Standards Development for Wireless Communications for Urban Search and Rescue Robots*

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In order to gather data in support of standards development for urban search and rescue robots, NIST is conducting a series of field tests to quantify the functionality and performance of various candidate robots. During these tests, manufacturers bring robots that may be appropriate for various urban search and rescue applications, and emergency responders put the robots through NIST-derived tests designed to measure their performance in key areas. During a set of field tests at the Montgomery County Fire Academy in Maryland in August 2006, members of the Electromagnetics Division and Intelligent Systems Division of NIST developed and carried out a uniform series of spectral analysis tests on each of the robots that participated in the event. We report here on results of this initial set of field tests of the wireless link.

1. Introduction

Robots have been employed with great success in a wide variety of settings where precise, repetitive, or dangerous tasks need to be carried out. For example, they are commonly found in heavy manufacturing facilities on the production floor where they weld, assemble, and even deliver parts.

A relatively new use of robots is in the urban search and rescue (US&R) environment. The majority of robots utilized in dangerous environments such as explosive ordinance disposal and search and rescue may be considered as extensions of one's eyes, ears, nose, and hands. In this manner, robots have the potential to provide enormous utility for responders that perform vital search and rescue missions at sites of disasters. Robotic sensing devices can access dangerous areas more efficiently in many instances, and can provide information on trapped or missing people while minimizing the danger to which responders expose themselves at such events.

Robots for the foreseeable future will be controlled either with a physical tether wire or a wireless communications link. In most US&R applications, a wireless link is preferable since it offers the robot increased range and flexibility in navigation. However, as we discuss below, the wireless link may be subject to interference and/or signal loss, either of which can degrade reliable performance of US&R robots. We report here on results of initial field tests of the wireless link during an exercise designed to promote standards development for US&R robots.

2. Performance-Based Standards Development

The nature of emergency response is one that covers a wide variety of potential scenarios – from building collapses, to earthquakes, to terrorist employment of weapons of mass destruction. Equally daunting are the diverse variety of technologies that need to work in unison in order for a robot to work properly. When looked at concurrently, one can imagine the potential difficulty in creating a set of well-understood performance goals and means of measuring whether systems actually meet them. Presently, no standards or performance metrics exist [1].

In order to address this need, the Department of Homeland Security (DHS) Science and Technology (S&T) Directorate initiated an effort in fiscal year 2004 with NIST to develop comprehensive standards to support development, testing, and certification of effective robotic technologies for US&R applications. From their initial efforts, the NIST/US&R Responder consortium was able to define over 100 initial performance requirements, and generate 13 deployment categories. The performance requirements were grouped into categories such as human-system interaction, mobility, logistics, sensing, power, and communications. For each requirement, the responders defined how they would measure performance [2].

In the area of communications, the performance requirements specified by the responders included

(1) Expandable Bandwidth: *Will support additional operational components without loss of data transmission rate sufficient to allow each component to perform its function.*

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(2) Range—Beyond Line of Sight: *Must be able to ingress specified number of feet in worst-case collapse. Worst case is a reinforced steel structure.*
(3) Security: *System must be shielded from jamming interference and encrypted.*
(4) Range—Line of Sight *[no notes]*
(5) Data Logging—Status and Notes: *Ability to pick up and leave notes.*

Items (2) and (4) were designated as critical in the initial standards development effort, scheduled for preliminary draft by the end of the calendar year 2006. These items depend on the technical specifications of the robot's radio link, as well as the radio environment in which the robots are deployed.

By assisting in the process of creating such standards, DHS seeks to provide guidance to local, state, and federal homeland security organizations regarding the purchase, deployment, and use of robotic systems for US&R applications.

NIST has since organized the standards effort through American Society for Testing and Materials (ASTM) E54.08 – Homeland Security Standards. In this effort, industry representatives and US&R responders have endeavored to slice the problem into manageable categories. The head of each working group is responsible for producing his or her standard test method that objectively measures a robot's performance in a particular area. Ultimately, the response organization will be able to determine which robots best suit their requirements. Robot researchers and manufacturers will benefit from the definition of test methods and operational criteria, enabling them to provide innovative solutions to meet the universal requirements.

3. Performance testing in representative radio environment

One key step in this performance-based standards creation process has entailed testing robots utilizing specially designed test-beds; i.e., standardized obstacle courses. In these tests, commercially available robots have been put through a series of real US&R training scenarios with responders operating the robots. Tests have been carried out at facilities in Nevada, Texas, and Maryland. During the testing done in Texas and Maryland, wireless communications were sometimes found to be problematic when several robots attempted to communicate simultaneously. At the last event, in August 2006 at the Montgomery County Fire Academy in Maryland, members of the Electromagnetics Division of NIST developed and carried out a uniform series of spectral analysis tests on each of the robots that participated in the event.

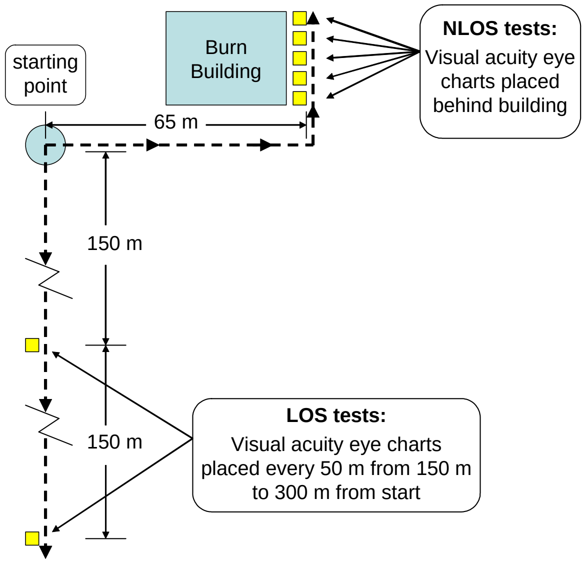


Figure 1: Diagram of the Montgomery County Fire Rescue Academy tests for wireless communications showing the communications LOS and NLOS tests.

3.1 Wireless communications test logistics: During the Montgomery County tests, we gathered a substantial amount of data on the technical specifications of various US&R robots and on the typical radio-interference environment when several robots were deployed simultaneously. In both line-of-sight (LOS) and non-line-of-sight (NLOS) tests the operator and a NIST engineer were stationed in a fixed location (see the dot labeled "starting point" in Figure 1) while the robot moved away.

In the LOS test, the robot moved away from the operator down a long driveway as shown in Figs. 1 and 2. Markers that included visual acuity eye charts were placed every 50 m between 150 m and 300 m from the starting point. Control of the robot was monitored continuously, while video data transfer from the robot was checked at each marker.

For the NLOS tests, the robot moved about 65 m away from the operator in an LOS condition, then turned the corner behind a five-story building, which provided the NLOS condition. See Figs. 1 and 3(a). Markers were placed every three meters behind the building, as shown in Figs. 1 and 3(b), to test whether and when the robot lost data and control capabilities.

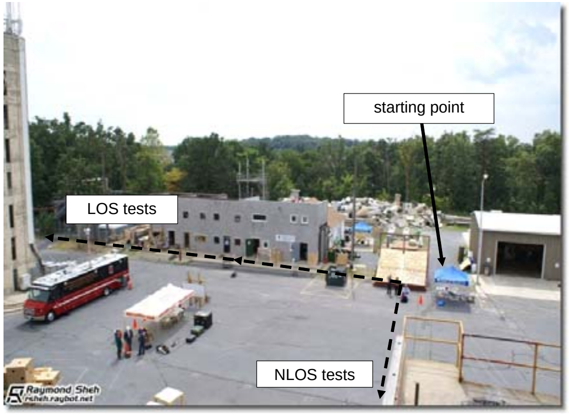
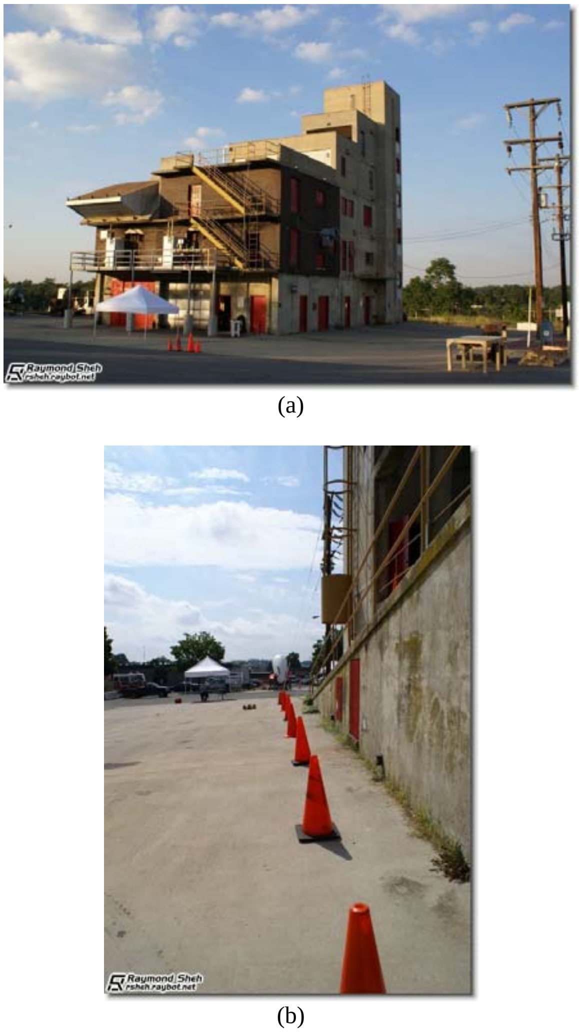


Figure 2: Location of the wireless communication tests. For the LOS tests, robots start at the blue tent shown by the arrow, and proceed down a long driveway to the left. For the NLOS tests, robots leave the tent and proceed down a path perpendicular to the first one, to the rear of a tall building. Photo courtesy of Raymond Sheh.



(a)

(b)

Figure 3: For the NLOS tests, the robots moved away from their operators (a) along the right side of the burn building then (b) around the back side of the building. At each orange cone, the robot stopped and attempted to send data from an eye chart back to the operator. Photos courtesy of Raymond Sheh.

3.2 Physical environment: The environment was relatively open with only a few large structures in the area. One was a five-story tall concrete building known as the "burn building" (shown in Fig. 3(a)), where our NLOS tests were carried out. The ground was covered with a concrete or asphalt surface throughout the test area.

3.3 Radio interference environment: As can be seen in the data below, most of the robots operate in the "industrial, scientific, and medical," or "ISM" frequency bands. There is no regulation for licensing or frequency coordination in these frequency bands; thus, the spectrum is readily available for use in commercial applications. While protocols that minimize interference between systems in these bands were often used by the robot designers, when the ISM frequency bands get crowded or when one user has a much higher output power than the others, interference can occur—even on frequencies quite removed from the robot under test. We saw cases where transmitters in the 1760 MHz band knocked out video links in the 2.4 GHz frequency band.

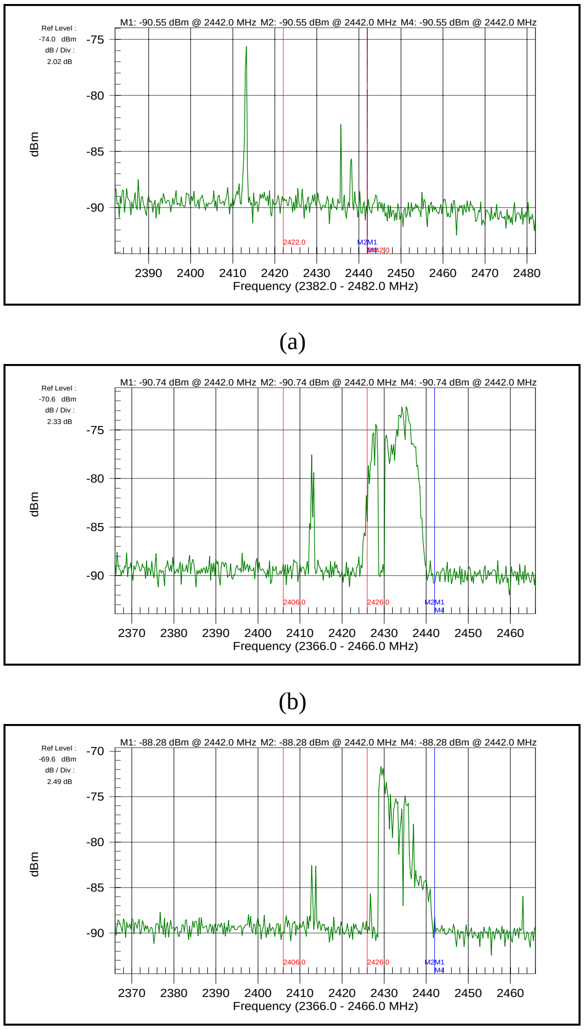
4. Test results

We collected several types of data relevant to understanding the wireless environment and characterizing robot performance including

- frequency of operation
- type of data transmitted (i.e., video or control)
- output power level
- hardware placement for items such as antennas
- radio-interference environment
- physical environment

These data are summarized in Table 1. Several of these items may interact with and influence the performance of others. As a result, we saw a range of success in transmissions for the various robots deployed in the tests, depending on their set-ups and which robots were nearby.

In particular, the radio interference environment had a significant effect on the robots' ability to successfully complete the tests. Several of the robots used similar frequency bands and wireless access schemes, such as



(a)

(b)

(c)

Figure 4: Example of radio interference on an analog video link transmitting at 2.414 GHz from a nearby robot. In (a) the 2.414 GHz robot is approximately 65 m away from the operator and the signal level is high enough for good reception. In (b), the robot is 100 m away and its video signal becomes choppy. In (c) at just under 150 m separation between robot and operator, the 2.414 GHz signal level becomes significantly weaker than a neighboring 802.11b signal, and the video link is broken.

802.11b. Robots utilizing higher power levels often overwhelmed those with lower power levels. An example of this is shown in Fig. 4 for a robot that utilized an analog video link centered at 2.414 GHz. As the robot moved away from the operator, its signal became weaker than those from nearby robots. After a separation of just under 150 m, the link was lost, even though the robot was using an analog modulation scheme that is normally quite robust in weak-signal conditions. Interference—both in-band and out-of-band—was the most significant impediment to radio communication success and had a negative impact on 10 out of the 14 robots we tested.

The issue of radio interference clearly needs to be addressed because it degrades the reliability of US&R robot performance in situations such as those where multiple robots using the same frequency bands are deployed. Interference from nearby robots during field tests may also impact our ability to develop meaningful standards for radio communications.

5. Improving wireless communications for US&R robots

A wide range of options exist for mitigating the interference results experienced during this initial set of radio tests. Some are currently being investigated by robot manufacturers. Some of these options include

5.1 Frequency coordination: In this scenario, robots are assigned specific control and telemetry frequency bands. Frequency coordination would be relatively straightforward for narrowband control and telemetry channels because they may fall into the existing licensed land mobile radio channels already utilized by emergency responders.

It would be difficult to assign frequencies for US&R robot use in the ISM bands since these bands are unlicensed and open to noncommercial users. However, use of the new 4.95 GHz spectrum allocated for licensed public safety use may enable transmission of broadband data such as video in US&R robot applications.

5.2 Transmission protocols: Several modulation formats and access schemes have been developed to mitigate interference from collocated wireless systems. Already mentioned are the 802.11 protocols that utilize encoding and error correction to minimize interference. Systems with even more robust error correction such as 802.16 will be available in the near future [3].

Another option for minimizing interference to broadband data that would normally be transmitted in the ISM bands would be to reformat them into narrowband data and send them over existing licensed frequency bands. For example, sending still photographs instead of streaming video would drastically reduce the bandwidth needed and may enable use of licensed bands with frequency coordination.

5.3 Output Power: Increasing the radiated output power level is one method of increasing the potential for maintaining a wireless link. However with this option there is also the potential for increased interference to other systems and, at high output power levels, a potential health risk for human exposure. The U.S. Federal Communications Commission (FCC) specifies safe limits of human exposure to radio-frequency energy and these are reflected in legal output power levels. A higher output power level also correspondingly decreases battery life, a particular problem for US&R robots, which are battery powered.

5.4 Priority access: Priority access protocols could be adopted that would ensure coordination of assets such as US&R robots. This coordination would need to take place among public safety agencies, and also between all response agencies and commercial enterprises that may share a given band of spectrum. One approach would be to create hardware and software that would sense users in a particular area and grant priority access to public safety agencies during times of emergency. Because of the large amount of equipment already in use in the ISM band, the 4.95 GHz and potentially new public-safety frequencies in the 700 MHz spectrum may be the best candidates for this approach. These bands have sufficient bandwidth, and standards and hardware are still being determined at this time.

5.5 Multi-hop Communications

One strategy for increasing the range of wireless systems such as US&R robots is with multi-hop communications employing relay transceivers that receive, amplify, and retransmit a signal. Digital repeaters are currently being used in a variety of applications by military and industry. However, research is underway to use deployed robots or first responder radios as repeaters in multi-hop systems.

6. Summary

Emergency responders may one day be able to leverage the use of robots for US&R missions. However, to efficiently deploy robot technology, a set of performance-based standards and associated test methods need to be developed. NIST, through the Department of Homeland Security, is working to develop standards that will ensure secure and robust wireless communications.

While standards and test methods specify a minimum level of radio performance for US&R robots, for successful communications a many-faceted approach may need to be taken. Part of the answer may come in the form of technological advancement, such as new access schemes or software-defined radios that allow interoperable communication schemes for the different entities that seek to utilize them. Part of the answer may also come from coordination of access among civilian and public safety in a particular frequency band, and also among public safety agencies as the gravity of an incident escalates.

Through continued participation in the standards development process, US&R and public safety agencies can help ensure that the needs of their communities are heard and incorporated into the standards development process.

Acknowledgement

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[2] National Institute of Standards and Technology, "Statement of Requirements for Urban Search and Rescue Robot Performance Standards-Preliminary Report" http://www.isd.mel.nist.gov/US&R_Robot_Standards/Requirements%20Report%20(prelim).pdf .

[3] TIA Roadmap 2006.

Table 1: Summary of Data Collected August 19-20 at the Montgomery County Fire Rescue Training Academy

Robot	Video (MHz)	Control (MHz)	Output Power (W)	Success	Failure Due to Interference	Issues with Interference
1	2400	900	0.5	--	NLOS	yes
2	2432	2432	0.2	LOS, NLOS	--	no
3	2437	2437	0.2	LOS, NLOS	--	no
4	2414	2414	?	--	LOS, NLOS	yes
5	2400 (analog)	900	?	--	LOS, NLOS	yes
6	2400	2400	1	LOS, NLOS	--	yes
7	1760	900	1 control, 2, video	LOS, NLOS	--	no
8	1756	900	?	--	LOS, NLOS	yes
9	2400	35	0.1?	--	LOS, NLOS	yes
10	1400	35	0.1?	LOS, NLOS	--	no
11	5200	5200	?	NLOS	--	yes
12	2400	2400	?	LOS, NLOS	LOS, NLOS	yes
13	2400	?	0.1	--	LOS, NLOS	yes
14	2400	2400	?	LOS	NLOS	yes
15	900	75	?	--	--	--