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Application of virtual reality in teleoperation of the military mobile robotic system TAROS

[1]MOHAMMED GAFFAR, [2]ABDUL RAHMAN

1 Assistant Professor, Department of AIML, Lords Institute of Engineering & Technology

234 Student, Department of AIML, Lords Institute of Engineering & Technology.

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Abstract

Aspects of a complicated control system for a teleoperated military mobile robot, known as the Tactical Robotic System (TAROS), that pertain to virtual reality and general support to a human operator are presented in the article. Particularly noteworthy is the novel and distinctive virtual operator station system, which places the operator in a virtual environment with visual input from the robot and camera views, including stereovision, using the HMD Oculus Rift. The virtual operator station replaces what would otherwise be a huge room with pricey equipment in a portable and affordable manner. Another device that aids the operator in remote manipulation chores is mentioned as well: the anti-collision system, which guards against careless motions of the manipulator arm damaging the robot's mechanical components.

Introduction

These days, mobile robots operated by trained human operators are widely used in a variety of fields, particularly those where direct human deployment would be either extremely dangerous (such as firefighting, explosive disposal, etc.) or impossible (such as the reconnaissance of extremely small spaces, areas with lethal radiation or other dangerous substances, foreign planets, etc.). Military applications that pose a risk of troop harm or even death fall under the latter category. basic shape on a typical screen. 1–3. If the operator is expected to execute intricate manipulation duties and the robot has, for instance, a very sophisticated manipulator arm with several degrees of freedom, this might become unpleasant or even dangerous. By using virtual reality, the Department of Robotics (VŠB-Technical University of Ostrava, Czech Republic) has been creating sophisticated control systems for teleoperated mobile robots that solve these issues. 4–6 too high and having machines (robots) replace them is especially advantageous, at least for the riskiest assignments. Losing a mobile robot will always be more tolerable than losing a person, despite the fact that they are still highly costly. Usually operating from a distance, the operator of a remotely operated mobile robot depends only on information from sensors and cameras, which are usually shown in a displayed.

Figure 1. Military mobile robot Tactical Robotic System (TAROS) V2 (source: archive of VOP CZ s.p.; author: Radim Hora´k).

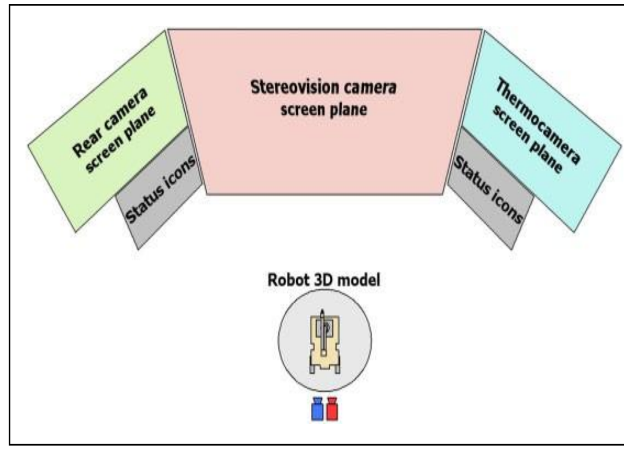
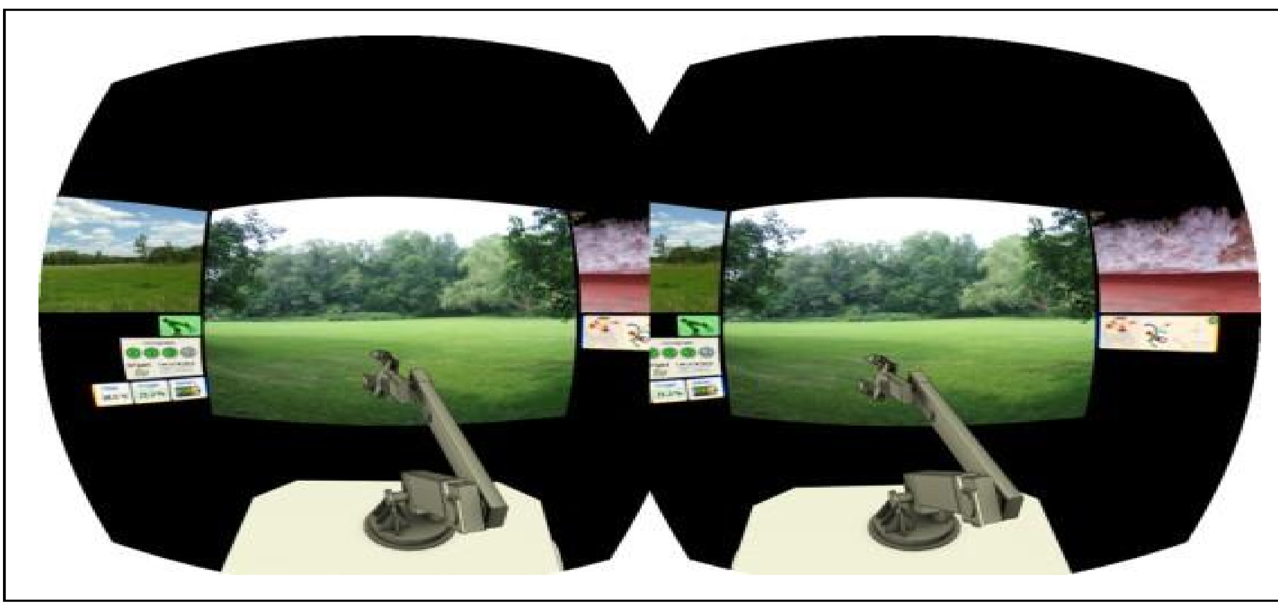


Figure 2. Schematic representation of content of the virtual operator station.



The latest version was created for the military mobile robot *TAROS*.

Robotic Tactical System The Czech business VOP CZ s.p. is the scientific and research partner of TAROS V2. (Fig. 1) It is an autonomous robotic mobile system that was created in 2013 as part of the Center for Advanced Field Robotics in collaboration with Czech institutions. 7. The robot was designed to fight and assist Special Forces, mechanized forces, and reconnaissance in a hazardous and complicated operational environment. 8. One of the basic modules of the robot has a manipulator arm with five degrees of freedom and a universal gripper, with an overall reach of 2.1 meters and a load capacity of up to 20 kg. The robot may be modularly modified to meet the real requirements of the military unit. This manipulator module has cameras positioned close to the gripper, and the operator uses a cutting-edge virtual reality control system to manipulate the arm.

Virtual operator station

The control system's graphical user interface is a cutting-edge virtual operator station. The system operates on a physical operator station, which is a sturdy computer case; however, in contrast to other common applications, the operator is not looking at a screen within the station. Rather, he is wearing an Oculus Rift10 head-mounted display (HMD) device9 that simulates being in a virtual room or area, the virtual operator station, which is generated by the control system. This method's primary goal is to build an operator station that is much superior than what would be physically feasible, particularly in outdoor settings. A virtual operator station might have numerous extremely big displays and even be able to show stereovision pictures, but a real operator station can only have one or a few modest flat screens.

Elements rendered in the virtual station. Two virtual cameras in the 3D space are used by the operator to see the content of the virtual operator station. These two cameras don't match any actual physical cameras on the robot; their optical settings are precisely set to meet Oculus Rift specifications (to maximize the wide angle of view), and their rotation (yaw, pitch, and roll) is influenced by head movements of the operator (through Oculus Rift tracking sensors). In this manner, the operator has unrestricted access to the virtual environment.
A number of huge planes that resemble computer monitors—or more accurately, a movie projector screen—are placed in front of and somewhat around the operator in the virtual room (Figures 2 and 3). The photos from a few real cameras are overlaid onto each screen. Images from the stereovision cameras on the arm close to the gripper are shown on the biggest plane. Images from a thermovision or night vision camera, the primary driving camera on the robot's chassis, and other crucial information (sensor readings, status symbols, warning icons, etc.) are shown on the somewhat smaller planes around it. It is also possible to display important indicators right over camera photos.

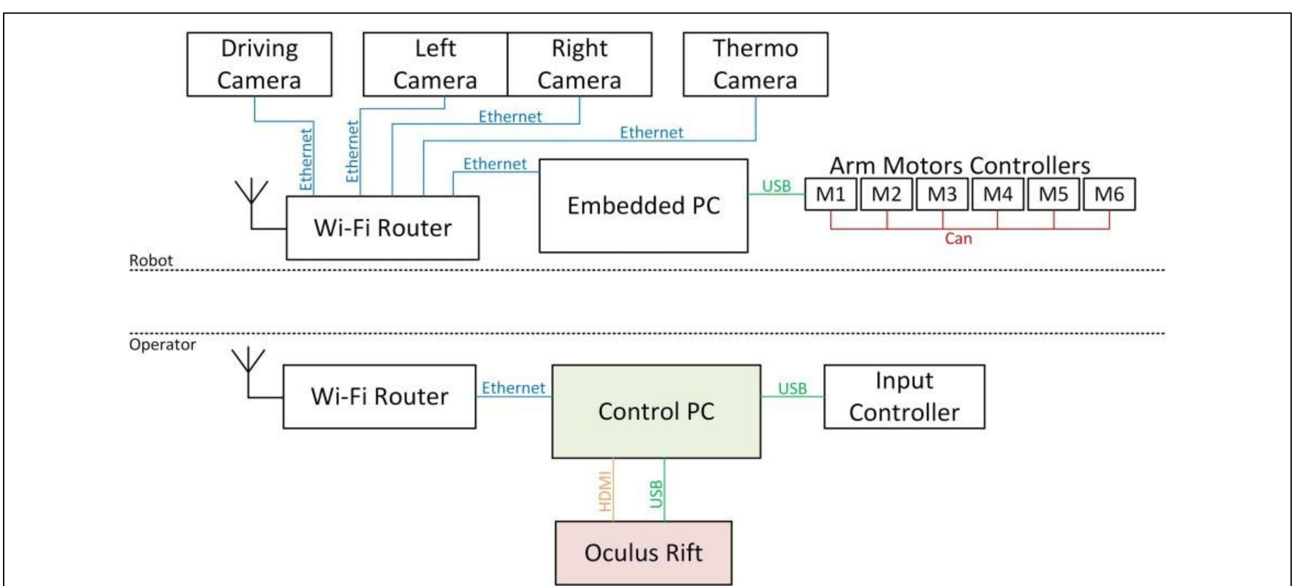


Figure 4. Interconnection of the main hardware components of the control system in the chain robot – operator station.

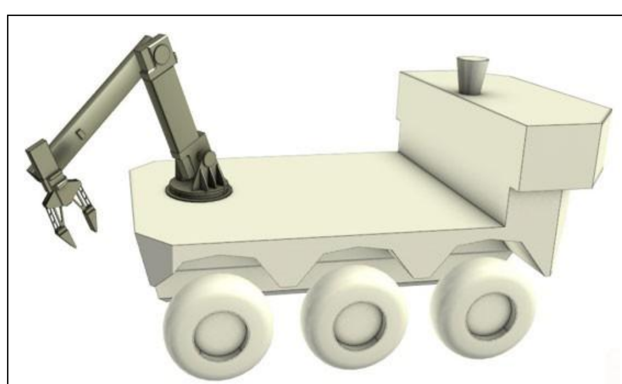
A tiny 3D copy of the mobile robot that replicates the real robot's manipulator arm's location is shown on the "floor" of the virtual room.

Software implementation. Two apps, both written in Microsoft Visual C++, make up the TAROS control system. The embedded PC on the robot (see Figure 4) is running a single program called "Server," which is in charge of coordinating with the arm motor controllers. The control PC at the operator station is running the second program, "Client." Wireless Ethernet (Wi-Fi) allows the client and server to communicate in both directions. Using DirectX for rendering and hardware acceleration of 3D visuals, the client creates the virtual operator station in Oculus Rift. Rectangles having a texture filled with real pixel data from pictures obtained from the matching camera are the screen planes described in the preceding chapter. The z-axis, or vertical axis, of the virtual 3D environment is aligned with these planes, while the other two axes spin them in the direction of the observer. The computer-aided design (CAD) data is used to construct a somewhat reduced mesh model of the robot in 3D. The virtual scene has to be produced twice (once from each virtual camera and eye) in order to be shown in Oculus Rift. The two views are combined into a single image and sent to the HMD device after being processed by geometric and chromatic post-processing algorithms implemented by the Oculus Rift SDK to eliminate optical deformations occurring later in the HMD itself (this occurs automatically, and the algorithms are hidden from the programmer) (Figure 3).

Stereovision cameras

Stereovision cameras (two cameras placed next to one another at a predetermined distance that is comparable to the between human eyes) provide a three-dimensional stereoscopic image of the robot's surroundings, which may be very helpful to the operator, particularly while performing arm manipulation tasks (depth perception). How to relay the 3D perspective to the operator is the question.The fundamental idea behind the HMD gadget makes it ideal for this work. Directly displaying the pictures from actual cameras to each person's eyes in the HMD would be the simplest and most natural method. The user would experience what it would be like to stand where the robot is. However, this method has a number of issues. In this situation, the cameras must have highly unique optical characteristics, particularly a considerable field of vision (more than 100◦ diagonally) and the unusual ratio of 9:10 (vertical orientation). Any other numbers would need cropping and scaling the visuals, which would reduce the HMD device's field of vision. Motion sickness is an additional issue. Because Oculus immerses the user in virtual reality, the brain anticipates that all sensations will match what the eyes perceive. In direct opposition to signals from other senses, such as the inner ear, the pictures move as the robot or the arm containing the cameras moves. The previously indicated representation of camera pictures on a virtual screen plane was selected as an alternative approach after some testing on many test participants (see below). For stereovision cameras, separate pictures are shown for each eye on the main screen (Figure 3). The final appearance and feel are quite comparable to seeing a 3D movie on a screen in a 3D theater. Many writers have previously used this idea in general; Cineveo, or Virtual Reality Cinema, is one example. 11 The primary cause of motion sickness is eliminated as the brain perceives the "cinema" as a stationary virtual environment.

Test results. Fifteen individuals of various ages (ranging from 18 to 65) were chosen to test the two aforementioned techniques of displaying stereo-vision camera pictures in Oculus Rift. After adjusting to the HMD device for a while, each participant evaluated his or her emotions, particularly motion sickness. This was carried out independently for both approaches, and there was often a few days between experiments. The rating range is 1 to 5, where 1 denotes little motion sickness that develops over time and 5 denotes severe motion sickness that develops within a relatively short period of time. The average figures for the 15 people who were split up into three age-based groups are shown in the



following table.

Convergence. In the virtual 3D environment, the virtual screen plane is produced at a certain distance from the viewer. Additional depth information is introduced by the 3D graphics, and things inside them may show up in front of or beyond the screen. All other things are constantly in front of the virtual screen, and items that are infinitely far away—or at least extremely far away—are positioned precisely at the distance of the virtual screen if the physical cameras have parallel optical axes. The issue with this simple method is that there is a significant depth conflict at the boundaries of the screen plane, the scene seems very near, and things in the pictures appear to collide with the robot's 3D model. Applying Horizontal Image Translation (HIT) to the pictures prior to their application to the virtual screen planes is one potential remedy. The convergence point is altered by this extremely basic software alteration of the pictures (moving pixels horizontally); to move the convergence point further away from the observer, the images must be pushed outward. A pixel may have the consequent total convergence in the HMD device beyond infinity if the pictures are too much displaced. This would induce eye strain since the eyes would not be able to concentrate on such a spot at all because they cannot spin outward. In virtual reality (VR) X, the maximum HIT value is equivalent to the screen plane's parallax pmax.

whether the arm is in a good configuration for his current manipulating task (Figure 5).

Individual elements (moving parts) of the 3D

where X is the horizontal resolution of the Oculus Rift screen in pixels, f_x is the horizontal field of view (FOV), d is the distance of the projection plane and d_s is the dis- tance of the virtual stereovision camera screen plane from the user in the virtual world (in meters).

The $p_{\max}$ value is in LCD pixels, but because the camera image pixels do not map 1:1 to LCD pixels, the images must be shifted by p'ders of the direct current (DC) motors in the arm.

The applied solution uses a quite simple but extremely effective and quick method. All parts of the arm and the robot are covered by a set of

Figure 5 shows the arm and robot in an interactive 3D model that is not connected to the virtual operator station. where Xc is the horizontal resolution of the camera pictures, ws is the virtual screen plane's width (in meters), and w' is the plane's width in pixels when it is shown on the LCD. Because certain things are now positioned below the virtual screen, this change improves the perception. The HIT value can be fixed (always equal to p') in most circumstances. However, in other situations, it could be preferable to determine the optimal HIT value by analyzing the camera photos. This is particularly true for indoor applications when none of the pixels in the images indicate items that are extremely far away (the HIT value can be bigger than p').

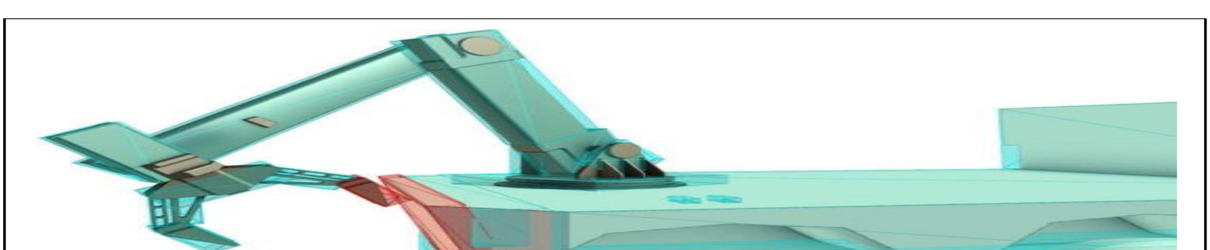
3D model of the arm

As already mentioned above, the virtual operator station contains also an interactive 3D model of the robotic arm at its actual position. This helps the operator when he can- not see the arm by other means because thanks to it he knows how the individual joints of the arm are rotated and

model are rendered with a proper transformation matrix generated from the real values acquired from the incremental enco-

Collision detection and prevention. There was implemented also another practical feature related to the 3D model of the arm and knowledge of the joint positions – anti- collision system. The purpose of this system is to prevent damage done to the arm or other parts of the mobile robot by predicting imminent collisions and overriding the opera- tor's commands in these situations.[12]

manually created *bounding boxes* enclosing the shape of the mechanical parts as tightly as possible (Figure 6).



The locations of all bounding boxes connected to all moving components during arm movement are determined by extrapolating the arm joints' present velocities; their positions are determined "in the near future."

$$q_i^{ext} = q_i + v_i t_{ext}$$

where q_i is the real actual angle of the particular arm joint, v_i is the corresponding angular velocity and t_{ext} is the cho- sen extrapolation time.

Extrapolation is required since using the arm joints' true locations would only identify collisions that have already occurred and not enable prevention. Intersection tests between pairs of bounding boxes are then performed using the extrapolated locations. The total number of potential n-box pairings is If just one of the fifteen axes is present, the junction is disregarded. Because the arm's components are often rather basic in design, adopting boxes as bounding volumes avoids excessive mistake and

2 2(n — 2)!

However, it is beneficial to check just predetermined pairings of boxes since not all pairs may realistically collide. There are 26 bounding boxes (c = 325) in the TAROS model; however, only 94 pairings have been examined.

The system notifies the arm's control system if an intersection is detected, and depending on the estimated severity of the collision, the drives are either slowed down or stopped entirely. The collision calculation is done in two stages: the first uses text = 0.12 s (a detected intersection results in a slowed down movement), and the second uses text = 0.03 s (all movements are stopped). Any convex body's crossings may be found by using the Separating Axis Theorem to compute box-box intersections. According to the theorem, if and only if two convex bodies are not crossing, their projections will not overlap onto a line known as the "separating axis." 13, 14 It can be quickly implemented for box pairs and just 15 possible separation axes need to be verified. 15. If even a of Oculus Rift further increased the quality of the immersion because of its higher resolution and better frame rate. Testing proved (see Table 1) that the chosen method of rendering induces considerably less motion sickness than direct display of stereovision cameras to individual eyes unintended operational volume reduction. This subsystem doesn't put more strain on the hardware of the control system because of its very effective positive impact in box-box inter- section testing.

Conclusion

The advanced graphical user interface of the TAROS oper- ator control system described in this article is still in devel- opment, but a fully functional version has already been implemented and tested on TAROS and on some other mobile robots created by the Department of Robotics, VŠB-TU Ostrava.

The innovative virtual operator station makes control of a mobile robot very intuitive and can mediate 3D view from stereovision cameras with very low cost and without requiring the use of large equipment. Oculus Rift DK1 and DK2 versions were used in the development with very good results. The final consumer version in Oculus Rift.

The robot is not bothered by the negative impacts of his environment, such as direct sunshine, which may be unpleasant when using ordinary computer displays, since the operator controls the robot with the HMD device on his head. However, there is a drawback to this as well: the user is unable to perceive possible threat sources nearby. By adding cameras to the HMD device and displaying their photos in the virtual world, this might be resolved in a future iteration. Because the operator can concentrate more on the actual manipulating task rather than using the manipulator arm, real-time rendering of a 3D model of the arm along with the anti-collision system discussed in the article's last section has already been extensively tested in numerous real-world applications and proven to be very effective.

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