RoboCupRescue 2013 - Robot League Team
MRL Rescue Robot (Iran)

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Abstract. In this paper the Mechatronics Research Laboratory (MRL) rescue robot team from Azad University of Qazvin and its robots are explained. We have designed and produced new advanced autonomous robots, tele-operated robot and a new flying robot for different situation. The main goal of this activity is to achieve a practical rescue robot for real situations such as earthquakes. We have also arranged to initiate some research programs on autonomous mobile robot such as simultaneous localization and mapping, navigation strategies, collision avoidance algorithms, sensor fusions, automatic victim detection and search algorithms.

Introduction

Each year many earthquakes take place in many countries like Japan, USA, Turkey and Iran. One of the most important factors in rescue operations is to find and save victims in time. Besides, a rescue scenario usually takes place in unstructured and unstable environments, requiring the use of a combination of complex mechanical designs and control strategies both in software and hardware levels. So implementing high technologies such as robotics could be helpful for search and rescue operations.
In this paper the MRL rescue robot team and its robots are explained. The MRL Rescue Robot team is planning not only to take part in Robocup competitions, but also to design and present a practical robotic solution for real disaster situations such as earthquakes which are very common in our country.
Obviously, based on the environmental situation, special robots with proper abilities are required. In other words, there could be no unique robotic solution for a rescue mission in every disaster situation. As a result we have designed different robots with different maneuverability. For example NAJI-I and NAJI-IV are two types of robots designed by MRL Rescue robot team, with a high power and flexible mechanism which besides overcoming hard obstacles, are also capable of supporting a powerful manipulator for handling objects. Fig.1 illustrates NAJI-I in Japan-2005 and NAJI-IV in China-2008.

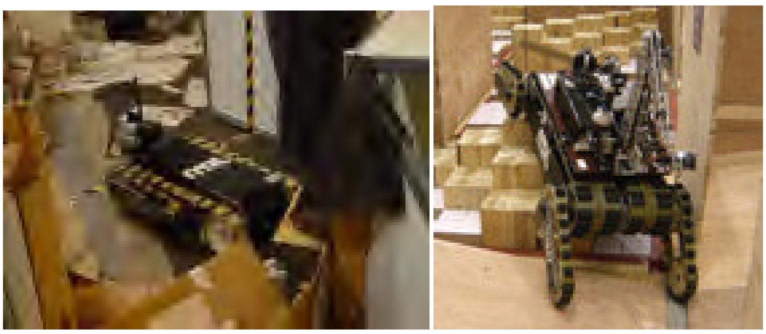

Fig. 1 NAJI-I in Japan-2005, and NAJI-IV in China-2008

NAJI-III is a modified version of NAJI-I which is more powerful and flexible while it is lighter and smaller. In 2008, we designed a new Autonomous robot NAJI-V for the competitions. Fig.2 illustrates the NAJI-V and NAJI-III in China2008. We achieved 2nd place in china 2008 using this two robots.
There are so many rough and hard terrains in a disaster situation which the rescue robot should be fast enough and low weigh to pass and explore environment quickly while remain stable. So we developed a new design with 4 arms named NAJI-VI which is equipped to roller cylinders in its bottom.

Fig.2 Right side NAJI-V (Autonomous Robot in) and NAJI-III in China 2008

NAJI-VI with the new stylish is now very stable and more efficient than previous ones, plus, using a new Mechanical design in NAJI-VI makes this robot more power full and effective in Step-Fieled zones. In other word NAJI-VI is a combination of NAJI-I and NAJI-III. By this new design, the power of NAJI-I in Climbing and the power of NAJI-III in Step-Field passing are combined, and more ability than our previous robots is enhanced. Figs 3 illustrate NAJI-VI in US 2007.

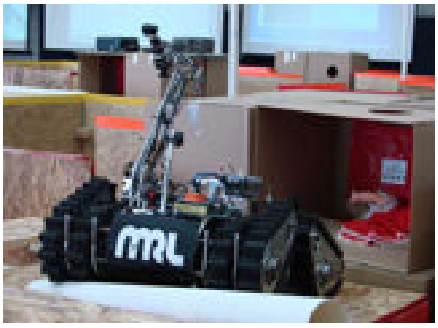

Fig. 3 NAJI-VI in US 2007

NAJI-I, II and NAJI-III are good examples of such robots while NAJI-VI with a novel mechanical design is faster, flexible and more stable.
One of the factors which help the NAJI-VI to have a better performance is that NAJI-VI's caterpillar covers whole body and makes it capable of crossing obstacles such as step fields easily. Fig, 4 illustrates NAJI-VI in Austria 2009 which using this robot we achieved third place.

Fig. 4 NAJI-VI in Austria-2009

In 2010, we designed two new robots for the Singapore competitions; NAJI-VII a tele-operated robot and NAJI-VIII an autonomous robot. NAJI-VIII, facilitated by most required sensors, is an autonomous mobile robot to carry out different research programs and is also suitable for the yellow and radio off zone arena. Due to improvements in autonomous arena the mechanical platform of autonomous robot is improved as well. Therefore, NAJI-VIII uses a four wheeled differential moving system so that it can cross easily the sloped floor arenas.

All our robots are powered by Embedded PC based on Linux (PCT[1] Linux) and a software framework(NRR Server[2]) which are able to process data and control the robot in Real-time. Fig, 5 illustrates our autonomous robot called NAJI-VIII also Fig 6, illustrated this robot in mexico 2013.

Fig. 5 NAJI-VIII

[1] Home made Linux distribution
[2] Naji Rescue Robot Server

Fig. 6 NAJI-VIII in mexico2013

One of the main issues in rescue robot field is manipulators. We designed a new manipulator for 2011 competitions. These manipulators with 6 degrees of freedom will make us able to reach victims in 1.6 meter height. Fig. 7 illustrates our new designed manipulator.

Fig. 7 our new manipulator

A rescue robot contains 2 general accessories: a mobile robot platform and a manipulator.
Our mobile robot consists of 4 legs attached to main body. Each of These legs has two parts as shown in Fig-8(QUAD-ARM robot with MANIPULATOR).
Second part of the leg has a self-relative movement to the first part of the leg with a series of gears. This caus-

es the robot to have a capability of driving both parts of the leg with one motor and gearbox. This property helps robot to have more flexibility in rough terrain surfaces.
Another marked property of this robot is using light-weighted materials. For example we used fiber carbon material for the main body or titanium and aluminum alloys for the other parts. We also used resistant polymer materials for mobility parts.
Power generators of this robot contain two Maxon dc motors coupled with a worm gearbox which gives 0.5m/s linear velocity to robot.
Another important part of our rescue robot is its manipulator. This manipulator has 7 degrees of freedom which is able to reach 140 cm height. End effecter of this serial manipulator is attached on a 3-degree of freedom wrist which gives robot a capability to search the holes and tight places. To increase the flexibility of the manipulator, the wrist is mounted on a prismatic which has 24cm coarse as shown in the picture.

Fig. 8 QUAD-ARM robot with MANIPULATOR

Fig. 9 QUAD-ARM robot with MANIPULATOR IN MEXICO 2013

We had problems with our 4 wheel autonomous robot NAJI-VIII Last year. For example, when exploration decided turn right or left in ramp field, the robot was unstable and as a consequence, the distances wasn't accurate in the expeloration algorithm, therefore, This year we have designed a new autonomous robot with new specifications .Generally this robot has 4 wheels, the front wheels have the ability to steer about 80 degrees which creates more flexibility to explore tight places in the field without slip. Some pictures of solid works 3d design can be seen in Fig 10.

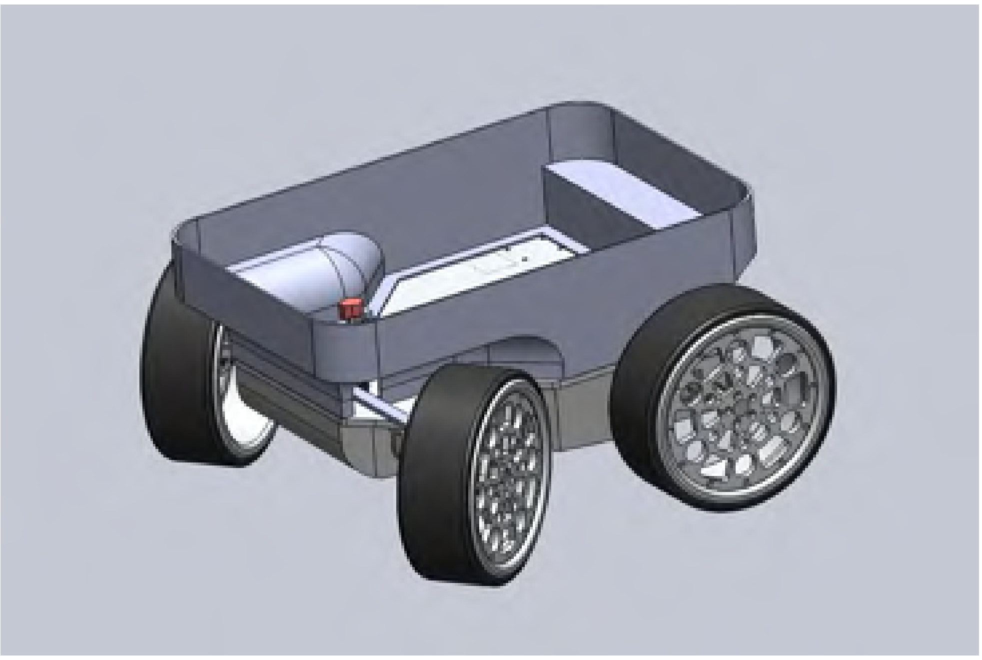

Fig 10. New autonomous robot for 2013

Another aspect that we concentrated on was weight. In order to reduce the robot's weight and improve the robot's mobility, we used aluminum, titanium and fiber glass. We also used high friction rubber for the wheels to prevent sliding on slopes. Besides, all parts of this robot have been manufactured precisely with high precision machinery like CNC and wire cut.

We are designed new electrical & control system for this robot . It is more reliable and fast in communication now.

As mentioned earlier, our ultimate aim is to develop and manufacture robots for helping people in real disasters. Due to this goal, we started our research on flying rescue robots last year. We implemented and prepared a flying robot to be used in rescue mission, named QUADVIN-Flyer-I. The QUADVIN-Flyer-I is shown in Fig. 12. This robot is suitable for flying over impassable arenas and gathering information about environment. This robot is equipped via IMU, laser scanner, un-board real-time PC, camera and sonar sensors, being capable of flying autonomously or manually. Collision avoidance, transmitting camera and SLAM information to an earth-working robot in case of autonomous mission or to an operator station in case of manual missions are other abilities of the implemented robot.

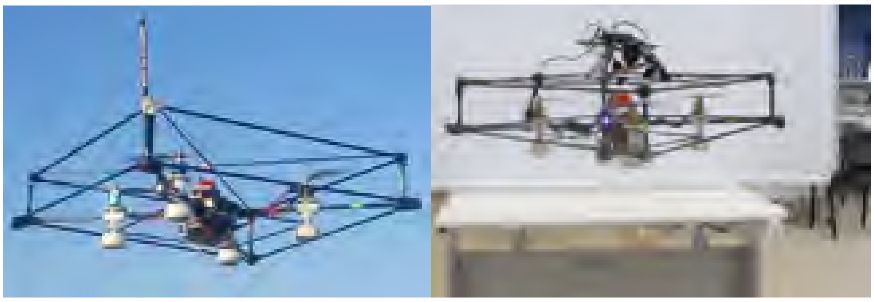

Fig. 12 QUADVIN-Flyer-I

1. Team Members and Their Contributions

1.	A. H. Mashat	Team Organizer, Electronic
2.	A. Karambakhsh	Software
3.	M.Esmaeili	Software
4.	A.Zandesh	Electronics
5.	M. Dadvar	Electronics
6.	B. Mahdikhani	Electronics
7.	P.Alamirour	Electronics
8.	M. A. Mashat	Mechanical
9.	M. Rahmani	Mechanical
10.	A.Hagi Mohamad Hosseini	Mechanical
11.	S.Habibian	Mechanical
12.	M.H.Rasooli Fard	Mechanical

Azad University of Qazvin	Sponsor

2. Operator Station Set-up and Break-Down (10 minutes)

In the rescue operation it is compulsory to set-up and break down as soon as possible in less than 10 minutes. We've designed a Mobile Control Pack (MPC) including notebook, joystick, access point, antenna, I/O extension board and a case with appropriate connectors so that the operator can setup and drive in user friendly environment. Fig.13 illustrates the Control Pack and GUI of the robot.

2. Software Overview

The software controller is developed to be executed on Real-time Linux. Moreover, it is equipped with intermediate software layer to communicate with RT-HAL in lower level and Wireless LAN in higher level. The low level software (NRRServer) sends the generated path, Log file and sensors data to central computer in the operator station in semi-autonomous. In fully autonomous, NRRServer sends the data to a laptop which is located on the robot.

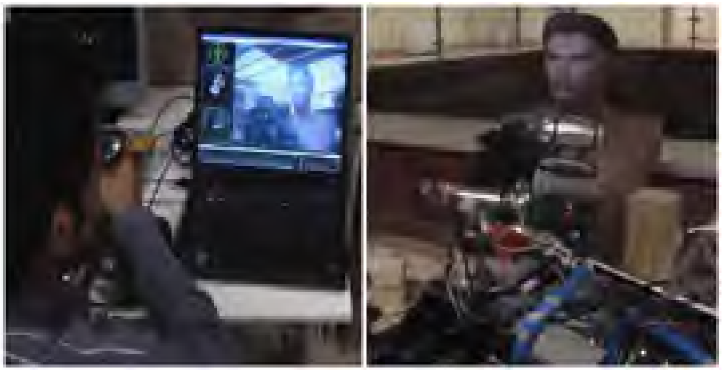

Fig. 13 Control Pack and Operator that's running the Robot and a sample of GUI

2.1 Real Time Hardware Abstracted Layer (RT-HAL)

It should be noted that for executing a high level control algorithm in a robot and consequently decreasing the system dependency on intermediate devices, employing an abstracts layer is unavoidable. To approach this goal the Real Time Hardware Abstracted Layer (RT-HAL) is designed in modular form on Linux Kernel RT-HAL in order to directly access to the lower layer (hardware) and upper layer (high level controlling process). NRRServer implemented on RT-HAL.

- Collecting the sensors data
- Sensor fusion and data processing and noise filtering
- Low Level controlling
- Localization and Mapping
- Navigation and obstacle avoidance
- A communication interface to high level process

Sensors data will be collected by associated data acquisition module and passed to sensor fusion process to be fused and acquire a better perception of environment. RT-HAL by implementing the driver as a device files, prepares a base for high level application to send their controlling command to actuators. Consequently NRRServer decreases the high level application independency and prepares the standard API to communicate with the hardware which leads to code the application in any programming languages.

3. Hardware Overview

The old robots which are based on differential drive system are equipped with sonar sensors, Laser Scanner, CO_2 sensor, thermopile array detecting infra-red sensor, IMU, digital compass, optical encoders and digital/analog cameras. The computational system in old robots is PCM 6892, PCM 8200, PFM 620s and GENE-8310 by 512 MB Compact Flash Memory, 128 MB RAM. The operating system is PCT-Linux which optimized and equipped with Hardware Abstracted Layer for best performance but we have some problem with this hardware such as power consumption, low reliability in robot strike and hang up them.

Therefore in new hardware design of robots, the 32 bit Arm-based processor is generally used, with high frequency and low power consumption. This processor can lead us to use the confident LAN protocol to transfer data between controller and robot. The previous connection of robots were serial connections, suffering from low speed, upgrading this protocol to LAN can break the limits in serials connectivity.

4. Autonomous Robot System Overview

The robot system overview is designed based on three levels: High, Abstraction and Low level; from top to bottom including the following steps orderly:

- Localization: Given sensors and a map, where am I?
- Vision: Is there any victim's signal, what should I do?
- Mapping: Given sensors, how do I create a useful world model?
- Searching Algorithms: Given an unknown world but a known goal and local sensing, how can I get there from here?
- Kinematics: If I move this motor somehow, what happens in other coordinate systems?
- Control (PID): What voltage should I set over time?

Fig 14 illustrates autonomous robot data processing and control system.

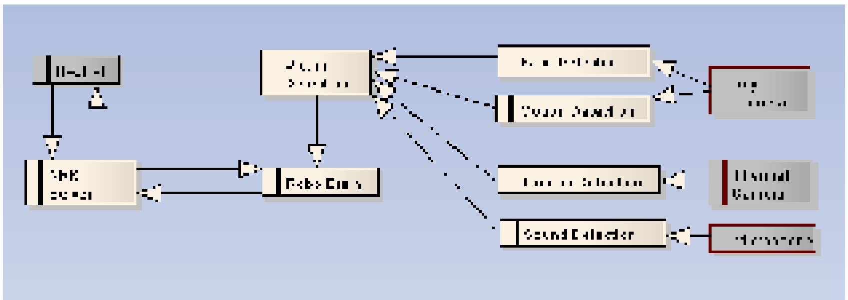

Fig. 14 Overview of autonomous robot

5. Semi - Autonomous Robot System Overview

The control scheme of our remote robot is partially autonomous. It means that the cameras images are sent to the computer and processed by operator to navigate the robot. All other sensors, information are also sent to the operator to investigate the arena and detect all possible victims.
Although the map generation is both autonomous and manual, when a victim is located, operator has to define the victim conditions based on the sensors data. In order to save time, a proper GUI is designed with several push bottom keys to define the victim's condition just by clicking the mouse button.
All the sensors' data are collected in a data bank to be used even off-line after the operation.
In the new hardware design, UDP protocol is being used, while it is not too complicated to implement protocol on the arm microcontroller. In this case transferring data and commands between robot and controller gets easier.
In addition, this policy provides more reliability and efficiency, quick debugging, appropriate PCB size and flexibility in control system. Besides, due to of high frequency, the differential pairs are routed according to the rules of coupling impedance in PCB design.
In the last design, the design suffered from unsuitable power distribution. To solve this problem isolated power switching from Traco-power Company such as TEP-150WI and minimax DC-DC convertors is used. These choices prevent brown-out voltage when current increments.
Fig 15 illustrates the high level overview of semi autonomous robots.

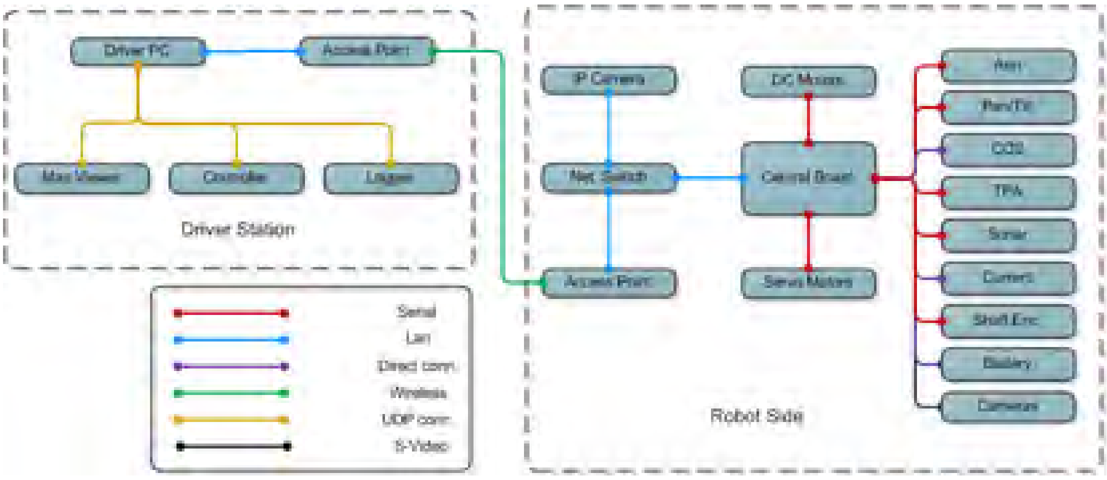

Fig. 15 High level overview of semi-autonomous robots

6. Flying Robot Overview

Quadrotors is an emerging rotorcraft concept for unmanned aerial vehicle (UAV) platforms. The vehicle consists of four rotors in total, with two pairs of counter-rotating, fixed-pitch blades located at the four corners of the aircraft [paper 1]. Having four rotors, the quadrotor can be controlled without using swash plats to change the pitch angle of the blades unlike the helicopters. This simplifies both the design and maintenance of the quadrotor. Moreover, using four rotors enables the quadrotor to remain stable in flight and carry more payload than other flying platforms. This makes the quadrotor a suitable platform for being used as an autonomous robot which can carry equipments like laser scanner, camera, on-board real-time PC, and etc.
Dynamic model of quadrotor and its navigation equations are presented in two frames named earth-frame and body-frame shown in Fig. 16.

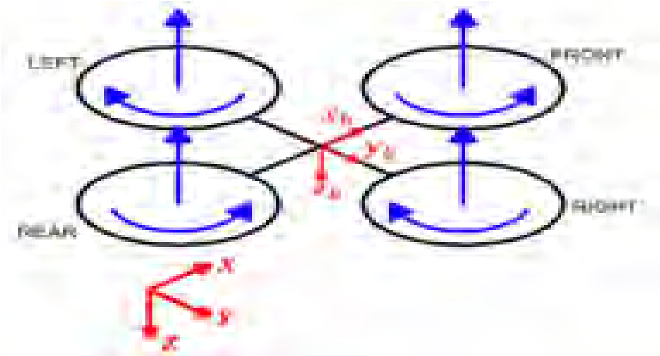

Fig. 16. Quadrotor control and navigation frames

Quadrotor dynamic behavior can be modeled as a 6-DOF rigid body [paper2] and a MIMO control unit is required to control it. Fig. 17 shows the low level control system of a quadrotor.

Fig. 17 low level control system

In high level control unit, navigation information and orders received from artificial intelligence (AI) unit are taken to account and the decision effects of the quadrotor behavior [paper 3, paper 4].

7. Robot Navigation

The first stage in the used method for robot navigation is to define a middle target (next step) near the robot. This middle target should be next to the robot and has the appropriate situation in terms of secure positioning and placing in a right direction toward final destination. This type of target defining will be performed in any step throughout the program. In this method the robot will never reach the target, while the target is permanently changing. For this purpose a buffer is used in order to save the scanned map in each moment. By each movement, position of the robot in buffer is checked and the best middle target to enrich better identification of the environment is defined. The formula below defines the appropriate point as middle target:

$$\begin{aligned} d_x &= R_{spx} + D * \cos(\theta_{ang}) \\ d_y &= R_{spy} + D * \sin(\theta_{ang}) \end{aligned} \qquad (1)$$

where D is the distance between the robot and barrier and θ_{ang} the angle, d_x and d_y are coordinates of target and R_{spx} and R_{spy} are fixed coordinates the robot respectively. Note that position and angle of the robot is considered fixed and due to occurred changes in distance and angle of obstacles to the robot in each movement, this distance and angle are recalculated. In other words, the robot is assumed fixed, while obstacles are moving.

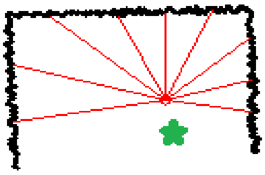

Fig. 18 proposed buffer in robot

The algorithm applied on autonomous robot for robot navigation and finding appropriate paths is a fuzzy algorithm, by which first the walls and barriers seen by the LASER scanner sensors is drawn on the memory and then a target is defined in local map of robot buffer. Figure 18 shows the proposed buffer in the robot.
In this algorithm an input and two outputs is considered. To explain more precisely, the algorithm takes the angle between the position of the robot which is considered fixed in the buffer and position of the target, while its outputs are the exact amount of force required to be applied to the motors connected to the right and left wheels of the robot [Figure 19].

Fig. 19 Fuzzy system diagram

Since, the target point is sensitive to changes in environment and reflexes the sudden changes; the Kalman filter is used to soften impacts of these sudden changes. This filter helps to soften the path obtained from initial target of fuzzy system.

Where z is an input for Kalman filter, Q and K are covariance noise and Kalman gain, $\hat{x}$ and $\hat{x}'$ are previous and current estimation respectively. P is covariance error. Further information can be found in [9].

8. Localization and Mapping

Localization and map building is a fundamental problem in mobile robot system which has been studied extensively in the robotics literature. The localization is performed by gradually building a map of the surrounding while simultaneously using this map to compute its position. Thus; it is crucial for mobile robot to be able to compute the position correctly in every situation. In order to have an accurate localization and mapping, Scan matching approach has a key role in localization process. The robot was equipped with sensors to get information of the environment around. Among existing sensors, laser range finder has been the most widely used one because of its high accuracy and reliability. Dead reckoning such as odometry (wheel rotation count) may conventionally be used, to estimate a robot position. Due to unbounded position error generated by the odometry, it doesn't suffice alone for localization.

Scan matching methods are based on matching the range scans, obtained by a laser range finder, taken at different times from the environment and updating the position estimation established based on the match result. These techniques can be classified into three types: point to point, point to feature and feature to feature.

In the point to point approach [1-3], the raw data of distances, collected from two different positions, are individually weighted and aligned to estimate the relative robot position.

In this field; the Iterative Closest Point (ICP) algorithm [4] use the simple metric for finding corresponding points such that two scans describe the same geometry. This method uses a distance metric for finding only the "closest" corresponding points in order to match two sequential scans. To achieve our goal in improving localization, we have implemented an iterative closest point (ICP) [1] and TrimmedICP algorithms which are based on point to point matching technique.

Metric-based Iterative Closest Point (MbICP) algorithm [5] uses Euclidean distance metric including both the rotation and translation estimation process in order to address two separated IDC problem. MbICP is designed to improve convergence when the initial orientation error is noticeable.

The Weighted Scan Matcher (WSM) presented by Pfister [6] combined the basic ICP idea with some properties of the Function Optimization approach. WSM models three uncertainty errors as correspondence, measurement and bias errors. This model is used in a Maximum Likelihood fashion, which actually is a Function Optimization problem.

This year we are working to implement the robust Scan matching such as WSM, MbICP instead of ICP which have been used during previous competitions.

Fig 16 shows result of our implementations in real arena in China 2008.

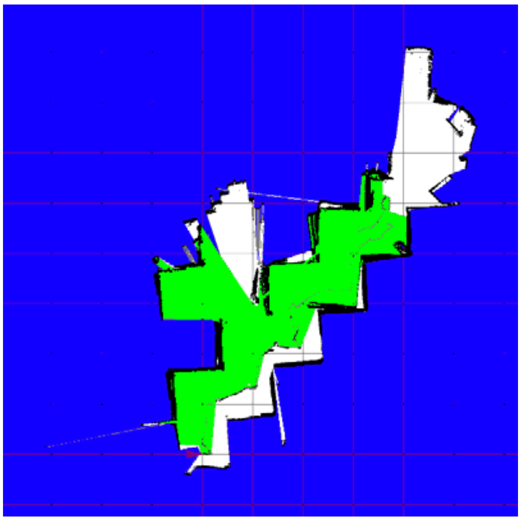

Fig. 20. Map result in real environment, China 2008

9. Map merging algorithm

We employed an autonomous robot and two tele-operated robots for the competitions, therefore, at least two maps are expected to be generated in the arena. For merging these maps we designed n GUI. Using this GUI, the operator can merge maps in mission time limitation. Fig. 21 illustrates two independent maps generated by two robots and in Fig. 22 two maps are merged.

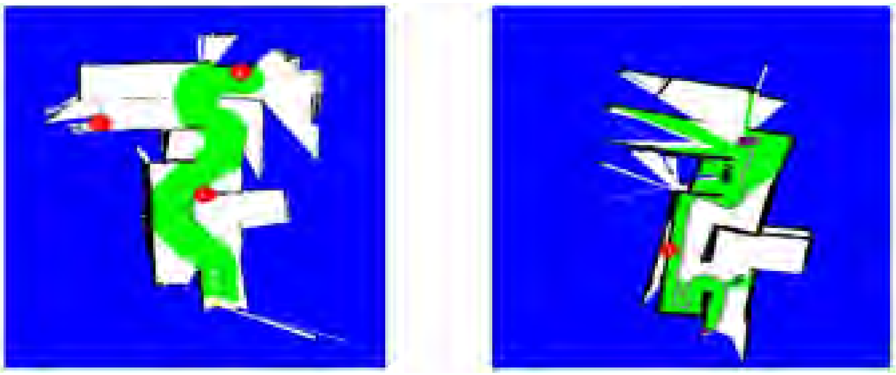

Fig. 21 two independent maps generated by two robots

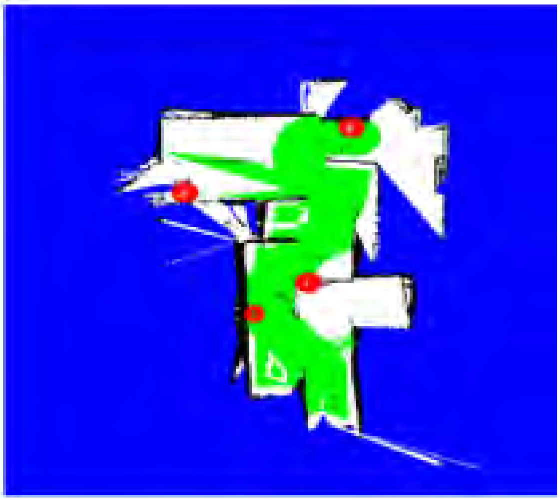

Fig.22 Map merging result

10. Victim Identification

For victim identification we have used a set of diverse sensors based on victim's characteristics. In other words, these sensors each work on a specific feature of a victim such as body shapes (face, hand, body …), height, sound, CO2 and motion. In this regard one of the most reliable features that can help the robot to identify a victim is temperature. A living body a human being is 37 centigrade degrees. In order to take advantage of this feature, TPA sensors are mounted on the Rescue Robot and its output us directly used to identify a victim.

Another technique that can be used to recognize a victim is to mount a camera on the robot and then perform an image processing method on the photos taken by the camera. During recent years, different types of image processing techniques are used in diverse fields of study, while face recognition, color segmentation, shape detection, texture extraction are just few of them.

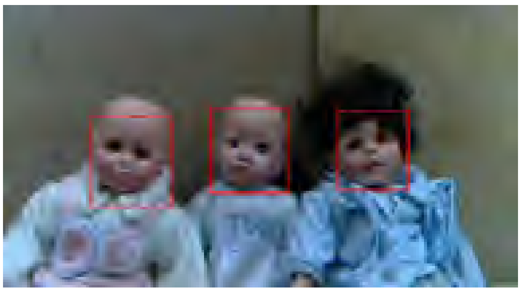

Figure 23- performing face recognition for victim detection

Since face recognition technique requires a more qualified circumstance (like better lightening and etc). During last two years, victims have been placing in small holes with low or no light. Besides most of the time they are placed in a position that the faces are not recognizable. All of these problems, mentioned above lead to application of other recognition methods like color detection. These methods can help to reduce the processing space [figure 23].

One of these image processing based methods is SIFT, which recognizes an object based on characteristics of a set of points in the image. These points are chosen based on some properties like repeatability, being resistant toward changes in the scale of the image, changes in the environment light and changes in the point of view.

In other words, by performing the DOG function which is convolution of a gauss function of G(x, y, δ) and an image of I (x, y) and a contrast condition, the points are chosen. Each point has a specific feature vector; these vectors are compared in each image and finally the image with the most compatibility with the base image is marked as that specific base image. It is also useful to convert the image into grayscale. Below are some figures explaining this method.
Another high speed technique which could help match a pattern in an image is cross correlation. This technique is first implemented in Matlab then based on predefined functions in C++ the implementation in opencv is completed. To implement this technique, first an edge detection process is performed on the selected object. An edge detection process is also taken place on the whole image. Then the edge detected object is moved through the edge detected image as a frame and by using formula (2) the difference between the object and each point of the image is calculated. Unfortunately this method is so vulnerable to changes in light and angle. Figures 24 and 25 show this process.

$$r[i][j] = \sum_{jj=-Nj/2}^{jj<Nj/2} \sum_{ii=-Ni/2}^{ii<Ni/2} (mask[jj+Nj/2][ii+Ni/2] - \overline{mask})(image[j+jj][i+ii] - \overline{image}) \quad (2)$$

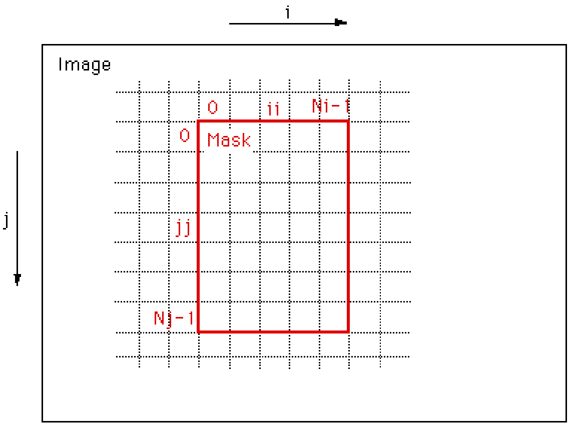

Fig. 24 moving the pattern frame on the image

Fig. 25 object selection and recognition in the same direction

Another feature found in some victims is motion detection. Detecting and reporting a movement of a victim will help the robot to gain more scores. This can be achieved by reducing the images and defining changes in the environment [Figure 26].

Figure 26- movement recognition

11. Robot Locomotion

All Tele-Operated robots are equipped to caterpillar locomotion system and autonomous robots have wheeled based locomotion system.

12. Team Training for Operation (Human Factors)

Our goal is developing a user friendly GUI system with minimum operator training requirement. It has straightforward drive and control and the complex systems like mapping are independent from diver and carried out autonomously.

13. Possibility for Practical Application to Real Disaster Site

Our Tele-Operated robots are designed for practical application at a real disaster site and they had good performance in real tests but the autonomous robots need more develops specially in mapping and exploration algorithms and are under progress.

14. System Cost

Most of the mechanical parts of the robots are designed and built by our team members. Depends on the type of the motor we have bought our DC servomotors from Faul Haber, Maxon and Dunkermotoren company. Ultrasonic sensors, Motor Driver MD03 and digital compass are bought from Devantech Robot-Electronics. Other sensors, Wireless-LAN card and electronics parts are bought from local shop. The cost for each robot differs depending on the size and complexity of the robot but approximately each robot cost us about 9000-15000 $US.

15. Lessons Learned

The urban search and rescue (USAR) robot requires capabilities in mobility, sensory perception, planning, mapping, and practical operator interfaces, while searching for victims in unstructured environments. So the robots should have high power and flexible mechanism to overcome the hard obstacles and it should be intelligent in control and map generation and victim detection as well. In the case of full autonomous robots the victim detection, path finding and exploration in an unknown area are the critical problems.

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