Applied Robotics for Installation and Base Operations for Industrial Hygiene (ARIBO-IH)

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***Abstract*— A framework is proposed for industrial hygiene inspection using a remotely-operated ground vehicle with multiple sensor payloads attached to it for detecting various hazardous gases and chemicals. A control scheme and a graphical user interface between the vehicle and operator is strictly mandated for tasks requiring remote inspection. This paper presents recent results validating the industrial hygiene framework using the proposed system during sensor tests.**

I. Introduction

Throughout the Army, Industrial Hygiene (IH) teams are responsible for inspection, environmental reconnaissance, and emergency response. Industrial hygiene is an integral part of installation force protection and is an important component of an installations toxic industrial chemical spill planned response. Current best practices for conducting the IH mission requires direct human exposure to these hazardous environments. Robotic systems offer the potential to remove humans from these dangerous situations while maintaining the reliability and accuracy of the response team. Applying robotic solutions to this domain also contribute to the Department of Defense (DoD) unmanned systems goals outlined in the Unmanned Systems Integrated Roadmap FY2011-2036 [1]. Furthermore, robotic IH solutions are a force multiplier because these systems can be sent into a hazardous environment, parked, and allowed to collect data autonomously. Additionally, using robotic platforms for the IH environment is faster and safer than equipping and decontaminating a human. Finally, if successful, this project has potential DoD-wide application.

A. Trends

Aging stocks of munitions and newly developed systems are creating larger quantities of dangerous materials that require monitoring and potentially, emergency response. In the current austere fiscal environment, enlarging a trained, professional IH team is a significant challenge. It is desirable to reuse/re-purpose existing inventory and to improve efficiency where possible. One way to accomplish this goal is to automate tasks using technology such as robots and networked systems. This automation can allow a smaller team of trained personnel to effectively manage a large group of tasks.

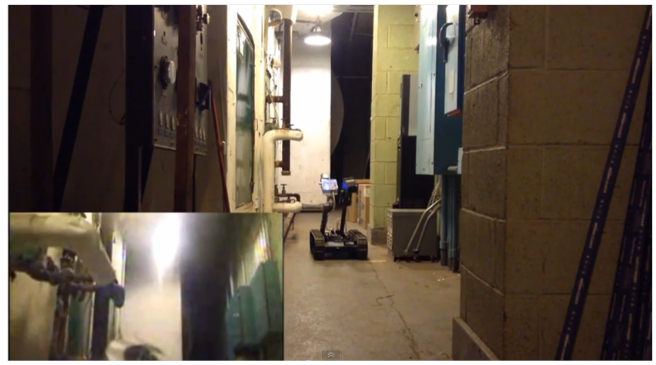

Fig. 1. ARIBO-IH prototype vehicle inspecting a gas leak in a notional hazardous site.

B. Problems

An Industrial Hygiene mission is to reduce soldier and employee exposure to environmental factors and stresses including: chemical (e.g., liquid, particulate dust, fumes, mist, vapor and gas), physical (e.g., electromagnetic radiation, temperature, ambient pressure, noise, vibration and ionizing radiation), and biological (e.g., agents of infectious diseases, insects, mites, molds, yeasts, fungi, bacteria and viruses) elements. The majority of hazards come from industrial processes on Army installations. Army industrial hygiene personnel are at risk from exposure to these hazardous environments in the conduct of their duties. Additionally, rapidly equipping human teams for response to incidents and post-action decontamination pose difficult challenges.

C. Benefits

Through the use of robotic-enabled ground vehicles in a structured, controlled environment, the ARIBO-IH pilot will increase researchers, manufacturers, and users understanding and familiarity of these systems in real-world operational scenarios. The ARIBO-IH pilot safely provides the service of IH inspections, removing the human IH professional from a potentially hazardous situation while reducing cost. Additionally, the project will facilitate the design, standardization, deployment, and supervision of the resulting ARIBO-IH inspection robots. Finally, by using United States Military Academy (USMA) cadets as researchers, they are exposed to Army technologies and systems at the beginning of their

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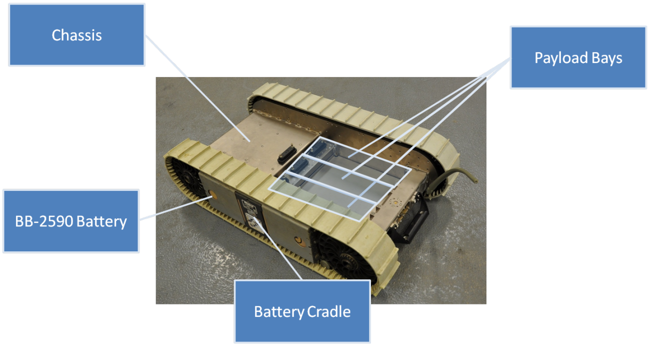

Fig. 2. Anatomy of the Packbot.

careers. The benefits of generating officers with technological backgrounds in robotics systems is paramount to achieving the DoDs long term unmanned systems goals.

D. Example Uses

The robotic systems developed under this project could be employed in a number of situations to include:

- Environmental reconnaissance in routine industrial hygiene tasks and emergency response
- Weather station at the emission source
- Ventilation duct inspection
- Investigate suspected terrorist devices
- Site abatement or mitigation projects

This paper presents a solution to the industrial hygiene problem using a small ground vehicle equipped with a sensor package. A control scheme for the system (Fig. 1 is implemented to allow for unattended operation in a known environment. Sec. **??** details the kinematic and dynamic model for the system. The hardware and software components are found in Sec. **??**. Section V presents validation results and sensor testing.

II. Mobility Platform

The iRobot PackBot is a fielded small robot used primarily for bomb disposal. The design is "semi-modular" where payloads can be installed to the base chassis, but they can only be installed in specific configurations, and when the software is properly configured. The integration of new payloads is often difficult and expensive. The vehicle uses military BB-2590 Li-Ion rechargeable batteries. While they have been widely deployed to both Iraq and Afghanistan, the Packbot is very expensive to purchase and maintain and overall reliability has been a challenge. There are two different generations: the obsolete 500 version and the current production 510 version. Many parts are interchangeable between the two models. The U.S. Army has discontinued the Packbot and no longer supports it as a program of record.

With a large inventory of unused and unsupported robots, the RS-JPO (Robotic Systems Joint Program Office) funded a 12 month effort to implement IOP (Interoperability Profile V2, using JAUS which is the Joint Architecture for Unmanned Systems). Creating a kit design for retrofitting all fielded PackBots would reduce costs of maintaining the aged fleet. The standardized version of the PackBot makes a good research platform for a number of reasons:

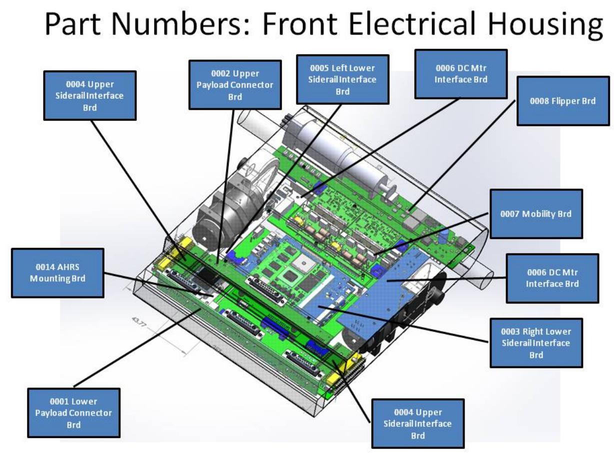

Fig. 3. Front assembly interface board.

- Open architecture
- Design is completely government-owned
- Designed for IOP V1 compliance
- Cost relatively low

The research platform became known as GVR-Bot (Ground Vehicle Robotics is a branch of TARDEC). It changed the radio frequency to 2.4 GHz so it could easily connect over standard existing wireless Internet protocols. All of the internal electronics of the robot were replaced with new motherboards, interface boards, and motor controllers. Bootloaders were added to the internal control boards (allowing flashing of all the software without disassembling the robot). See Fig. 3 for an example circuit board.

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III. User Interface

A standardized graphical user interface (GUI) was developed to be robust and intuitively usable by anyone. First and foremost the GUI is responsible for relaying environmental sensor and navigation data. The GUI is standardized for any ground robot that is able to traverse through a 3 degree of freedom (DOF) work space (X,Y, Theta) through an underactuated controller. The user is able to control the robot's movement with a single virtual joystick controlling forward motion and turning. A wrapper is written to translate the joystick commands to actual motor commands. To use this GUI for other ground robot platforms, all that would need to be developed is the wrapper code that translates the joystick into movement. The second joystick is dedicated to allowing the user to manipulate the camera in real time, allowing for control over a pan-tilt unit attached to the camera base which the user can point to view regions of interest. The camera feed and joystick bandwidth is automatically adjusted and delegated based on the bandwidth that is available at a particular instance between the robotic platform and the control unit. While the control unit can be anywhere in the world, thus allowing the robot user to operate it through the internet cloud, there is better overall performance as well as lower latency in video stream and sensor data when the control unit is within the same compound as the robot. In ideal conditions, the user would be able to see and respond to any obstacle that is close by within low response time deltas, however under most conditions this isn't possible. Low level obstacle avoidance aids the user basic navigation and reduces the probability of a crash that may be unforeseen by the user. The probability of the robot crashing into an obstacle cannot be completely mitigated because of real world delays in the data stream, loss of user's focus, lapses in data due to packet loss, the camera view is facing away from the obstacle, or connection loss.

and based off of WPI's Robot Web Tools (CHRIS PUT A CITATION HERE http://robotwebtools.org/)-

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As mentioned in the previous paragraph, the GUI allows the user to utilize 2 joysticks with 1 being for robot motion, and the other for camera pan-tilt motion; this 2 joystick scheme constitutes the first control mode. The GUI is designed to feature 2 more control modes. The control modes change the level of autonomy the robot exhibits during its mission. This, of course, requires for the different control modes to be hard-coded into the robot to ensure full functionality, both in terms of autonomous motion and safety of equipment in the facility being traversed. The change in control modes helps reduce the probability of mission failure or loss of robot if the control unit loses connection to the robot. The modes also change the level of involvement of the user in navigation duties, thus allowing the user to focus on higher level duties such as finding sources of contamination or thorough sterilization of the robot's local environment. This reduction of mental fatigue on the user helps increase missions success.

The second navigation mode provided through the GUI lets the user move the robot via way-point navigation, which is done through an interactive map of the compound that is provided to both robot and control unit prior to start of the mission. The robot is given way-point locations to reach on the interactive map by the user during the start of its mission to alleviate future bandwidth needs as the mission progresses, and distance from the control unit increases. All navigation modes utilize the map update when differentials are found, obstacle proximity alerts, and environmental sensor warnings.

The power subsystem built into the package includes a switching regulator to step down 12V from the PayBreak interface chip into 5V to be used for the sensor package. The microcontroller is powered from the in-out side of the switching regulator because the microcontroller needs more voltage to ensure stable operation. The switching regulator can output over 2 Amps of current while maintaining over 4.75V. Theoretically, the power supply can deliver up to 10W of power. The power supply can drive a large sensor load if required with little drop is supplied voltage. The prototype delivered 5.006V with no load and 4.986 with the full sensor load. This meets the requirements of the sensors. This meets the needs of the sensors. This power also meets the requirement of being powered by 2 BA-2590 batteries up to 2 hours because the batteries each have 14 Ah, with the full system operating, the current drain does not exceed 3A. The power system used for the prototype can support much more powerful sensors in the future.

The Arduino microcontroller is used to process the sensor data and generate the data packets that are sent through the IP tables on the robot and wirelessly to the OCU to be stored in a database and displayed for the user. The code makes it possible for any user to modify, add, or subtract the current sensors used in order to fit the desired application. Furthermore, the paybreak housing pins are wired in order to allow access too many of the pins needed on the Arduino, which is shown Annex 5. The structure of the sensor packet is scalable for future years to add additional information. The received data was saved in a database to provide a history of the event's readings. We maintained the existing OCU to ensure the user does not have to learn a completely new control interface. A sensor toolbar was developed to mesh with the robot's current user interface to provide live data readings. When a sensor reading passes a dangerous threshold, the toolbar will change colors to alert the operator. Under each sensor, a button will display a graph of the sensor's history.

The sensor, power, and microcontroller subsystems all worked together to meet the interface, functional, and performance requirements of the completed system. Sensors were able to accurately detect the presence of a selection of harmful gasses, interface with the PackBot software to transmit and display data, and the system was able to store the data obtained on the mission.

IV. Navigation

Paresh here.....

V. Sensor Testing and Results

Since gas sensors are inherently inaccurate due to their manufacturing processes and biases, each sensor had to be calibrated by graphing the output of each sensor compared to the known gas in the testing environment. The testing environments consisted of 1.0 liter sealed containers with the sensor inserted into one end and a septum for needles inserted in the other as illustrated in Fig. 4. The 1.0 liter volume simplified the calculations in parts-per-million (ppm) and each gas was introduced to the environment via a syringe and needle.

By comparing the sensor output (x-axis) to the known concentration of gas in the testing environment (y-axis), a curve is formed, which can be best fit to an exponential curve by focusing the comparison on moderately to severely dangerous gas concentrations, which is approximately 2,000 to 10,000 ppm. The best fit equation for the most accurate test is used in software to correct the sensor output to the most accurate output for transmission to the operator through

Fig. 4. Testing environments (from left to right): MQ-4, MQ-6, MQ-7, and MQ-8 sensors.

the OCU. Fig. 5 displays the graph for the MQ-4 (Methane) sensor along with the graphs for MQ-6 (Liquefied Petroleum Gas), MQ-7 (Carbon Monoxide), and MQ-8 (Hydrogen) sensors.

Using the correction equations in the code with the given sensor outputs, the final results fairly closely match the expected concentrations. Granted they are not extremely accurate, but the corrected outputs will be able to discern the difference between a safe and a dangerous environment. Table 1 details the MQ-4 sensor results and the results for the MQ-6, MQ-7, and MQ-8 are detailed in Annex 4, Tables 2 4 respectively.

VI. Conclusions

Industrial Hygiene monitoring and response functions possess the potential for improving efficiency and safety through the use of robots. Robotic systems such as the GVR-bot can remove humans from dangerous environments while accurately and reliably conducting tasks that are critical to operations on all Army installations. These improvements in efficiency and safety can be obtained in a fiscally responsible manner through the use of existing Army systems. Additionally, research conducted at the Academy benefits the Army long-term by exposing future officers to Army programs and technology at the beginning of their career.

References

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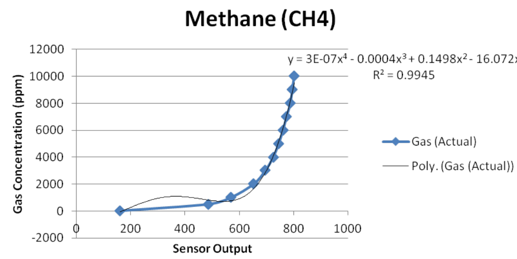
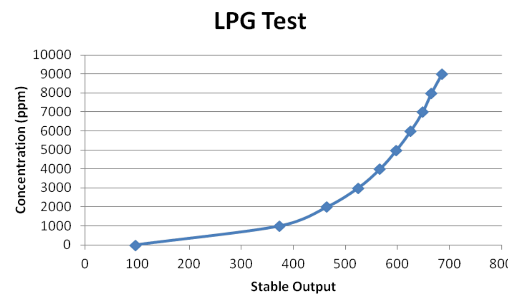
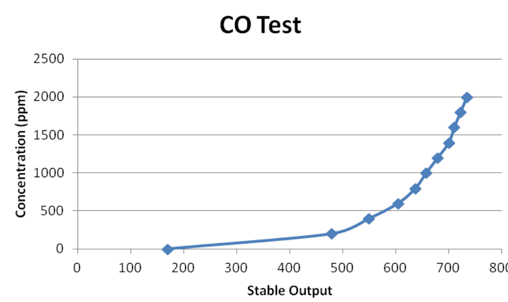


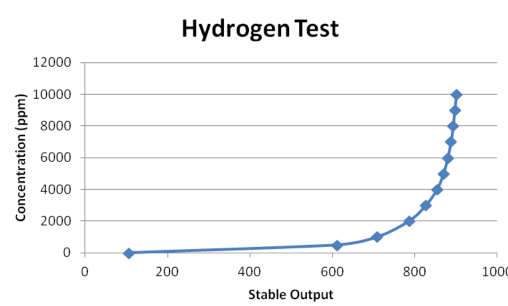
(a) Methane



(b) LPG



(c) CO



(d) Hydrogen

Fig. 5. Dangerous gases and liquids testing.