PROMOTION IN RESCUE ROBOT
According to the Experience Gained by Participating in Bam Earthquake Rescue Operation

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Abstract: Nowadays rescue robots are used in some rescue operations. Increasing the speed and accuracy of victim detection with sensors and equipment which are installed on the robot and yet increasing human safety factor of rescuers are among the advantages of using rescue robots.
By the experience of rescue operation in Bam earthquake and participating in some robocup competitions, a new four-wheeled robot has been designed which has highly operational capability. In initial part of this article, robot locomotion and controlling in different situations and the method of connection operator with robot are surveyed; then, sensors which are used in for navigation and victim detection are explained. At the end, the method of generating the map of robot’s movement route, which is very important for identifying the trapped victim's location in a rapid rescue operation, was studied.

1 INTRODUCTION

In December 2003, a severe earthquake destroyed one southern Persian city called Bam. This earthquake was the most devastating earthquake in the Middle East. Writers of this article who have been designing and building several robots, joined the rescue teams with their rescue robots and searching devices for detecting victims.

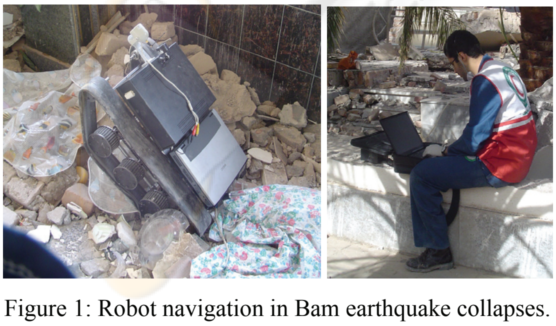

Figure 1: Robot navigation in Bam earthquake collapses.

By the experience of Bam earthquake, another rescue robot was designed and built whose characters would be describe in this article. This robot has high movement capability which could traverse the obstacles easily. The electronical and software parts of the robot have the ability of distance navigation, victim detection, and generating the map of victim places.

Individual Height adjustment of each wheels, carrying baby robot with ability of separating from the main robot and going through the small hole which the main robot could not goes, rapid ability for changing from four-wheeled to the track situation and mapping ability in both systems are among interesting idea which are used on this robot.

2 ROBOT LOCOMOTION AND OTHER MECHANISMS

The designed rescue robot is based on the four-wheeled robot mechanism. The design and production of it is so that the robot has a high capability of movement so that it can traverse the obstacles and unevenness easily. This robot is made using modern technology.

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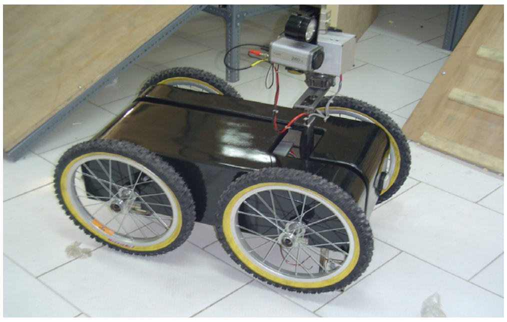

Figure 2: The robot.

The designed robot has four moving wheels and its dimensions are 87*50*80 cm. The weight of robot is about 32 kilograms. Four DC 12 V engines are used for the moving system of the robot each of them acts independently. The velocity of the robot is about 1 m/s and the rotation speed is 30 degrees per second.

The central computer which has the duty of processing, receiving and transmitting the data is an industrial PC (PC-104). Four packs of batteries of Ni-cadmium type are used to supply robot energy.

This robot uses the height adjustment system and the height of each wheel can be adjusted separately. By using this system the robot can easily climb the obstacles. Also in those cases where the patrol area is crowded, and there is a possibility for the bottom of the robot to collide with the obstacles, the height of robot could be increased to remove this problem. The changing range of the height in this robot is about 10 centimeters and the height is adjustable at the speed of two centimeters per second.

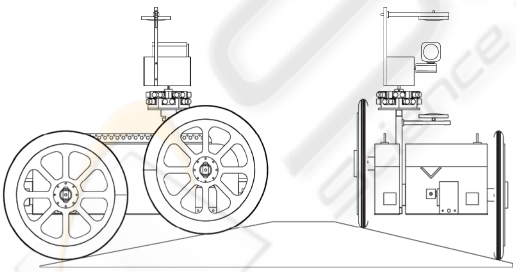

Figure 3: The height adjustment system.

In order to increase the moving ability, an innovative suspension system is used in this robot. This suspension system is devised in the form of a joint at the middle of the robot. This joint is capable of being locked at any angle and can help robot to traverse the obstacles and unevenness. The freedom degree of the joint is between -20 to +20. The time needed for the joint to be locked is about three seconds.

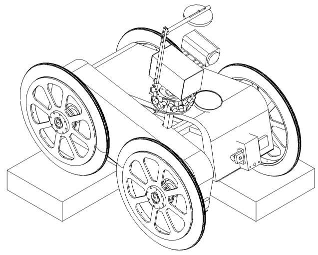

Figure 4: Joint suspension system of the robot.

To control the robot, three moving cameras are used. One of which is at the front the other at the back and the last one is located on the top of robot. The camera which is located on the robot is equipped with two Omni-directional mirrors above and under the camera. These mirrors give the robot the opportunity to have a visual angle of 360 degrees vertically.

Under the pedestal of the camera, there are 12 Sonar sensors which have the duty to help the robot in measuring the distance and also to obtain the map of environment.

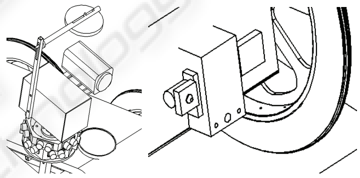

Figure 5: Pan-tilts and omni-directional mirrors.

The speed of the cameras at the back and front which are moved by RC Servos is about 50 degrees per second and the speed of the camera on the above is about 10 degrees per second.

For increasing the moving ability of the robot in special environments, and the ability of changing the moving system, four-wheeled tracked are used. It could be very rapid to change this situation.

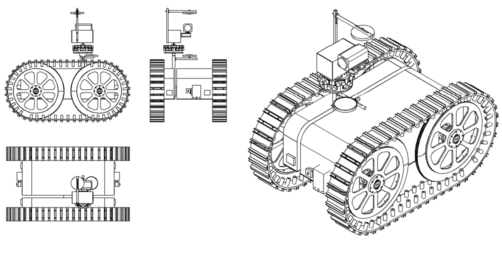

Figure 6: Track system.

In order to increase the searching ability of robot, a baby robot is used which is located inside the robot and it will exit whenever it is necessary. This baby robot is linked to the main robot through a cable.

The moving system of this robot is of the four-wheeled type, its dimensions are 15*10*8 cm and it weighs 1 KG. Two DC (12 V) engines are used in its moving system. The moving speed of the robot is about 0.2 m/s.

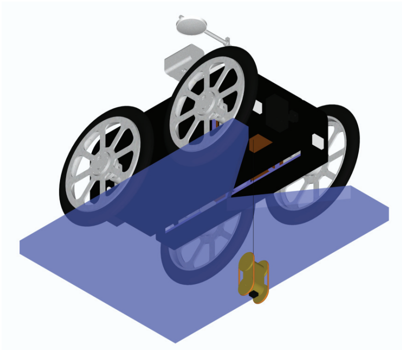

Figure 7: Baby robot.

3 CONTROL METHOD AND HUMAN-ROBOT INTERFACE

Controlling the robot is a partial autonomy. The major part of the controlling effort is performed by the operator and some movement decisions are made by the robot itself with the prior permit of the operator (which will be activated in the robot guiding software). Some of these decisions are: to automatic prevent collisions with the surrounding environment and to automatic return the robot to the starting point. But the software is designed so that the human decisions are considered prior to the robot decisions. For instance, in a narrow place the operator may deem it reasonable for the robot to collide with the walls so that it can pass the narrow entrance; therefore the orders of the operator are considered prior to the automatic decisions of the robot.

Regarding the mechanical specifications and the moving situation of the robot, three situations are defined for its movement: slow speed, medium speed and fast speed. The operator determines which of the above mentioned speeds shall be selected. But when the robot moves on a slope, the robot's movement will be set automatically according to the angle of the slope (which will be measured by ADXL330 accelerometer) and the software setting in which speed of the robot, while moving on the slope, is determined.

Moreover the PID controller is used to correct the mechanical errors and to adjust the exact speed of the robot in different situations.

4 COMMUNICATION

Regarding the fact that the robot is a PC base, W-Lan was used to establish connection between the robot and the computer (operator). Moreover, since in some regions it is impossible to establish wireless connections because of the high rate of noise, the capability of making connections through wire was added to the above system so that establishing the connection is practical even for long distances (several kilometres). A wire gathering system is devised inside the robot which could spread the long wire simultaneous with the robot's movement when connections shall be established through wire. In this way the wire will not hinder the robot while moving and it does not interfere with the robot's movement.

Table 1: W-Lan Specification.

Frequency	Channel/Band	Power (mW)
5.0 GHz - 802.11a	4	100

Through displacing a few simple jumpers which are devised on the robot and also through activation of the multiple choices exist in the provided software, we can easily determine the method for establishing connection with the robot.

To transmit the video pictures and voice, the 3W video transmitter with 2GHz frequency are used.

5 SENSOR FOR NAVIGATION AND LOCALIZATION

The baseline of navigation in a robot is to use graphical and video pictures sent by various cameras and Sonar system installed on the robot. Processing data, sent by cameras, is performed by the operator and the data sent by sonar system will be processed by a central microcontroller.

In addition to sonar system, several photo sensors are also installed on the robot's critical movement points which prevent robot colliding with the surrounding environment. According to the robot maximum speed, the identifying distance of obstacle by sensor is adjustable in a way that the robot will not collide the obstacles.

In order to locate the robot, a combination of data sent by various sensors are used which reduce the errors (that are inevitable). Increasing the rate of certainty in identification, grouping and also eliminating of the ambiguities & conflicts are among the benefits of this work. To perform the data combining system, it requires selecting and using the group of techniques harmoniously to achieve the best answer.

In order to apply the intelligent combination of data from the viewpoint of data processing, the high level method is used.

These sensors include:

- Four encoders which are mounted onto the motor shafts.
- Digital compass plus µ-metal to eliminate the noise of engines which could completely disable the digital compass sensor.
- the accelerometer sensor which obtains the robot's vertical angle in two vertical directions robot (using ADXL330 IC which most importantly is used to obtain the vertical angle (zx, zy) of the robot and to measure the height of the distance traversed by the robot).

To use the data provided by these sensors for illustrating the map, the following definitions shall be considered.

The break points: whenever the command for the robot's movement sent by operator through PC is interrupted or the Stop command is transmitted to the robot, that place will be considered as break point.

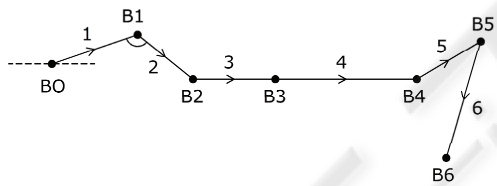

Figure 8: Break points for drawing map of robot's movement.

Note 1: the angle and the measure of the traversed distance from the previous break point and also the vertical distance of the robot from the horizontal line of the starting point will be desirable at the break point.

Note2: B3 is also defined as a break point here because the robot's movement in the straight direction is interrupted although it continued to move without changing its direction.

Note3: having the data about the robot's location (angle and the distance) at the break points, in an ideal condition we could illustrate the route map of robot in an accurate and simple way. This is the advantages of the break point definition.

The movement route: the robot's route of movement is obtained through connecting the vectors of break points.

Note4: the specifications stated in note 1, will be stored in the side memory of the robot in a special arrange. Whenever the investigating operation is finished, returning to the starting point could be automatically delegated to the robot by using the reversed combination of the stored data and real time data provided by the sensors simultaneously. (Obviously facing changes in the environment is unavoidable thus just in the ideal situation saved break points are used for returning to the start point and in real situation the real time data of sensors which could rectify the previous errors are used to obtain the new break points.)

Note5: Advantages of storing the data about break points in the side memory:

- The automatic returning of robot even in cases when the operator and the robot are disconnected.
- Access to the data in different steps of movement in order to perform the combining operation of the data provided by sensors (sensor fusion) to obtain a relatively accurate mapping.
- Access to the complete information of the route stored inside the memory so that in case the robot and PC are disconnected, the information could be transferred to PC (after returning of the robot).

6 SENSORS FOR VICTIM IDENTIFICATION

The most important method to identify the victim, is using pictures transmitted by the cameras which are installed on the robot (three cameras are installed on the robot but by using an analog switcher, the operator selects one of the pictures provided by one of these cameras to be transmitted.

And besides we can use:

- CO_2 gas sensors for detecting the victim's breathing.
- Installation of highly sensitive stereo microphones on the robot helps the operator to find the victim.
- LM75 IC for measuring the temperature of the environment.
- The non-contact thermometer sensor model IL301, with D:S (30:1) for measuring the body temperature of the victim from a far distance.
- Also a motion detector is installed on the robot which is sensitive to any trivial movement in the environment.

7 ROBOT MECHANIC AND LOCALIZATION

Firstly, we describe the mathematical equations of localization differential mechanism and then by using those equations, we could generate four-wheeled robot and tracked robot equations with acceptable accuracy.

7.1 Differential Drive

Figure 9 shows a typical differential drive mobile robot. In this design incremental encoders are mounted onto the two drive motors to count the wheel revolutions. The robot can perform dead reckoning by using simple geometric equations to compute the momentary position of the vehicle relative to a known starting position.

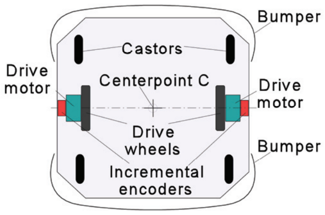

Figure 9: A typical differential drive mobile robot (top view).

20 Part I Sensors for Mobile Positioning For completeness, we rewrite the well-known equations for odometry below. Suppose that at sampling interval I the left and right wheel encoders show a pulse increment of N_L and N_R, respectively. Suppose further that:

$$C_m = \pi D_n / n C_e \quad (1)$$

where:
C_m = conversion factor that translates encoder pulses into linear wheel displacement
D_n = nominal wheel diameter (in mm)
C_e = encoder resolution (in pulses per revolution)
n = gear ratio of the reduction gear between the motor (where the encoder is attached) and the drive wheel.

We can compute the incremental travel distance for the left and right wheel, $\Delta U_{L,i}$ and $\Delta U_{R,i}$ according to:

$$\Delta U_{L/R,i} = C_m N_{L/R,i} \quad (2)$$

And the incremental linear displacement of the robot's center point C, denoted ΔU_i, according to:

$$\Delta U_i = (\Delta U_R + \Delta U_L)/2 \quad (3)$$

Next, the robot's incremental change of orientation was computed:

$$\Delta\theta_i = (\Delta U_R - \Delta U_L)/b \quad (4)$$

Where b is the wheelbase of the vehicle and ideally measured as the distance between the two contact points between the wheels and the floor.

The robot's new relative orientation θ_i can be computed from:

$$\theta_i = \Delta\theta_{i-1} + \Delta\theta_i \quad (5)$$

And the relative position of the center point is:

$$x_i = x_{i-1} + \Delta U_i \cos \theta_i \quad (6)$$
$$y_i = y_{i-1} + \Delta U_i \sin \theta_i \quad (7)$$

where:
x_i, y_i = relative position of the robot's counterpoint c at instant i.

7.2 Tracked Vehicles

Yet another drive configuration for mobile robots uses tracks instead of wheels. This very special implementation of a differential drive is known as skid steering and is routinely implemented in track form on bulldozers and army vehicles. Such skid-steer configurations intentionally rely on track or wheel slippage for normal operation (Figure 10), and as a consequence provide rather poor dead-reckoning information. For this reason, skid steering is generally employed only in tele-operated as opposed to autonomous robotic applications, where the ability to surmount significant floor discontinuities is more desirable than accurate odometry information. An example is seen in the track drives popular with remote-controlled robots intended for explosive ordnance disposal.

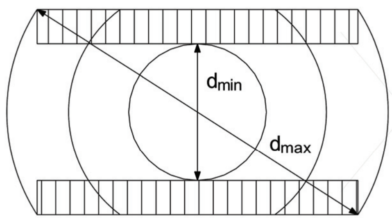

Figure 10: The effective point of contact for a skid-steer vehicle is roughly constrained on either side by a rectangular zone of ambiguity corresponding to the track footprint. As is implied by the concentric circles, considerable slippage must occur in order for the vehicle to turn.

7.3 Four-wheeled Vehicles

Obtaining the robot route map is one of the issues about which designer really concern. For this, there are simple mathematic equations. The robot route map equations parameters are described below. These equations are valid while wheels revolutions are equal, it means that the robot should go forward, backward or rotate at its place and could not use these equations in complicate movement. In rotation, robot changing angle is calculated and it has no movement.

Table 2: Parameters of movement route for four-wheeled robots.

Dimensional distance traveled by wheel for each encoder pulses	Ct
Effective width of robot divided by two	O
Incremental travel distance for the left and right wheel in the straight movement	ΔUR1 = ΔUL1
Incremental travel distance for the left and right wheel in u turn movement	ΔUR2 = ΔUL2
Number of pulses received by left and right encoder	NR,i = NL,i
Wheelbase of the vehicle, measured as the distance between the two contact points (wheels & floor)	b

The mathematic equations of robot route movement are described below:

$$\sin \alpha = O / b \quad (8)$$

$$C_m = \pi D_n / nC_e \quad (9)$$

$$\Delta U_{L1} = C_m N_{L,i} \quad (10)$$

$$\Delta U_{R1} = C_m N_{R,i} \quad (11)$$

$$C_t = C_m \times \sin \alpha \quad (12)$$

$$\Delta U_{L2} = C_t N_{L,i} \quad (13)$$

$$\Delta U_{R2} = C_t N_{R,i} \quad (14)$$

$$\Delta U_i = (\Delta U_{R1} + \Delta U_{L1}) / 2 \quad (15)$$

$$\Delta \Theta_i = \Delta U_{R2} / b \quad (16)$$

$$\Theta_i = \Theta_{i-1} + \Delta \Theta_i \quad (17)$$

$$X_i = X_{i-1} + \Delta U_i \cos \Theta_i \quad (18)$$

$$Y_i = Y_{i-1} + \Delta U_i \sin \Theta_i \quad (19)$$

If compass sensor or gyroscope use more than encoders, $\Delta\Theta_i$ parameter is directly obtained from sensors and other movement route equations shall use without change.

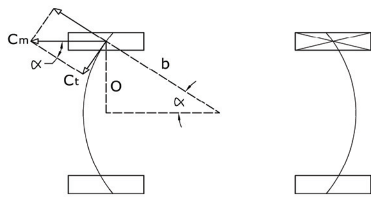

Figure 11: A typical four-wheeled drive mobile robot (top view).

8 MAP GENERATION

The map generation process, for illustrating the route of robot's movement is studied on this part. The recorded data, observed by cameras and also the piece of information were received by various sensors, illustrated on the map of robot movement (in form of a general report for the robot performance). This part consists of two parts called automatic mapping and manual mapping which the automatic mapping is chosen as the default. The work procedure is as follows:

Data about shaft encoders exist on the robot, and the data received through the digital compass sensor are transmitted continuously from robot. The computer firstly combines the received data and applies a series of error correcting algorithms to reduce the errors of shaft encoders (sensor fusion) and then the coordinates of the robot in each second will be obtained. By using these coordinates, two dimensional routes of robot's movement will be illustrated. Meanwhile, the data provided by gas and voice sensors, transmitted by the robot, will be saved in the computer and they will be illustrated on the map at the place which they were received. In addition, some tools are designed for the operator by which the operator can record its observations and insert information in the map.

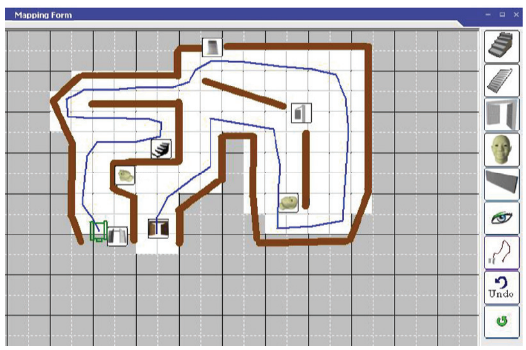

Figure 12: The scheme of the software used to illustrate the route map.

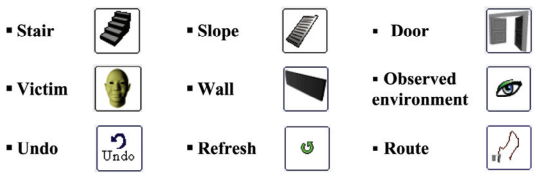

Figure 13: Symbols which are used in map generating.

Whenever the operator realizes that at the place where the robot locates or at its surroundings, there is a stair, wall, door, slope, or a victim, it can locate a symbol of what it observes on the route map.

By using *observed environment* button and while navigating the robot, the operator will mark the places visited by the robot to prevent the repetitive visiting and then, saves time. For returning to the previous situation the operator just need to press *undo* button.

While working, whenever the robot and the computer are disconnected or whenever major errors in the coordinates data or the data provided by sensors are observed which may caused as a result of robot damage, the operator can select the manual mapping choice to illustrate the route. In this way, he can enjoy the benefits of software in controlling the robot and will face fewer errors.

In case that operator uses each of the above objects in a wrong place, the software has the ability to delete the object by a right click or to replace it by a left click. The places in white colour show that they are observed by the operator.

While observing an injured person, and placing its symbol on the route map, another form will appear for the operator in which the operator should enter the related data to be recorded and also to be used for the next reportages.

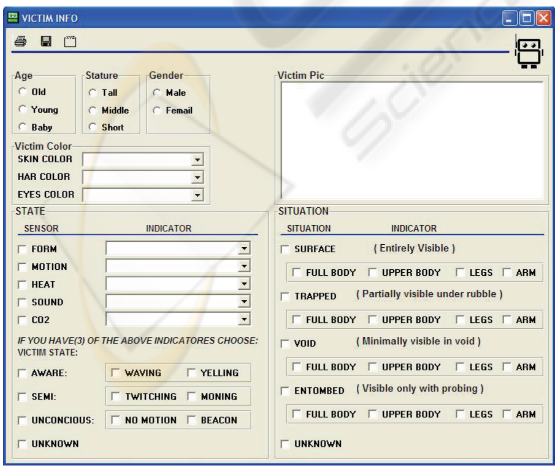

Figure 14: Form for recording the victim data.

9 CONCLUSIONS

Height adjustment and suspension systems enrich the robot to go through the entirely destructed buildings; however, it is not possible for it to cross some obstacles such as steps. Robot mapping system acts perfectly inside the buildings, but in the open areas or the rubble it needs to improve. In the improvement plan, these limitations must be removed. In its final version, laser scanner and radio positioning will be installed. The received information plus the other sensors data result in a better mapping achievement. It order to accelerate its movement on the steps and through the obstacles, some changes will be applied on the wheels and the motion system.

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