Tri-Bot: The Self-Reconfigurable Modular Robots

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Abstract—*This paper present about the design and development of the magnetic self-reconfigurable micro robots, which is designed to use for unpredictable task, the clusters of these robot can take any shape based on the defined mission. The cube shaped robot developed by the researchers of MIT named M-blocks can exert on forward and backward torques, about three orthogonal axes, in total six direction the single cubic robot can employ pivoting motion, can roll across the surface and can join to other cubic robots. Controlling this M-block is difficult, and the independent movement of the block at given position is extremely complex, the shape cube is not feasible for the moving of the block. The tri-bot is introduced, which has a spherical ball connected with two arms shape of diamond chopped on the pointed edge which has electro magnet on all the faces, the tri-bot can get attached with other tri-bot as the provided structure. It can move independently with the tire arrangement on the sphere. A novel magnetic system to enable the neighbor tri-bot identification with Machine Learning algorithms to take the autonomous figure, and makes the robot intelligent with more data. This design empowers the robot to move easily and get the unpredictable task done.*

Keywords: **Magnetic Robots, M-Blocks, microbots, robotics, artificial intelligence, machine learning, Mobile robotics, micro robotics, tri-bot**

I. INTRODUCTION

ROBOTS have become the part of our day to day life in the form of various devices, designed particularly for the assigned task, the modular robots M-blocks was introduced a decade ago by the MIT researcher that aims at increasing the utilization of robots by modularizing their architecture. Many robotic systems have been designed and proposed that can change their configuration and perform the task at hand. to create robotic systems capable of autonomously changing shape in order to match the system's structure to the task at hand [1]. These 50mm cubes are autonomous robots that have no external actuated moving parts, and no tethers. The modules realize pivoting using inertial force actuation. A flywheel located inside the module, (oriented in the plane of the intended motion), is used to store angular momentum before a braking mechanism is used to decelerate the flywheel and, during a short duration, exert a high torque on the module. If this torque is sufficiently high, the module breaks its magnetic bonds with its neighbours and pivots into a new location. An individual module can move autonomously in an unstructured environment using this pivoting (rolling) locomotion. A module can also move on a 3D lattice of identical modules, achieving a desired trajectory on a planar surface or making convex and concave transitions to other planes. The modules can also jump over distances up to several body widths wide. This broad range of motions enables the M-Block system to achieve a wide range of shape changing and locomotion capabilities. [2]. In order to facilitate the implementation of new primitive behaviours, the 3D M-Blocks are further extended in this work to include a novel type of magnetic fiducial which allows modules to detect information about their neighbours. These fiducial tags, called Magnetic Fiducial Tags (MFT), provide globally unique identification codes for each face of a collection of modules. MFTags include relative orientation of the connection between the reading module and the tag being read, and encode information passively, allowing the system to accurately determine its global configuration even when a fraction of modules is either disabled or are passive elements.

For several years there has been a very noticeable uptick in papers on machine learning applied to robotics and control problems. Reinforced learning techniques seem to be well suited for some of these tasks (beating human champion at Go is an impressive feat, and so is winning at DotA 2), but are not without their own issues. Among those are difficulties of choosing a reward function, danger of "reward-hacking" (behaviour that maximizes reward while violating some unmodeled constraints, see [3] for some remarkable examples), need for detailed and resource-intensive learning

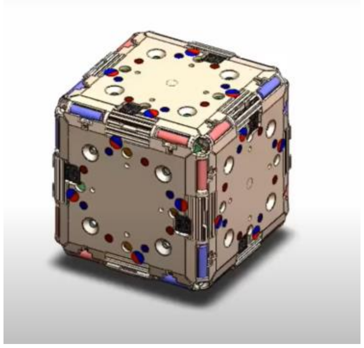

Fig. 1: 3D Design of M-block

Fig. 2: Prototype of M-block

The figure 1 show the 3D design of the M-block 2.0 by the MIT Researchers which has electro magnets on its faces, magnets on the edges, flywheel and actuators in the cube. The figure 2 is the prototype of the M-block. This work focuses on a system of modules which have information only about their direct neighbours, global input from a stimulus source (i.e. visible light), knowledge about gravity, and occasional wireless communication with a higher-level controller. The initial behaviours that introduced Path following and Line formation. The ability for a Modular self-reconfigurable robot system to delegate many of the details of each module's movements to be autonomously implemented by the individual modules based on local information, while still allowing centralized control when necessary, improves the system's ability to scale effectively. While there have been similar proposed decentralized control strategies for modular self-reconfigurable robots.

However, the shape of the cube faces many difficulties for the autonomous moment, the actuator moment with the flying wheel is not that accurate to get the exact position we intended, so the below design in introduced.

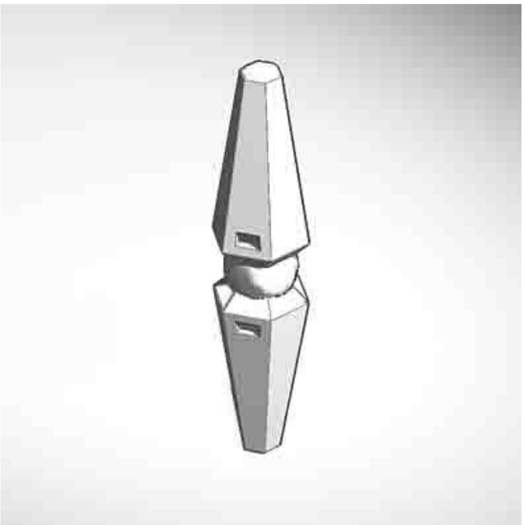

Fig. 3: Structure of Tri-bot

The figure 3 describes the design of the Magnetic Self-reconfigurable robot which has spherical shape supported by the two arms with micro gyro-motor, both the arm and the sphere has electromagnet that can connect to the neighbouring robot and get the specified structure.

II. RELATED WORK

Till the date, the research is done on the base of the M-block which has the cubic structure. Chain and hybrid systems are typically designed to self-reconfigure using complicated implementations which approximate simpler models, such as the sliding cube model [4] or the pivoting cube model. There have been several systems which attempt to implement the sliding cube model, but these systems have been limited to two dimensions. Additionally, there are systems which are able to self-reconfigure in three dimensions, but these systems all diverge from the simplicity offered by the sliding and pivoting cube models.

While there have been many simulated algorithms and control hierarchies that have been presented which accomplish distributed behaviours [13], most of these works abstract away various challenges that real-world modules would face. There have been several works which present decentralized algorithms operating on actual hardware, including the UBot [5], the ATRON [14] system, and several others. However, few of these systems provide a clear path to being able to reconfigure according to a generalized 3D movement framework, which limits the reconfigurability and scalability of these systems. There are many works introducing various algorithms and control strategies similar to those we propose in this paper, and we are not claiming the behaviours we present are novel. This work from 2014, provides an overview of some of the existing academic work involving decentralized control strategies for MSRR and robot swarms.

The work regarding other cubic lattice based particular automated frameworks [1]. Self-reconfiguring lattice based particular robots can be comprehensively sorted by two traits: the method of headway and the association instrument. Maybe the richest model for headway is named the sliding 3D square model. In this model, 3D squares decipher (i.e. slide) starting with one grid position then onto the next. In spite of its hypothetical straightforwardness, we know of no equipment which executes this methodology in the general 3D case. We do know of two frameworks, [6] which execute a 2D variant of the sliding block model in the vertical plane and two frameworks, that work evenly. Not just are these frameworks mechanically intricate, it is not clear how any of these frameworks could be reached out to 3D.

The other defining characteristic of any modular robotic system is its connectors. Many modular systems use mechanical latches to connect neighbouring modules. Mechanical latches typically suffer from mechanical complexity and an inability to handle misalignment. Other systems such as the Catoms [7], Molecule, and EMCube use electromagnets for inter-module connections. Electromagnets consume more power and are not as strong as mechanical latches. Electro permanent magnets are an attractive alternative because they only consume power when changing state, but they still require high instantaneous currents to actuate and are not readily available. In contrast to all of the systems just mentioned, M-Blocks use a simple mode of locomotion (pivoting), a simple inertial actuator (a flywheel and brake), and a simple bonding mechanism (permanent magnets). Actuation through inertial control has been used extensively in space and underwater robotics as well as several earth-bound applications. [8] We know of only one modular robotic system, the Xbot [5], that uses the inertia of the modules to induce pivoting, but the necessary forces are applied externally; the system is only two-dimensional; and the modules are constrained to 180-degree rotations.

M-Blocks was upgraded by Computer Science and Artificial Intelligence Laboratory (CSAIL) into 3D-M Block [2] in 2015. M Blocks are unidirectional cubic robots because of their fixed inertial actuator. Further enhancements have been made on M Blocks and MIT developed blocks that are capable of moving in almost 6 directions. These blocks are named as 3D M Blocks. These 3D M Blocks are improved version of the previous MIT's M Blocks. In 3D M Blocks inertial actuator instead of fixed at one face it can reorient itself in the direction according to the desired movement. It can move in 6 directions by exerting torque forward and backward about three mutually perpendicular axes. These 3D M Blocks uses same approach of angular momentum for its movement and also uses same magnetic bonding system for its connection with other blocks as in simple M Blocks.

III. DESIGN

The basic design consideration of the tri-bot modules is to develop flexible, strong and easily moveable robots that can efficiently perform tasks in an uncontrolled environment without the need of human intervention, as tri-bot is intended to operate in a harsh and rough environment, the design needed to allow for roughed and sealable modules. Modules and connectors needed to cover their internal electronic and mechanical components and protect them from dust, moisture, and physical impact.

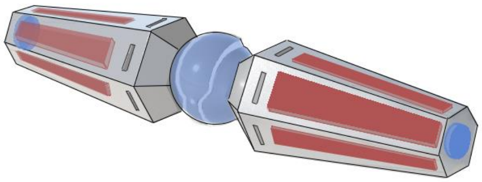

Fig. 4: The Electromagnet positions of the Tri-bot

The Fig. 4 illustrates the design of the tri-bot, the colours on the figure shows the positions of the electromagnet that is to be placed on the modular robot. The sphere supported by two arms that is bendable in all direction by the use of gyro motor. The building materials needed to be resistant to abrasion and other deleterious effects. It is required to perform locomotion, manipulation and self-reconfiguration tasks in the presence of obstacles in an uncontrolled environment. To be effective in real applications, tri-bot modules should have enough torque to move and lift a reasonable number of neighbouring modules and exert force whenever it is needed. The outer layer of the robot will be made up of graphene composite to increase its strength, as it should get any damage in the drastic conditions.

This required maximizing the power of magnets while the size of the modular robot is to be reduce as possible. A link of Bot modules should be aware of their environment, which allow them to avoid obstacles and also navigate in the environment. This also includes the ability of sensing and communicating with other Bot modules and forming of structure through the machine learning and reinforced learning. The sensory information might have to be fused for autonomous decision-making or being linked to the main controller. Some modules may need to move more often and spend more energy while some other modules may not move at all. In addition, the power source of some modules may fail. The power transmission in the robots has the electromagnetic charging system as one bot can transfer its power to another bot and the network continues.

IV. CONTROL

One possible approach to control of such systems is generating trajectories using optimization techniques in style of Tedrake, Posa et al [9]. If a general equation of movement is of the following form

$$H(q)\ddot{q} + C(q, \dot{q}) + G(q) = B(q)u + J(q)^T \lambda, \quad \varphi(q) \geq 0, \lambda \geq 0, \quad \varphi(q)^T \lambda = 0, \tag{1}$$

q ▯ R_n – generalized coordinates vector, λ – reaction forces, then we can discretize it using Euler implicit method

$$qk - qk+1 + h\dot{q}k+1 = 0, \quad Hk+1(\dot{}\, qk+1 - \dot{q}k)+ \quad +h(Ck+1 + Gk+1 - B_{k+1}u_{k+1} - J^T{}_{k+1}\lambda_{k+1}) = 0. \tag{2}$$

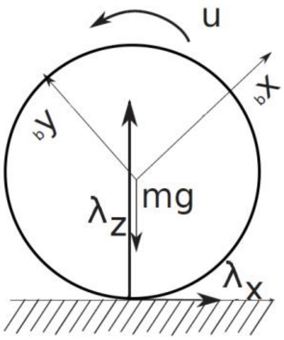

Fig. 5: Principal Force of sphere

We can add initial and terminal conditions as constraints (as inequalities if we so desire, thus it is possible to specify them as intervals). Using optimization and, if necessary, regularization with subsequent relaxation, we can deduce trajectory and control function. For now, let us limit ourselves to a more tractable problem. If we want to launch a bot to a desired point via jumping, this can be achieved. In flight, bot's position of governed by simple laws of ballistics. To hit our target, we must supply the necessary initial velocity via control.

The equation of ballistics is

$$V_0^x t_f = x_0, \; V_0^z - g t_f = 0, \tag{3}$$

where $t_f = V_0^z / g$ is the time in flight. Substitution yields

$$\frac{V_0^x x \; V_0^z}{g} \tag{4}$$

$$V_0^x = \int_0^{t1} \lambda_x \, dt, = \int_0^{t1} (\lambda_z - g) \, dt \tag{5}$$

Let us suppose that the direction of movement in contact point does not change, it is moving backwards and $\lambda x = \mu \lambda z$. Then, substituting (5) in (4),

$$\int_0^{t1} \mu \lambda_z \, dt \; \int_0^{t1} (\lambda_z - g) dt = x_0 g \tag{6}$$

$$\lambda_z = \frac{g - u \sin\theta - \cos\theta \, \theta^2}{1 + \sin^2\theta - sign(V_1)\mu \sin\theta \cos\theta} \tag{7}$$

Then our robot will gather the desired velocity at $t = t1$ by pushing itself from the ground. To start the flight, we only need to set $\lambda z = 0$, and again, we can do so by choosing u in (7). Thus, the control law must switch at time $t = t1$.

V. HARDWARE

The tri-bots casing holds about twelve rectangular and two circular electromagnets on the arms of the sphere ball, and the spherical ball is coated with magnet all around, which has a tire on the center which enable the movement of the robot. The dynamic modules are outfitted with on-board control, calculation, activation, and correspondence abilities. They can proceed onward a structure shaped by the detached modules. The electromagnets can transfer its energy to another robot so that the energy it is using to attach to another module, can the charge the bot itself. Every module is controlled by a specially crafted PCB which incorporates a 32-bit ARM microchip and a 802.11.4, XBee radio from Digi International. two 3.7V, 125 mAh LiPo batteries associated in arrangement control the modules.

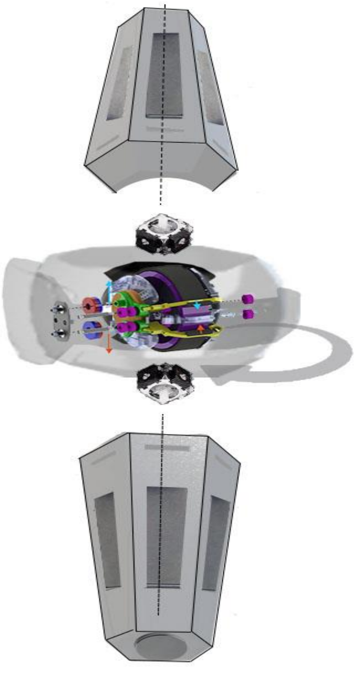

Fig 6: Module design

The fig 6 show the design of the modular robot consists of gyro motors for the movement of the gyro arms and for the turning of robot while moving which helps to change the direction of the wheel. The actuator, flywheel can take jump to the position it is required to attach. The robot consists of primary mechanical assemblies: a frame which holds the central assembly which in turn supports the flywheel and the braking mechanism. In addition, the central assembly holds the four batteries in the arms which power the module and two of the printed circuit boards (PCBs) which control it. The exploded view in Figure 6 shows the frame, central actuator, flywheel, batteries, and control PCBs. The two insets in Figure 2 show actual photos of the finalized central assembly with all components including the braking system. The braking mechanism is omitted from the exploded view because it is shown in better detail in Figure 6. At the core of the central assembly is a brushless motor and flywheel which, together with the braking mechanism, generate the torques required for all module movements and central assembly plane changes. The entire central assembly is supported by two arms on a diagonal rotational axis which extends through two opposite corners of the sphere. frame. As the central actuator rotates about this diagonal axis, the flywheel aligns with each of the module's coordinate axes. The goal of the redesign of the bot was to extend the functionally to three dimensions while maintaining robustness and keeping the components as simple and mass producible as possible. In order to extend the original M-Blocks concept to three planes, [10]. However, it proved difficult to fit three separate sets of flywheels, motors, and brakes inside the modules while maintaining a torque density sufficient to perform lattice reconfiguration. Despite the added complexity of having to change planes, the advantage in power of a larger single flywheel proved to be the better solution. The redesign has focused on replacing complex actuators with simple ones while also attempting to utilize under actuation where possible. For example, the flywheel brake is built from a coil, two magnets, and a simple linkage. In contrast, the original M-Blocks employed a hobby-style servo motor which was large and prone to failure. Additionally, the orientation of the flywheel with respect to the module's frame is now controlled by the primary inertial actuator and a locking mechanism instead of an additional motor.

When operating on a lattice, groups of modules that share the same pivot axis are able to coordinate their actuators in order to move together. Not only does this increase the stability of the motion due to longer pivots but it also decreases planning complexity when attempting to relocate groups of modules on a lattice. Assemblies of modules are able to move together in the environment by first reconfiguring in order to approximate a wheel or sphere and then simultaneously applying their inertial actuators. An additional type of group movement involves small groups forming meta-modules to more precisely control their trajectories. The modules can be oriented such that their actuators are aligned in orthogonal planes allowing control over additional degrees of freedom. When a disjoint group of modules is self-assembling, these meta-modules can serve as intermediate assemblies to increase the speed of the aggregation.

In order for modular robots to realize self-assembly and robust operation, the unit modules need to be both self-contained and independently mobile. Although researchers have produced modular systems in which the modules can locomote independently, most of these systems are limited to controlled environments [11], [12]. In contrast, the robot is independently mobile, and they show an ability to move through difficult environments. Although they only have a single actuator, they can exhibit several motions including rolling, spinning in place, and jumping over obstacles up to twice their height. This diverse set of motion primitives enables novel motion algorithms. One method that we use to drive a robot towards a specific goal is to implement a bimodal behaviour. When the module's actuator is aligned with the goal location, the actuator is used to apply a moderate amount of torque that causes controlled rotation toward the goal. When the module is not aligned with the goal, we stochastically reorient the module using a high torque that causes unpredictable movement. A group of bots executing this behaviour can self-assemble into a lattice structure.

Fig 7: The bending of the tri-bot

The tri-bot can move its arms in three axes, it becomes easy to get the three-dimensional lattice structure the figure 7 shows the modular robots bending ability by the control of the microcontroller, the rendered figures describe it can take structure easily and changeable. The interested in exploring a wide breadth of control and planning algorithms. Due to their natural tendency to self-align, combined with their on-board sensing and independent movement capabilities, we believe that the modules will have the ability to move robustly and correct for errors. An additional algorithmic challenge is deciding how we can best use the modules' inertial actuators to jump and the wheel for the travelling large assembly through an open environment.

Fig 8: Structure assembling of the tri-bot

The figure 8 show the rendered image of tri-bot taking a structure of hand, the movement of the finger can be on the movement of the robot arm as finger movement. Although the faces bond to each other - due to edge geometry any tri-bot attached only through face bonds or the sphere bonds forms lattice configuration. An important goal of the tri-bot is to provide robust lattice reconfiguration. The range of different attempted motions. A motion is considered a success if after three attempts the module moves to its desired lattice position. The two most common failure modes were insufficient torque and disconnection from the lattice, the bot movement and the control of the single bot, the connectivity with the other bots is complex issue, this complexity can be reduced through the machine learning algorithms.

VI. DISCUSSION

I have introduced the tri-bot design and structure as an advanced designed of the M-blocks developed by the MIT researchers Daniela Rus and team, the self-reconfigurable modular robot that can take any shape, structure and is designed for the unpredictable task, Modular self - reconfigurable systems have the promise of making substantial technological advances to the field of robotics in general. Their promise of high versatility, high value, and high robustness may lead to a radical change in automation. Currently, a number of researchers have been addressing many of the challenges. While some progress has been made, it is clear that many challenges still exist. Movements like jump and corner climb, all vertical movements are equally difficult because they are against gravity and locking mechanism comes in to play. In these movements locking mechanism is very important because when the block rotates vertically all of its weight is acting on magnetic lock. This paper is about the enhancement in the design aspect of the modular robot which could be easy to take any shape and do the various task depending upon the conditions, the robotic module contain sphere with the two arms which has with the microcontroller, gyro motor and electromagnets. They are capable of accomplishing different kind of movements as discussed above. These modules are robust and small which is an essential attribute when we analyse a modular robotic system. The power storage and the re-charging system with mutual induction from the link of the robot, if one bot is connected to the charging pot, the whole can be charged through the mutual induction.

In the future this design will be efficient to take any structure and do any task smoothly, it will able to complete the task with the control of the electroencephalography headset or brain to machine interfaces, the advancement in the machine learning will enable they robot themselves to learn to take structure with group of robots and to complete the task autonomously. The combination of the complex algorithm of Artificial Intelligence and the stable hardware will achieve the greatness of modular robots. The future development in the battery technology and electronics, the size of the bot can be reduced much smaller, this could enable the various application of modular robots in the upcoming days. I will develop and implement the real model of this design with the access of advance resources and laboratory.

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