Development of a Networked Robotic System for Disaster Mitigation

-Navigation System based on 3D Geometry Acquisition-

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***Abstract*— In this paper the authors present the current progress of a networked robotic system intented to be deployed at disaster areas. This system is formed by three mobile robots: two twin crawlers that will have search-and-recognition tasks gathering information about their surroundings, and an outdoor-wheeled rover that will approach the area and which will also carry the two crawlers. The communication system for these robots consists of a wireless local area network that will have an operator located at a safer distance controlling them. As a final communication objective, the integration of a satellite-based IP communication linked to the japanese satellite ETS-VIII is scheduled. In order to be able to navigate the crawlers remotely, a wireless LAN camera and a Laser Range Finder (LRF) sensor have been mounted on both of the crawlers. These LRFs will scan the area where the crawler is at, obtaining a detailed point-based 3D image. A special focus of this paper is made on the possibility of maneuvering the crawlers based only on the remotely-acquired LRF and camera's information.**

I. Introduction

Every year, multiple natural disasters occur, namely earthquakes, floods, wild forest fires, tornados, cyclons; destryoing partially or completely houses, buildings, roads, bridges and usually leaving victims or the bodies of victims inside such locations. Giving the high probabilities that the already weak structures will totally collapse, gases, chemicals or any other harmful leaks may have been produced. A human-based recognition and rescue operations should not be the first approach to examine these hot spots for survivals.

There are many reasons why a teleoperated robot-based operation should be put on the scene [1]-[4]. With a robotic system working at the destruction area, it will be safer for a human rescue team to look up for hazardous spots, bodies, or survivals. Having an operator at a prudent, less risky position, maneuvering, for instance a rover, will gather information about the environment giving a better understanding of its current conditions. A robotic system that includes a "human-in-the-loop" instead of an totally autonomous one is sensed as a system on which the rescue team can rely on, as mentioned in [3].

Japan is, due to its geographical location, rather prone to experience these unfortunate events, just like the Hanshin-Awaji earthquake showed in 1995 [5]. This is why since 2003 the Japanese Ministry of Internal Affairs and Communications (MIC) is supporting the development and implementation of a robotic system capable of collect vital information that will lead into the understanding of the structural conditions of the examined area and the rescue of surviving victims.

Fig. 1. An artistic view of the proposed robotic system.

In this paper, the authors present the current progress of a networked robotic system supported by the MIC. An artistic view of the whole robotic system is shown at Fig.1. This progress is shown by the performance obtained at two separated simulated disaster sites. Both of these "tests" were made as a preparation to demonstrate the early capabilities of the three robots working together in a possible mission scenario. The authors will explain the configuration and results exhibited by the two sibling crawlers and will focus in the possible navigation of the crawlers utilizing only a CMOS wireless LAN camera and a compact laser range finder sensor (LRF) mounted on each of the crawlers. The design of a graphical user interface that will incorporate critical data for the operator to be able to control both of the crawlers will also be considered.

This paper is organized as follows: in section two an overview of project is presented, the hardware and software general configuration of the crawlers and the outdoor rover are described in section three, the proposed navigation based on the laser range finder and a graphical user interface protoype are shown in section four. Finally, the results of the performance tests of the robotic system are given in section five.

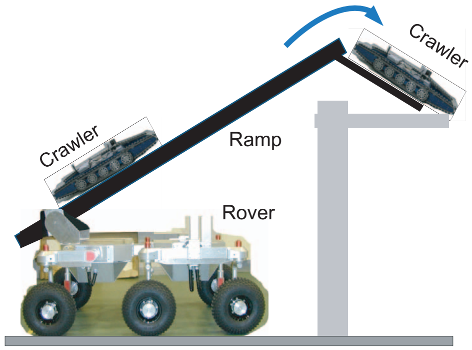

Fig. 2. Conceptual view of the rover approaching a building and deploying the crawlers

II. Overview of the Project

As mentioned in [6], this system includes three mobile robots; a six-wheeled outdoor rover and a pair of identical crawlers. The outdoor rover will be deliver at a prudent, safe distance from where the ground station is located, using a helicopter or any other secure transportation. The main purposes of the outdoor rover are: create a 3D map of the area that it has covered using a laser measurement system (SICK) sensor and a omni-directional camera; exploiting the information it produces from its sensors onboard it will overcome any possible obstacle from the operators location until that of the disaster area; and finally it will deliver the smaller crawlers it has carried inside the approached zone. Assuming inside the affected area there is a building, the rover will get close enough to it to be able to extend its ramp so that the crawlers can climb up to the desired entrance point. This concept is drawn at Fig.2.

Before, during and after the crawlers have been deployed, the rover will serve as an access point for the wireless network of the crawlers and a bridge to a satellite-based communication link with the Japanese experimental satellite ETS-VIII. The radio of the covered area of the satellite's shadow is estimated to be between 300 [km] and 400 [km], and the recommended distance between two terminals should be more than 700 [km]. If there is only one terminal inside the satellite's shadow, and its antenna has a diameter of 1.20 [m] the communication link will have a baud rate of 1.5Mbps. Within the satellite's shadow it is possible to handle up to four terminals, but only two different terminals can be connected at a time. Even though the baud rate of the satellite is small compared to that of a wireless LAN, it becomes useful as an initial information gathering system if ground infrastructures for the communication are damaged by a disaster.

Since the crawlers will have recognition tasks to complete, they will have to separate considerably from the entrance point. To solve this issue, "repeaters" of the acces point's signal will be carried on each of the crawlers leaving them at strategic points from where the crawlers can continue the mapping of the environment.

The main point of the crawlers is to gather the necessary information so that 3D geometry data can be recorded and analyzed to determine hazardous areas inside of the building's structure and if there are victims still remaining inside of it. Also this information it is simultaneously used to aid the sibling crawlers explore the area. The analysis of the generated maps can be done at the ground station from where the operators control the robots.

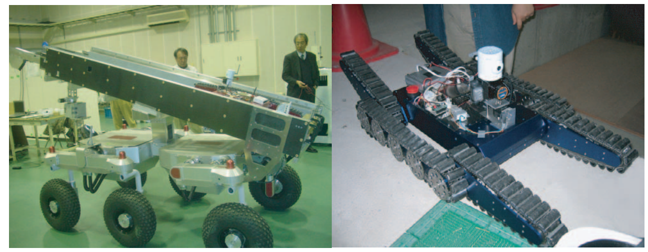

Fig. 3. Actual configuration of the big rover and the crawlers

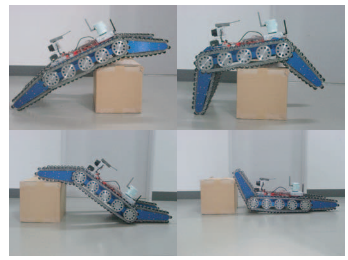

Fig. 4. The design of the crawler allows it to go over objects much higher than itself

III. System Description

Several different approaches have been proposed for the design of a rescue robot, where each of them are based on its specific task [7]. The design adopted for this project was thought to have a wider range of rescue applications rather than just a specific one [8]-[11]. Fig.3 depicts the rover and the crawlers current configuration.

The two crawlers have identical configurations, and their chasis differ from the PackBot used in [2] on how many *flippers* they have. The two extra flippers at each crawler give extra grip power and maneuverability, so that the operator will be allowed to have much easier access to more restrained places. Climbing stairs, going over higher obstacles and moving around debris of a building can be done with ease with this configuration. Fig.4 shows the dexterity of one of the crawlers when going over an obstacle.

A. Indoor twin robots

The general configuration of the crawlers is depicted in Fig.6. Both of the crawlers have four driving and steering motors, two of which can be used to guide the front and rear flippers to reach higher ground or to level the whole robot. A wireless LAN camera (Corega, CG-WLNC11MN) using IEEE802.11b, is mounted on each of the crawlers facing its front flippers, granting the operator a view of the immediate possible obstacles and the orientation of the robot itself. These cameras are a not intended to be a permanent solution for the navigation system, but rather be an aid to the operator in case the maps from the 3D sensors are not requiered.

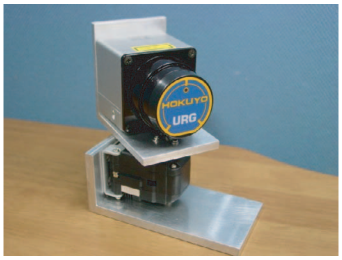

Fig. 5. The Hokuyo laser range finder used for navigation mounted on the servo motor that will rotate it.

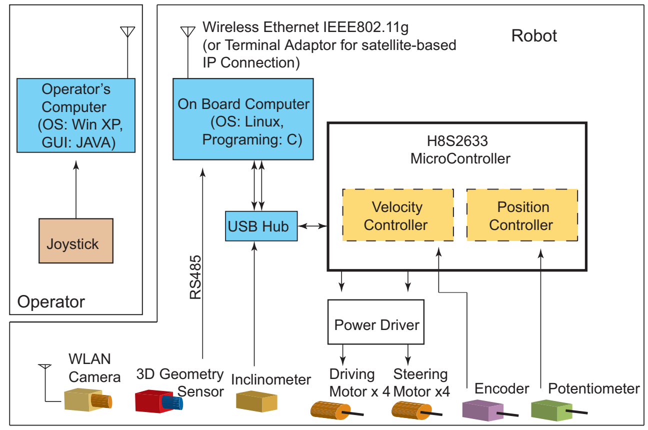

Fig. 6. Description of the hardware and software of the robot system

The camera connects directly to the wireless LAN of the whole system through its assigned IP address liberating the onboard PC of each crawler from the task of processing and transmitting the video stream. A scanning laser range finder (URG-04LX, Hokuyo) is installed just under the wireless camera and attached to a servo motor that rotates them 180^o. This laser range finder will take high definition 3D geometry data that will be used to create a map of points of the environment surrounding the robot and offer an overview of the environment around the crawler. This last feature is necessary for the navigation task as the operator has a better understanding of the environment than with just the camera feedback, as given in [6]. The laser range finder can scan an area up to 240^o, with an angle resolution of 0.36^o and an accuracy of $\pm 10mm$, it consumes only 2.5W and weights only 160g. Fig.5 shows the laser range finder and the servo motor on which it is mounted.

All the information coming from the potentiometers, encoders and the laser range finder is managed by the onboard computer, a Cube-Lite PC (FA System Engineering Co., LTD) running on Linux. It has an AMD Geode GX533 400MHz processor, 512MB RAM and USB, RS232 and LAN ports. The Cube-Lite PC is connected to the operator's computer through a wireless LAN network powered by an access point. In the near future, the network range will be increased using "repeaters" that will take the signal coming from the access point, amplify it and then broadcast it again. The movements of the crawler are controlled by the operator using a joystick connected to the computer through a USB port.

B. Outdoor Rover

The outdoor rover is a six-wheeled, teleoperated robot which will cover an open area creating 3D maps that will help human reconnaissance teams to approach the area safely. This robot has a ramp that can carry both of the sibling crawlers from its deployment zone until the area where the crawlers are desired to be put. The general configuration of the rover is almost the same as the one of the sibling crawlers, the major difference is how the navigation is accomplished using the combination of line laser scanner (from SICK) and a omnidirectional camera instead of the smaller laser ranger finder and the wireless LAN camera at the crawlers.

IV. NAVIGATION FOR SMALL ROBOTS

There are many different studies about how navigation in robotics should be handled: which media should be used, what kind of devices give the best performance, control considerations, delay [8],[12], etc. Just as [10] mentions, teleoperation technologies allow operators interact through robotic systems with environments physically apart from the controlling location.

In this project we implemented the navigation of the crawlers based on a wireless LAN camera and a laser range finder. The wireless LAN camera can send Motion JPG video stream at a rate of 6fps with a VGA resolution quality and a rate of 20fps with QVGA quality. The laser range finder sends the information of the points at the scanned area through a USB 2.0 interface at a rate of 12Mbps.

The main functions of the camera are: to let the operator perceive possible hazards and to let the operator know about the orientation of the robot with respect of its environment. Both of these objectives are accomplished when the camera is set over the laser range finder, facing the front flippers of the crawler. The height at where the camera is placed lets the operator get a better view of the immediate obstacles and how apart they are from the path of the robot. Even though the quality of the image received is not high, it is enough for the operator to take decisions on where to send the robot without compromising its integrity.

In the experiments mentioned above, the bandwith consumption of the whole network due to the video streaming did not represent an issue, because the channels on which the data and the video stream were separeted so that they would not interfere with each other's bandwidth. After some tests, it came to the authors attention that the image was freezing constantly even when the robot was not very much far away from the closest access point. The reason for this was that the camera mounted on the crawler works with a IEEE802.11b, making its range smaller than that of one using IEEE802.11g.

A. Comparison of the devices

When the conditions around the crawler do not permit normal visualization using the wireless camera streamed video, the operator should be able to trusts on other ways to be capable of keeping the mission on track. In this project, in order to solve such possible scenario the laser range finder presented above it is used. In addition to this compact laser range finder, a line laser scanner (from SICK) is set up under the ramp of the rover to have the same capability on it.

While camera-based navigation is an appropiate navigation method due to its streaming characteristic, when the creation of a map or a database is required other methods must be implemented. This is why in this project the authors propose a navigation using primarily the laser range finder. The wireless LAN camera will be used as fail safe in the cases the laser range finder is not available, not required or to detect events that may occur between two scanning phases.

When using a camera as in the experiments mentioned above, if the illumination is poor, the camera's image can not be a source of meaningful information. The inherent delay due to the distance of the camera with its closest access point brings outdated data that is necessary for the operator to maneuver the crawler safely. A major concern is the importance of the reduction of the bandwith due to environment reasons such as walls, metal debris, etc. Since it is streaming video when the crawlers reaches a zone where the reception of the signal decreases, the feed will be cut inmediately letting the operator without a visual feedback and a sense of where the robot is. In addition, the camera used is not a stereo camera but a regular CMOS wireless LAN which can not give by itself a depth understanding of the displayed image.

Despite the fact that the camera has various limitations for its use, the laser range finder used in this project can deliver a complete scan of the environment independently of its conditions. Even when the robot may be located in low-bandwith transmissions zones, the information sent from the robot to the operator requires a very low amount of bandwith compared to that of the camera. Also, once a scan of the surroundings of the robot has been sent, the operator can move the crawler in any direction within a radio of 4 meters. During this time the crawler can reach a better position where the signal of the network can be stronger and the possibility that the bandwith will rise to a normal level, higher. A disadvantage of the usage of the laser range finder is that in order to take a scan the rover must stop until the scan has been completed; also if there is any kind of change in the environment within any two given scans, information of such change can not be registered.

When combining both the camera and the laser range finder, the operator gets two different alternatives to rely on to accomplish the remote operation of the robot. The camera does not require the robot to stop which gives to the operator a better maneuverability, in the same way, when the camera can not be used due to the location of the robot, the laser range finder will always be capable to give the necessary information to navigate. This is the main reason why the authors will base the navigation of the crawlers on 3D LRF-generated maps.

B. Scanning Modes

Depending on what resolution or which objective is intended, the operator can decide among to scanning modes: a Quick Scan mode and a Full Scan mode. In the "quick" scan mode, the laser range finder takes up to 10 seconds to complete a scan with a resolution of 1.5^o. In this mode the user is able to make a fast check up on the area surrounding the robot but is lacking of an appropiate resolution. In the "full" scan mode, the laser range finder finishes a complete scan with the highest resolution the scanner can deliver: 0.5^o. To achieve this resolution, the scanner takes about 30 seconds to complete the 180^o the servo motor will rotate. At full mode, the operator can use the created map to visualize an area of 4 meters where the operator can order the crawler to move in any direction. In Fig.7, a scan using the quick and full mode is presented.

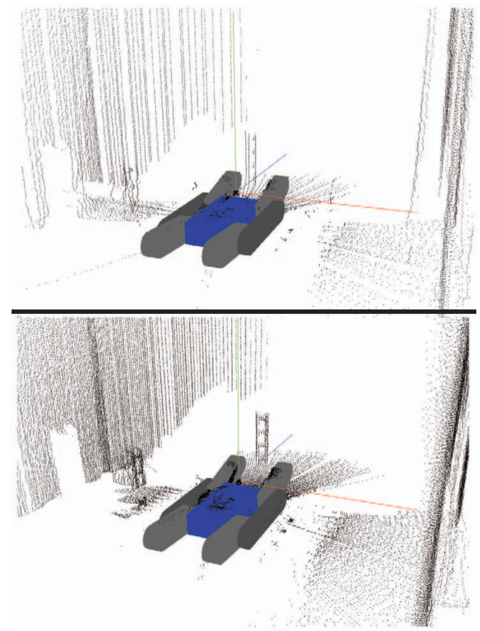

Fig. 7. Screenshots of the 3D geometry data obtained from a quick(above) and a full scan

Independently of what kind of scan the operator is interested on, three basic steps were designed to help the operator move the crawler using only the scanner generated maps. These steps are: Acquisition, Localization, and a Simultaneous Localization And Mapping.

In the first step, the crawler must completely stop and then given the command the operator sent, the laser range finder will take a quick or a full scan. The data is then passed to the onboard computer which transmits it to the operator where a JAVA 3D application will transform the spherical coordinates of each point into cartesian coordinates and display them accordingly.

The localization step consists of gathering the odometry information from the inclinometer and the encoders coming from the two flipper motors and the direction motors, in this way the operator can have an approximate of the position of the crawler in its environment.

As the third step, a Simultaneous Localization And Mapping algorithm is desired as part of the navigation system, however this stage has not been implemented yet. This forms part of this project's near future goals.

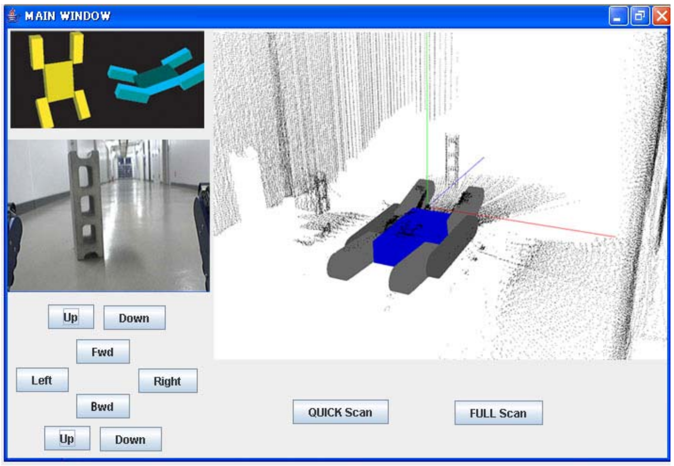

Fig. 8. Java3D and the 3D geometry data model, helps the operator understand the orientation of the robot

Fig. 9. One of the crawlers at the Collapsed House Simulated Facility in Kobe

C. Prototype GUI

Incoming information must be gathered, organized, and displayed in a proper manner for the operator to be able to take decisions based on that information [2], [9]. How readable and understandable that information is presented is one of the key factors for the remote navigation to be successful.

In this project, once the laser range finder has finished a scan, the data are sent over to the operator's computer where they are handled. Here, a basic graphical user interface (GUI) has been developed to present to the operator the information requiered for navigation. The GUI is written on Java and it includes a Java 3D component that shows the latest map taken by the laser range finder. Inside of this component, a model that represents the crawler's orientation inside the created map corresponding to the environment is presented. The orientation of the model is representing the incoming odometry data from the crawler. The information of the angles at which the front and rear flippers are pointing to are also included as a Java 3D animation component inside of the general frame of the GUI. The video stream from the camera is shown in its commercial application. Command buttons are also integrated to the GUI so that the operator can control the crawler from the keyboard, mouse or a joystick. The information displayed at the GUI is presented at Fig.8.

V. Performance Tests

In March 2006, a demostration of the actual capabilities of the rover and the two crawlers will be held in Saitama prefecture. In this demonstration, various tasks should be accomplished, these tasks are:

- The rover must go around an open-wide area, avoiding obstacles and carrying safely the two crawlers until the desired deployment zone has been reached.
- The rover should safely deliver the crawlers inside the desired deployment area and once the crawlers have been deployed, it should serve as the main access point for the wireless network the two crawlers will connected to. In this demostration the required repeaters will be put manually, however, in a real mission the crawlers will carry them onboard and leave them on an appropiate location.
- The rover should be able to collect information of the terrain and the approached zone's conditions using a line laser scanner (SICK LMS291) together with a co-axis omni-directional camera, as mentioned in [6].
- Once the two crawlers have been deployed, one will to the third floor of the building, while the other should go down to the first floor.
- Each of the crawlers must send the video stream coming from the wireless LAN camera onboard and the 3D geometry data coming from the scans done by the URG laser range finder.

Looking towards this demostration, two previous exercises have been done with meaningful results. The first of them was carried out at the Collapsed House Simulated Facility, in the International Rescue System Institute, Kobe Laboratory in Hiogoku prefecture. The second one was done at the IHI Aerospace Co. facilities, in Saitama prefecture.

In the first "practice" at Kobe, only one of the crawlers was tested. At the Collapsed House Simulated Facility, there is a simulated disaster area that includes debris of a destroyed building, broken tables, fallen wardrobes and so on. Our tests were done in an area that includes stairs. Fig.9 shows how the area looked like during the tests. In this scenario the main objectives of the practice session were:

1) Try the designed hardware and software under real conditions.
2) Remotely operate the crawler, having the operator in a different location and without prior knowledge of how the location looked like.

One characteristic that was desired at the exercise was poor illumination. Given this condition, a powerful LED lamp was used to iluminate the closest area to the crawler so that the operator could have an easier understanding of what was in front or behind the robot. Unfortunately the lamp was not bright enough and the image received by the operator was not comprehensible. Hence the usage of the laser range finder

Fig. 10. Crawler climbing the rover's ramp up to the mezzanine

became critical to make possible the teleoperation of the crawler.

In the second test at Saitama, the exercises included the outdoor rover and one of the crawlers. The first stage of the exercise consisted of running the extensible ramp of the rover up to a mezzanine inside one of IHI Aerospace Corp. buildings. Once the operator of the rover obtained enough confidence manipulating it, the crawler was put at the beginning of the ramp and then it climb up to the mezzanine. The ramp had an angle of 40^o and a length of 8 meters, the crawler is shown in Fig.10 climbing towards the mezzanine.

During this test it was noticed that the friction between the carbon fiber and the rubber covering the flippers and main chains of the crawler was not sufficient to allow the crawler climb the ramp properly. This is why sand paper was paste at both sides of the ramp matching in this way with the position of the crawlers chains.

On the second part of the exercise, the rover was maneuvered around an open area at a field located outside of one of the facilities at IHI Aerospace Co. and brought back inside the building, with the operator controlling it remotely. The crawler was manually put at the second floor of the building where the tests were taking place. There, the crawler went up to the third floor climbing over stairs and then covered some 20 meters until it reached an emergency exit, for a total length of about 30 meters. This was accomplished using only one access point.

VI. Conclusion

In this paper the results of experiments at the Collapsed House Simulated Facility, in the International Rescue System Institute, Kobe Laboratory and at the IHI Aerospace Co. as well as the navigation system used to maneuver the crawler have been presented.

In the first location only one of the two crawlers was tested. In this occasion, the operation was rather difficult and due to poor control on the speed of the motors,from which one of the main tracks of the crawlers was broken. Visual feedback was also an issue since illumination was poor inside of the facility. Both of these matters were fixed and helped the authors obtain experience on the maneuvering of the crawler.

At the second location, the experience adquired at the Kobe Laboratory helped anticipate possible problems that could have arised otherwise. Here, the prototype GUI was used to help partially the operator control the crawler. In addition, the crawler and the outdoors rover were used together simulating a real rescue scenario in which the crawler was delivered to a mezzanine with a height of approximately 6 meters.

VII. Future Work

This is still a developing project on its firsts steps hence much work is yet to be done. In the near future, however, a stable fully functional GUI will be implemented, a simultaneous localization and mapping algorithm is expected to be added to the navigation system allowing the operator to rely most of the controlling of the robot to the virtual image presented in the Java 3D component at the GUI.

VIII. Acknowledgements

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