Royal Institute of Technology

Efficiency Evaluation of Simulated USAR Control Methods

Author:
Magnus Olsson

Supervisor:
Petter Ögren

April 12, 2013

Abstract

This essay details a 3D simulation of a number of control methods used for maneuvering of teleoperated USAR robots. The implementation was produced in the Unity3D engine. The simulation implemented different variations on field-of-view angle, turning algorithms, and camera view perspectives. An evaluation using volunteer test operators was conducted and discussed. The sample size was too small to draw any definitive conclusions. Further testing is advised.

Referat

Denna uppsats behandlar en 3D-simulering samt användartester av flera olika kontrollmetoder som används vid fjärrstyrning av obemannade räddningsrobotar. Implementationen skapades med Unity3D-plattformen. De styrmetoder som testades var olika stora synfältsvinklar på kameran, olika algoritmer för att styra robotens svängning, samt olika kameraperspektiv. Användartester med frivilliga testförare genomfördes och diskuteras. Provstorleken var för liten för att kunna dra några definitiva slutsatser. Ytterligare tester rekommenderas.

Contents

1 Introduction

Teleoperated Urban Search and Rescue (USAR) robots is a quickly developing technology and, with the robots' increasing refinement, will most likely play a larger role in future rescue missions in environments too hazardous or inaccessible to human beings. However, controlling these unmanned vehicles offers many challenges. There are numerous kinds of advanced sensors one can employ to convey environmental information, but combining them and presenting the information in an intuitive way, especially without too heavy cognitive load for the operator, is a problem many are continuously working on. Challenges lie in conveying information that range from poor visibility and steep inclines or depressions to protruding debris. All of which demand a high level of situational awareness being delivered from a wide array of sensors to the operator. This while still having the operator being able to focus on his task or mission.

In this essay I will attempt to isolate and compare variations in control variables. The different approaches will be modeled and implemented, to the best of my ability, using the Unity 3D engine. Performance will be measured using a custom made obstacle course, with test subjects attempting to navigate and complete tasks while being monitored and timed.

2 Problem statement

Unmanned USAR vehicles can be called upon to operate in extremely complex and varying environments. They can be extremely difficult to navigate and hostile to delicate machinery. The robot must both avoid collisions and be able to efficiently survey the area for targets, such as human survivors. It is therefore critical for their operators to achieve a high degree of situational awareness to be able to make optimal judgment calls, especially since lives may depend upon it.

This situational awareness is, hopefully, attained though an array of sensors and the way in which this data is compiled and conveyed to the operator. There are however innumerable ways to present the environment to the operator and this is the subject of an active field of research.

Determining which control schemes are the most efficient can really only be done though user evaluation and testing, which is what this essay aims to undertake.

3 Background

The main purpose of unmanned search-and-rescue robots is to go where humans cannot. Typically, these are environments which are very hostile to humans, such as a radiation filled reactor room or surveying a damaged building which may collapse. Such robots are in daily use across the world and their refinement is an active field of research.

The most advanced robots are now being equipped with advanced technologies such as LIDAR[1] and stereoscopic head-mounted displays[1]. However, with limited resources, turning to simulation is an excellent choice. The advantages of simulating USAR robots are many. For example, failure does not result in physical damage to your expensive and delicate robot. One is also able to test many different concepts and circumstances with both low cost and quick development time.

With likely more widespread deployment of USAR robots in the future, it would be very beneficial to allow even inexperienced operators to carry out missions with reasonable efficiency. Simulation can provide a great way to allow novices to evaluate control schemes and interfaces, which is exactly what this essay explores.

4 Approach

The purpose of this essay is to explore and evaluate a number of control methods for maneuvering a USAR ground vehicle as efficiently and precisely as possible. To adequately judge these different control methods, they would need to be evaluated in scenario which resembles what this robot may face in an actual mission. With limited resources and actual robotics expertise, a 3D simulation of a robot and environment was a natural choice. The game development platform Unity3D was selected to facilitate the simulation, with external 3D entity models being imported from other modeling software.

A testing environment for the vehicle was created with the purpose of providing obstacles, objectives and a method of measuring performance among the different control methods. The main objective is to navigate inside a smoke filled building and find as many incapacitated victims (targets) as possible, while keeping collisions to a minimum and without wasting time. The building also lacked any kind of lighting, requiring a spotlight mounted on the USAR vehicle. The smoke and poor lighting were added to try and increase the difficulty of maintaining navigational and orientation awareness.

Test subjects were recruited to act as operators for the USAR vehicle and navigate the course with a given set of instructions. Their performance was observed, recorded

[1] Laser Imaging Detection and Ranging

and evaluated based on a number of metrics. These metrics were course completion time, number of collisions and number of targets found. They were also subjected to a short interview after completing the testing, mainly to query about their perceived orientation awareness and cognitive load. Some factors that are typically an issue for real-life USAR vehicles were disregarded in this simulation. These factors include things such as video link quality from the robot?s camera (resolution, frames per second and latency). In a live scenario they may have real impact on operator performance and awareness[2].

4.1 Control methods

Examination of three different areas of control was decided. These areas are field-of-view (FOV), turning algorithm and view perspective. The rationale behind testing different values of FOV was that low field-of-view gives a clear and undistorted image, with peripheral vision suffering. High field-of-view, however, allows for the operator to see a great deal of the surrounding area at once with the downside of distorting the image. Ability to judge distance and speed are negatively impacted by high FOV[3]. In an attempt to demonstrate these differences, the test environment has a target hidden in a corner which is much more easily missed if the operator has a low field-of-view. Controlling the direction of travel was implemented in two different ways. The first simply behaves like a car, with the front wheels turning at an angle. To be able to turn, the car needs to be moving either forwards or backwards. The second turning algorithm simulates caterpillar bands such as those found on a tank. This allows for 360 degree turning on the spot without any forwards or backwards momentum. To demonstrate the difference in agility between the two methods, the test course has a couple of tight spaces where the vehicle needs to turn around to get out again.

Perspective has been implemented in a first-person-view variant and a third-person viewing the vehicle from behind. Having a view of your entire vehicle from behind aids navigating tight squeezes, since the operator can see whether e.g. the wheels are about to collide with the obstacles. To test whether this advantage exists, the test course was constructed with a deliberately narrow doorway which just barely allows the USAR through. Third-person-view is also accompanied by a higher view-height above ground, which may affect speed and distance perception.

4.2 Testing methodology

Volunteers were recruited to participate in the testing of the different control schemes. They all received exactly the same instructions and were then observed. For this evaluation there was a sample size of eight volunteer operators. The tests were performed in front of a stationary computer monitor with keyboard and mouse as input devices. Apart from having the control button layout explained, they were instructed to try and locate as many red targets as possible, in the fastest possible time and without colliding with walls or obstacles. The time and result was recorded by the supervisor while the number of collisions was handled by the simulation implementation itself. The specific challenges that were hypothesized to favor certain control settings were paid extra attention to and noted. Because the subjects would be familiar with the environment after having navigated it once, only one play-through was timed and added to the data set for evaluation. The participants were however allowed to try the course one more time, with the other variation of the control method, to then be interviewed afterwards about his or her preference. To clarify, if the test subject was evaluated and benchmarked when using a 60 degree field-of-view, he or she was then allowed to test 120 degree field-of-view without being timed. The tester was then queried on how the two settings compared and which was preferable.

5 Implementation

5.1 Environment

The main testing environment consists of a large building with a fairly spacious main lobby. The 3D model of the building was freely available on the Unity3D asset marketplace. The building?s lobby has some obstacles added to it, with rough geometry representing a reception counter, an office desk and some other decorative furnishings. These serve as obstacles to navigate around and avoid collision with. A few separate rooms have also been created, with one of the connecting hallways being a very snug fit for the simulated USAR robot.

Throughout this entire environment, there is a thick artificial fog added and very low light conditions. Both of these serve to limit visibility a great deal, aiming to challenge the test subjects? sense of orientation, both locally and globally. The poor visibility also presents a challenge to the situational awareness, making it challenging to avoid collisions with obstacles.

Scattered in the building are also a number of brightly colored models (or targets), symbolizing unconscious or otherwise incapacitated victims. These targets are not visible until the USAR vehicle is fairly close, and are often hidden in corners or behind desks.

5.2 Vehicle

The vehicle design is a simple chassis with four wheels, all of which have collision boxes. As is evident in the upcoming subsection, the wheels do not always function as simple car wheels. Perched atop the vehicle is mounted a manually controlled camera, which is where the test subjects field-of-view originates from. The camera is able to rotate, within certain restrictions (90 degrees), and is controlled by moving the computer mouse. A spotlight is also connected to the camera, shining a cone of light in the direction the camera faces.

Collisions are detected and registered for all of the components of the vehicle.

5.3 Control configurations

5.3.1 Field-of-view

The camera has a variable field-of-view (FOV) setting which is measured in degrees. Trials were performed with two different FOVs, 60 degrees and 120 degrees. Increasing FOV distorts the surrounding environment and may diminish the operator?s ability to judge speed and distance to objects accurately.

5.3.2 Turning algorithm

The direction of travel is controlled with the WASD or arrow keys on the keyboard. The first type of turning is practically identical to that of a car, requiring the vehicle to be moving to turn. The second method rotates the vehicle around its axis without needing forward momentum, similar to caterpillar bands on a tank.

5.3.3 Perspective

Two different perspective options were implemented. A first-person-view, looking out from the mounted camera on top of the vehicle, as well as a third-person-view showing the entire vehicle from a rear perspective. When these two modes were compared, rotation of the camera in first-person-view was disabled, as having camera control when in third-person-view did not quite make sense.

6 Results

All eight test subjects found every single target in the course. One target was placed specifically to be difficult to spot with low field of view, but all participants had a good look-a-round. Thus the only measured benefit of higher field-of-view was a faster completion time.

The difference in perspective between first- and third-person seemed to yield a difference in number of collisions with the environment. Operators who had a third-person view of their vehicle were better able to avoid having their wheels nudge a corner or backing into a wall. The intentionally narrow doorway which was implemented to try and provoke a significant difference between the two perspective views failed to do so, but navigating the rest of the environment suggested third-person-view being slightly superior in terms of collision avoidance; First-person-view produced twice as many collisions. The total completion times where nevertheless closely matched, with no significant difference.

The different turning algorithms showed a significant difference in completion time, with the wheel-based turning-algorithm taking 60% longer to complete the course. This was mainly due to the laborious nature of trying to turn around in a confined space, requiring repeated back and forths while turning.

6.1 Interview answers

Of the two FOV choices, all participants favored the higher field-of-view. The reason given was typically that they felt they had better awareness of their immediate surroundings.

Of the two competing turning methods, it was immediately clear that car-like wheel drive was thoroughly disliked. Both volunteers reported that they felt it was unsuitable for navigating confined spaces.

Surprisingly the first-person-view was more appreciated than third-person, despite the latter producing worse results. The operators found that their camera view was often obstructed by walls and other geometry when using third-person-view, which annoyed them.

7 Discussion

Experimenting with different implementations in a simulated environment can certainly provide good data and indications for further research and testing. In this very limited study however, with most configurations having only a single data point, the results can at best provide material for a mere speculative discussion. That being said, one can at least attempt to draw some speculative conclusions based on the results.

The faster completion time demonstrated by the higher field-of-view was perhaps attributable to getting a quicker overview of your surroundings, allowing less time to be spent in each place. As mention previously, the different FOV settings did not lead to any test subject missing a target. The participants were simply very thorough in their exploration and did not let a narrow field of view stop them from checking every nook and cranny. However, in a real world scenario it may not always be practical to constantly turn around to inspect all corners. With time being a factor, having a wide angle peripheral view will likely save time.

An issue in the implementation was likely responsible for an unfair advantage for the operators with high FOV. Due to the nature of the simulated smoke in the Unity3D engine, turning the camera so your peripheral view looked forward granted longer view range through the supposedly thick smoke. This unfair advantage resulted in easier navigation and is likely one of the factors leading to faster completing time for the high FOV drivers.

The testers? dislike of the car-wheel algorithm came as no surprise. Navigating such tight quarters without bumping into things is understandably easier when you are able to face the correct way before applying forward momentum.

At first glance, it may seem odd to simulate third-person-view in a USAR vehicle, reasoning that such views don?t exist in real life. There are however (at least) two ways of achieving this in the real world. A computer program could use proximity sensors or LIDAR to build a real-time 3D map of the environment surrounding the robot. In this 3D map a model of the robot could be superimposed and the camera position chosen freely. The second way, which has seen real-life use[4], is to have the ground vehicle accompanied by a flying UAV, giving a bird?s eye view and acting as an extra camera angle.

As mentioned in the results section, players surprisingly preferred first-person-view over third-person, despite worse results. This was reportedly due to walls sometimes blocking the camera view in this simulation when turning around. To prevent this, one could implement a form of collision detection with the camera to zoom closer when a wall is between the camera and vehicle. Another possible reason was the fact that the camera was positioned further behind the vehicle in third-person-view. This results in more smoke between the view-point and the terrain in front of the vehicle, effectively making obstacles visible later than in first-person-perspective.

One major issue with trying to draw conclusions based on user testing and benchmarking of this kind is that the results are only valid for this specific testing environment. Had the conditions and challenges been different the result may have differed from the current findings. Ideally, a robot could perhaps be modular with components and user interface being adaptable to the particular situation at hand.

8 Conclusions

Having a modest eight test subjects spread across six different control configurations undeniably lacks any real statistical foundation on which to base robust conclusions. More extensive testing with preferably a longer test course is needed to better determine which control methods are superior. The test operators? individual skill was also a major confounding factor in this study.

With these qualifiers in mind, the user evaluations were clearer in some areas than others. Using caterpillar bands over car-style wheels, for example, appears significantly more suitable for this kind of scenario.

The testing of field-of-view and camera perspective did not yield as dramatic opinions and results. Higher FOV had an unfair advantage in terms of visibility through the simulated smoke which certainly influenced the perceived edge in performance. The third-person-perspective was disadvantaged due to implementation issues, which may not manifest in the real world.

Additionally, Unity3D was found to be an excellent platform for simulations of this kind. The free edition of the software is still a powerful tool and provided for a relatively short development time.

References

[1] A. Amanatiadis and A. Gasteratos, *Stereo Vision System for Remotely Operated Robots*, March 2010.

[2] J. Y. C. Chen, E. C. Haas, and Barnes, *Human Performance Issues and User Interface Design for Teleoperated Robots*, page 6 November 2007.

[3] J. Y. C. Chen, E. C. Haas, and Barnes, *Human Performance Issues and User Interface Design for Teleoperated Robots*, page 2, November 2007.

[4] B. Larochelle and G.-J. Kruijff, *Multi-view operator control unit to improve situation awareness in USAR missions*, September 2012.