Experiments with Attitude:

Attitude Displays for Teleoperation

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Abstract – *Attitude control refers to controlling the pitch and roll of a mobile robot. As environments grow more complex and cues to a robot's pose sparser it becomes easy for a teleoperator to lose situational awareness. Information from separated attitude displays may be difficult to integrate with an ongoing navigation task and lead to errors. In this paper we report an experiment comparing a gravity referenced display (GRV) with a standard fixed camera with separated attitude indication. Results show shorter task times and better path choices for users of the GRV.*

Keywords: Robotics, Teleoperation, Attitude Display, .Gravity Referenced View

1 Introduction

Attitude display for ground vehicles is very different than for aircraft. With aircraft the problem is that in instrument flying or instrument augmented flying the pilot can lose sight of the actual horizon and become confused over his plane's orientation. In this case the actual horizon is presumed to be horizontal and the problem is orienting the pilot to this horizontal reference.

For ground vehicles rather than losing orientation vis a vis an invisible horizon, the teleoperator usually has a clear view of the surface being navigated. What he lacks are cues as to how that surface is oriented. For a fixed camera this can be a big problem because "horizontal" appears to be whatever is normal to the camera. Misperception of attitude was the only problem that McGovern [5] found in a review of egocentric teleoperation accidents at Sandia. Operators kept rolling over robots on grades and were uniformly surprised because they thought they were on relatively level ground
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While pitch (tilt) can also generate illusions of flatness they are generally less debilitating than those related to roll. Pragmatically, the effect may be because "flipping" is less likely than rollover but data [2] also indicate that robot roll is less well perceived than tilt. Taking an ecological stance we might ask "how do people do it?" A person would never find themselves on a grade without realizing it the way Sandia robot operators remained oblivious to their robot's pose. One reason may be proprioceptive but compelling visual cues are also available to help us realize when we are on a grade because our view is typically oriented normal to gravity. When visual and proprioceptive cues conflict as in a fun house a sense of orientation becomes difficult to maintain. One might expect to find similar effects in teleoperation with a gravity referenced view (GRV) helping the operator maintain awareness of attitude in settings where there are some reference points such as the horizon and losing its benefits for "non referenced" settings such as an interior void within a rubble pile where walls, ceilings, and floors may be indistinguishable. An even less ambiguous GRV display can be created by including portions of the robot's body within the camera view. This effectively converts the camera view from an inside-out (egocentric) to an outside-in (exocentric) display in which the visible parts of the robot's body provide an indicator of roll and to a lesser extent tilt.

Situational awareness especially with respect to robot pose and attitude has been a persistent problem in urban search and rescue robotics. Murphy [6] reports that in her team's work at the World Trade Center site teleoperated robots were frequently flipped or rolled, often without the realization of their operators. The lack of visual cues to orientation within a rubble pile makes maintaining awareness of attitude particularly difficult although the very irregularity of the terrain may be somewhat less deceptive than the uniformly slanted natural terrain that appeared horizontal to McGovern's operators [5].

There are actually two closely related issues involving robot control and attitude: 1) accuracy in estimating current attitude and 2) accuracy in predicting changes in attitude associated with traversing terrain.

The first issue was addressed by Heath-Pastore [2] who conducted an experiment using pre-recorded video and audio clips taken from either a fixed (no attitude indication) or gravity referenced camera mounted on a vehicle driven over rough terrain. The subject's task was to adjust the tilt and roll of a gimbaled control to reflect the robot's attitude. Adjustments for roll were very accurate for subjects using the gravity referenced camera but poor for other conditions and measures.

A GRV camera might also be expected to improve awareness of the surrounding terrain because surfaces which appeared horizontal would be normal to gravity while those which appeared slanted would depart from the normal. The reported experiment compares a GRV display integrating attitude with scene information with a fixed camera display equipped with a separate attitude indicator. The participants were not asked to estimate attitude directly as in [2] but instead navigated through irregular terrain. The dependent measures reflected their ability to avoid rollovers and sharply slanted surfaces.

Experiments were conducting using a high fidelity mobile robotic teleoperation simulation [7] developed using the Unreal Tournament game engine [2]. The simulation of the NIST Urban Search and Rescue areas was modified to accommodate gravity referenced views and substantially larger interior and exterior environments were constructed for the experiment.

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2 Method

2.1 Experiment Task

The experiment used a between groups design comparing two forms of attitude display for teleoperating a simulated USAR robot described in Lewis, Sycara, and Nourbakhsh [4]. The forms of display were: separated attitude indicator with fixed camera and gravity referenced roll with fixed tilt camera. To evaluate the effects of attitude display in teleoperating the robot, subjects are asked to travel between five beacons in specified sequences for an indoor and an outdoor environment. The outdoor environment contained mountains, ravines, and other sloping planar features to challenge the fixed camera illusion of horizontality. The indoor environment had rubble covered, difficult to distinguish walls, ceilings, and slanted floors to obscure references used for orientation. Both terrains were very rough causing the robot to rollover if it went too fast over too steep a grade. To drive the robot safely the subject needed to keep it on as flat ground as possible and to slow down when the robot could not avoid steep grades.

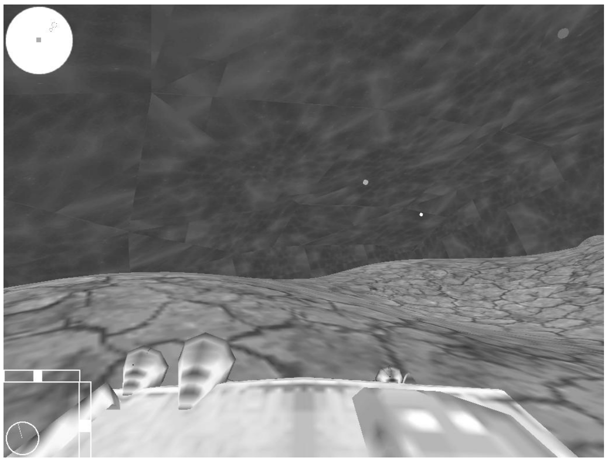

Figure 1. Fixed Camera in out-door environment (note the linear attitude display in lower left corner

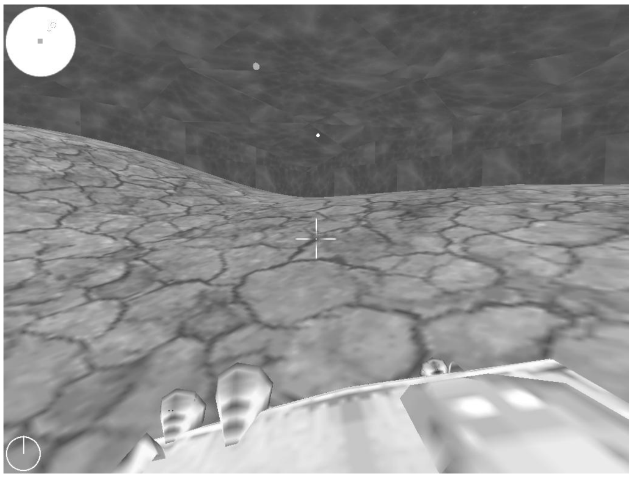

Figure 2. Gravity Referenced View (GRV) (note the indication of roll provided by the tilt of the robot's body)

Demographic information, a continuous log of the robot's location, attitude and control input and a posttest survey were collected to help identify the effect of the attitude display on teleoperator's remote perception control behaviors and strategy

2.2 Performance Measures

The following indices used to explicitly or implicitly measure the situation perception and control are described in this paper.

Confidence Level (CL): A subjective rating on a five point scale (0-4) of the participants' confidence in their awareness of pitch angle, roll angle, dangerousness of slopes, and likelihood of rollover.

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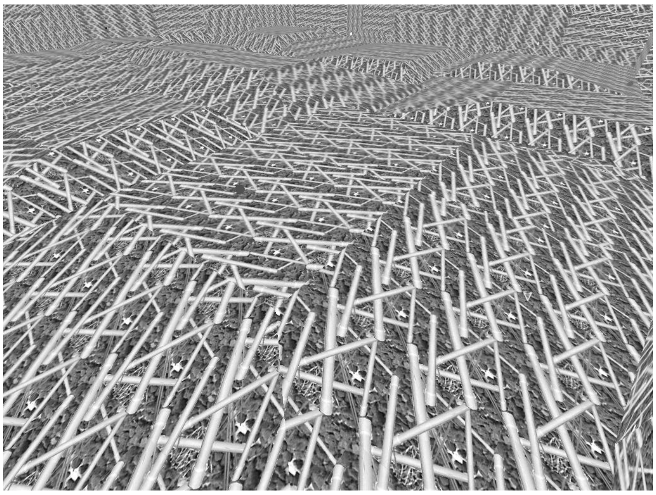

Figure 3. Rubble filled in-side environment

Time: The time required to visit the sequence of beacons. With better situation awareness, less time should be needed because participants could choose either more direct paths or flatter paths that allowed them to go faster. The environments were designed in such a way that there were unique "best paths" between the beacons

Rollovers (TRO): The amount of time a robot has spent rolled over or recovering from a rollover. Participants were instructed to avoid rolling over. Good performance on this measure required good estimates of current and predicted attitudes.

An indication used to investigate control behavior and strategy was:

Time spent backing: The percentage of time used to move the robot backward indicating a poor choice of path or prediction of terrain..

2.3 Experimental Simulation

The simulation was based on the UTUSAR interactive virtual environment built to model the the National Institute of Standards and Technology (NIST) Reference Test Facility for Autonomous Mobile Robots [7]. The system architecture is showed in figure 2.

The simulated robot is a four wheeled ground vehicle. Realistic dynamics were modeled using the Karma Physics engine. The vehicle simulation is based on its mass, center of gravity, friction, torque, etc. The environments built for the experiment include an indoor environment, an outdoor environment and a training environment. Five spheres of different colors were added into the environments to provide beacons the participants must try to reach. The indoor environment is an artificial

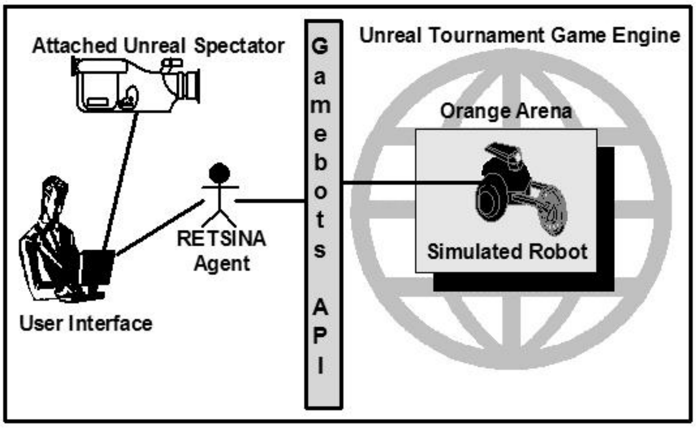

Figure 4. System Architecture

environment constructed by planes with different slope angles. The floor, ceiling and walls are constructed in the same way to simulate the confused environment where attitude cues are very limited. The outdoor environment is a simulated hilly land with some cues for attitude awareness. The training environment is a simplified combination of indoor and outdoor environments.

Visual feedback was achieved by attaching a view point corresponding to a fixed camera or a gravity referenced camera mounted on the ground vehicle. For fixed camera, horizontal (roll) and vertical (pitch) linear scales were overlaid on the left bottom of the screen to indicate the roll angle and pitch angle.

2.4 Procedure

26 participants divided into equal groups took part in the experiment. One group controlled simulated robots with a fixed camera and separate attitude indicator. The other group controlled simulated robots with a GRV display. Demographic information was collected at the start of the experiment. The participant was then allowed 10 minutes of practice in the training environment. After the practice session the participant was randomly assigned to either the indoor or outdoor environment. Upon completion in that environment the participant repeated the task in the other environment. Participants were allowed up to 20 minutes in the outdoor and 30 minutes in the indoor environments.

In each session, the participant followed instructions displayed on the screen to move the robot from the current beacon to the next designated beacon. After each session, the subject was given the posttest questionnaire.

3 Result and Discussions

3.1 Situational Awareness and Confidence Level

The average confidence levels for judging robot pose varied little between indication (pitch, roll, dangerous, or rollover) or group (fixed camera, GRV). As shown in Figure 5 only the perception of likelihood of rollover seemed to favor the GRV although this difference failed to reach significance.

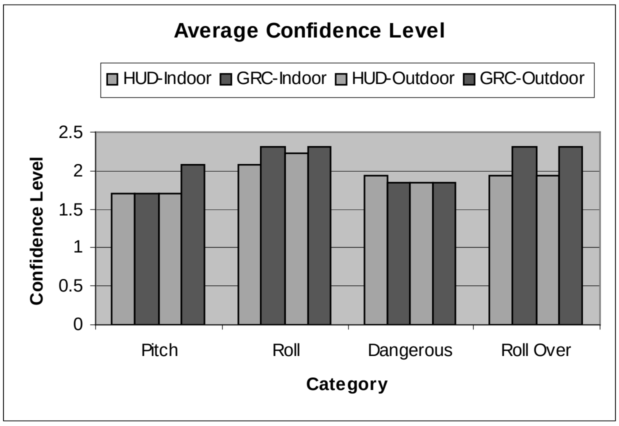

Figure 5. Confidence Levels

3.1.1 Time to Completion

The time taken to complete the circuit of beacons reflects several aspects of the perception and control tasks. To complete the traversal in a short time the participant must select relatively direct and flat routes to reduce the time spent in traversal while avoiding costly delays associated with rollovers. As shown in Figure 6, participants in the GRV condition were significantly faster, $F_{1,24}$=7.031, p = .014, than those using a fixed camera with a separated attitude display.

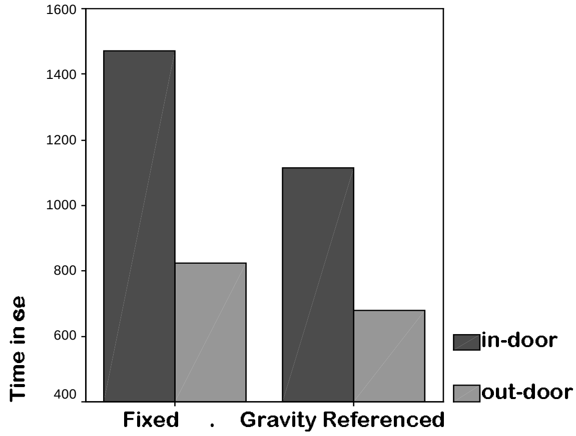

Figure 6. Task Times

3.2 Strategy and Time Spent Backing

Another measure of situational awareness and ability to control the robot is the degree to which participants were able to plan and choose successful paths through rough terrain. One measure of this capability is the percentage of time that is spent backing-up the robot to recover from unsuccessful path choices. On this measure, as well, participants using the GRV display showed superior performance, $F_{1,24}$=6.11, p=.021, with significantly less time spent backing up and choosing new routes.

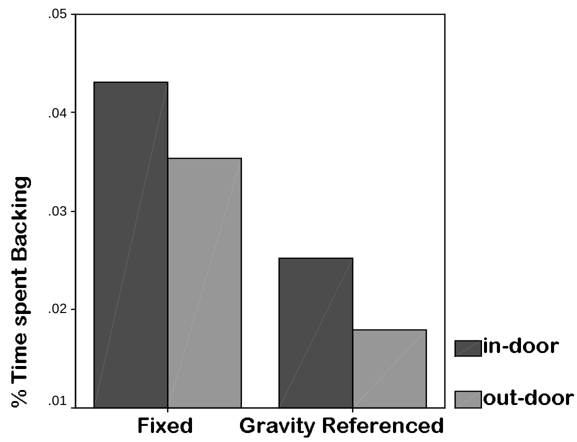

Figure 7. Percent Time Spent Backing

4 Recommendations and Conclusions

Using a commercial game engine is a fast, cheap, and effective way to study problems in robot teleopration. The current study supports several valuable conclusions and recommendations for teleoperating mobile robots.

1) GRV can make operators more situationally aware of a vehicle's attitude.

GRV indicates roll angle through the slope of the robot's body that forms an integral part of the navigational view. When attitude information is made available on a separated display it is more difficult for the operator to incorporate this information in navigation and planning. Our results not only replicate Heath-Pastore's [2] finding that GRVs can lead to better estimation of roll but demonstrate that this improvement in situational awareness extends to prediction and choice of safer more efficient paths through irregular and difficult to navigate terrains.

2) There appears to be a relationship between the awareness of roll angle and perception of pitch angle.

Although the GRV used in this experiment was referenced only to roll, participants using it had similar levels of confidence in the judgments of pitch to those in the fixed camera condition who had explicit indication. Indirect measures of pitch perception such as rollovers suggest that GRV users were not appreciably handicapped by this lack of indication. Whether a better integrated indication such as a HUD pitch ladder could improve performance further would require more experimentation.

3) The conditions favoring GRVs are relatively uncommon and may limit the use of the technique to domains such as urban search and rescue or military applications in which confusing environments and stressful operation are expected.

In an initial pilot study we found several off the shelf environments, which appeared to meet our requirements, were insufficiently confusing to show clear differences between the displays. Where there are sufficient cues such as a horizon or perpendicular walls, neither explicit attitude displays nor GRV are needed for situational awareness. In naturalistic observation such as McGovern's [5] survey of accidents, mishaps due to loss of situational awareness were relatively infrequent although operationally significant.

We consider GRV to be only one of a growing number of techniques needed to make human interaction with mobile robots easier and more fruitful. Robots should probably be equipped with safeguards to prevent them from falling into holes, exploration and mapping utilities to keep us from getting lost, camera control and perceptual routines to scan the environment, and a host of other assists that will continue to take us further from direct teleoperation.

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