Morphius: A Self-configuring modular robot that navigates through cracks and debris for inspection

***Abstract*—Modular robots are made up of mechanically constrained smaller robots with different degrees of freedom. These smaller robots can either detach or attach together to get a desired structure or configuration. The existing technology in this field consists of robots with homogeneous modules that lack the decision making capability and are not currently applicable in disaster struck area for inspection.**

To improve their performance, heterogeneity has been introduced in its structure making it possible to design versatile, application tailored modules having decision making capability. Each module will independently be able to perform a specific task depending on the attributes and given characteristics with self-configuring and reconfiguring capability. At the same time all the modules communicate and share their data with each other to collectively accomplish the goal. We have also introduced wheels for effective and faster locomotion and self-docking capability using a neutral connector. This paper addresses the two main challenges while developing such modular robotic system - intelligence and speed, in the field of rescue operations with adaptive morphology.

***Keywords*—Modular robot, Self configurable, Heterogeneity, Self-docking, Wireless communication, Autonomous, ArUco markers.**

I. Introduction

In the past two decades around 10 lakh deaths have been reported worldwide due to earthquakes, landslides, storms and hurricanes; almost 1.5 lakhs were only from India. Over 15% of these were late deaths - deaths due to injuries that become prominent with the passage of time - could have been avoided had disaster management been more efficiently carried out. Doctors refer to this time as the golden hour, which is the period of time after a traumatic incident during which immediate medical assistance can save a person's life. Some injuries like haemorrhage, brain injuries and internal bleeding deteriorate rapidly. So it is necessary to keep the time lag between injury and treatment bare minimum.

Rescue operations conducted worldwide mostly employ trained professionals and dogs. Equipment such as video cameras and high sensitivity listening devices are used in order to locate a person moving or responding to rescuers calls [1]. Depending on the scale of destruction, the process of extrication can extend over 24 hours. These environments pose a risk to even the lives of rescuers as there is imminent danger of a further collapse in event of an earthquake. Recent reports prove the usefulness of robots in these fields as they enable rescuers to analyse the environment remotely. They had better speed and did not require much manpower. But because of their large size and power requirements, these robots are not efficient enough. This is where the concept of multi robot systems can be used. Due to the increasing demands in functionality, adaptability and robustness engineering innovations brought forth the idea of multi robot systems - systems which work in a distributed manner to complete a task. Inspired by biological systems, scientists proposed the use of self organising modular robotic system [2].

Through this paper we try to overcome the problems related to intelligence, speed and increased locomotion. Morphius aims to deal with the surrounding environment specifically targeting disaster struck areas and would try to utilize its functions for the assisting the rescue operation.

II. Literature Survey

The most important thing in a rescue operation is the speed at which the help arrives to the victims. Flexibility to reach the remote location is another key aspect which decides the efficiency rescue operations and rate at which the injured people are provided with medical care. The technology has been consistently evolving toward providing a solution for such scenarios. There have been multiple attempts to provide a robotic solution to such areas. There are key terms associated with such systems. The research is required to go through all the attempts that have been made and to step upon already developed solutions and rectify their limitations and faults to make them efficient and better the desired application.

A. Basic terminology & concepts related to MRS

To understand already developed series of modular robots, it is important to understand the key terms and definitions related to modular robotic systems (MRS). Modular Robotic Systems: Characteristics and Applications - A detailed report [2] covers overall terminology related to the MRS and also provides key insights in the domain of modular-robotics. The four fundamental components that define a modular robotic systems are *"Module, Information, Task and Environment (MITE)"* [2]. This report also discusses about the problems associated with certain systems and their feasibility.

It is also necessary to classify the robotic system in standardized format depending on the four components (MITE) [2]. We can create different types of MRS by varying these components. There are about 94 [2] developed modular robots existing today each one having unique features and mechanism.

B. Existing MRS

Existing technologies include M-TRAN III [3], SMORES [4], SQ-BOT [5], UBot [6] among many others and have distinctive features like size, locomotion mechanism, structure, behaviour etc. Analysis of different existing modular robotic systems provides different perspective with which a particular problem was solved. Analysing the particular problem and designing the system accordingly by considering the variable, dependent and independent parameters is the key to get an optimum MRS. Following are two of the most advanced MRS existing today.

1) M-TRAN III: Design inspired by locomotion of reptiles, M-TRAN III [3] was developed in 2007 as a successor of M-TRAN II (2003) and original M-TRAN (2000). Homogeneous modules made of same shape and mechanism to connect. It uses most of modern technology of wireless communication through its different modules. The shape of each module gives M-TRAN [3] huge flexibility of different morphologies by combining itself with other similar modules.. Because of reptile locomotion, M-TRAN is comparatively slower than others.

2) Room Bots: EPFL University project developed for different morphology and heavy lifting. The design is sturdy, large and can hold up large weights. Room bots are helpful in heavy load lifting and can be used to transport heavy loads. Room bots [7] have lesser flexibility compared to M-TRAN III [3]. Because of the heavy torque lifting motors, room bots have to compromise on the size of each module. As the size increases, it reduces the probability of going through narrow holes and cracks.

M-TRAN III [3] compromised on speed to get more flexibility, whereas Room Bots compromised on size of each module to get more heavy lifting. Each modular robotic system has to find a balanced system to solve a certain problem. For a particular application we can compromise on the components that won't affect the performance of the system as much. The existing systems are not deployable in practical environments due to constraints on their locomotion and/or structure. And those which can be employed in such conditions are either expensive, slow and lack the decision making capability. If we can provide a solution by bypassing such factors, we can achieve our desired goal.

III. System design

The basic block diagram of Morphius' modular robotic system is as shown in the figure 1. The number of modules to be included is variable and will be decided by the desired application. Currently we are working with one eye module for testing and prototyping purpose. But it can be extended to multiple modules having different sensors and actuators. This block diagram just represents how it will interact with the base module which will be driving the modules when necessary.

The software part comprises of the use of 5x5 ArUco markers for identifying a particular module and also for aligning the module for proper linking. The pi-camera at the front of every module detects the ArUco marker on the module it needs to be attached to. The marker is used for uniquely identifying the module, calculate its distance and estimate its pose. This information is used to align the modules as they come closer to each other to be linked.

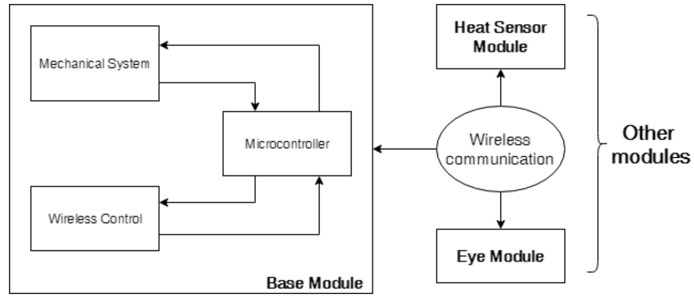


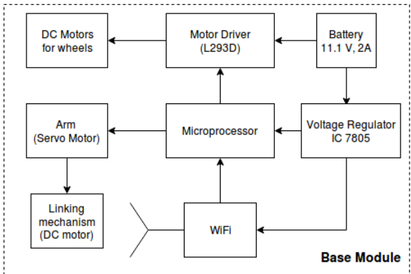
Fig. 1: Block diagram of the system

The eye module consists of a camera with high resolution. This camera is primarily used for mapping the area besides helping the robot to plan its path [8]. This is done using a visual Simultaneous Localisation And Mapping (SLAM) algorithm [9]. A set of points in the Region Of Image (ROI) are tracked through successive frames to estimate the relative position of the module so that it creates a map of its surrounding terrain. Images from the camera can also be monitored in real time on the network. The eye module is also used to identify the type of terrain and determine whether it can move forward or not. The module is trained to identify the terrain using classification with the help of a convolutional neural network.

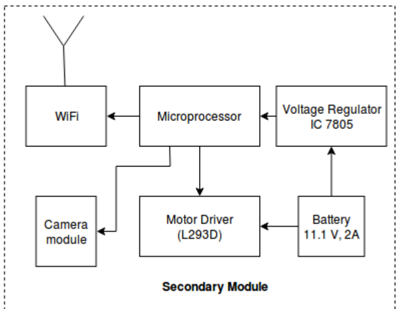
IV. Hardware assembly

The block diagram of configuration of components involved in base module is as shown in the figure 2a. The base module includes microprocessor to control the base module which receives signal from other modules (Figure 2b) via WiFi. The dimensions of this module are bigger compared to the other module so that it is stable enough to lift other modules linked together. The structure of the modules are made out of 3mm acrylic sheets and the mechanical connection mechanism is 3D printed out of Polylactic acid (PLA) fiber. The basic components used are:

- Motors:
  - DC gear motor with 100 RPM and a high stalling torque was used for the base module. For other modules this is replaced by low torque compact motors.
  - A servo motor having high torque of 5KG used for arm mechanism such that it can lift heavy modules. In case of eye module servo will also be used to pan the camera.
  - Micro gear DC motor with 100 RPM and a high torque for the linking mechanism.
- Microprocessor:
  - *Raspberry Pi model 3B* [10] which has a *Quad Core 1.2GHz Broadcom BCM2837 64bit CPU* [10] was used as our central processor.



(a) Base module



(b) Secondary Module

Fig. 2: Block Diagrams of the modules

  - Controls pwm for Servo and Wheel motors. Also receives messages through WiFi. It also implements machine learning and image processing for aligning the modules.
  - This board was chosen as CPU for each module for the machine learning and image processing to be done through python. We can use any PyBoard having python modules and opencv libraries.
- Battery:
  - Lithium-Ion rechargeable battery providing 11.1V and 2Amps of current
  - Used as power of source for entire module and will power servo, microprocessor, motor driver, Wi-Fi and respective sensors.
- Voltage Regulator:
  - IC7805 was used to provide 5V supply to the micro-processor from the supply of 11.1V battery
  - Also provides supply to DC motors used for wheels and Servo Motor
- WiFi:
  - In-built WiFi on the Raspberry Pi 3B model was used for communication.
  - Better than Bluetooth in terms of coverage, connectivity and speed.
  - Advantage is we can remotely access all the modules remotely once they are set on same network.
- ArUco Markers:
  - Augmented Reality Marker (ArUco) is a marker consisting of black and white matrix denoting 0 and 1. And it can store information in this matrix (Figure 4)(4x4, 5x5, etc.).
  - We are using 5x5 matrix with different IDs for identifying each module uniquely.
  - These markers are also used for pose estimation and distance calculation between any two modules. These markers help each module to align themselves with respect to the other module.

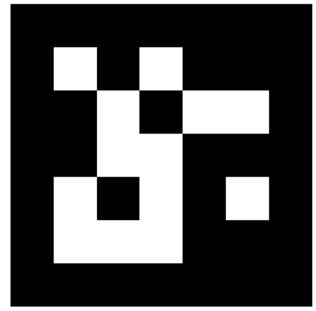


Fig. 3: An ArUco Marker of 5x5 Matrix with ID = 0

- Camera
  - A pi-camera used by all modules and would be used for detection of aruco markers. And then it will send signals to CPU, which will relay signals to motors for correct alignment with other module.
  - A webcam or a camera with at least 2Mp resolution for mapping only on the eye module.
- IR sensor:
  - For obstacle detection and path planning. It is also used to calculate the height of the obstacle.
- Wheels
  - 106mm Diameter and 44mm thick wheels for the base module to enhance the stability
  - 70mm Diameter and 21mm thick wheels for the other modules to make them compact.
  - Castor wheels for providing stability to the smaller modules.

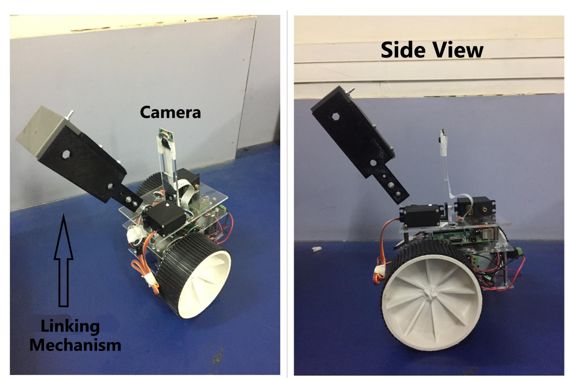


Fig. 4: Assembled Base Module with Linking Mechanism

V. Linking mechanism

The key part of any Modular Robotic System(MRS) is its linking mechanism. Depending on the application of the MRS, the mechanism is decided. The key parameters involved while deciding a linking mechanism are:

- Weight of each module.
- Working environment.
- Size of the module.
- Algorithm for the configuration.

For Morphius, the surrounding environment is a rough terrain having uneven surfaces, debris and cracks. Also, Morphius should have maximum speed possible while traversing through such area. So, if we remove constraints on the size of the module and use high torque sturdy motors with strong body, we will require a physical linking mechanism to hold each module firmly throughout its operation.

The mechanism used has been shown in the figure 5. It comprises of three bevel gears(G1,G2 and G3) and one micro geared DC motor. The DC geared micro-motor is attached to one of the bevel gears(G1) which in turn rotates the main gear which has a bolt at its shaft. The rotating gear causes the bolt to move back and forth allowing it to lock into the arm of the other module. This entire mechanism is mounted inside a casing - 3D printed - using PLA material. Polylactic acid or PLA. This entire assembly is attached to a servo on the base module which helps align the arm in the z direction.

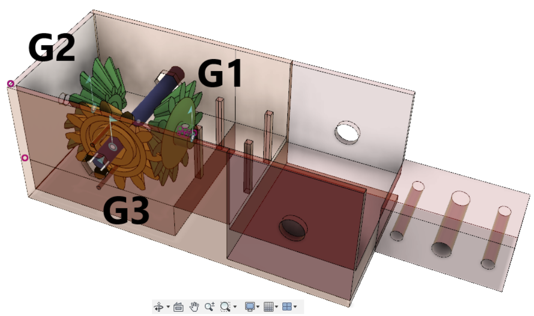


Fig. 5: The 3D printing parts of the linking mechanism

VI. Testing and Analysis

Each module of Morphius can independently work on its own and can gather vital information. But in some cases it might require other modules to overcome an obstacle or to gather some extra data. In that case the linking mechanism plays a vital role in joining any two modules.

The linking part of one module needs to be perfectly aligned with the other module's linking part in order to link with each other. For this we used ArUco Markers for perfect alignment of the bots in 3D space. ArUco Markers provide us exact location and orientation of the bot in 3D space (Figure 6). With the feedback from the camera, CPU provides signals to respective motors (wheels for x-y plane and servo for z-plane) and it aligns itself with the other module.

After aligning with the other module, actuation mechanism starts. The micro-motor situated inside the mechanism will start rotating the bevel gear(G1) and it will turn G3, this will result in the unwinding the screw (Figure 7) . After some time the screw will come out completely (Figure 8) and if the other

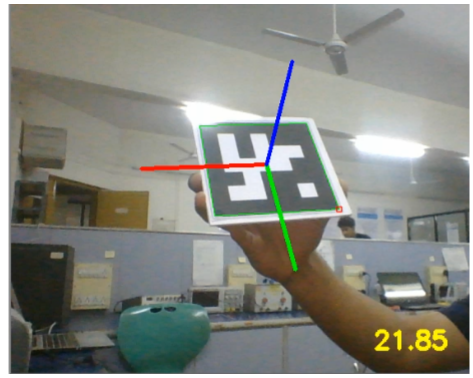


Fig. 6: Pose estimation using ArUco Marker in 3D space.

module was in correct position with the module, the screw will enter the other module and similarly the screw from the other module will enter this module. They both will lock each other and form a physical connection.

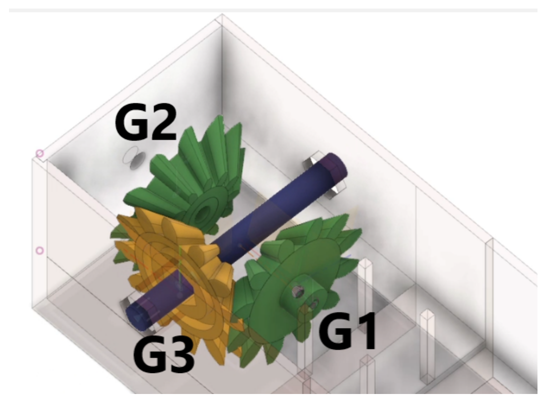


Fig. 7: Screw in closed position inside the mechanism.

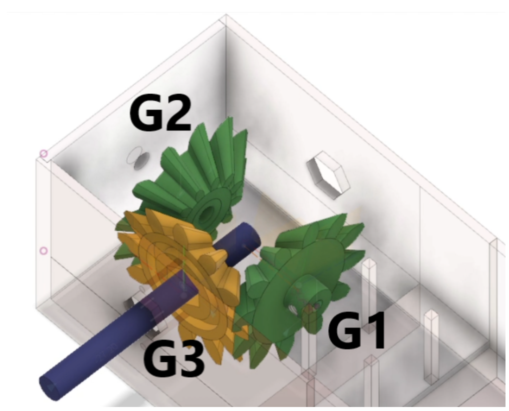


Fig. 8: Screw in opened position outside the mechanism.

This mechanism can handle heavy weights (up to 7Kg) without creating any hindrance to the locomotion of the module. The weight balance of the entire module has been correctly modified in order to avoid toppling even after lifting other modules.

VII. Conclusion

The results of the work done on Morphius show us the potential in the speedy-modular-robots that can be used in rescue operations. The work yielded a prototype of Morphius having two modules. The shifted axis of the bot has not compromised the stability yet provided a compact design. The speed of motors have been limited to 100RPM can be controlled depending on the type of the terrain using PWM (Pulse Width Modulation). The time required for establishing a physical link between two modules has reduced considerably with the help of ArUco Markers and Cameras. It also uses image processing and machine learning for analysing the type of terrain and deciding the morphology.

Morphius can be deployed in the rough terrains of disaster struck areas to gather vital data which can be extremely helpful in speedy rescue operations. The developed prototype has sturdy mechanism as well as sturdy structure to handle wear and tear over long duration. With decision making capability and improved speed in linking mechanism and in locomotion, Morphius has shown that modular robots are now ready to be deployed in real life scenarios to assist humans.

VIII. Future Scope

The modules can be comprised of different additional sensors and actuation mechanisms such as grippers in order to perform certain tasks. Heterogeneity is essential in such applications as they increase the accessibility and functionality of the system. This idea can be exploited with the help of Morphius. Different processors can be used to improve the processing speed, to improve data mining as well as increasing the accuracy. If 3D printers with better resolutions are used, the linking mechanism can be made more compact and precise.

Morphius has been kept as an open source project and is open for further future developments. A basic structure has been provided with necessary software and hardware. The proposed MRS provides a platform for developers to develop different modules with help of the base modules.

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