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.

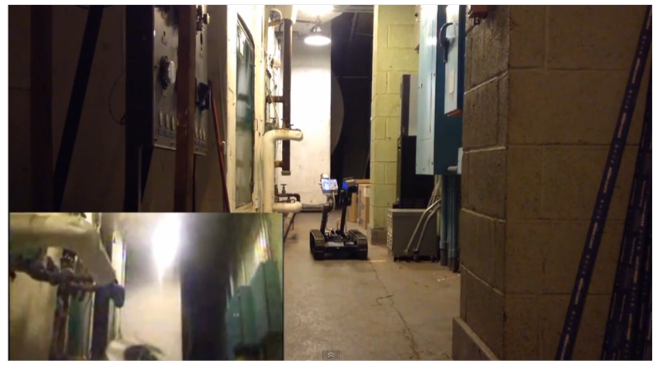

Fig. 1. ARIBO-IH prototype vehicle inspecting a gas leak in a notional hazardous site.

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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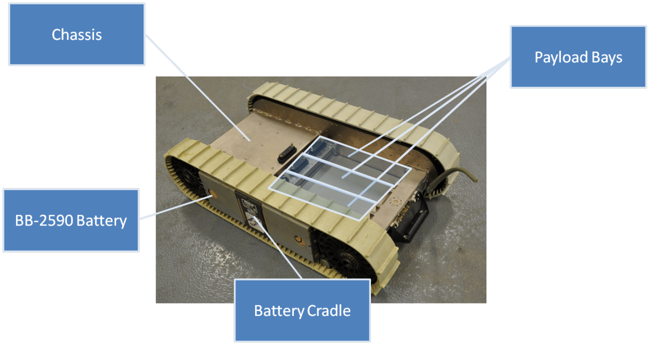

Fig. 2. Anatomy of the Packbot.

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. Chassis Design

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

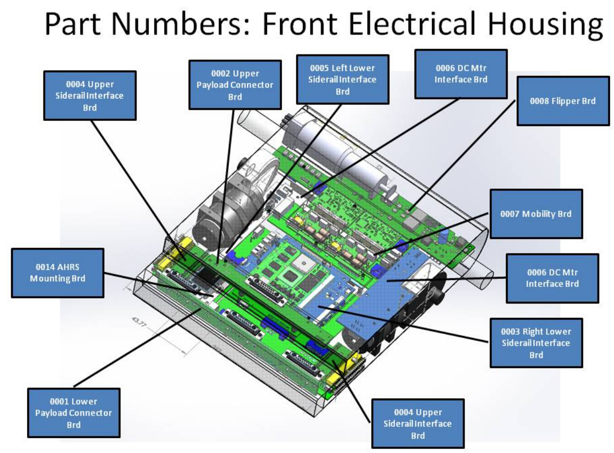

Fig. 3. Front assembly interface board.

fleet. The standardized version of the PackBot makes a good research platform for a number of reasons:

- 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.

III. User Interface

A standardized graphical user interface (GUI) was developed to be robust and usable by anybody. First and foremost the GUI was responisble for relaying hygine and navigational information. 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 was written to translate the joystick to actual motor commands–all that would need to be developed for an individual robot is the wrapper 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 configuration allows the user to point and view whatever is needed. The camera feed and joystick bandwidth is controlled based on the bandwidth that is currently possible between the robot and the control unit. While the control unit can be anywhere in the world–the controller is based in the web and based off of WPI's Robot Web Tools (CHRIS PUT A CITATION HERE http://robotwebtools.org/)-there is better performance when

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

the control unit is within the same compound for less delay in image and other signals. In ideal conditions the user would be able to see and respond to any obstacle that is close by, however under most conditions this isn't possible. Low level obstacle avoidance helps the user to not cause a crash that is unable to be seen by the user, because of real world delay or if the camera was facing the wrong direction to see the obstacle.

Another feature that has been built into the GUI is controlling based on way points instead of direct control over the robot. This allows for the user to click on the map to command the robot to navigate to the destination if possible. A 2D map is generated using SLAM from a LIDAR mounted on the robot–only differentials in the map are sent over the network. So while the initial connection may be slow, the delay during use is reasonalble. The 2D point that the user inputs is then fed into the navigation stack to attempt to reach the end goal. A third mode that the robot can be put into is pure autonomous navigation where the user can view what the robot is doing but won't have any control over the robot. The controller's multiple functionality allows for the user to pick the most appropriate mode of operation for a particular point in time, or to help the robot if it ever gets stuck. This is an important consideration when developing a GUI that is meant for long term industrial use, as all robots will eventually encounter something that they don't know how to deal with.

IV. Recharging

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 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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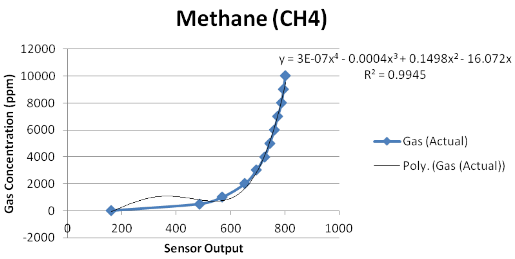
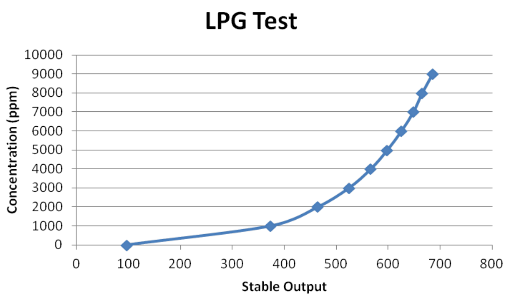
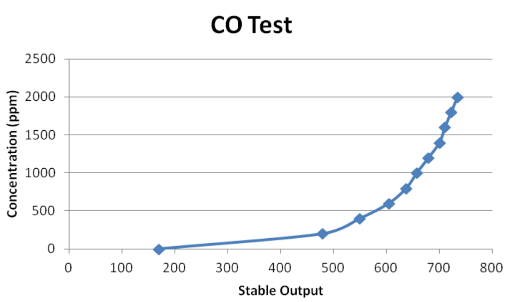
[2] C. Korpela, M. Orsag, and P. Oh, "Hardware-in-the-loop verification for mobile manipulating unmanned aerial vehicles," *Journal of Intelligent & Robotic Systems*, vol. 73, no. 1-4, pp. 725–736, 2014.



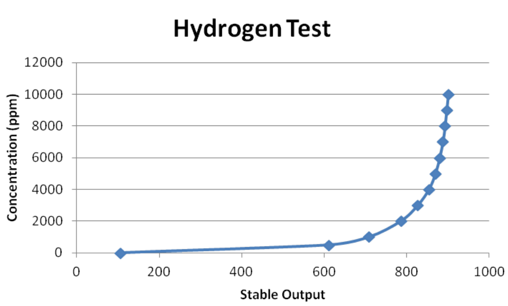
(a) Methane



(b) LPG



(c) CO



(d) Hydrogen

Fig. 5. Dangerous gases and liquids testing.