SENSOR EXPERIMENTS TO FACILITATE ROBOT USE IN ASSISTIVE ENVIRONMENTS

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ABSTRACT
In this paper[1], we describe the mobile robot and sensor research and development toward assistive devices ongoing at the National Institute of Standards and Technology (NIST). Through mobility research projects, NIST has been studying advanced sensor navigation technology for indoor mobile robots and a novel Home Lift, Position, and Rehabilitation (HLPR) Chair. This assistive device can provide independent patient mobility for indoor tasks, such as moving to and placing a person on a toilet or bed, and lift assistance for tasks, such as accessing kitchen or other tall shelves. These functionalities are currently out of reach of most wheelchair users. One of the design motivations of the HLPR Chair is to reduce back injury, typically, an important issue in the care of this group. The HLPR Chair is currently being extended to be an autonomous mobility device to assist cognition by route and trajectory planning. Localization sensor technologies are being studied for use in combination with the HLPR Chair. This paper briefly describes a mobile robot (HLPR Chair) and its onboard sensors. We then describe performance measurements of absolute positioning and obstacle detection sensor technologies towards combining them with the mobile robot into a cost effective home or assistive care facility, patient transfer and rehabilitation system.

Categories and Subject Descriptors
C.4 [Performance of Systems]: Measurement techniques;
J.3 [Life and Medical Sciences]: Health;
J.7 [Computers in Other Systems]: Command and control.

Keywords
localization sensors, robot, mobility, patient lift/transfer, rehabilitation

1. INTRODUCTION
In 2005, the NIST Intelligent Systems Division (ISD) began the Healthcare Mobility Project to address the staggering healthcare issue of patient lift and mobility. ISD researchers looked at currently available technology through a survey of patient lift and mobility devices [1]. That report showed that there is need for technology that includes mobility devices that can lift and maneuver patients to other seats and technology that can provide for rehabilitation to help the patient become independent of the wheelchair.

An additional area investigated in the survey was intelligent wheelchairs. NIST has been studying intelligent mobility for the military, transportation, and the manufacturing industry for nearly 30 years through the Intelligent Control of Mobility Systems (ICMS) Program. [2] NIST is researching a standard control system architecture and advanced 3D imaging technologies within the ICMS Program. The NIST Healthcare Mobility Project is then applying them to intelligent wheelchairs where NIST has begun outfitting the HLPR Chair with computer controls. Although throughout the world there are or have been many research efforts in intelligent wheelchairs, as exemplified in [3] and too many others to list here, the authors could find no sources that have applied: (1) standard control methods, nor (2) the most advanced 3D imagers prototyped today to intelligent wheelchairs. Therefore, NIST began developing the HLPR Chair to investigate these specific areas of mobility, lift and rehabilitation, as well as advanced autonomous control.

Relative and absolute position sensors and sensor networks are necessary for computer-controlled, mobile, assistive-care devices. Sensor technologies for providing absolute positioning of mobile robots in assistive care facilities, the home, or even industrial manufacturing facilities have been studied for many years. These studies have uncovered a wide range of technologies. A 1997 study by Borenstein, et. al., [4] defined seven categories for positioning systems: (1) Odometry, (2) Inertial Navigation, (3) Magnetic Compasses, (4) Active Beacons, (5) Global Positioning Systems, (6) Landmark Navigation, and (7) Model Matching. Some or all categories numbered (1) through (3) are typically used for onboard vehicle relative positioning. Absolute positioning indoors has advanced since the 1997 study. Recently, the authors researched categories (4) through (7) above and found many relevant absolute positioning system technologies. We list and provide a reference for many of these technologies here as a more recent compilation divided into: non-line-of-sight and line-of-sight positioning technologies and improvements to positioning technology using software.

Non-Line-of-Sight (nLOS) Indoor Positioning technologies:

- Ultrasonic with Radio Frequency [5] (cricket)
- Global Positioning System (GPS) and Pseudolites [6]

- Ultrasound Indoor Positioning System [7]
- Ultra Wideband [8]
- Indoor GPS [9]
- Radio Frequency Identification (RFID) [10]

Line-of-Sight (LOS) Indoor Positioning technologies:

- Laser line-scanning range finder to landmarks [11]
- Laser fanning range finders to landmarks [12]
- Cameras and fiducials [13]
- Magnets in the floor grid [14]
- Photographing the navigation path [15]
- Bar Code Readers [16]
- Non contact switches/beam break sensors

Improvements to Positioning Technology using Software:

- Simultaneous Localization and Mapping (SLAM) [17]

The authors reviewed the characteristics of the above technologies, including non-line-of-sight vs. line-of-sight technologies, size, weight, cost, etc. towards providing an inexpensive, advanced assistive care device for patient transfers throughout facilities and/or the home. A general and scalable sensor technology that provided the best characteristics for this application was RFID technology. Experiments using active and tunable RFID technology will be discussed in section 3 – RFID for Mobile Robots Research.

This paper describes: the HLPR Chair intended to acquire the sensor technology further presented; past research and performance measurements of RFID and flash LIDAR (light detection and ranging) sensor technology for use within an assistive care facility or the home; NIST experiments toward autonomous robot use of RFID technology; and a planned HLPR Chair demonstration. A conclusion and future plans section follows with a references list in the last section.

2. HLPR CHAIR

A novel assistive care device was recently invented at NIST called the HLPR Chair. [3] A prototype of the device, shown in Figures 1 and 2, is based on a manual, steel, inexpensive, off-the-shelf, sturdy forklift. The forklift includes a U-frame base with two casters in the front, stabilizer casters in the rear and a rectangular vertical frame. The lift and chair frame measures 58 cm (23 in) wide by 109 cm (43 in) long by 193 cm (76 in) high (when not in the lift position) making it small enough to pass through even the smallest, typically 61 cm (24 in) wide x 203 cm (80 in) high, residential bathroom doors. The HLPR Chair frame could be made lighter with aluminum or composite or plastics instead of steel. The patient seat/stand mechanism is a double, nested and inverted L-shape where the outer L is a seat base frame that provides a lift and rotation point for the inner L seat frame. The L frames are made of square, aluminum tubing welded as shown in the photograph. The outer L is bolted to the lift device while the inner L rotates with respect to the seat base frame at the end of the L as shown in Figure 1.

The frames have a rotation point above the casters at the very front of the HLPR Chair frame to allow for outside wheelbase access when the seat is rotated π rad (180º) and is the main reason access to other seats is available. Drive and steering motors, batteries and control electronics along with their aluminum support frame provide counterweight for the patient to rotate beyond the wheelbase. When not rotated, the center of gravity remains near the middle of the HLPR Chair. When rotated to π rad (180º) with a 136 kg (300 lbs) patient on board, the center of gravity remains within the wheelbase for safe seat access. Heavier patients would require additional counterweight.

Patient lift is designed into the HLPR Chair to allow user access to high shelves or other tall objects while seated. The HLPR Chair lift (see Figure 3 - left) is approximately 0.9 m (36 in) to reach what a typical, standing 1.8 m (6 ft) tall person could reach. This is a distinct advantage over marketed chairs and other concepts. [3]. The additional height comes at no additional cost of frame and only minimal actuator cost.

Lift is achieved by a 227 kg (500 lbs) maximum lift actuator that can support 681 kg (1500 lbs) statically on the HLPR Chair prototype. The actuator can be replaced with a higher capacity unit if needed. The actuator connects to a lift plate with a steel chain that is fixed to one end to the HLPR Chair frame and to the lift plate at the other end. The actuator pushes up on a sprocket over which the chain rolls, providing 0.9 m (36 in) lift with only a 0.45 m (18 in) stroke actuator. The outer L-frame is bolted to the lift plate. Rollers, mounted to the lift plate, roll inside the HLPR Chair vertical C-channel frame.

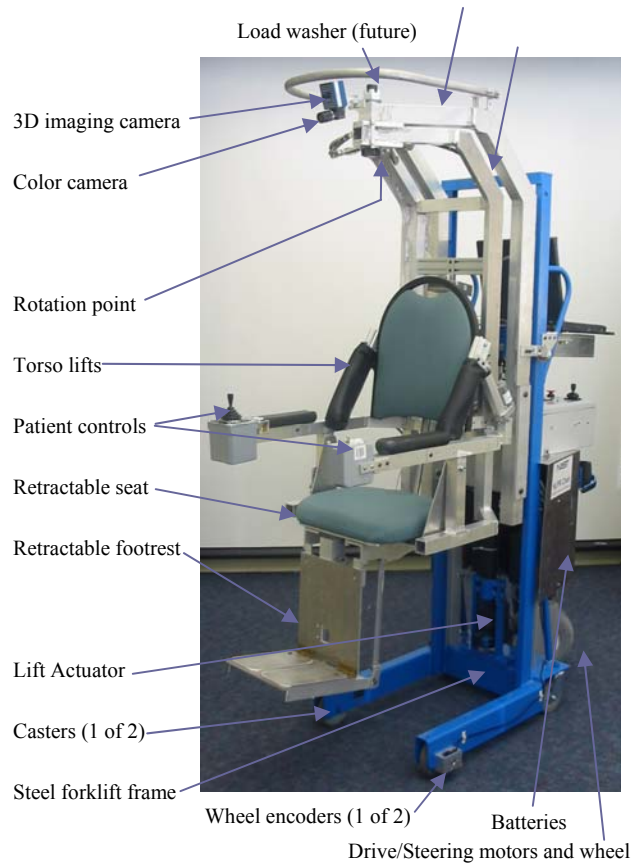

Figure 1 –Photograph of the HLPR Chair prototype

To accomplish the rehabilitation configuration, the HLPR Chair footrest and seat rotate behind the patient while he/she is lifted with torso lifts (see Figure 3 – right). However, instead of being placed low on a seat, the patient lift continues to move up lifting the patient as they move their legs beneath them to standing position. The HLPR Chair's open U-frame base allows access to

the floor directly beneath the patient for standing. The concept also allows patient slings for standing or sitting and gravity unload for patient legs in the rehabilitation configuration.

Figure 2 – Photographs of the HLPR Chair in the mobility configuration showing the side view (left) and front view relative to a typical doorway (right).

Figure 3 – HLPR Chair prototype shown in the patient (left) lift and (right) rehabilitation configurations.

It is estimated that 1 in 3 nurses or caregivers will develop back injuries [1]. Most injuries occur because the patient is relatively heavy to lift and access to them is difficult when attempting to place the patient onto another seat. Wheelchair dependents have difficulty moving from a seat to their wheelchair and back without a caregiver's help or other lift mechanisms. The HLPR Chair was designed with the patient lift, as explained previously, to not only access tall objects, but to also pick up and place the patient in other chairs, on toilets, and on beds. Figure 4 shows the concept of placing a patient onto a toilet. The HLPR Chair prototype has been shown to perform these configurations.

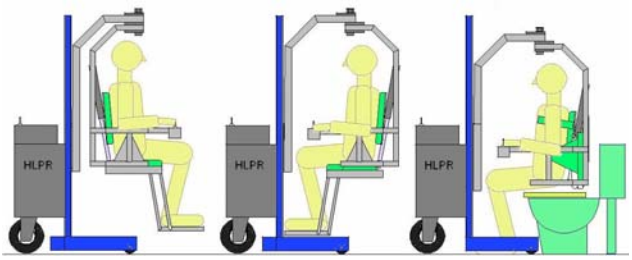

Figure 4 – Graphic showing the concept of placing a patient onto a toilet or chair with the HLPR Chair. *The patient drives to the target seat (left), manually rotates near or over the seat (middle) while the torso lifts support the patient and the seat retracts, and then is lowered onto the seat - toilet, chair or bed (right)*

The HLPR Chair is intended for use in assistive care facilities or the home to support patient transfer tasks and leg rehabilitation. Manual, and recently computer controls, [3] have been developed for the HLPR Chair. The assistive device testbed was modified to include encoders, attached between its frame and front caster wheels, a computer and computer interface electronics. The encoder design included adapting a shaft to one side of each caster wheel, passing it through a bearing attached to the frame and to an encoder. The encoders provide 3600 pulses per revolution allowing fine measurement over a 12.7 cm (5 in) diameter caster wheel or approximately 90 pulses per cm (230 pulses per inch) of linear travel. The relatively high measurement accuracy of the wheels will support development of accurate path planning and control algorithms for the HLPR Chair.

Under computer control, drive and steering are controlled by an onboard PC laptop computer that interfaces to off-the-shelf input/output (I/O) devices housed in the box beneath the PC and connected through a universal serial bus (USB) interface. This design was chosen as a simple developer interface to the HLPR Chair prototype knowing that the computer and its interfaces can be significantly reduced in size as future commercial versions are designed. Software drivers for the HLPR Chair drive and steer control were written in C++ under the Linux operating system.

NIST and the University of Delaware (UD) are teaming to use the NIST reference software control architecture for intelligent machines called "Four Dimensional/Real-time Control System (4D/RCS)" and UD's robot behavior generation. [18] NIST has recently applied 4D/RCS to a Defense Advanced Research Project Agency (DARPA) Project called LAGR (Learning Applied to Ground Robots). [19] The basic premise of the 4D/RCS hierarchy is to sense the environment around the robot, to place the sensed information into a world model (map), then plan and generate appropriate navigational paths and input these paths into the robot actuators in real time. As a second phase LAGR task, NIST developed standard interfaces between control modules for simple algorithm integration. The authors plan to adopt a similar open control architecture on the HLPR Chair so that advanced 3D imagers, such as the ones shown in figure 1, absolute positioning, and robust control algorithms can be plug-and-played to address the variety of patient mobility controls and sensors that may be needed.

3. RFID FOR MOBILE ROBOTS RESEARCH

Dead reckoning using the HLPR Chair wheel encoders provides reliable robot navigation information to the robot controller for only short-distances. Within an assistive care facility, the regularity of doors and halls may be confusing to a mobile robot. Hence, absolute positioning sensors mounted within the facility are required to ensure that through the use of dead reckoning, the robot does not drift from its relative a priori map location stored within the robot. Of the listed sensor technologies in the Introduction section, the authors chose nLOS positioning technology because of typical walls and obstructions hindering LOS sensors in assistive facilities. We briefly reviewed and weighted their characteristics, including: maturity, size, weight, cost, ease of installation and use, etc. towards providing an inexpensive, HLPR Chair position sensor. RFID technology was chosen as a useful, low cost and scalable technology for robot absolute positioning.

3.1 Previous RFID Research

Typically, RFID is used in assistive care and other medical facilities for asset tracking. [20] It has been used for determining where wheelchairs are located within a medical facility for quick retrieval by facility staff for patient use and, as in the National Science Foundation study, to assist Alzheimer patients with finding their eyeglasses, etc. [21]

RFID technology for localizing robots is also not new. In a study by Kulyukin, et al., they list several past research efforts using RFID for robot navigation. [22] They said: "Kantor and Singh used RFID tags for robot localization and mapping. Once the positions of the RFID tags are known, their system uses time-of-arrival type of information to estimate the distance from detected tags. Tsukiyama developed a navigation system for mobile robots using RFID tags. The system assumes perfect signal reception and measurement and does not deal with uncertainty. Hahnel et al. developed a robotic mapping and localization system to analyze whether RFID can be used to improve the localization of mobile robots in office environments. They proposed a probabilistic measurement model for RFID readers that accurately localize RFID tags in a simple office environment." References for these efforts are listed in [22] What is important to summarize is that RFID technology is mature, available off-the-shelf and is ready for use.

3.2 RFID Performance Measurements and Scaling

Furthering past RFID research, NIST recently completed some performance measurements of this technology to understand it's usefulness in assistive facilities and the home. For example, to localize a robot within a facility or at a particular door along a hallway of similar doors requires a variety of different RFID tags or a method for adjusting the power of each tag to limit RF interference from one tag to the next and a method for positioning tags within the facility for best performance.

NIST recently began measuring the performance of RFID technology to understand how to scale the RF power for use in confined areas. An RFID[2] active tag and detector, which are based on 433.92 MHz International Standards Organization standard, active (battery powered), anti-collision (read many tags simultaneously) technology, were used. The manufacturer specifies these units to have ranges from 1 m to 76 m (3 ft to 250 ft) where tags simply emit a data signal every 1.8 s to 2.2 s and the reader simply receives the tag data transmission. Measurements were made using a single RFID tag mounted inside a thin metal box with the cover left off or covered with a metal lid and a single hole drilled through the cover to allow minimized RF transmission from the box into the environment. The detector was held by hand. This inexpensive method for tuning an RFID tag is intended to be an effective way to localize indoor mobile robots like the HLPR Chair. Photographs showing the experimental apparatus are shown in figure 5 and graphical results are shown in figure 6. The graphic shows a home layout with a tag located at points A and B and the resulting colored-in pattern of approximate tag reading coverage for the various covered or not covered tag configurations.

In one experiment, the tag was: placed in a bathroom that is centered within the first level of a home, left uncovered, tested, then covered with two different hole diameters in the lid, and retested. The second experiment included placing the tag in the kitchen without a cover on the metal box but, with metal box sides. The home walls were made of painted gypsum (drywall) board with wood support structure. There was little difference in tag detection distance measurements with the masonite bathroom door closed or open. This is a good characteristic since it cannot be assumed that doors of this type will be open or closed.

An a priori facility map will be integrated into the HLPR Chair memory. The map will include a single or dual active RFID tag system(s) tuned for unique areas within the home or medical facility. In the home, a unique map can be easily achieved as room layouts are typically not regular. In medical facilities, room layouts can be very regular where hallways of similar doors typically make it difficult to ensure access to the correct patient's room. A single RFID tag can be tuned for a specific location, such as the center of the home, on different levels, on various facility wings or at hallway intersections to inform the HLPR Chair where it is in the home or facility.

4. POWERED CHAIR NAVIGATION DEMONSTRATION USING RFID

The LAGR (Learning Applied to Ground Robots) vehicle design is based from a powered chair. Added to the chair are dual stereo and other sensors and computer controls. As briefly described in section 2 - HLPR Chair, NIST has proven an open control architecture that allows control algorithms to be plug-and-played into the LAGR vehicle controller. Furthering the LAGR controller for indoor application as part of the NIST Industrial Autonomous Vehicles Project, a number of changes were made to the LAGR control system in order to transfer the military outdoor application to an indoor industrial setting. Two RFID sensors were integrated into the

[2] Any mention of commercial products is for information purposes only. This does not imply endorsement by NIST nor suggest that this is necessarily the best supplier for the product described.

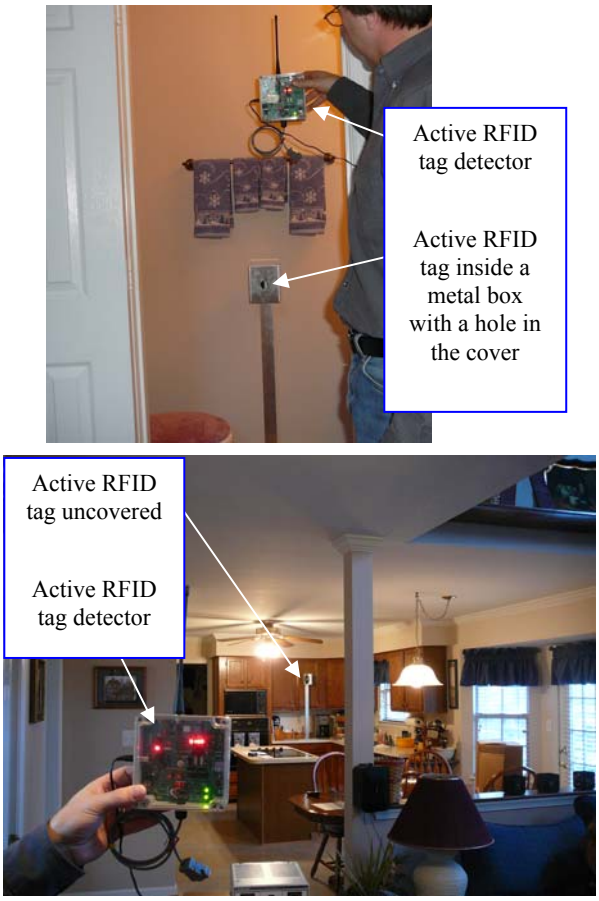

Figure 5: Experimental apparatus RFID tag and detector located in a home at (top) location A in the bathroom and (bottom) location B in the kitchen.

vehicle position estimate. An active tag RFID system was used allowing tuned tags to be placed up to a couple of meters away from the onboard vehicle receiver and giving freedom to choose their location. Tag tuning included adding a simple thin metal plate mounted to the tags' back and bent to tune detection regions from the original 4 m down to about 2 m. Tuning required initial testing for detection range prior to placement. Also, a passive RFID system was used including tags that provide a more accurate vehicle position to within a few centimeters. RFID systems updates replaced the outdoor GPS positioning system updates in the controller.

These two integrated systems are shown in Figure 7. Available passive tags can be integrated into the controller to allow the vehicle to get even more accurate positioning, which is necessary near machines or tray stations typically used by automated guided vehicles (AGVs).

The control system also needed to be less aggressive for safety of people and equipment. The outdoor system is allowed to hit a tree or a bush and never stops to wait for someone or something to get out of the way during a DARPA test. Instead the outdoor system will either turn around completely to find a different path or try to squeeze through whatever space is left. AGVs must detect people or objects in the path of the vehicle according to the American National Standards Institute (ANSI)/International Truck Standards Development Foundation (ITSDF) B56.5 Industrial Truck Safety Standard [23], which provided guidelines for our indoor demonstration.

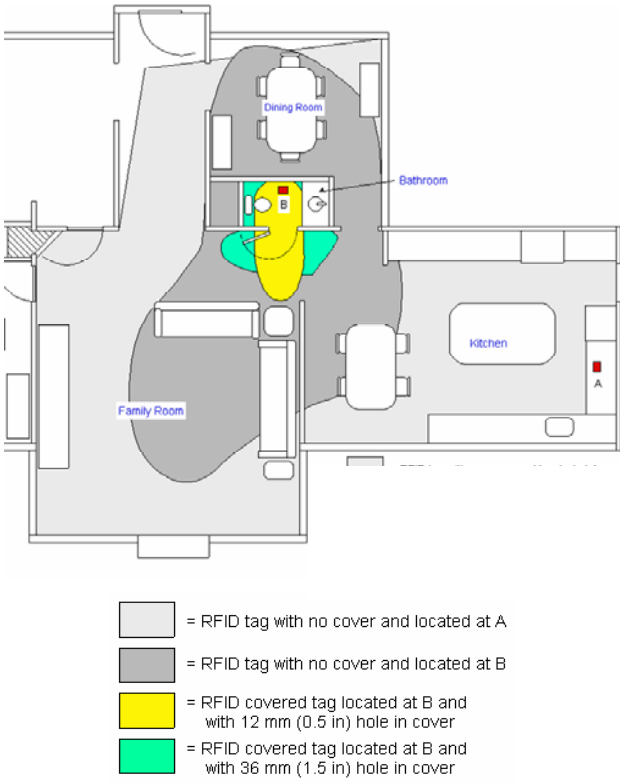

Figure 6: Graphical results of the RFID tag tuning experiment in a home.

The obstacle detection height was also changed for the indoor demonstration. Outdoors, good disparity among even fairly short obstacles such as logs and roots could typically be detected using onboard stereo cameras. Indoors, the obstacle height threshold was raised from 5 cm to 30 cm with typically large obstacles and poor stereo correlation causing false obstacles to be detected. A 3D imager with better obstacle and floor detection would allow better path planning by removing the false obstacles detected with stereo vision.

The experiment demonstrated performance of the LAGR robot navigating through an unstructured environment including a garage and a working machine shop. The robot was started next to its charging station in the autonomous vehicles laboratory (garage). It detected a passive RFID tag placed on the floor (see figure 7) and updated its knowledge of its current position at the start point of the route. A laptop on the robot displayed an overlay of the live video from each of the two stereo color camera pairs, with obstacle detection, color classification, and 2D range information, as well as a high-resolution/short range map and a lower resolution/longer range map of the facility (see figure 8).

The robot has a programmed stored path shown in pink on the high level map. The measurements taken when building the map were not very accurate (i.e., rounded to within a meter). Further, straight lines were used as estimates of the true path. Therefore, there is a fair amount of error in its measurement of heading. If it

blindly followed the pink path it would run into the yellow cabinet. The disparity between the two camera images in each stereo pair provides an estimate of range to each section of the cabinet. From the range estimate, the slope and height of the cabinet are determined. Since tall and/or vertical surfaces should be avoided, both maps are updated with an obstacle where the cabinet is located.

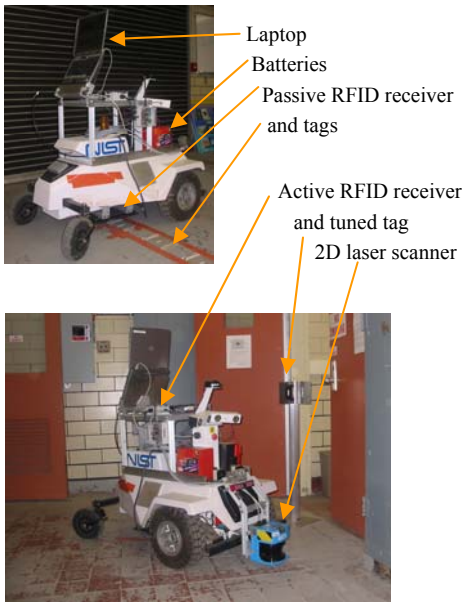

Figure 7. LAGR/IAV vehicle at demonstration start position (top) and after heading through doorway (bottom).

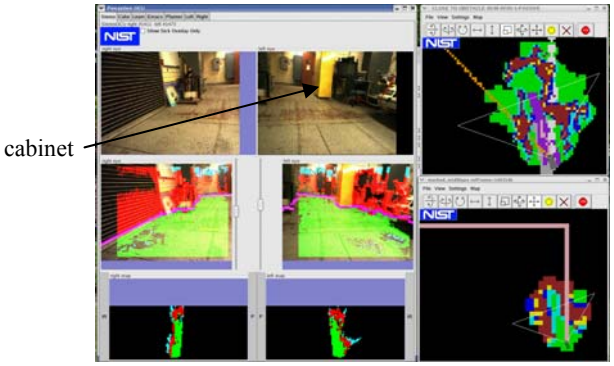

Figure 8. LAGR AGV Graphical Displays – right and left stereo images (upper left); images overlaid with stereo obstacle (red) and floor (green) detection and 2D scanner obstacle detection (purple) (middle left); right and left cost maps (lower left); low level map (upper right); and high level map (lower right).

Obstacles are shown as red overlays in the image and as brown/red marks in the map. The robot then chooses a path slightly to the left of the cabinet. Given its ability to sense the relative position of obstacles, the robot does not need a particularly accurate positioning system. It drives forward updating its position using only the wheel encoders and inertial measurement unit (IMU) for about 8 m until it senses the active RFID tag mounted on a portable stand just before the point where it will need to turn 0.8 rad (90º) to exit the room. It can sense this tag from about 2 m away. If the tag could have been detected farther away it could not update the position as accurately. If the detection range were more limited there would be an increased risk of passing the tag without detecting it.

When this tag is detected, both the current position estimate and heading are corrected. The heading is corrected by comparing the difference between the measurements made using the IMU and encoder data at the first passive RFID tag near the charger with the known locations of each tag from a table stored previously. For example if the IMU/encoder output had indicated that the vehicle had gone northwest, but the second tag is known to be north of the first the current IMU/encoder, heading should be corrected 0.4 rad (45°) clockwise. The programmed path indicates a left turn just after the position associated with the active RFID tag. The robot turns left, primarily relying on stereo to find a doorway to pass through and onto the shop floor and on for another 10 m until passing over another passive RFID tag.

The programmed path includes annotations to pause at certain positions, including the position of this tag. If this vehicle had the ability to carry parts, for example, instead of simply pausing, the tag could trigger a docking maneuver to load or unload parts during this pause. After a timer counts down, the robot resumes movement and continues on its approximately planned path. The programmed path down the lane is simply a straight line, but the robot can not drive a straight trajectory since the lane is partially blocked on one side by a set of lockers and on the other at different locations by chairs, trash cans, machines, etc.

The robot is programmed to stop only if necessary, such as if a person is standing in the center of the lane. It will adjust its trajectory if the lane is only partially blocked and it can still find a path wide enough for itself and an additional safety margin. In this case, it continues past the obstacles. The robot continues on its preplanned path, turning at each of three additional active tags before coming to a halt at a final passive tag about 70 m from the start position.

We determined that with absolute positioning using tuned RFID tag technology, inaccurate a priori map directions to the goal, and an onboard controller developed for the LAGR project sufficiently navigated a mobile robot through an indoor, unstructured facility. However, obstacle detection sensing using stereo vision did not provide adequate knowledge of walls, floors, and sometimes, obstacles due to the disparity issue with stereo vision. The next section explains experiments using a different type of obstacle detection sensor.

5. FLASH LIDAR EXPERIMENTS TOWARD USE ON MOBILE ROBOTS

Beyond inexpensive absolute positioning using RFID, onboard vehicle obstacle detection sensors are required. In recent years, flash Light Detection and Ranging (LIDAR) has developed into a potentially useful and cost effective, compact sensor that provides relatively fast range information to obstacles. It is becoming useful as a 3D mobile robot sensor for detecting obstacles, the floor, etc. NIST has been studying these devices for several years. The next sub-sections discuss experiments performed at NIST toward their use on assistive robots or in assistive facilities and the home.

5.1 Standard-sized Obstacle Detection

NIST has recently studied the use of flash LIDAR on mobile robots for industrial and healthcare mobile robots. For industrial use and relevant to this paper, experiments were completed for the automated guided vehicle (AGV) industry toward improving the B56.5 safety standard for industrial vehicles. Through the use of a segmentation algorithm and combining the intensity and range data, a flash LIDAR sensor can clearly detect AGV standard-sized obstacles in the vehicle path. [3] Figure 9 shows a test apparatus with standard sized obstacles used for the AGV industry.

Figure 9 – Test Apparatus

Figure 10 shows the results of using flash LIDAR and an obstacle detection and segmentation algorithm for the experimental setup shown in Figure 9 where the resultant (left) range and (right) segmented object images are shown.

5.2 Obstacle Detection and Path Planning

Another NIST experiment used a 3D flash LIDAR for obstacle detection relative to an early version of the HLPR Chair for use by the blind in navigating obstacle-laden areas. Figure 11 shows the results of a segmentation algorithm combined with intensity and range data to determine obstacle location with respect to a mobile robot. In this experiment, the flash LIDAR unit was mounted to an early version of the HLPR Chair for use as

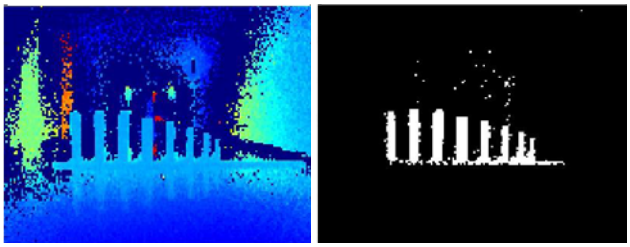

Figure 10 – Results of the obstacle detection and segmentation algorithm for the experimental setup shown in Figure 8. The resultant (left) range and (right) segmented object images are shown.

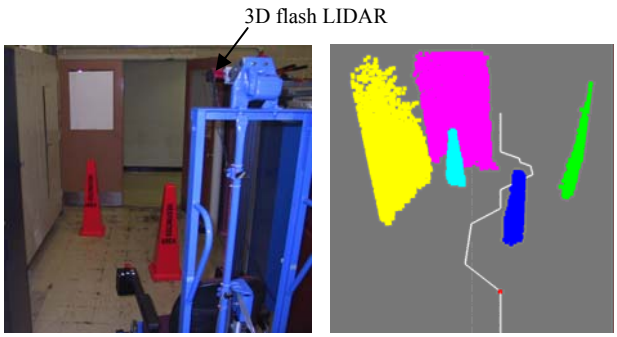

Figure 11 – (left) Test scene and (right) range data of objects and path planned around objects.

a fixed height testbed for the sensor. Again, the sensor clearly detected the obstacles. A path planner was also developed to show a clear path around the obstacles and through the doorway to the clear hallway.

5.3 Detection of Facilities

Another experiment using a newer version 3D flash LIDAR toward assistive facility use included data collection of the entrance and inside of a bathroom and toilet area. This experiment was used to determine the usefulness of this technology for a near-term autonomous HLPR Chair demonstration to drive in, dock with a toilet and return outside of the bathroom. The demonstration is explained in Section 6. HLPR Chair Demonstration. In figure 12 (top), the image clearly shows the various doorways leading into and through to the toilet area of the bathroom. The sensor provides range information on each of the (176 x 144) pixels. Figure 12 (bottom) shows images of the (left) toilet and surrounding walls and (right) smoothed range data and intensity data of the toilet to be used for obstacle segmentation as in previous experiments.

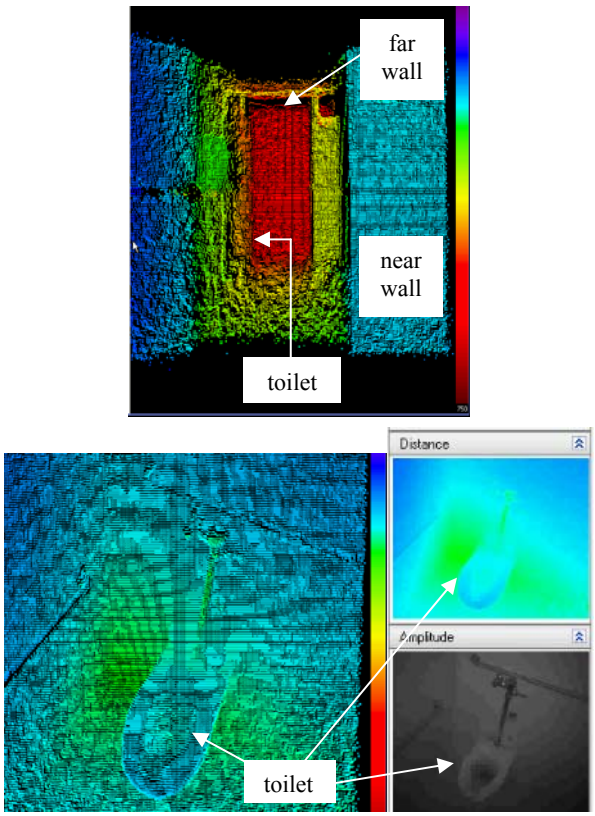

Figure 12: Flash LIDAR scan data showing (left) walls looking into the bathroom from just outside, (center) the toilet and surrounding walls of the planned demonstration area, and (right) distance (smoothed data) and amplitude (intensity) data of the toilet.

6. HLPR CHAIR DEMONSTRATION

The authors plan to integrate the HLPR Chair testbed with the LAGR-based 4D/RCS controls, tunable RFID technology, and flash LIDAR as described in this document to facilitate a demonstration. Through a federal grant, University of Delaware (UD) studied the unique navigation challenge of the HLPR Chair. [18] This three-wheeled, single-wheel drive and steer system is

unlike most power chair configurations having dual-wheel, skid-steer and drive and therefore, required a unique control solution. Figure 13 (top) shows a graphic of the map of the planned demonstration to manually drive the HLPR Chair to a NIST facility bathroom door, place the HLPR Chair into autonomous mode, and autonomously drive the HLPR Chair to dock with the toilet. After docking, the HLPR Chair will then reverse motion and navigate back out of the room to the starting position. Figure 13 (bottom) shows a screen capture of the UD simulation of a trajectory to the toilet using the differential flatness paradigm as outlined in [18].

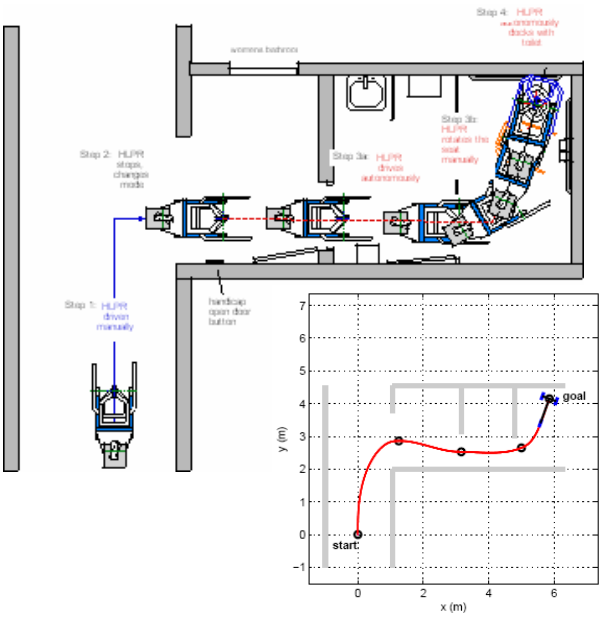

Figure 13: (top) Graphic showing a top view of the HLPR Chair route into a bathroom and docking with a toilet, (bottom) Screen capture of the UD simulation of a trajectory to the toilet.

The differential flatness paradigm was used to plan the entire trajectory to the goal point within the demonstration scenario. In the simulation, three via points were chosen as intermediate points between the start and the goal. In the implementation, it is considered that the HLPR Chair arrives at a via point when it reaches within a nominal error distance to the point. In the actual experiments, we expect to localize the states of the vehicle and the obstacles through on-board flash LIDAR.

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8. CONCLUSIONS

This paper has described the HLPR Chair patient assist technology and experiments using tunable RFID technology for use as an inexpensive absolute positioning sensor, as well as flash LIDAR toward use as an obstacle detection sensor. Plans have been made for performing a demonstration using the HLPR Chair as an assist device to transport a patient autonomously into and through a bathroom to dock with a toilet. Although RFID technology was chosen as the absolute positioning technology for our experiment, we reference many useful indoor positioning technologies toward a useful reference list of these devices that can be applied to many indoor (and some outdoor) robot tasks.

Future efforts will be to transition the HLPR Chair technology toward public use and to collaborate with other organizations to foster additional HLPR Chair technology development, performance measurements and standards.

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