Implementation and Assembly of a Robotic Module for the MECABOT-3 Reconfigurable System

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Abstract
Autonomous operation of robotic systems in un-known environments is currently one of the most significant fields of study in mobile robotics, with numerous research groups worldwide determined on solving its various associated challenges. This paper describes the principal features of Mecabot, a modular robotic system capable of modifying its physical configuration according to the type of terrain and obstacles it may encounter, designed in Nueva Granada Militar University for search-and-rescue tasks in urban environments (USAR).

Keywords: Modular robotic system, Autonomous mobile robots

I. INTRODUCTION
Search-and-rescue (SAR) can be defined as the combination of strategies, tactics and operations that allow to locate, provide aid and extract victims from disaster areas. Despite efforts aimed at a thorough evaluation of the overall status following the disaster, search-and-rescue operations pose great risks for both victims and first responders, due to the unpredictable nature of the disaster area and the elevated possibility of further (and different types of) hazards randomly taking place. Urban search-and-rescue (USAR) teams have specialized equipment caches at their disposal, yet most of these tools require direct human operation or intervention. This is the driving force behind research in USAR-oriented mobile robots such as Mecabot: development of fully-autonomous or remotely-operated systems capable of aiding USAR task forces in order to avoid endangering further lives [1].

Research in USAR-oriented robotics usually falls into two large groups: the design and/or adaptation of mobile robots and development of novel algorithms aimed at enhancing autonomous operation efficiency. Figure 1 illustrates an example of the former category: a search and rescue robot built at UNAM in 2013 [2], capable of interacting with victims by providing basic aid (water, communications) until human rescuers arrive at the precise location. For the latter, a set of high-level objectives must be paired with techniques oriented towards extraction of information regarding the workspace within the disaster zone, such as 3D reconstruction [3] [4].

One of the leading institutions on USAR-oriented robotics research is CRASAR (Center for Robot-Assisted Search and Rescue) from A&M university in Texas. In cooperation with industry and certified first responders, its mission is “improving disaster preparedness, prevention, response and recovery through the development and adoption of robots and related technologies” [5]. CRASAR has participated in several documented deployments of disaster robots worldwide, such as the search-and-rescue of survivors trapped in Ground Zero in the aftermath of 9/11, as seen in Figure 2.

Figure 1. Search-and-rescue mobile robot (Taken from [2])

Figure 2. USAR simulation of 9/11 Ground Zero performed by CRASAR (Taken from [5])
MECABOT SYSTEM
During USAR operations, first responder teams typically use several robots in order to perform highly specific tasks. Said approach entails an undesirable caveat: availability of all necessary robots according to the affected area’s assessment can compromise the teams’ response times, potentially endangering more victims’ lives in the meantime. The underlying principle driving the development of the Mecabot system is applying the benefits of modular robotics in USAR tasks such as inspection of hazardous or hard-to-reach entrapments. This is achieved by replacing a set of highly specific robots with a set of modules which can assemble into different configurations, thus altering the modular robot’s structure, kinematics and capabilities.

The first step in structural design of a modular robotic platform is establishing desired locomotion modes and physical interactions between modules such that the modular robot can traverse non-structured terrain. In other terms, the array of physical configurations that the robot can consequently adopt depends on the module’s mechanical structure and degrees of freedom, as well as the various forms in which two or more modules can be coupled.

A. Types of semi-module coupling
Mecabot-3 semi-modules possess a cuboid structure, where 4 of its 6 faces can act as coupling surfaces and are fully compatible with each other and one of the two remaining faces has a pivot capable of rotating 90 degrees. With this layout, three types of coupling are possible. The first option is the face-to-face coupling shown in Figure 3, which can rotate relative to the juncture and allows the pivot to accommodate further semi-modules.

Figure 3. Mecabot-3 face-to-face coupling

Figure 4 presents a face-to-pivot coupling, which concentrates two degrees of freedom in the juncture. Lastly, the pivot-to-pivot coupling illustrated in Figure 5 unifies three degrees of freedom in the juncture, thus emulating spherical links found in robot manipulators.

Figure 4. Mecabot-3 face-to-pivot coupling

Figure 5. Mecabot-3 pivot-to-pivot coupling

Assembly of the modular robot using combinations of these three types of coupling leads to interesting movement capabilities, such as the quadruped with rotation-enabled waist shown in Figure 6.

Figure 6. Mecabot-3 quadruped configuration with rotation-enabled waist

B. Coupling system
Design of robust coupling mechanisms in modular robots is of high importance when dealing with unstructured terrain, since it is not possible to guarantee proper module alignment before coupling takes place. To this end, the magnetic coupling system illustrated in Figure 7 is proposed. Each module
features a disk with two neodymium magnets embedded in alternating polarities. When two modules face each other, their disks can rotate 90 degrees in opposite directions in order to face the magnets with equal polarities (repulsion) or inverted polarities (attraction). Therefore, modules can repel or attach themselves without need for precise alignment.

![Figure 7. Mecabot-3 magnetic coupling system](image)

**C. Wireless communication and electronics**

In a substantial percentage of disaster situations, communications (either by land-line or cellphone networks) are lost due to infrastructure damage or network congestion. Consequently, all equipment or machinery carried by USAR teams which requires remote or autonomous operation must include independent communication capabilities [6]. If the disaster area is significantly large, information transmission must be carried out with a specified topology under consideration. Figure 8 presents three topology examples which are typically available in low-power wireless transmission protocols. Mecabot uses communications ICs based on the Zigbee wireless protocol to establish a Mesh-type (point-to-multipoint) network, which enables certain nodes as routers in order to buffer the coordinator node’s signals. This feature allows better signal coverage when debris or contamination within the disaster area poses significant interference [7].

Furthermore, modules can act as a wireless sensor network, acquiring and processing local information concerning the operation environment which is then transmitted to the coordinator [8].

![Figure 8. Network topologies for low power wireless transmission protocols.](image)

In order to use modules as wireless nodes, Mecabot uses a 32-bit microcontroller to process data perceived by sensors and forward it to the Zigbee transceiver and a 2000mA onboard battery provides power for all components.

![Figure 9. Mecabot-3 architecture](image)

The complete architecture diagram for a Mecabot3 semi-module is displayed in Figure 9. It is important to note that the flow of signals due to the diversity of subsystems (10 sensors, 5 motors) cannot be handled by a single processing unit and thus certain functions are relegated to auxiliary ICs.

**CONCLUSIONS**

Adaptation of existing mobile robotic platforms for USAR or design from square one of a mobile robot for USAR
applications requires thoughtful consideration of any and all limitations imposed by the disaster area to hardware, software and communications components. Features such as independent wireless communications and onboard power sources are mandatory.

Mecabot’s ability to assemble modules in diverse physical configurations is an important adaptation asset for exploration and traversal of various types of terrain present in disaster areas. However, kinematic intricacies associated to said configurations entail the need for versatile locomotion and path planning algorithms.

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**REFERENCES**


