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FUMA: Environment Information Gathering Wheeled Rescue Robot with One-DOF Arm

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Abstract— **Rescue robots are expected to become useful work partners for urban search and rescue (USAR) missions. Human rescuers who carry out these missions, frequently enter dangerous zones to search for survivors. However, due to the unstableness of the collapsed buildings or objects, rescuers' lives may also be threatened. For this reason, in order to reduce life-threatening risks, rescue robots can be deployed to carry out the job instead. Rescuers can now operate the robots at a safe distance while the missions are carried out. After the robots have gathered enough information in regard to the location of the victims and data about their physical conditions, rescuers can then enter the disaster site with enough knowledge to avoid harm and to rescue victims in the shortest time possible. This paper will present a wheel-type rescue robot we have developed for information collection purpose at disaster arenas that the robot was specifically designed for.**

Keywords: Rescue activities, wheel-type robot, human-robot interface, information collection.

I. Introduction

Intelligent rescue systems with high information and robotic technology have been expected to mitigate post-disaster damages and improve rescue operation efficiency, especially with a case like the 1995 Hanshin-Awaji Earthquake in Japan [1] [2]. In order to understand the functionality limits of rescue systems in search and rescue missions and to correct or improve the required technological aspects, it is necessary to conduct various experiments in a real-life collapsed and complex environment. However, as most laboratories do not possess such facilities, it is possible to participate in a competition called the RoboCupRescue Real Robot League. There the committees will setup three simulated disaster arenas (with increased in difficulty), and researchers in rescue robotic systems around the world can gather to discuss and test their robotic systems [3] [4]. At the same time, they can inspire and exchange information with each other.

High mobility and controllability are two essential criteria for rescue robotic systems. In addition, it is important to achieve fast robot deployment into different areas of the disaster sites for emergency requests. For this reason, mass-production and low-cost in the development of these systems are strongly emphasized. High mobility and controllability in rescue robots are useful not only for rescue missions but also beneficial to many other potential applications such as inspection work in sewers, security check at airports, observation among office floors and so on. Other possible applications involved for example are collection of environmental and/or human flow data and update the database frequently to prepare in case of emergency.

In the instance where buildings or underground complexes are damaged by disaster strikes but the degree of impact did not fully collapse the infrastructure, it may still contain high risk danger for human rescuers to enter. For this reason, we specifically developed a wheel-type mobile robot named FUMA, for entering such areas to search and gather information in regarding to potential survivors and damaged environments. Moreover, since most search and rescue missions using robotic systems are carried out at a safe distance, and thus we have placed crucial consideration of the importance of graphics user interface (GUI) usability and the efficiency of interaction between human operator and robot [5].

The core design principle of FUMA is to achieve fast mobility efficiency with a simple mechanical structure and more importantly, able to be controlled by any inexperience operator with user-friendly GUI. The consideration of waterproof design or protection against strong impact and dust were not emphasized. A 1-DOF arm is installed at the rear end of the robot to provide a high viewing position and a center of gravity (COG) balancing device when climbing over larger obstacles. It is generally understood that wheeled robots, without special mechanisms, encounter many difficulties when climbing over objects that are higher than the radius of its wheels. Nevertheless, incorporating this simple structure arm, FUMA is capable of climbing over obstacles that are much larger than the radius of its wheels. In order to achieve good climbing ability, referencing with various robot designs in previous works, most of their robots were made complex, which then became hard to control, maintain or manufacture. Matsumoto et al. have developed a biped type leg-wheeled robot that can climb over high obstacles and even stairs [6] [7]. Without the necessity of implementing additional mechanisms Matsumoto's robots were able to climb over various obstacles by integrating inverted pendulum, wheel- and biped-type robot designs, even the size of the wheels are small. However, the complexities of the mechanisms and the control algorithms made it difficult to operate and manufacture. Takita et al. have also contributed efforts in alternating the wheel mechanism structure to climb over stairs [8]. Nevertheless, due to the complex mechanism design, the speed was greatly reduced and with an addition of increase in overall size. Hirose et al. have developed a robot with one arm that is similar to FUMA, but with a crawler transmission [9]. The arm has 5-DOF movements that assists the robot in lifting or climbing, and is capable of grabbing onto objects if necessary. In order to achieve such purposes, strong power from the motors is required and thus bigger motors were installed. However, this then added much weight and increased size to the final robot design.

In order to avoid these problems, we propose a fast mobility efficiency wheel-type robot, FUMA, with a simple structure that is easy to control, maintain and manufacture. In this paper, we first present an overall description of the robot. Following this is the detailed explanation of: the operating system configuration, effective camera images for operation, teleoperation user interface, mobility, future work and potential applications. Finally the paper is summated by a conclusion.

II. WHEEL-TYPE RESCUE ROBOT

The aim of this research is to concentrate on developing a fast mobility environment information collection wheel-type robot for entering slightly damaged buildings or underground complexes after an disaster strike like earthquake. Nevertheless, it may still be too dangerous for rescuers to enter the region as the unstableness of the structures may collapse. Thus FUMA, as shown in **Fig. 1**, with 1-DOF arm serving as a high viewing position camera arm for obtaining a good surrounding view, and a COG balancing tool when climbing over obstacles with heights higher than the radius of FUMA's wheels, will be deployed to collect necessary information with equipped cameras and sensors. The wheels are controlled with differential drive by two 150W DC motors, where the 1-DOF arm is also driven by a 150W DC motor.

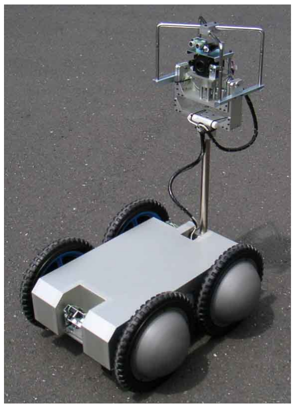

Fig. 1. FUMA - environment information collection type robot.

In general, robots that are considered excellent in dealing with uneven terrain are crawler-type robots. The main reason is due to its high adaptation to the terrain [10] [11]. Snake-type robots that are designed to enter narrow spaces and traverse in complex 3D environments also implement crawlers as a mean of transmission [12] [13]. However, many problems such as low mobility efficiency, complexity in the mechanism, weakness of crawler belts (falling off the sprockets and breaking), external objects tangling in the tracks, and etc., caused various difficulties in control, especially search and rescue missions.

In order to avoid such problems, we propose a fast mobility efficiency wheel-type robot, with a simple structure that is easy to control, maintain and manufacture. As for a general understanding that it is difficult for wheeled robots to climb over obstacles that are higher than the radius of its wheels. This arm installed on FUMA is the most important mechanism to successfully assist FUMA to travel over rubble in slightly damaged buildings and underground complexes. Though the design of the robot does not allow the arm to completely flip the robot in an inverted way, it is possible to rotate it up to 180 degrees (-90 to +90 degrees measured from horizontal position) and also lift the robot upwards as shown in **Fig. 2**. Furthermore, the mechanical structure of FUMA was specifically designed in such a way that even if the robot is turned towards sideways or being inverted, the robot operator could still control the robot to carry out necessary rescue tasks (**Fig. 3**). In addition, two fish-eye lens cameras are installed to provide wide and clear images of both the robot and its surroundings.

Finally, **Table I** sums up the general specifications of FUMA. Further details of the specifications will be discussed in the following sections.

III. OVERALL SYSTEM

A. Operating system configuration

The operating system is categorized into two sides. One is the operator side and the other is the robot side as shown in **Fig. 4**. A human operator controls FUMA from

Fig. 2. Camera arm capable of lifting up the robot.

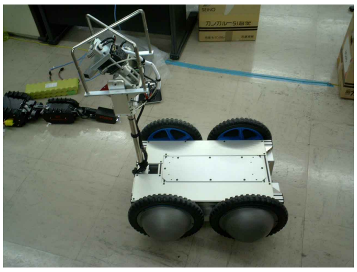

Fig. 3. Still possible for operation when upside down.

TABLE I
SPECIFICATION OF FUMA

Name	FUMA
Length (mm)	630 (1330 arms out)
Width (mm)	590
Height (mm)	890
Wheel radius (mm)	150
Mass (kg)	30
Speed (m/s)	1.0
Climbable angle (deg)	30
Climbable height (mm)	330
Battery life (min)	100
Communication	Wire/wireless LAN
Camera	CCD x5 (inc. 2 fish-eye lens cameras)
Sensor	Encoders, laser pointers, heat sensor, sonars, 3D attitude sensor and etc.
Robot side PC	Victor Interlink MP-XP7310LL
Operator side PC	DELL Inspiron5100
Battery	Ni-Cd 12V, 7000mAh x 2

a distant site by observing feedback camera images of the robot site. The communication between the two sides is via wire/wireless LAN (wireless LAN is the default communication method). When commands from the operator are sent to the robot side, a laptop PC will recognize the commands and send/receive necessary information to the central robot system. If the commands are for robot movement, the operator controls a SONY PlayStation2 Controller and the commands are sent to the robot side PC and further to the motor controller that is in charge of the motor drivers and motors. As for the three CCD cameras, their images are displayed by choice on the monitor screen of the operator side PC. The choice of which images to view is selected with the PS2 controller where an analog switcher via a firewire converter sends the selected image to the operator PC. A device controller is designed to control lights, sonars, laser pointers, and heat sensors. Two 1.2GHz video transmitters are equipped to send the front and facing-down fish-eye lens camera images to two video monitors located at the operator station.

An alternative method for transmitting these two fish-eye lens camera images via the wireless LAN network were considered, however, the reasons for separating the image transmission are firstly, due to often occurrences of signal disturbance over wireless LAN network that we have experienced at simulated disaster arenas, but video transmitter provided a much stable camera image; secondly, even if the signal disturbance is greatly influencing the transmission of camera images, separate transmission provides some insurance if one communication method has ceased to function; finally, due to great amount of data streams are already being sent via the wireless LAN network, an addition of these two fish-eye lens camera images into the system will further increase the difficulty of communication between the operator and the robot, especially at real disaster sites. Therefore, since the signal disturbance is unavoidable, we have decided to separate the transmission of camera images via different communication systems, and thus these fish-eye lens camera images are sent through 1.2GHz video transmitter, and have always provided good image quality.

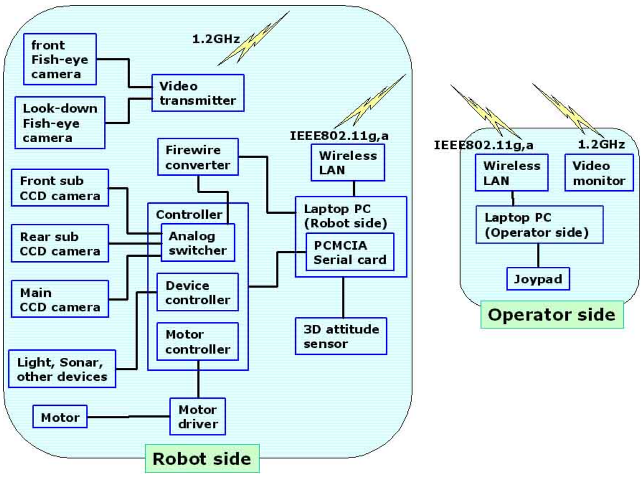

Fig. 4. Overall system diagram.

FUMA is a self-contained mobile robot designed with a very compact size. The actual internal device arrangement of FUMA is shown in **Fig. 5**. The laptop PC is powered by its own battery pack. Below the PC is where the control circuit and robot battery are positioned. The robot battery is a 24V/7000mAh Ni-Cd re-chargeable battery pack and is used for powering sensors, motors, controllers, control circuit and other devices. The overall running time of the robot is up to 100 minutes.

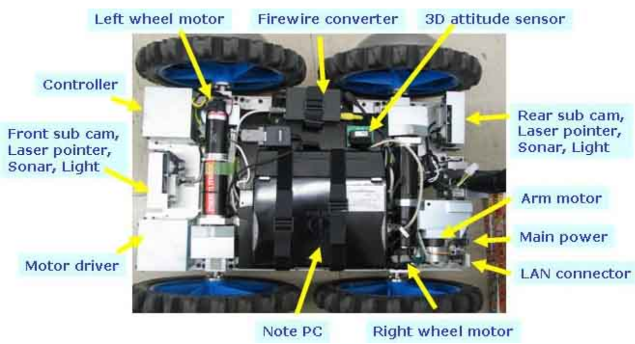

Fig. 5. Internal device arrangement.

B. *Effective camera images*

During search and rescue missions, most of the rescue robots are teleoperated by human operators. With current technology, although most rescue robots have certain level of built-in autonomous intelligence, such as autonomous map generation or stair climbing. However, very rare that the robots deployed have fully autonomous functionality. For this reason, human operator plays a critical role when carrying out rescue missions and thus effective environment information provided to the operator is particularly important.

Effective environment information here refers to effective camera images, since this is one of the most information that the operator can rely on when controlling the robot. Although maps generated automatically also provide good guidance to robot control, nevertheless, it is still too difficult to fully rely on these maps to steer the robots. Based on these considerations, after experimenting with various camera installments on mobile robots in our laboratory, the most effective camera installment for robot teleoperation provides images where the robot is always displayed at a fixed position in the center, along with clear view of the surroundings. Thus such camera installment is applied on FUMA and is believed to provide a very easy and effective robot control interface for either beginner or experienced operators. **Fig. 6** shows such installment.

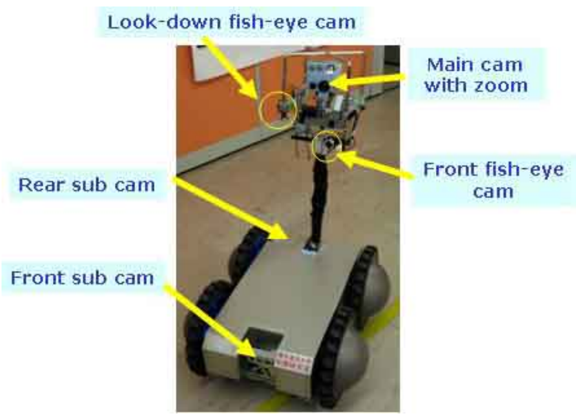

Fig. 6. Cameras installed on FUMA.

Among the five cameras, images of the main zoom in/out camera, front and rear sub cameras are transmitted via IEEE802.11g/a wire/wireless LAN network. These images are displayed with choice by an operator on the monitor screen of the operator PC. The selection is achieved by pressing necessary buttons on the PS2 controller where an analog switcher acts as the central processor for sending the image that the operator desires. The front and facing-down fish-eye camera images are transmitted by two 1.2GHz video transmitters, and are always displayed on two video monitors.

During operation, the operator usually relies on the two fish-eye camera images to steer the robot, as they provide wide images of the environment with the robot included in those views. However, since the image resolution is very low on these two fish-eye cameras, when detailed observation of the surroundings is needed, then the main zoom in/out camera is used. For objects close to the front or rear end of the robot, the front and rear sub camera images become very useful. It is very important to use these five cameras properly according to situations of the robot at a disaster site.

Within a damaged buildings or underground complexes, without care, the robot may cause post-disaster events to happen. For this reason, it is crucial that the robot operator has a clear view of both the robot and the environment as displayed in **Fig. 7**. Thus, incorporating these five camera images, and with the operator station setup shown in **Fig. 8**, it became very simple to steer the robot in any environment without bumping into surrounding objects. Moreover, the controllability of FUMA was improved with this well considered camera configuration. The critical point here is that the improved controllability greatly helps the mobility of a robot. This is because a good interface enables us to make full use of the mobility.

Fig. 7. Images from both fish-eye lens cameras.

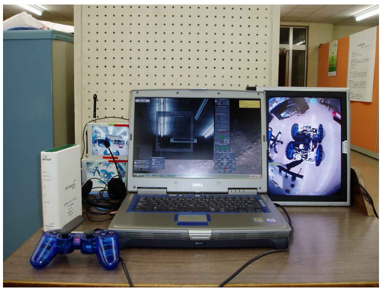

Fig. 8. The usual operator station setup.

When two or more robots are to be deployed for a rescue mission, FUMA could be used as both the lead robot for searching or a supporting robot by providing good environment images to other operators that does not have access to such images, especially for operators controlling small or long robots.

C. *Teleoperation user interface*

The next element of an effective rescue robotic system is the teleoperation user interface. The core design principle is to present all the necessary information to the operator with a user friendly GUI. Therefore, information including camera images, robot posture status, motor status and etc., are all available to the operator within a simple glance. **Fig. 9** shows the GUI of FUMA, developed using Borland Delphi on the Microsoft Windows platform.

Three CCD camera images are each displayed with the biggest viewing area in this GUI. There is a heat sensor to measure victim's body temperature and is positioned next to the main camera. The focus window is designed to

Fig. 10. Using the 1-DOF arm to climb over a high obstacle. The obstacle is 33 cm in height. The upper row shows the climbing over procedure facing forward. The lower row shows facing backwards.

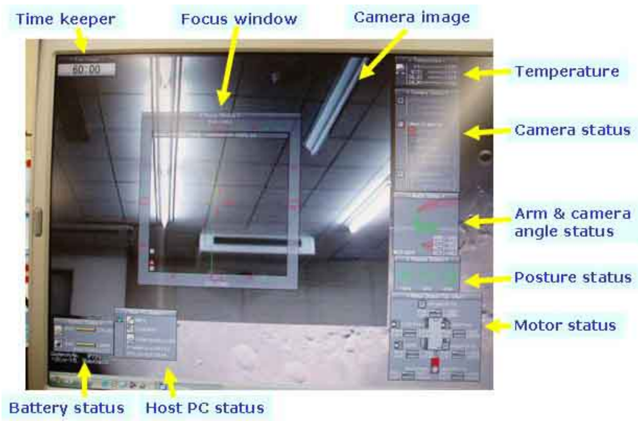

Fig. 9. GUI console.

guide where should the operator point towards to in order to receive accurate temperature readings. The purpose of placing the time keeper on the top left hand corner is to indicate how much time have past during a robot operation. The small temperature status window indicates external and internal temperature of the robot. The camera status window shows which of the three CCD cameras are currently in use. There is also the indication which shows if the laser pointers are turned on or not.

While the fish-eye lens cameras provide good views of both the robot and the environment, sometimes the operator may find it difficult to understand robot's 3D configuration. Therefore, the arm and camera angle and the posture status windows give such feedback information. Furthermore, there is the red line indication showing which camera is currently in use. Though this has been already indicated in the camera status window, the red line indication is easier to observe and having multiple accesses to this information is useful. Following on, the motor status window shows the current draw from each motors, and the host PC status window notifies whether the microphone or speaker are in use or not, plus indications of the camera frame rate and CPU usage. Finally, the battery status window illustrates how much capacity is still available from both the robot battery and the robot PC battery status.

Along side with these raw data, if information such as an environmental map display obtained by appropriate devices could also be presented, it will further enhance the usability and efficiency of this GUI console. Finally, the two fish-eye lens camera images have not only compensated the disadvantages of our GUI console, but have also further enhanced the observation viewable region of the environment and the controllability of the robot. Such analysis is clearly clarified in one of our previous works [14].

D. Mobility

For any wheeled robots, without additional device to assist with climbing over obstacles, it would be very difficult to rise over objects that are higher than the radius of their wheels. Although FUMA has large wheels of 15cm in radius, the ability of climbing over objects is still limited. In order to conquer higher obstacles, the 1-DOF arm becomes the most critical tool. Though the arm only has 1-DOF movement, if efficiently operated, it is possible to climb up to 33cm obstacles. Such experiments were performed and are shown in **Fig. 10**. The upper row shows the climbing over procedure facing forward. The lower row shows facing backwards.

The idea is to change the COG of FUMA by moving the arm upwardly or downwardly. The downward motion is mostly achieved by pressing the arm against the floor or some objects. At the same time, steer the robot to move toward the desired climbing direction. Though this process may be considered difficult for an inexperience operator, however, with actual experimentations, the same climbing procedure were able to be accomplished successfully by both beginners and experienced operators. These climbing procedures were completed by relying only on the camera images and not by directly observation of the robot.

FUMA was also brought to participate in competitions like the RoboCupRescue Real Robot League, and tested its mobility limits in variety of environments (**Fig. 11** and **Fig. 12**). From these participations, the final understanding is that FUMA is fully capable of slightly damaged office floor environments or buildings (so called the Yellow and Orange Zones in the competition), and as shown in Fig. 10, with the usage of the 1-DOF arm, FUMA is also able to climb over an step obstacle that is twice larger than the radius of its wheels. However, it still encounter many difficulties when negotiating with highly complex 3D environments (so called Red Zone).

Fig. 11. Climbing down from a slope.

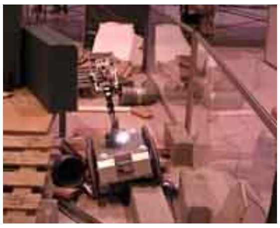

Fig. 12. Traveling in a 3D complex environment.

IV. Future work and potential applications

The integration of camera system, teleoperation user interface and mobility of FUMA provided a very effective and simple control interface in any environments. Nevertheless, many other aspects of FUMA is still yet to be completed. One of the important aspects is the development of autonomous map generation algorithm [15].

The main purpose of development of FUMA is for environment information collection in search and rescue missions. Nevertheless, it is possible to extend its usage to other applications [16]. A sample list of the possible extensions is as follows:

1) Patrol and guide work: using the fast mobility of FUMA, it can work as a patrolling or guiding robot in public facilities such as a office, train station, museum, etc.
2) Research platform: from the simple structure and extendibility of FUMA, it can be used as a research mobile robot platform that can traverse in rough 3D terrain, which rarely exists in low price.
3) Data collection: collect environmental and/or human flow data and update the database of these information among office floors.

V. Conclusion

This paper has presented a detailed description of a fast mobility environment information collection wheel-type robot, FUMA. The description was categorized in five sections explaining the operating system configuration, the effective camera images, teleoperation user interface, mobility, and future work and potential applications. FUMA was tested in various simulated disaster sites and have proved to be well functional in environments that it was designed for.

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