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A Study on Risk Assessment for Improving Reliability of Rescue Robots

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Abstract— Not only the performance is important for robot development, but also its reliability is another important perspective needed to realize robots in the real field applications. Rescue robot is one the extreme case for robot development. The rescue robot works with human operators and rescue responders in rescue missions occurred under some special situations, such as, collapsed building from earthquake. Under the circumstance with limited time, highly complex pathway and unexpected terrain, the rescue robot requires zeroed error in its operations; therefore, the reliability is the most important issue. Our study on risk assessment aims to improve the reliability of rescue robot in its development by considering separately for each subsection in the robot, then, combine them together. The results help improving our research and development on rescue robots significantly.

Keywords— rescue robot, reliability, risk assessment, hope

I. INTRODUCTION

Disaster can be happened by natural and sometime from human fault. It is an expected event that nobody is looking for it, since it can make a lost of properties, believes, hopes or may be lose more than that is a life after disaster is occurred will make a plan to solve and cure situation or make it slow down. Earthquake it make a building fall down sometime have a human inside a building

In rescue operation time is an important thing for everything and rescue team should be have knowledge and experience in that situation for help fast and safe so now a day technology has growth up very fast include tool for help rescue team for reduce time and safe they should know data from tool such vision, sound, temperature, breath and carbon dioxide and help to localize a human location in disaster one of solution is using rescue robot replaced human in high risk situation such chemical factory, nuclear plant, disaster from earthquake because a robot has value less than human it can do many thing to help like a human such searching, navigation, diagnosis and avoid risk from unknown environment such chemical, bomb, concrete crack or go into the situation that cannot control Rescue robot is a robot that used in extreme terrain on ground base or high risk

situation robot should be very strong and robust because some place cannot know the environment after disaster may be have a chemical, heat, water, nuclear radiation and gas it should have a sensor for diagnosis environment or victim and navigation system to localize a victim and make a data such as pathway and map to help rescue team and robot must be dust proof and water proof easy to startup and communication must have 2-ways communication with video and sound or may be have a thermal camera to help for search and diagnosis At BARTLAB we have been developed several version of rescue robot for robot competition. In real use robot should be high efficient, high reliability and robust and have a good size and light weight so we would like to researching and developing rescue robot in real use application for save a human life. In 2014 Thailand at Patumthani province the 6th floor building has collapse then BARLAB team deploy rescue robot named Tele-Op IV with 2 track for main drive and 4 flipper for fast and more stability on rough terrain for communication with robot and operator use wireless LAN signal to communicate with camera, microphone, non-contact temperature sensor, carbon dioxide sensor to diagnosis with victim. Now our team focus to make a hardware and software for high reliability for hardware need to be strong and robust because on rough terrain it too much vibration at robot system then we will find the risk for rescue robot for rescue operation for make a robot in high reliability.

Fig. 1. BART LAB Tele-Op 4 Rescue robot

II. LITERLETURE REVIEW

Robot reliability and risk assesment is very important method for help for design and test method because robot have many part combine together robot have a 3 main parts is mechanical part, electrical part and software inside each part have a risk inside. Most of robot failure [5][6] is following

- Printed circuit board problems

- Human errors
- Encoder problem
- Control system problem
- Programming and operation error
- Miscellaneous

And for basic failure have 4 types[6] that can be effect with robot reliability

- Human errors
- Random component failures
- Software failures
- Systematic hardware faults

Human errors occur from designer, operator, manufacture that assembly and robot part Failure that occur in robot lifetime is called random component failures it unpredictable. Software failure is very important part causes robot is controlled by software for reduce a risk that can make it occur by failure mode and effects analysis (FMEA), fault tree analysis (FTA), and testing.

III. ROBOT SYSTEM OVERVIEW

System integration have 2 main site 1.Station site 2.Robot site. Station site is side of robot operator use gamepad joystick to control a robot via wireless LAN 5.8 GHz 200 mW in TCP/IP protocol and have Operation Control Unit (OCU) run on Linux operation system and use Robot Operating System (ROS) is a software module management to manage between each software module can work together. Robot site TeleOp-4 Robot have 2 wheel track for driving system, 4 independent flipper, 6DOF manipulator, 4 Camera, Carbon-dioxide sensor, Non-contact infrared temperature sensor module, Microphone, Speaker and low-level of robot side to control a robot use 11 micro controller have 1 is master for communicate with computer via USB and have 10 is slave for control each DC motor communicate with master each together with I2C bus for high-level of robot side use computer for processing data from station side use Linux operating system and Robot Operating System (ROS) for main function for high-level this side have 2 main function for robot 1.Motor control 2.Sensing system Motor Control is a part for control each DC motor to control a speed and position of each DC motor of robot such motor left speed, angle of flipper, angle of manipulator. Sensing system is a system that integrates data from many sensors that are used to determine the data to be processed and decided together to make a robot known their own status for use in other decisions such temperature environments ,Carbon-dioxide environment, Its own position relative to the map that a robot has been created automatically

TABLE I. SPECIFICATION OF TELEOP-4 ROBOT

Item	Description
Chassis	
Length, Width and Height	60x60x50 CM.
Weight	55 Kg.
Speed	0.75 m/s MAX.
Driving System	Track
Main Driving System	2 MAXON Motor RE40
Independent Flipper	4 MAXON Motor RE20
Manipulator	
Weight	10 Kg.
Extension	1 m.
Degree Of Freedom	6
Base	180°
Link1	120°
Link2	90°
Head Roll	±180
Head Pitch	±90
Head Extension	30 cm.
Navigation and Mapping	
Laser Range Finder	Hokuyo UTM30-LX
Robot Controller	
Embedded PC	eBox1618
Microcontroller	16 PIC Microcontroller
Communication	
Wireless Lan 5.8 GHz	Ubitiqui Nanostation M5
Sensor	
Co2 Sensor	Infrared
Temperature Sensor	FLIR
Camera & Vision	
4 CCTV Camera Webcam	TUM
1 Hi-Def Webcam	Logitech
Battery	
6 Ni-MH 12 V 4.5 AH	24 V 13.5 AH
1 Li-Po 24V 5.5 AH	24 V 5.5 AH
OCU	
Length, Width and Height	60x60x50 CM.
Weight	10 Kg.
Display	2 15" LCD Monitor
Control	Keyboard & Joypad
Software	
BARTLAB TELEOP4 4.0	Robot
BARTLAB OCU 1.0	OCU

A. *Robot architecture*

For architecture of rescue robot have 4 main part 1.High-Level is send and receive data from station site is controlled by rescue operator get data and encode to send to low-level for control each motor and compute data from laser range finder for automatic generate 2D mapping in grid map occupancy 2.Low-level side is communicate with High-Level all the time and get the data from high and encode data via I2C bus then send a signal to motor driver for move a robot 3.Sensor side is

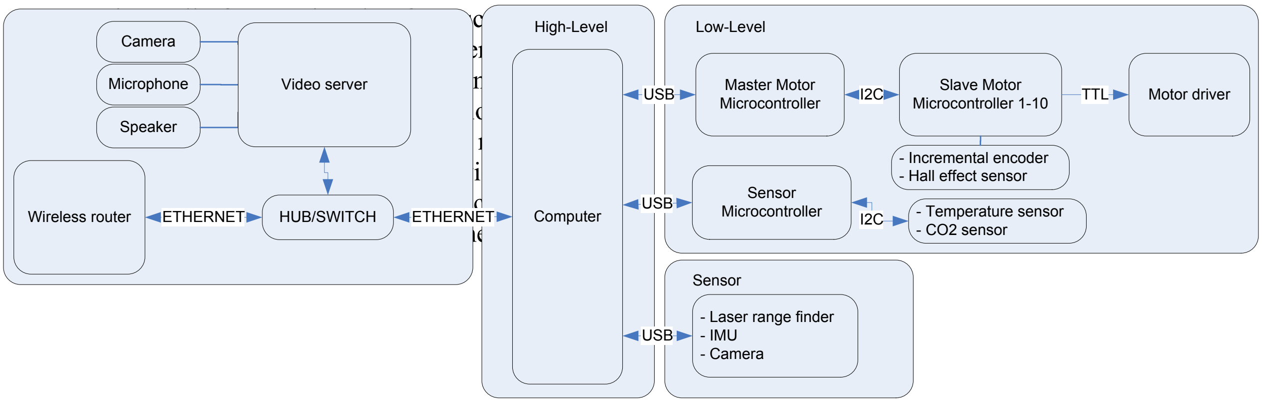

Fig. 2. BART LAB Rescue Robot Architecture

B. *High-Level control architecture*

For High-Level we development BARTLAB TELEOP4 4.0 software for use in TELEOP4 Rescue Robot base on Robot Operation System (ROS) work on Linux system have 9 main nodes for structure on ROS is designed for multiple program can run and work together in a same time for computation and communication with robot in a real-time 1.Auto victim detection use camera and image processing for auto detect victim used in autonomous robot and some teleoperation robot 2. Sensor Visualize is a node for show data from sensor in a robot for manual identify a victim this component include image from all of camera 3.Manipulator controller this node used for control robot manipulator 4. Localization node used in localize robot in a real world base on map that generated from Laser Range Finder 5. Interactive controller this node that interface with hardware for how to control a robot such forward, backward, turn left etc. for TELEOP4 use Joypad for control a robot. 6. Power management this node is important because while robot working in operation robot operator should know a power of robot for discussion in that situation 7.Navigation this node for autonomous mode used in some situation such robot station cannot communicate with robot may be communication signal down robot will change mode to autonomous mode automatic and can drive autonomous in exploration mode and can avoidance object and detect victim and then signal comeback operation can control a robot and get the data back in lost signal situation 8.Mapping this node will generate 2D mapping from Laser Range Finder data use SLAM technique and then visualize map data and show a real-time robot position, victim position and path navigate to victim 9.Base controller node is used control base such robot velocity, robot pose.

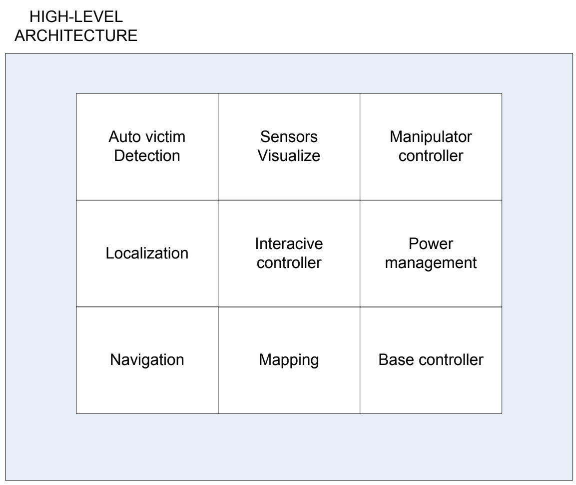

Fig. 3. High-Level control architecture

Fig. 4. Operation Control Unit (OCU)

C. *Low-Level control architecture*

For Low-Level control use dsPIC30F4011 microcontroller use in 2 main part 1.Master motor controller 2.Sensor Controller Master motor controller get data from high-level control via RS232 communication baud 115200 bps to interface with 10 motor microcontroller slave connect each together with I2C interface we design like a module if some module have a problem we will take that problem module out and then put a new one and for motor control each joint of robot used incremental encoder for close loop positioning such manipulator control or robot speed control low-level control and then logic to motor driver to drive a robot move. Sensor Controller interface with hi-level with RS232 baud rate 9600 bps this component interface temperature sensor, carbon-dioxide sensor and show data from sensor in GUI application on OCU with TELEOP OCU1.0

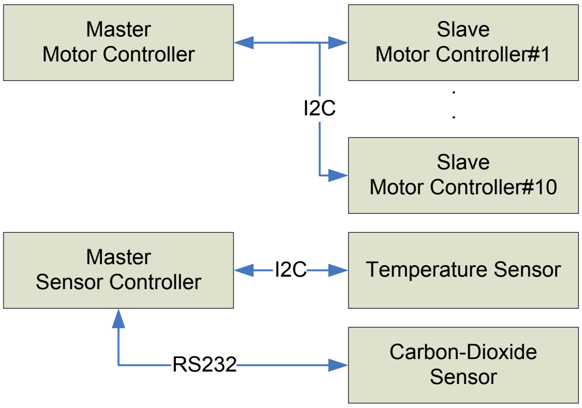

Fig. 5. Low-Level control architecture

D. *Victim Diagnosis Sensor*

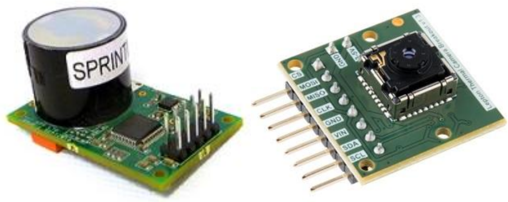

Fig. 6. Carbon-Dioxide(left), FLIR Temperature Sensor(right)

For diagnosis victim use 2 sensor and camera for detect human alive or not 1.Temperature Sensor use for measure temperature with non-contact type in figure 5 (right) use infrared technic for measurement 2. Carbon-Dioxide for measure carbon-dioxide in that environment and carbon-dioxide at victim breathe shown in figure 5 (left) all data of sensor will send to high-level via Sensor Controller to show to GUI at rescue operation station.

E. *Mapping*

We generate map automatic by rescue robot use ROS package HectorSLAM[2],[3] HectorSLAM is a opensource Simultaneous localization and mapping(SLAM) for generate 2D mapping we use this package on ROS for no requirement for odometry data we use gamepad for control a robot to collecting data to make a map for laser range finder(HOKUYO UTM-30LX) range for scan is 30 meters we use 180 degree for scanning data and rate for scan is 25 ms/scan for resolution of map is 0.05 m/pixel. A map will show for free space is white pixel and black pixel is obstacle and grey color is unknown space or not exploration.

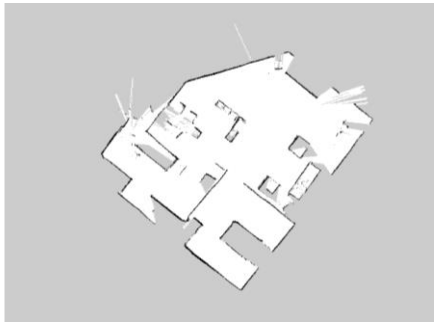

Fig. 7. 2D Occupancy Grid Map generate from HectorSLAM

IV. METHOD

For improving robot reliability for this paper will focus on shock, vibration, acceleration that take with robot component such motor encoder, embedded computer, PCB, electrical connection that can make a risk with hardware for method for measurement vibration and shock acceleration by inertial sensor module Xsens MTw a sensor give an acceleration in 3 axis for measurement diagram shown in Fig.8 A robot operator use wireless joypad to control a robot in rough terrain and attach IMU with a chassis of robot then IMU send a data to computer via wireless and save into log file for analysis.

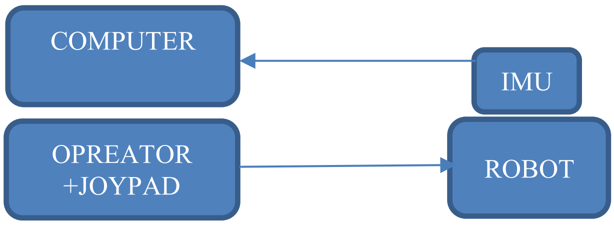

Fig. 8. Measurement diagram

In Fig.9 shown a risk assessment model[7] process have a 2 part one is risk analysis and risk evaluation for risk analysis is a process to identify hazard rate and estimate a risk. Risk evaluation is a compare estimate risk from risk criteria to determine a acceptable risk. Risk reduction is a process to implement and measurement to reduce a risk

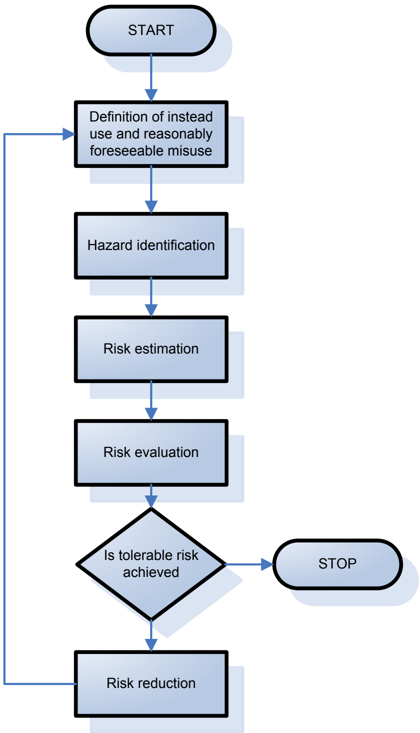

Fig. 9. Risk Assessment Model

A. Robot Reliability Measure

Reliability model is

$$R(t) = 1 - F(t)$$

$R(t)$ is a reliability function and $F(t)$ is unreliability function in most common reliability measure is mean time to robot failure (MTRF) is

$$MTTF = \int_0^\infty R(t)dt$$

And where h(x) is a hazard rate

$$R(t) = exp\left(-\int_0^t h(x)dx\right)$$

For recue robot is designed in module package then easy to change a new one or repair not effect a robot at all system for usage time for robot shown in table II

TABLE II. USAGE TIME TABLE

ITEM	Usage (Hour)
Power NI-MH Motor	1
Power Li-Po Electronics Control System	1
Power Li-Po Computer	1
Robot Control System	0.75

For battery reliability of robot shown in Fig.9 in each cell such cell R1 have 10 cells inside example $R_{cell} = 0.99$ calculation in series reliability is

$$R1(t)_{system} = R1_1 * R1_2 \ldots .R1_n$$

$$R_1 = 0.99^{10} = 0.90438$$

And parallel-serial reliability is

$$R_{NIMH6CELL} = 1 - \left(1 - (R1 * R2)\right)^3$$

$$R_{NIMH6CELL} = 0.9939$$

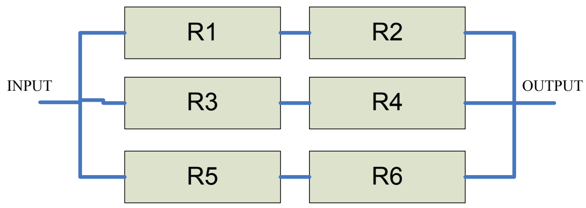

Fig. 10. Motor battery reliability model

Li-po has 6 cells $R_{LIPO} = 0.9414$

For microcontroller in robot control system use dsPIC30F4011 have constant failure = $\lambda = 2x10^9$ MTBF = 531,784,560 [11]

$$R(t) = e^{-(t/MTBF)}$$

TABLE III. MODULE RELIABILITY

ITEM	Reliability
Power NI-MH Motor	99.39%
Power Li-Po Electronics Control System	94.14%
Power Li-Po Computer	94.14%
Robot Control System	99.99%

V. EXPERIMENT AND RESULT

In experiment test at practice arena in Mahidol University faculty of engineering an arena arrange like world ROBOCUP 2015 rescue robot league use Tele-OP IV rescue robot and 1 operator with operation control unit (OCU) test in 1 hour operation control via wireless communication a robot is controlled by rescue operator with joypad robot operator control robot pass in yellow zone, orange zone, red zone, sand and gravel, climb up and down stair for time for operation of robot cannot did in time that design in 1 hour of robot operation that come from a terrain and slope second problem is wireless communication some time robot cannot interactive with operator by control with gamepad and camera monitoring . In Fig.10 show acceleration data Z axis from robot acceleration is high to 92.49 m/s^2 or 9.42 G and normally run on rough terrain shown in Fig.12 average acceleration measurement is 8.92 m/s^2 *or* 0.909 G

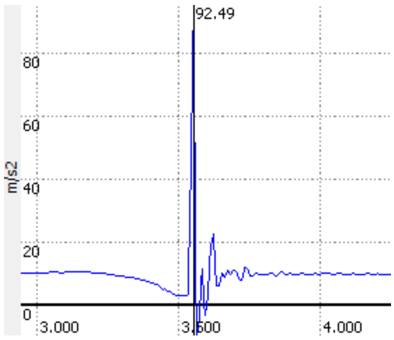

Fig. 11. Acceleration Z Axis

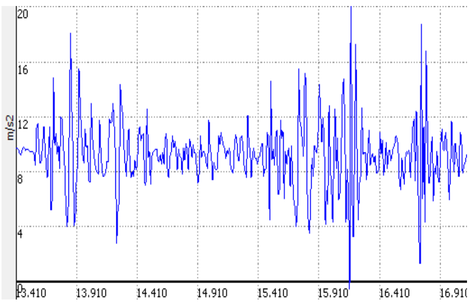

Fig. 12. Robot run on rough terrain

Fig. 13. Rescue arena for experiment(rough terrain)

VI. CONCLUSION

Risk assessment and risk reduction can be reduce and assessment first for power source for robot use to extend that some terrain hard to access and draw a current of battery that use time more that designed second motor encoder sometimes has sound from motor that a encoder disk from motor has problem that from vibration and highly shock but for another electronics component is fine except encoder and third problem from wireless communication that occur from direction of wireless access point.

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