automated error recovery is even more acute in the field of remote robotics, where human operators cannot manually repair or provide compensation for damage or failure.

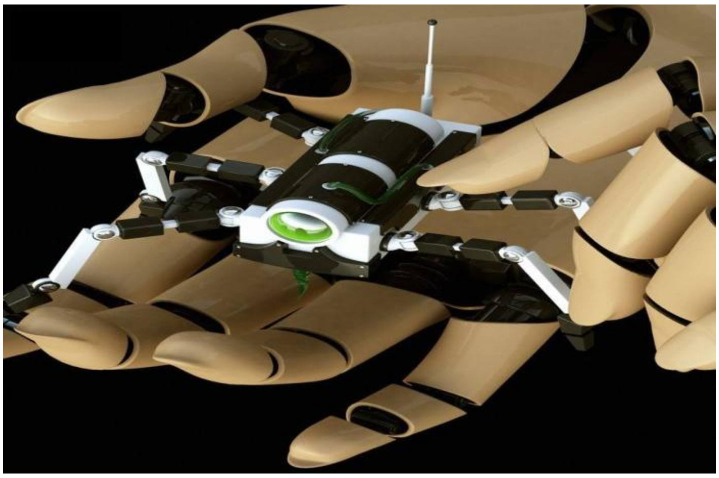


Fig 1.1 A Robot

Here, its explained how the four legged robot automatically synthesizes a predictive model of its own topology (where and how its body parts are connected) through limited yet self-directed interaction with its environment, and then uses this model to synthesize successful new locomotive behavior before and after damage. These findings may help develop more robust robotics, as well as shed light on the relation between curiosity and cognition in animals and humans.

2. SELF HEALING OR SELF MODELLING ROBOTS

When people or animal get injured ,they compensate for minor injuries and keep limping along. But in the case of robots, even a slight injury can make them stumble and fall .Self healing robots have an ability to adapt to minor injuries and continue its job . A robot is able to indirectly infer its own morphology through self-directed exploration and then use the resulting self-models to synthesize new behaviors. If the robot's topology unexpectedly changes, the same process restructures it's internal self-models, leading to the generation of qualitatively different, compensatory behavior. In essence, the process enables the robot to continuously diagnose and recover from damage. Unlike other approaches to damage recovery, the concept introduced here does not presuppose built-in redundancy, dedicated sensor arrays, or contingency plans designed for anticipated failures. Instead, our approach is based on the concept of multiple competing internal models and generation of actions to maximize disagreement between predictions of these models.

3. HISTORY

The basic concept of the common connection mechanism and applying it to the whole robot was introduced by **Toshio Fukuda** with the **CEBOT** (short for cellular robot) in the late **1980's**

The early **1990's** saw further development from **Mark Yim, Joseph Michael,** and **Satoshi Murata**. Michael, and Murata developed lattice reconfiguration systems and Yim developed a chain based system. One of the more interesting hardware platforms recently has been the MTRAN II and III systems developed by Satoshi Murata .. This system is a hybrid chain and lattice system. It has the advantage of being able to achieve tasks more easily like chain systems, yet reconfigure like a lattice system

Recently a research on a self reconfigurable star fish robot was done at the **Computational Synthesis Lab at Cornell University** in **2003.** Team members are **Josh Bongard**, **Viktor Zykov**, and **Hod Lipson**. This project was funded by the NASA Program on Intelligent Systems and by the National Science Foundation program in Engineering Design.

Fig 2.1 Victor Zykov, Josh Bongard, and Hod Lipson

Other Developments

- **AMOEBA-I (2005)**
- **Stochastic-3D (2005)**
- **Molecubes (2005)**
- **SuperBot (2006)**
- **Miche (2006)**

4. SELF-RECONFIGURATION PRINCIPLES

4.1 RECONFIGURATION STATES

Self-reconfigurable robots uses State Estimation procedure in order to decide whether to reconfigure or not. A simple behavior-based control strategy is used for control and reconfiguration of the Self-Reconfigurable robots

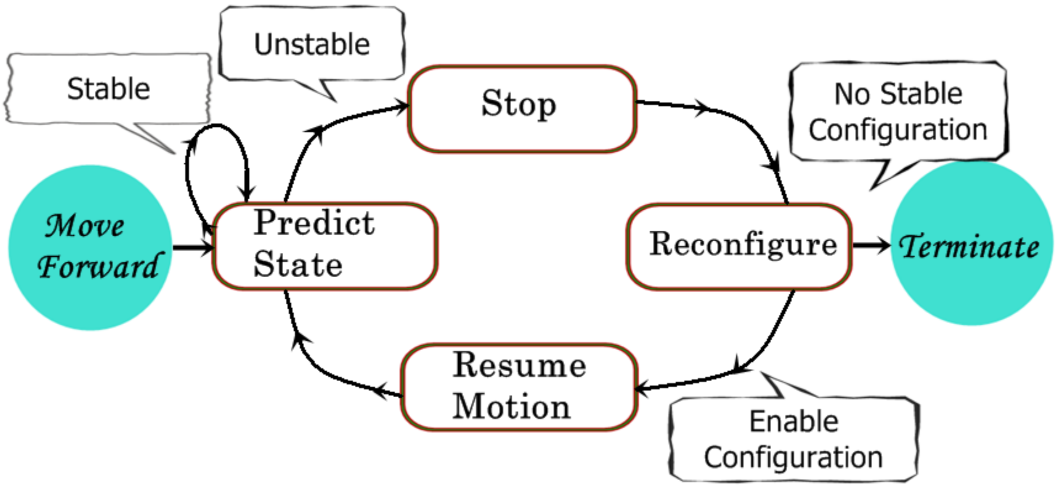


Fig: Stability reconfiguration stages in a Self-Reconfigurable Robots

The main working phases in self reconfiguring robots are :

I. **Predict state:** The state estimator in a self-reconfigurable always predicts its state in order to proceed for the locomotion ,if the sate is suitable for the robot it will do its task until the system becomes unstable for the locomotion

.

II. **Stop:** The state estimator predicts the roll and pitch of the vehicle and calculates its stability. When approaching terrain for which the current configuration is not suitable, the behavior-based controller stops locomotion.

III. **Reconfigure:** selecting the previous most suitable configuration, and reconfigures the robot accordingly before it proceeds. If the system fails to find a stable configuration, it will stop and redo same.

IV. **Resume Motion:** After a suitable reconfiguration has been enabled the robot resumes its motion.

4.2 SELF-RECONFIGURING MECHANISMS

Self-reconfigurable robots uses Some mechanisms during reconfiguration in order to achieve the accurate reconfiguration procedure

- **Bonding mechanism :** A mechanism that allows module to attach to other modules. Self-reconfigurable modules have the ability to selectively make and break attachments to other modules.

- **Reconfiguration algorithms :** A method that transforms a given robotic configuration to a desired configuration via a sequence of module detachments and reattachments.

- **Configuration :** The connectivity arrangement of modules in a system which describes which modules is physically attached and adjacent to which.

- **Configuration recognition :** The process of automatically determining a modular robot's connectivity arrangement.

- **Decentralized control :** A control system in which the controller elements are not central in location (like the brain) but are distributed throughout the system with each component sub-system controlled by one or more controllers.

5. TYPES OF MODULAR SELF-RECONFIGURABLE ROBOTIC SYSTEMS

There are several ways of categorizing Modular Self-reconfigurable Robots (MSR) systems. One is based on the regularity of locations for attaching; lattice vs. chain vs. mobile, and another is based on the methods of moving between those locations; stochastic vs. deterministic

5.1 LATTICE TYPE

A lattice based Self-Reconfigurable system has modules arranged nominally in a 2D or 3D grid structure. For this category, there are discrete positions that a given module can occupy. In contrast to chain-based architectures where modules are free to move in continuous space, the grid based structure of lattice systems generally simplifies the reconfiguration process. Kinematics and collision detection are comparatively simple for lattice systems. An example is shown in Fig

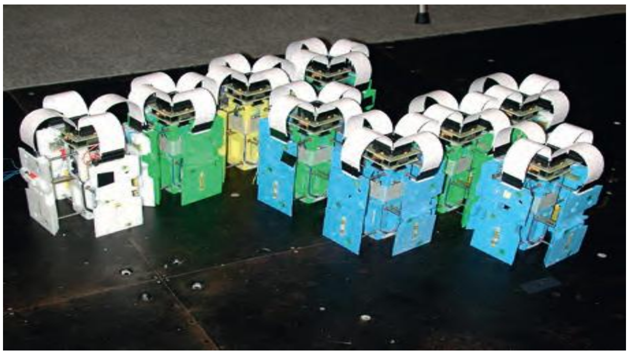


fig: A Lattice based Self-Reconfigurable Robots

5.2 CHAIN TYPE

A chain based MSR system consists of modules arranged in groups of connected serial chains, forming tree and loop structures. Since these modules are typically
arranged in an arbitrary point in space, the coordination of a reconfiguration is complex. In particular, forward and inverse kinematics, motion planning, and collision detection are problems that do not scale well as the number of modules increases. An example is shown in Fig

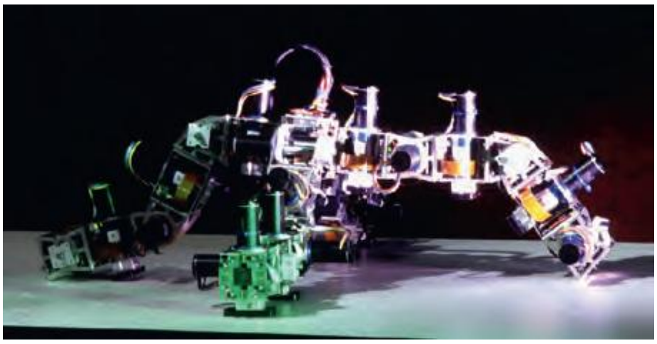


fig: A Chain based Self-Reconfigurable Robots

5.3 MOBILE TYPE

The mobile class of reconfiguration occurs with modules moving in the environment disconnected from other modules. When they attach, they can end up in chains or in a lattice. Examples of mobile reconfiguration devices include multiple wheeled robots that drive around and link together to form trains, modules which float in a liquid or outer space and dock with other modules.

5.4 DETERMINISTIC TYPE

In deterministic Modular Self-Reconfigurable systems, modules move or are manipulated directly from one position to another in the lattice or chain. The positions of each module in the system are known at all times. The amount of time it takes for a system to change from one configuration to another is determined. A module's reconfiguration mechanism requires a control structure that allows it to coordinate and perform reconfiguration sequences with its neighbors.

There are a growing number of existing physical systems that researchers are developing self-reconfigurable robots. One indication that this number is getting large is the development of a robot whose name is YaMoR (Yet another Modular Robot) . Table 1 lists many of the other instantiated modular robot systems. In addition to the name, class, and author, the table lists DOF(degree of freedom). This describes the number of actuated degrees of freedom for module motion (e. g. not latch degrees of freedom) as well as whether the system motion is planar (2D) or can move out of the plane (3D). The year is the estimated first public disclosure.

6. SOME OF THE CURRENT SYSTEMS

6.1 THE STARFISH ROBOT

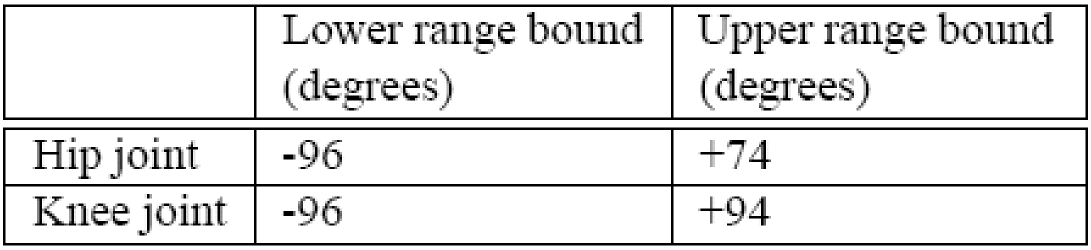
The target system in this study is a quadrupedal, articulated robot with eight actuated degrees of freedom. The robot consists of a rectangular body and four legs attached to it with hinge joints on each of the four sides of the robot's body. Each leg in turn is composed of an upper and lower leg, attached together with a hinge joint. All eight hinge joints of the robot are actuated with Airtronics 94359 high torque servomotors. However, in the current study, the robot was simplified by assuming that the knee joints are frozen: all four legs are held straight when the robot is commanded to perform some action. The following table gives the overall dimensions of the robot's parts.

Parameter	Value (mm)
Width and length of the body	140
Height of the body	85
Length of the upper leg	95
Height of the upper leg	26
Length of the lower leg	125
Diameter of the foot	12

Table 2.1 Overall dimensions of robot

All eight servomotors are controlled using an on-board PC-104 computer via a serial servo control board SV-203B, which converts serial commands into pulse-width modulated signals. Servo drives are capable of producing a maximum of 200 ounce inches of torque and 60 degrees per second of speed.

The actuation ranges for all of the robot’s joints are summarized in the following table



	Lower range bound (degrees)	Upper range bound (degrees)
Hip joint	-96	+74
Knee joint	-96	+94

Table2.2 Actuation ranges

This four-legged robot can automatically synthesize a predictive model of its own topology (where and how its body parts are connected), and then successfully move around. It can also use this "proprioceptive" sense to determine if a component has been damaged, and then model new movements that take the damage into account.

The robot is equipped with a suite of different sensors polled by a 16-bit 32- channel PC-104 Diamond MM-32XAT data acquisition board. For the current identification task, three sensor modalities were used: an external sensor was used to determine the left/right and forward/back tilt of the robot; four binary values indicated whether a foot was touching the ground or not; and one value indicated the clearance distance from the robot’s underbelly to the ground, along the normal to its lower body surface. All sensor readings were conducted manually, however all three kinds of signals will be recorded in future by on-board accelerometers, the strain gauges built into the lower legs, and an optical distance sensor placed on the robot’s belly.

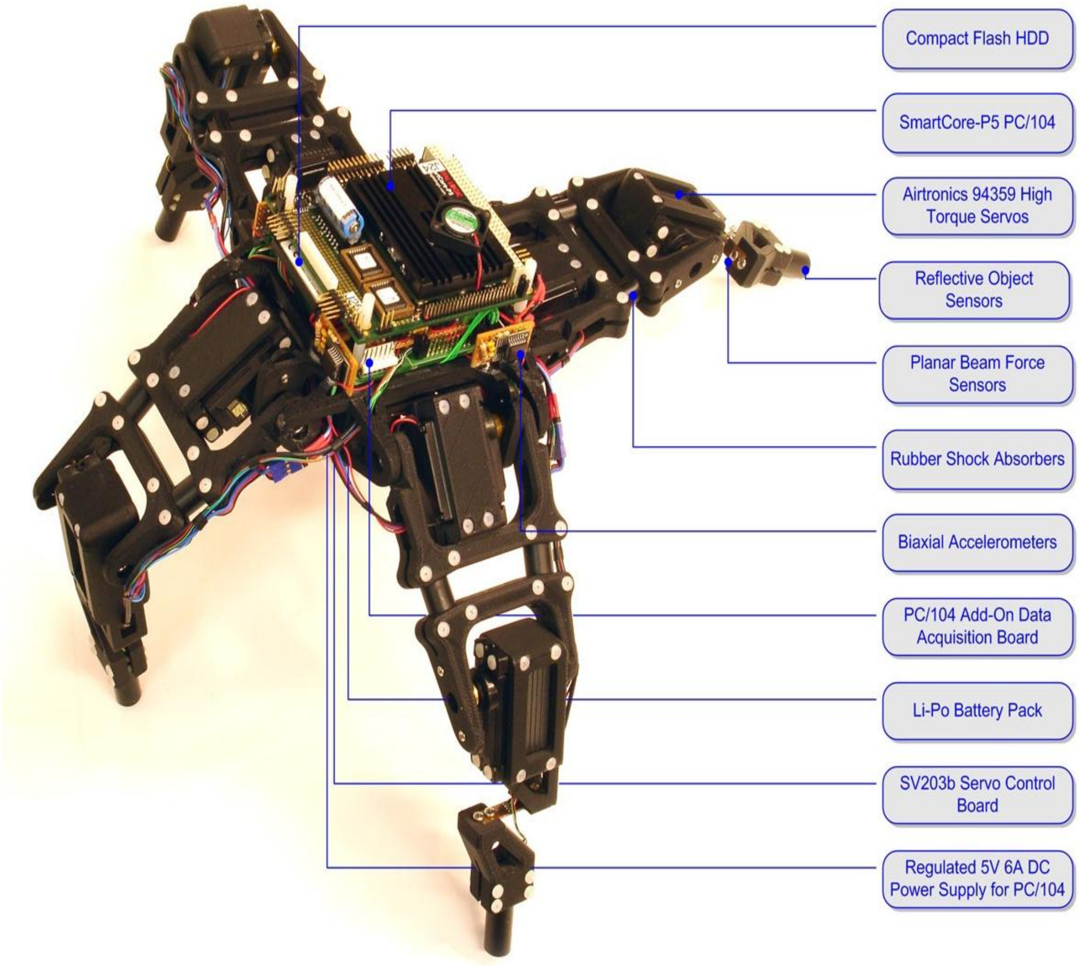


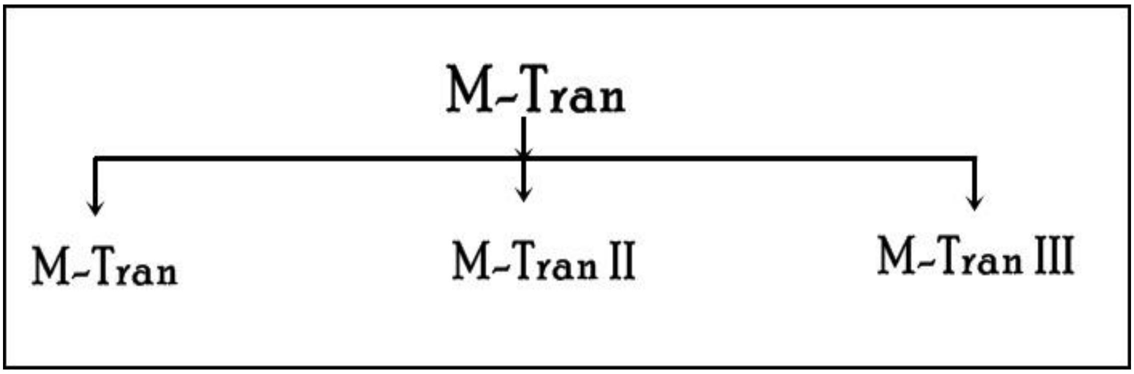
Fig 2.2 The body parts of a starfish robot.

6.2 M-TRAN

M-TRAN (Modular Transformer) is a **self-reconfigurable modular robot** that has been developed by Tokyo-Tech since 1998. A number of M-TRAN modules can form

- A 3-D structure which changes its own configuration
- A 3-D structure which generates smaller robots
- A multi-DOF robot which flexibly locomotes
- A robot which metamorphoses

M-Tran generation can be divided into 3 as



6.2.1 M-TRAN (M-TRAN I - 1998)

The M-Tran modular transformer robots developed in Japan can actually self-assemble and reconfigure themselves into different shapes to create new patterns of movement. The robots are composed of small modular building blocks that are organized in both lattice and chainlike systems, giving a large number of combinatorial possibilities.

The M-TRAN system can change its 3-D structure and its motion in order to adapt itself to the environment. In small sized configuration, it walks in a form of legged robot, then metamorphoses into a snake-like robot to enter narrow spaces. A large structure can gradually change its configuration to make a flow-like motion, climb a step by transporting modules one by one, and produce a tower structure to look down. It can also generate multiple walkers.

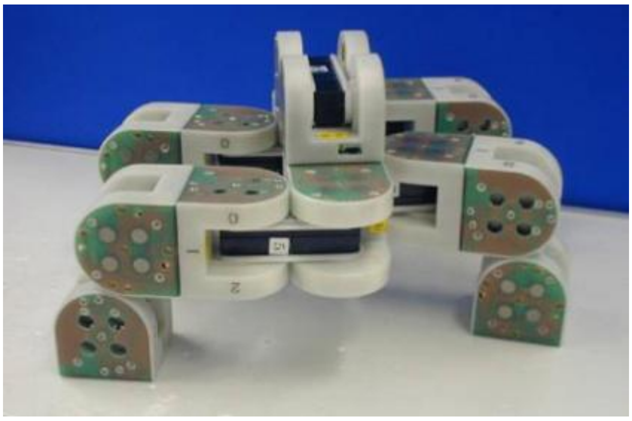
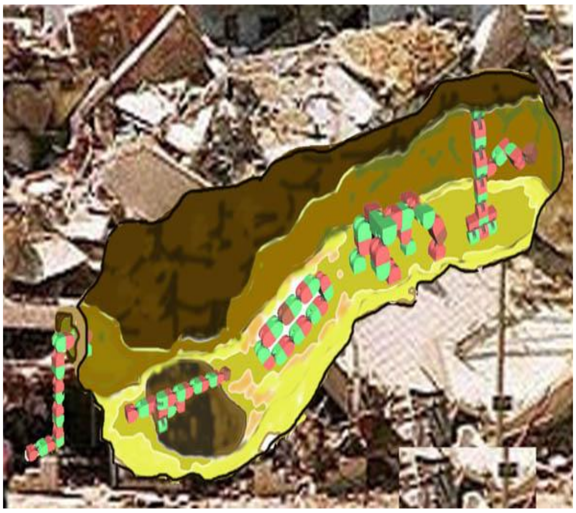
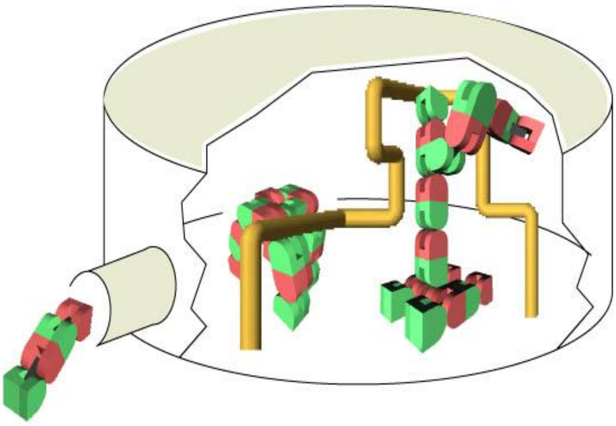


Fig: M-Tran I Robots

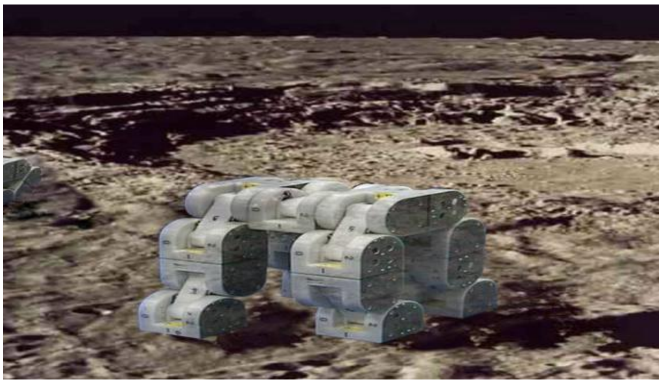
Possible applications of the M-TRAN are autonomous exploration under unknown environment such as planetary explorations, or search and rescue operation in disaster areas.



I. Search and rescue



II. Inspection



III. Unmanned space Exploration

6.2.2 M-TRAN II (2003)

The second prototype M-TRAN II has enough power for whole body motions, such as locomotion. As the modular robot changes its configuration, designing a locomotion pattern should be automated. Scientists have developed a program for this pattern generation, which uses CPG (Central Pattern Generator) network as a dynamic pattern generator and uses GA (Genetic Algorithm) for optimization. We modeled M-TRAN dynamics in the host computer and made repetitive dynamics simulation according to the GA process, and optimized locomotion patterns for several configurations of M-TRAN. Generated patterns are verified by hardware experiments.

6.2.3 M-TRAN III (2005)

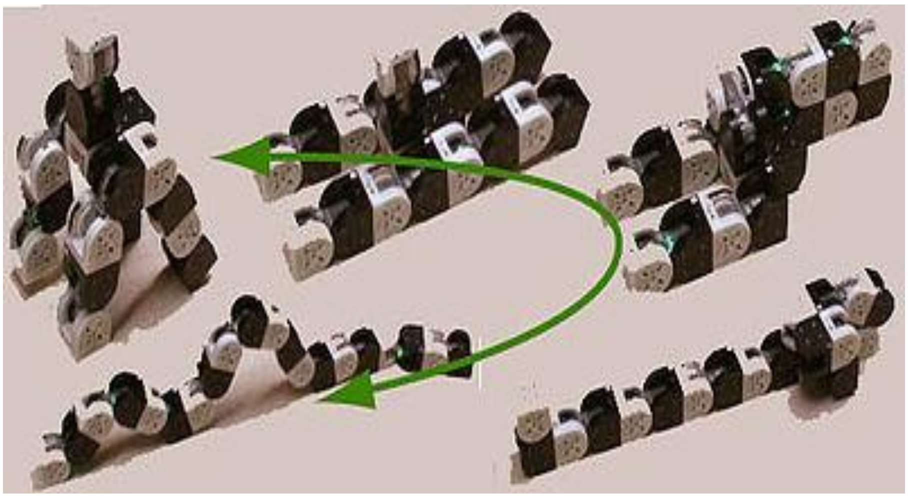


Fig: M-Tran III Robots

A hybrid type self-reconfigurable system. Each module is two cube size (65 mm side), and has 2 rotational DOF (degree of freedom) and 6 flat surfaces for connection. It is the 3rd M-TRAN prototypes. Compared with the former (M-TRAN II), speed and reliability of connection is largely improved. As a chain type system, locomotion by CPG (Central Pattern Generator) controller in various shapes has been demonstrated by M-TRAN II. As a lattice type system, it can change its configuration, e.g., between a 4 legged walker to a caterpillar like robot

.

6.3 THE MOLECULE

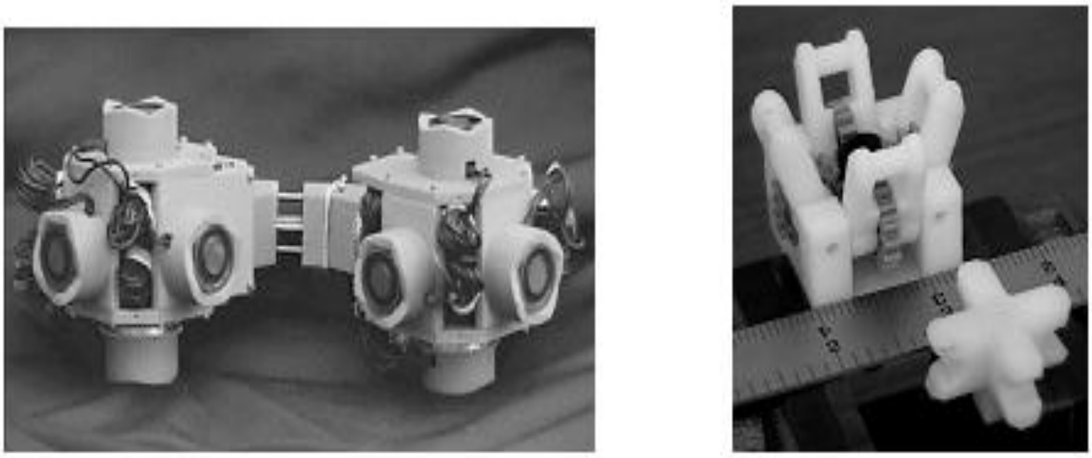


Fig : The robotic Molecule and The prototype gripper connection mechanism

Figure. (Left) The robotic Molecule. The Molecule is composed of two atoms, connected by an right-angle rigid bond. The **Molecule has 4 degrees of freedom**: two rotational degrees of freedom about the bond and one rotational degree of freedom per atom about a single inter-Molecule connector. The connectors have been implemented with electromagnets. (Right) The prototype gripper connection mechanism. The gripper is a male-female design. The male component is in the upper left and the female component is in the lower right Molecules will either have all male components or all female components as connectors. This does not cause a problem because the Molecule design naturally partitions 3D space into two regions. A single Molecule can only occupy one of the regions and can only connect to Molecules in the other region.

A Molecule robot consists of multiple units called Molecules; each Molecule consists of two atoms linked by a rigid connection called a bond (see figure). Each atom has five inter-Molecule connection points and two degrees of freedom. One degree of freedom allows the atom to rotate 180 degrees relative to its bond connection, and the other degree of freedom allows the atom (thus the entire Molecule) to rotate relative 180 degrees relative to one of the inter-Molecule connectors at a right angle to the bond connection. We have already prototyped the Molecule (see figure.)

Current design uses R/C servomotors for the rotational degrees of freedom. A new feature of our prototype is the use of a gripper-type connection mechanism (see figure). In our previous design we used electromagnets as the connection mechanism, but electromagnets have several disadvantages including continuous power consumption to maintain connections and requiring a sheath to prevent unwanted rotation about the axis of connection. Since a sheath must extend beyond the bounding sphere of the atom to allow it to interlock with its mating sheath, a binding condition in introduced restricting mating motion to a face-to-face approach (a sliding approach, in which the two mating faces come into contact by sliding past each other is not possible because of sheath collisions). A gripper type connection mechanism, in which the gripper arms can retract into the bounding sphere of the atom allows sliding face-to-face approaches and atom rotations in place. Also, since the gripper arms are driven by a non-back drivable worm gear mechanism, they will maintain their grip when electrical power is no longer applied, decreasing the power consumption of Molecule self-reconguration.

The rotating connection points on each atom are the only connection points required for Molecule motion. The other connection points are used for attachment to other Molecules to create stable 3D structures. Each Molecule also contains a microprocessor and the circuitry needed to control the servomotors and connectors. The diameter of each atom is 4 inches (10.2 cm.), making the atom atom distance in the Molecule approximately 5.7 inches (14.4 cm.). The weight of the Molecule is 3 pounds (1.4 kg.).

7. APPLICATIONS

Compared with fixed morphology robots, Self-Reconfigurable robots are flexible in that they can adapt to a wide range of tasks and environments. However, this flexibility may compromise performance or cost.

Fixed morphology systems can be optimized for a particular known task, therefore, MSR robotic systems are particularly well-suited for tasks where the operating conditions and ability requirements are not known or not well specified a priori. The following set of application examples illustrate some areas that would benefit from the development of a mature MSR system.

7.1 SPACE EXPLORATION

One application that highlights the advantages of self-reconfigurable systems is long-term space missions. These require long-term self-sustaining robotic ecology that can handle unforeseen situations and may require self repair.

Fig: A Self-Reconfigurable Robot used in NASA’s Space Research

Self-reconfigurable systems have the ability to handle tasks that are not known a priori especially compared to fixed configuration systems. In addition, space missions are highly volume and mass constrained. Sending a robot system that can reconfigure to achieve many tasks is better than sending many robots that each can do one task.

The exploration of space presents numerous challenges, including an unpredictable environment and significant limitations on the mass and volume of equipment used to study that environment. Since one set of modules can be reconfigured to perform many tasks, Self-Reconfigurable robots can solve both the unexpected challenges while occupy little space and weight as compared to multiple devices. Graceful degradation due to failure is particularly important for robots operating in space – a component malfunction can potentially lead to mission failure. The redundant nature of Self-Reconfigurable systems gives them the ability to discard failed modules. Modules can also be packaged in a convenient way so as to meet the volume constraints of spacecraft. Once on site, modules can be used to build structures, navigate across terrain, perform scientific studies, etc.

Self reconfigurable robots will serves as an important inspiration source for the space self assembly techniques. These robots are made of autonomous modules that can connect to each other to form different configurations. The connection between modules are dynamic and can be changed autonomously by the modules themselves. Because of this dynamism, communication among modules can be adaptive to topological changes in the network. Furthermore, since each module is autonomous and self-reconfigurable (has its own power, controller, communicator, sensors, actuators and connectors), modules in a self-reconfigurable robot collaborate and synchronize their actions in order to accomplish desired global effects. All these features are essential in self-assembly system. We can think of a reconfigurable module as a structure component, and a configurable robot as the final self-assembled system.

7.2 SELF-ADAPTIVE FURNITURE WITH A MODULAR ROBOT [ROOMBOTS]

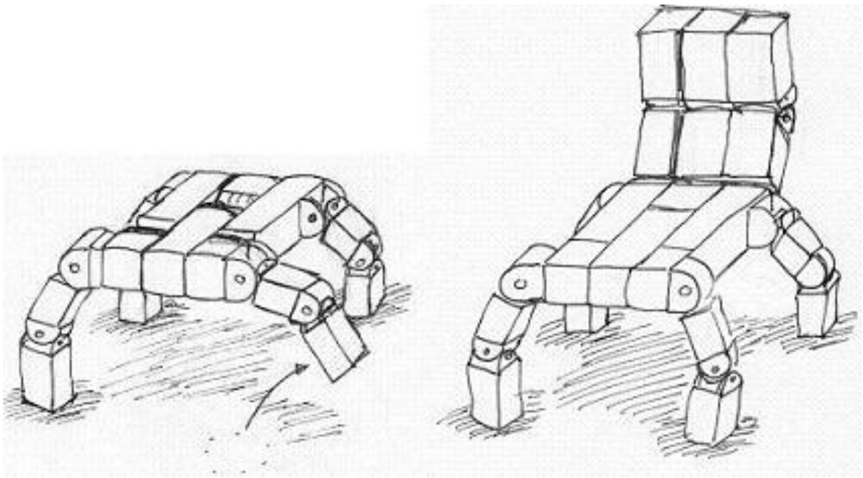


Fig : Self-Adaptive Furnitures

Future working and living environments will be composed of places where people and new technologies cohabit seamlessly. a movement is observed towards integrating technologies in everyday artifacts, ranging from tables to walls and even carpets or kitchen furniture. This new field is referred to as roomware or interactive furniture. It addresses the design and the evaluation of computer augmented room elements like doors, walls, furniture with integrated information and communication technology.

Although roomware projects deal with user interaction, users have few possibilities to contribute to the design. This project intends to design and control modular robots, called Roombots, to be used as building blocks for furniture that
moves, self-assembles, self-reconfigures, and self-repairs depending on the users preferences.

Roombots have the following features

- Roombots have the ability to change their shape in accordance with the changing environment

- They can be automatically re-assembled after their failure.
- Roombots can morph their shapes which is suitable for a person who use it.

7.3 SEARCH AND RESCUE

Disaster areas such as those around collapsed buildings or other structures present another type of highly unstructured unpredictable environment where the use of an Self-Reconfigurable robot could be beneficial. For example, the Self-Reconfigurable system could take the form of a snake which can more easily squeeze through small void spaces to find victims. Once found, the robot could emit a locator beacon and take the form of a shelter to protect the victim until rescued.

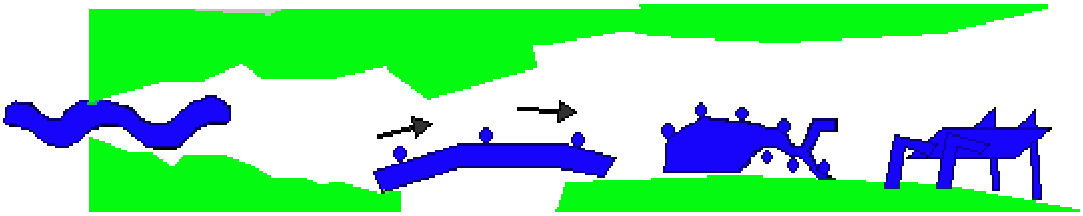


Fig: A modular robot moving or executing tasks by adapting itself to the external environment.

Self-reconfigurable robots are highly desirable in tasks such as fire fighting ,search and rescue after an earthquake, and battlefield reconnaissance, where robots must encounter unexpected situations and obstacles and perform tasks that are difficult for fixed-shape robots.

For example, to maneuver through difficult terrain, a metamorphic robot may transform into a snake to pass through a narrow passage, grow a few legs to climb over an obstacle, or become a ball to roll down a slope. Similarly, to enter a room through a closed door, a self-reconfigurable robot may disassemble itself into a set of smaller units, crawl under the door, and then reassemble itself in the room. To rescue a child trapped deep in rubble in an earthquake, a set of small robots may form a large structure in order to carry an oxygen cylinder that would be too heavy for any individual robot.

7.4 INDUSTRIAL ROBOTS

7.4.1 HyDRAS and CIRCA

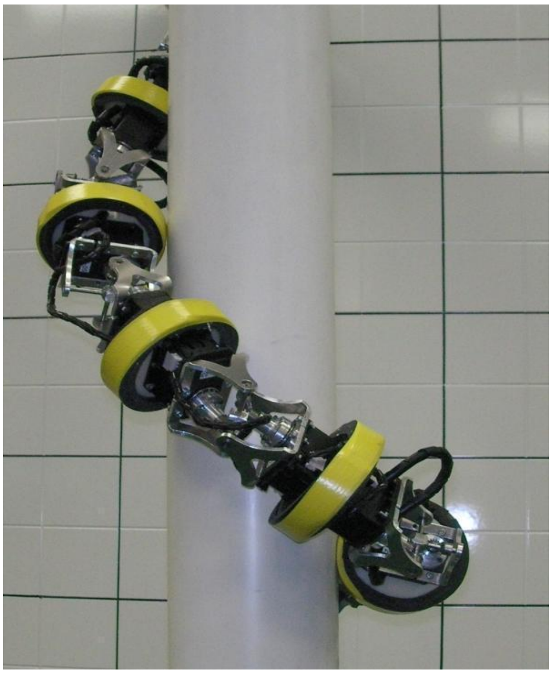


Fig: **CIRCA – A Snake like robot Climbing on a Pillar**

Researchers at the Robotics and Mechanism Laboratory at Virginia Tech have designed a series of serpentine self reconfigurable robots that are able to climb poles and inspect structures too dangerous or inaccessible for humans. The robots coil themselves around a beam and roll upward using an oscillating joint motion, gathering important structural data with cameras and sensors. Two examples of such robots are.

- **HyDRAS** (Hyper-redundant Discrete Robotic Articulated Serpentine for climbing)
- **CIRCA** (Climbing Inspection Robot with Compressed Air)

The **HyDRAS** models use electric motors, while the **CIRCA** uses a compressed air muscle. Currently the robots are tethered to laptops, but future designs will incorporate a microprocessor and power source, allowing them to operate independently. All robots in the series are roughly three feet long, though the **CIRCA** is lighter than the **HyDRAS**

7.4.2 New SCARA robots and PC-based control platform enable easy automation solutions

Fig : New SCARA robots and PC-based control platform enable easy automation solutions

The prospect of a robotic production line might seem well beyond the financial constraints of most small businesses but industrial robots are improving productivity in smaller companies every day. **KUKA** Robotics new high speed **KR10 SCARA** robot is designed for customers needing highly reliable and precise automation solutions of long reach tasks. The new 4-axis robots when combined with **KUKA** Robotics' user friendly PC-based control platform gives customers an extremely easy to learn and use, pick-and-place automation solution. The new **SCARA** family of robots is expected to find application in a diverse range of industries including the appliance, automotive, aerospace, consumer goods, logistics, food, pharmaceutical, medical, foundry and plastics industries and in multiple applications including material handling, machine loading, assembly, packaging, palletizing, welding, bending, joining, and surface finishing.

The **KUKA KR10 SCARA** robot family includes 600mm and 850mm reach models and are capable of handling payloads up to 10kg. The robots' highly accurate link and gear combinations and optimized control loops in the kinematic chain give the robots unrivalled repeatability. The low weigh of the robots ensures optimum acceleration values and maximum working velocities which minimizes cycle times.

"These new **SCARA** robots are ideal for customers with pick and place, assembly or material handling applications where precision, reliability and speed are key," said Kevin Kozuszek, director of marketing for KUKA Robotics Corporation. "Additionally our easy to use KUKA control technology enables simple installation, start-up and programming of our customer's robots."

KUKA Robotics Corporation, with its parent company **KUKA Roboter GmbH**, Augsburg, Germany, is one of the world's leading manufacturers of industrial robots, with an annual production volume approaching 10,000 units, and an installed base of over 75,000 units. The company's 5 and 6 axis robots range from 3kg to 570kg payloads, and 635mm to 3700mm reach, all controlled from a common PC based controller platform.

8. ADVANTAGES

Modular self-reconfigurable (MSR) robots are robots composed of a large number of repeated modules that can rearrange their connectedness to form a large variety of structures. A Self-Reconfigurable system can change its shape to suit the task, whether it is climbing through a hole, rolling like a hoop, or assembling a complex structure with many arms.

These systems have three promises:

- **Versatility** : The ability to reconfigure allows a robot to disassemble and/or reassemble itself to form morphologies that are well-suited for a variety of given tasks.
- **Adaptability** : While the self-reconfigurable robot performs its task it can change its physical shape to adapt changes in the environment.
- **Robustness** : Since the system is composed of many repeated parts which can be rearranged during operation, faulty parts can be discarded and replaced with an identical module on the fly, leading to self repair
- **Low cost** : Self-Reconfigurable systems can lower module costs since mass production of identical unit modules has an economic advantage that scales favorably. Also, a range of complex machines can be made from a set of modules saving the cost versus having multiple single function machines for doing different tasks.
-

9. FUTURE DIRECTIONS

The grand challenges for MSR robotic systems were the results of a workshop where a group of researchers in the MSR robot community gathered and then presented in. A proposed ultimate goal for these systems would be to one day use them in vast numbers for practical applications where un-supervised, adaptive self-organization is needed. Five grand challenges that, if overcome, would enable a next-generation of modular robots with vastly superior capabilities are summarized here:

9.1 Self-repairing systems

A demonstration of a self-healing structure made up of many distributed, communicating parts would require rethinking algorithms for sensing and estimation of the global state, as well as truly robust hardware and algorithms for re-configuration that work from any initial condition. A concrete example would be having a system blown up (randomly separated into many pieces) then self-assembling, or recovering from failure of a certain percentage of faulty Units

Dr. Joshua Bongard from University of Vermont has invented robots that can self-heal. For example, they detecting a missing leg and invent a new way to continue walking.

9.2 Self-sustaining systems

To survive without human help, a robot needs to be able to generate its own energy. So Chris Melhuish and his team of robotics experts at the

University of the West of England in Bristol are developing a robot that catches flies and digests them in a special reactor cell that generates electricity.

9.3 Self-replicating systems

A **self-replicating machine** is an artificial construct that is theoretically capable of autonomously manufacturing a copy of itself using raw materials taken from its environment. The concept of self-replicating machines has been advanced and examined by Homer Jacobsen, Edward F. Moore, Freeman Dyson, John von Neumann

9.4 Self Fueling Systems

Robotics Technology is developing a robot that consumes biomass, such as plant material, and converts it to electricity to power itself. The whimsically-named Energetically Autonomous Tactical Robot (EATR) is intended for jobs where regular, conventional fueling would be impractical, such as military recognizance.

10. DESIGN CHALLENGES

10.1 Hardware design challenges

The planning and control side of self-reconfigurable modular robots are far ahead of the hardware side, despite many brilliant and novel ideas.

- Limits on strength, precision, and field robustness (both mechanical and electrical)
- Limits on motor power and motion precision and
- Hardware/software design: Self-reconfiguring systems should have more tightly coupled hardware and software than any other existing system.
- **Limited resources:** modular robots are limited by power, size, torque and other resources. One of the main challenges here is to improve battery density and fuel storage for modules.

10.2 Application challenges

- Space exploration and Space colonization applications
- Construction of large architectural systems were difficult
- Deep sea exploration/mining
- Search and rescue in unstructured environments
- **Self-repair and self-replication:** modular robots have the unique capability to recover from damage and replicate structures. One of the biggest challenges is to create practical algorithms that take advantage of this capability.

11. Conclusion

Although the possibility of autonomous self-modeling has been suggested, here it was demonstrated for the first time a physical system able to autonomously recover its own topology with little or no prior knowledge, as well as optimize the parameters of those resulting self-models after unexpected morphological change. These processes demonstrate both topological and parametric self-modeling. This suggests that future machines may be able to continually detect changes in their own morphology (e.g., after damage has occurred or when grasping a new tool) or the environment (when the robot enters an unknown or changed environment) and use the inferred models to generate compensatory behavior. Beyond robotics, the ability to actively generate and test hypotheses can lead to general nonlinear and topological system identification in other domains, such as computational systems, biological networks, damaged structures, and even automated science. Aside from practical value, the robot's abilities suggest a similarity to human thinking as the robot tries out various actions to figure out the shape of its world.

12. Reference

- http://ccsl.mae.cornell.edu/research/selfmodels/
- http://www.mae.cornell.edu/ccsl/papers/Science06_Bongard.pdf
- http://www.mae.cornell.edu/ccsl/papers/Nature05_Zykov.pdf
- http://en.wikipedia.org/wiki/Self-Reconfiguring_Modular_Robotics