Requirements of a Standard Robot Platform for Unstructured Environment Research

Jennifer CASPER, Mark MICIRE, Brian MINTEN, Whitney HOWELL
jcasper@asrobotics.com, mmicire@asrobotics.com
bminten@asrobotics.com, whowell@asrobotics.com
American Standard Robotics, Inc.
St. Petersburg, FL 33701, U.S.A.
http://www.asrobotics.com

ABSTRACT

Robotics researchers currently are using insufficient and varying robotic platforms to investigate issues crucial to the successful development of a remote reconnaissance tool for the emergency response and Urban Search and Rescue (USAR) communities. To date, no platform has been available to enable the direct and equal comparison of higher level intelligent systems. USAR robotics researchers need a standard robot platform specifically designed for research in unstructured environments. Such a platform would accelerate the advancement of the research essential to the advancement of remote reconnaissance. This paper discusses both the current state of the practice and requirements of the domain in the context of creating a platform that would meet the diverse needs researchers and responders alike, while staying within their budgetary constraints.

Keywords: Robotics, Unstructured, Urban Search and Rescue, Research, Standards

1. INTRODUCTION

Robotics researchers currently are using insufficient and varying robotic platforms to investigate issues central to the development of a remote reconnaissance tool useful for USAR, emergency response, and other unstructured environments. Designed for use in other domains, these are platforms are typically expensive, yet deficient for use in unstructured environments. Use of such platforms is impeding research essential to improving safety for personnel who must operate in hazardous environments.

Although dedicated research in emergency service robotics has been performed for over five years, the establishment of standard robot platforms has yet to happen. Robotic platforms currently put to use are at no greater than stage 1 Technical Readiness Level [1] for unstructured environment use. This situation is echoed by researchers who: 1) have expressed the need for improved equipment to enhance locomotion and sensor modularity and 2) who have yet to field robots capable of safely and effectively operating in all levels of difficulty within the NIST Reference USAR Testbed, seen at search and rescue competitions held by RoboCup and the American Association of Artificial Intelligence (AAAI). It is clear there is a great need for a standard robotic platform.

In addition to understanding the demands of the environment, it is also necessary to consider market forces. In order for a platform to be used by more than a token few, it must be affordable by the majority. American Standard Robotics, Inc. (ASR) has created a platform design that it believes will provide researchers with an inexpensive, adaptable platform that can operate in unstructured environments.

The paper presents a summary of the background research performed in support of a preliminary platform design. Current research initiatives on robotics in unstructured environments as well as results from user surveys are discussed. Also presented is a brief synopsis of the current state of technology available for researchers. This technology is evaluated based on researchers' needs. The paper concludes with a brief description of the new platform design that is currently in progress.

2. RELATED WORK

The term "unstructured environment" has come to have different definitions for different groups. Fire rescue personnel consider an unstructured environment to be a rubble pile or a structurally damaged area. Many research labs, however, would consider even a well-kept lawn to be unstructured. These large discrepancies illustrate the gap between researchers and the field personnel working in these environments. This gap could only be narrowed by giving both camps equipment that can be utilized in both situations.

Robotics research in unstructured environments largely falls into five areas: the robotic platform, human-robot interaction (HRI), sensor development and/or integration, control and communication, and development of software infrastructures/architectures.

To date, a research robotics platform has not been developed that is both low-cost and able to traverse unstructured environments. Research groups have individually developed platforms or modified existing platforms that were originally designed for other purposes. This practice results in hardware and software often being "hacked" together, at the expense of time that could be spent doing higher level research.

Robotic Platforms

There is no shortage of research being done on robotic platforms for unstructured environments [2][3][4][5][6][7][8][9]. This research can be further broken down into two sub-areas: platform robustness in unstructured robotics and platform standardization. Many platforms developed in research labs offer robust mobility within select unstructured environments. However, these platforms are typically designed specifically for a particular problem, or to compensate for an issue found in another platform. Many of these platforms lack professional design input or field testing, and are consequently not ready for use in other unstructured environments.

Several companies, such as iRobot, Foster Miller, Remotec, and Inuktun Services have developed platforms that are able to traverse extremely harsh, diverse terrain. iRobot and Foster Miller have ruggedized platforms that have been fielded by US armed forces. Although the PackBot and Talon have proven their worthiness on a battlefield, their costs range from $45,000-105,000. Remotec, Inc. and other EOD robot manufacturers' equipment was designed for bomb disposal, and is typically too cumbersome for use in USAR. Inuktun Services Ltd is unique in that they were one of the first companies to address USAR's needs, but their platforms were originally designed for teleoperated pipe inspection, and hence lack the flexibility needed by researchers.

None of the approaches outlined so far addresses the need for a standard USAR platform, as has been recognized by research groups and professional field teams. ASR has made it their priority to develop a low-cost standard platform that will bridge the divide between robotics researchers and professionals in the field.

Human-Robot Interaction

The majority of research being conducted on robotics in unstructured environments is focused on HRI issues [10][11][12][13][14][15][16][17][18][19]. This research has immensely improved the usability of robotics for untrained (and even trained) users. With HRI being a research domain still in its infancy, progress has been preceded at a much faster rate than the platforms themselves. We are coming to the point, however, where this progress will be governed by the capabilities of its hardware and software foundations.

Software Development

There is certainly no shortage of "standard" robot architectures, or at least proposals. Within the scope of military applications alone, there exist JAUS, SoSCOE, TCA, UCAV, 4D/RCS, and others. Groups outside the military, such as the OMG, RETF, and OROCOS have also been pushing for standardization of robotics software (and, necessarily, hardware) components so as to support interaction and facilitate system integration.

The chief difficulty facing such standardization, or even the creation of a single general-purpose architecture, is the sheer number of tradeoffs in the design space. A close second is the inherent difficulty of implementing any moderately general purpose architecture. Frequently, the need for many design patterns that are unique to the field is only realized with a generous amount of robotics experience.

It would be impossible to create an architecture that is all things to all users. The choice of implementation language alone has been the cause of seemingly endless heated discussions between those in the community. The best a designer can hope to do is to provide a set of comprehensive and robust, yet easily understood interfaces that users can program to. Further, for this system, it is important to not forget that the final end user of the system may not be a researcher or software developer, at all.

Sensor Development

The current state of the art in the USAR field includes cameras, FLIRs (Forward Looking Infrared), and gas and radiation detectors. Field personnel frequently jeopardize their health and life by entering unsafe or unknown environments. One primitive solution to this has been to duct tape a sensor onto a pole in an attempt to further their reach or distance them from the potentially toxic environment. A slightly more sophisticated solution utilized by robotics researchers working with USAR teams has been to crudely fasten a sensor to a mobile platform and monitor for alarms via the robot's audio or video link. Researchers have also turned their attention toward improving the sensor interfaces [15][16].

Control and Communications

In the lab setting, many environmental conditions can be controlled and/or anticipated. In a disaster scenario, all bets are off. Often, wireless communication is virtually non-existent or subject to so much interference that it is wholly unreliable. The robotics research community works with both wireless and tethered communications. Much of the work being done in the wireless arena has to do with increasing signal strength through various methods, or extending effective communications range despite poor signal strength [20][21]. Research involving communication and control for tethered robots has decreased over the past few years. Researchers are focusing more on tether design and introducing new control algorithms for tethered robots [22]. Control issues involving wireless as well as tethered communication in unstructured environments will be addressed while developing this platform.

By surveying the current state of the art, obvious shortfalls are apparent. To successfully develop a standard platform for unstructured environments, the four areas of research discussed above must be considered.

3. REQUIREMENTS

ASR began investigating the need for a standard unstructured environment research robot two years ago. The data gathered shows that there is a market for such a platform, and that it might be made to rapidly grow with platform availability. The following two subsections summarize the results of the investigative survey. The primary research involved interviewing target users to determine their requirements. The secondary research includes information obtained from trusted, outside resources.

Primary Research

ASR surveyed robotics researchers and USAR professionals from six organizations between July and November of 2004 to determine what they required from a standard robot platform. 87% of the respondents were unstructured environment researchers. The research organizations covered diverse research agendas in mobile robotics, artificial intelligence, computer vision, multi-agent collaboration, and human-robot interaction. The remaining 13% represented USAR teams. Questions were grouped into 12 categories representing various aspects of a robotic system.

NOTE: The survey results are not statistically significant. The results represent a small sample of the robotics research population. Although the survey sampling is not statistically significant, the results do reveal robotics researchers' needs. The respondents had varied opinions considering robot platforms, but held a commonality in working with unstructured environments.

The two distinct groups provided requirements from two very different perspectives. Researchers had sensor, computational, and software requirements dictated by their work, while the USAR responses were dominated by the demands of the unstructured environment itself and the support infrastructure available during field work.

The survey results supported the need for an inexpensive platform within the $2,000 to $5,000 range. The results also indicated that mobility, computational power, runtime, and expansion are important platform characteristics. Sensor requirements varied with response, indicating that specific research topics may dictate sensor requirements, making optional, tailorable sensor packages desirable.

In addition to the above respondents, ASR contacted representatives from the National Institute of Standards and Technology (NIST) to provide input. The purpose was to discuss the platform requirements from their perspective as active researchers in the field of unstructured environment research. The initial platform discussion focused on the following topics: chassis/mobility, sensors, and command and communications. Discussion topics surrounding the chassis included materials, large diameter wheels/tracks that would permit inverted operation, illumination, ruggedization, and conveniences such as integrated handles. Sensors were discussed within the framework of their contribution to the platform's two primary tasks: navigation and victim identification (see Table 1). A key trait was that these sensors should be able to be used while inverted.

Navigation	Victim Identification	Other
Encoders	Stereo microphones	Pyro-electric
Accelerometers	Speaker	
Compass	Stereo color vision	
Camera on a stick	Omni-directional IR camera	
Flash LADAR	CO_2	
	Mobile phone signal tracker	

Table 1: Suggested sensors for navigation, victim identification, and other.

The most important aspects of this platform were that it be modular, low cost, based on an open architecture, and capable of operation in unstructured environments. Modularity enables the researchers to adapt the platform to their specific research needs, and a low cost platform was obviously preferred over a more expensive platform. More researchers can afford a platform that costs between $2,000 and $5,000 than one that costs more than $20,000. An open architecture provides versatility and flexibility in platform development. It harnesses the power of a large developer community and makes it easier to share key advances. Finally, it was imperative for the platform handle unstructured environments, such as those found in the NIST Search and Rescue Arenas [23][24][25]. This capability allows the research platform to navigate outside of the laboratory.

Secondary Research

An inexpensive standard robot platform for unstructured environment research could be utilized by different groups. At $2,000 - $5,000, the platform would be accessible to research organizations, academia, industry, and hobbyists.

The Institute of Electrical and Electronics Engineers (IEEE) Robotics and Automation Society (RAS), recognizes 29 international and 39 national academic robotics groups. According to Robotic Trends, Inc., there are 53 international and 49 national groups. Approximately 46 teams competed in the five years of USAR competitions at RoboCup and the AAAI conferences. An estimated 71% of these teams designed and constructed unique platforms for competition. The USAR competition saw a 200% increase in number of competitors between 2001 and 2002. However, the growth rate leveled off between 2003 and 2004; each year hosting 21 competitors. Note that these numbers neither include all small academic and research organizations involved in robotics research, nor do they reflect the hobbyist market. They do, however, provide a low estimate of the potential number of platform users.

The strong federal initiative for defense related science and technology is encouraging organizations of all sizes to focus research efforts on durable and ruggedized technology. As stated in the project proposal, the Department of Homeland Security (DHS) has appropriated $75 million out of its $1 billion budget for the rapid adaptation of commercial technology for DHS. In the American Association for the Advancement of Science (AAAS) October Status Report on R&D in FY 2005 Appropriations, the Department of Defense and Homeland Security are expected to receive increases in appropriated research budgets. ASR expects further growth in the number of organizations using robotic technology in unstructured environments.

4. CURRENT PLATFORMS

Twenty-four companies that provide diverse mobile robot platforms, accessories, and/or software were identified. These companies offer products that can be purchased today. The following three sources were used to find the companies:

1. www.ieee.org
2. www.robotictrends.com
3. www.spawar.navy.mil

There is limited public information available on the twenty-four private companies listed. The information presented in the following paragraphs is mostly extracted from the companies' websites.

None of the companies listed provide an inexpensive platform capable of operating in unstructured environments. Only three of the twenty four companies produce platforms in this price range (see Table 2).

ActivMedia has been providing robotics researchers with platforms for many years. The Pioneer-AT is equipped with four wheels that are somewhat large for the robot's size, giving it a degree of ground clearance. The wheeled mobility allows it to traverse semi-rugged environments such as lawns. However, it is neither inexpensive nor capable of operation in more rugged environments. Acroname has traditionally been hobbyist-oriented. Their newest platform has shown itself able to traverse modestly unstructured environments and climb stairs. The platform cost was reported as being more than $10,000, which does not meet the inexpensive criteria. Additionally, the platform is not well suited for research, is lacking computational capacity, and it is unable to carry a sensor payload of significant size. Lastly, Arrick Robotics produces a mobile research platform costing approximately $2,000. This product falls in the same market as ActivMedia's platforms. However, the platform is not capable of operating in unstructured environments such as the red section of the NIST Urban Search and Rescue Testbed.

Other companies listed in these sources provide robotic equipment, accessories, or software, but at a premium price point. Three companies, Foster-Miller, Inuktun, and iRobot, have been successful in developing high-end mobile robot equipment for unstructured environments in industrial and military applications. Their equipment starts at $10,000 per unit, however, and frequently does not provide the flexibility needed to conduct research.

Name	Description
ActivMedia Robotics www.activmedia.com	Robot product line is intended for research use. Platform cost is not in the $2,000-$5,000 range. Platforms made for structured environments.
Acroname www.acroname.com	Traditionally, this company has targeted the hobbyist community whose needs are not as great as the research community. Their newest platform works well in unstructured environments, but still has an estimated cost of more than $10,000 (figure provided by Acroname representative at AAAI2004 conference) and does not provide onboard computation. The Garcia platform is similar to ActivMedia's platforms. It is

	capable of running in structured environments and costs approximately $2,000.
Arrick Robotics www.robotics.com	Arrick has a small research robot that was not designed for unstructured environment use, but costs approximately $2,000.

Table 2 Three robot manufacturers with product offerings that might be made to work in unstructured environments at a reasonable cost.

5. CONCLUSIONS

Robotics manufacturers have historically been drawn to niche markets having have very specific needs and requirements. As a result, the platforms produced have become a large collection of machines targeted to highly-specific requirements, and are not adaptable to other applications and domains. Research in unstructured environments, conversely, has very broad needs and requires a robustness that few manufacturers have been able to satisfy. Considering these facts, as well as the lack of monetary motivation on the part of the manufacturers, it wouldn't appear that the situation would resolve itself.

In contrast to most existing systems, ASR's system provides the end user with an assembly of functional "building blocks" that are adaptable to the task at hand. The chassis is minimal by design and attempts to maximize the payload capability of the system. Unique to this system, the mobility is field-swappable and user-customizable. Finally, sensors, computation, communication, and power systems are all interchangeable to maximize the platform's utility in multiple domains.

The platform's design process utilized three innovative approaches: designing the platform to operate in a worst-case unstructured environment (USAR) from the start, assigning robotics and USAR specialists to drive the development, and allowing the recommendations and requirements of researchers and field users to directly influence the course of development. A platform tailored for USAR reduces the need for researchers to forcefully adapt existing platforms designed for more stable, structured environments. Input from users was solicited before development started through a survey, and is continually being sought during the development process.

The platform design stemmed from the requirements of researcher and field user alike. It is a delicate balance between affordability and flexibility. Its foundation lies on a rugged and modular chassis which allows the user to adapt the system to the environment and task at hand. Wireless operation is augmented by tethered operation for use in RF inhibitive environments. The platform size is small enough to be easily transportable by one person and yet is large enough to negotiate significant obstacles, climb stairs, and carry a meaningful payload.

To date, no robotics platform built for research or field use provides the flexibility or level of standardization that ASR's system will provide. The design ensures that the creativity of the researcher is able to be expressed while maintaining a common basis for constructive comparison to other robotic systems and algorithms.

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7. REFERENCES

[1] J. Mankins, "Technology Readiness Levels", Technical Report, Advanced Concepts Office, Office of Space Access and Technology, National Aeronautics and Space Administration, 1995.

[2] J. Casper, M. Micire, and R. Li Gang, "Inuktun Services Ltd. – Search and Rescue Robotics", **The 3rd International Conference on Continental Earthquakes**, Beijing, China, July 12-14, 2004.

[3] I. Erkmen, A. Erkmen, F. Matsuno, R. Chatterjee, and T. Kamegawa, "Snake Robots to the Rescue!", **Robotics & Automation Magazine**, IEEE, Vol. 9, No. 3 , September 2002, pp. 17 – 25.

[4] M. Guamieri, P. Debenest, T. Inoh, E. Fukushima, and S. Hirose, "Development of Helios VII: An Arm-Equipped Tracked Vehicle for Search and Rescue Operations", **Proceedings 2004 IEEE/RSJ International Conference on** Intelligent **Robots And Systems**, Vol. 1, September 28-October 2, 2004, pp. 39 – 45.

[5] S. Hirose and E. Fukushima, "Snakes and Strings: New Robotic Components for Rescue Operations", **Proceedings Of The 41st SICE Annual Conference**, Vol. 1, August 5-7, 2002, pp. 338 - 343.

[6] B. Hudock, B. Bishop, and F. Crabbe, "On the Development of a Novel Urban Search and Rescue Robot", **Proceedings of the Thirty-Sixth Southeastern Symposium on System Theory**, 2004, pp. 451 – 455.

[7] D. Perrin, A. Kwon, and R. Howe, "A Novel Actuated Tether Design for Rescue Robots Using Hydraulic Transients", **2004 IEEE International Conference On Robotics And Automation**, Vol. 4, April 26-May 1, 2004, pp. 3482 – 3487.

[8] H. Stone and G. Edmonds, "HazBot: A Hazardous Materials Emergency Response Mobile Robot",

Proceedings 1992 IEEE Robotics and Automation, Vol. 1, pp. 67-73.

[9] M. Yim, Et Al., "Modular Reconfigurable Robots, an Approach to Urban Search and Rescue", Xerox Palo Alto Research Center, http://www2.parc.com/spl/projects/modrobots/publications/pdf/hwrspaper2.pdf, Accessed March 8, 2005.

[10] M. Baker, R. Casey, B. Keyes, and H. Yanco, "Improved Interfaces For Human-Robot Interaction In Urban Search And Rescue", **Proceedings of the IEEE 2004 International Conference On Systems, Man And Cybernetics**, Vol. 3, October 10-13, 2004, pp. 2960 – 2965.

[11] M. Baker and H. Yanco, "Autonomy Mode Suggestions for Improving Human-Robot Interaction", Proceedings of the **IEEE 2004 International Conference on Systems, Man and Cybernetics**, October 10-13, 2004.

[12] D. Bruemmer, R. Boring, D. Few, J. Marble, M. Walton, "'I Call Shotgun!': An Evaluation Of Mixed-Initiative Control For Novice Users Of A Search And Rescue Robot", **Proceedings of the IEEE 2004 International Conference On Systems, Man And Cybernetics**, Vol. 3, October 10-13, 2004, pp. 2847 – 2852.

[13] J. Burke, R. Murphy, "Human-Robot Interaction in USAR Technical Search: Two Heads Are Better Than One", **Thirteenth IEEE International Workshop on Robot and Human Interactive Communication**, September 20-22, 2004, pp. 307 – 312.

[14] J. Casper and R. Murphy, "Workflow Study On Human-Robot Interaction in USAR", **Proceedings of the IEEE 2002 International Conference On Robotics and Automation**, Vol. 2, May 11-15, 2002, pp. 1997 – 2003.

[15] D. Hestand and H. Yanco, "Layered Sensor Modalities for Improved Feature Detection", **Proceedings of the IEEE 2004 International Conference on Systems, Man and Cybernetics**, October 10-13, 2004.

[16] M. Nanjanath and R. Volz, "Scale Estimation for Robots in Urban Search and Rescue", **Proceedings of the 2004 IEEE/RSJ International Conference on Intelligent Robots and Systems**, Vol. 2, September 28 – October 2, 2004, pp. 1462 – 1468.

[17] J. Scholtz, J. Young, J. Drury, and H. Yanco, "Evaluation of Human-Robot Interaction Awareness in Search and Rescue", **Proceedings of the IEEE 2004 International Conference on Robotics and Automation**, April 26 - May 1, 2004, Vol. 3, pp. 2327 – 2332.

[18] H. Yanco and J. Drury, "Classifying Human-Robot Interaction: An Updated Taxonomy", **Proceedings of the IEEE 2004 International Conference on Systems, Man and Cybernetics**, October 10-13, 2004.

[19] H. Yanco and J. Drury, "'Where Am I?' Acquiring Situation Awareness Using a Remote Robot Platform", **Proceedings of the IEEE 2004 International Conference on Systems, Man and Cybernetics**, October 10-13, 2004.

[20] J. Nickerson and S. Skiena, "Attention and Communication: Decision Scenarios for Teleoperating Robots", **Proceedings of the 38th Annual Hawaii International Conference On System Sciences**, January 3-6, 2005, pp. 295c - 295c.

[21] W. Howell, S. Patel, and B. Minten, "UDP Performance Over an Ad Hoc Network for Mobile Robotics", **Proceedings of the 2004 International Conference on Wireless Networks**.

[22] D. Perrin, A. Kwon, and R. Howe, "A novel actuated tether design for rescue robots using hydraulic transients", **IEEE 2004 International Conference on Robotics and Automation**, Vol. 4, April 26-May 1, 2004, pp. 3482 – 3487.

[23] A. Jacoff, B. Weiss, and E. Messina, "Evolution of a Performance Metric for Urban Search and Rescue Robots (2003)", **Performance Metrics for Intelligent Systems Workshop Proceedings**, August 2003, Gaithersburg, MD.

[24] http://robotarenas.nist.gov/competitions.htm

[25] http://robotarenas.nist.gov/rules.htm