

# *Improving the Control Behavior of Unmanned Ground Vehicle (UGV) using Virtual Windows*

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*Abstract*— In this paper we provide a description of a new application of virtual windows technique to enhancing real time tele-operation of UGV vehicles, where we use a live video (coming through a wireless camera) from the real vehicle displayed on a head coupled displays that are fixed in place of the windows of the driver cockpit room

*Keywords*; *Unmanned Ground Vehicles (URV); Remote Tele-operation; Virtual Windows; Motion parallax*

## I. INTRODUCTION

The real world offers a visual richness that we cannot emulate with any kind of display available today, but within the limitations of the hardware we can try to produce an acceptable illusion of reality. **Error! Reference source not found.**

The illusion of reality is important for many applications, and normally is developed in two forms; the first form is called the Virtual Reality where the user is put in a virtual world created by computer or 3d graphics providing the user with the illusion that he is inside that world, the second form can be called Virtual Window and is simply when the system provides the user with the illusion that he is looking or he is setting in a different place than his real physical place, for example the user is setting in his home, but the system makes him feel that he is in the jungle.

If we look to the problem of vehicle tele-operation (remote operation of unmanned vehicles) we can see that it falls in second form, where the operator is setting in a remote location far from the controlled vehicle, and the remote environment is transferred to him as real-time video through a wireless camera,

The process of vehicle remote operation is hard and difficult task, especially for untrained operators, where they easily lose their situational awareness, or have a poor judgment of the attitude and depth, or fail to detect obstacles in the way, and even if a vehicle is semi-autonomous (for example it can

follow a route) or is supervised, different factors may still affect and reduce the task performance [2].

so to enhance the efficiency of the remote operation and to increase the performance of the operator we need to increase the illusion of reality, to provide the user the illusion of being inside the vehicle itself, so the ultimate goal is that the user shouldn't be able to distinguish if he is inside a real vehicle or a virtual vehicle.

In this paper, we are going to propose a new idea in the way to achieve that ultimate goal, we will focus on what to show in the screens in front of the driver and make him feel that they are the windows of the real vehicle; from the related work we can see that this is the first study to use a live video from the real vehicle displayed on a head coupled displays that are fixed in place of the windows of the driver cockpit room.

## II. RELATED WORK

### A. *Virtual Reality and Virtual Windows*

There are two types of systems that provides us with the illusion of reality Virtual Reality and Virtual Window, most previous studies focused on the first type; the virtual reality, in both types a different number of techniques is researched to achieve the required behavior

Most current virtual reality environments are primarily visual experiences, displayed either on a computer screen or through special stereoscopic displays, but some simulations include additional sensory information, such as sound through speakers or headphones. Some advanced, haptic systems now include tactile information, generally known as force feedback.

In this study we also focusing on the visual experience of the user in order to achieve the illusion of reality, we should notice that there are two types of displays that are used to achieve the illusion of reality:

## Head Mounted Displays

To achieve the illusion of reality, we want real-time three-dimensional (3D) interactive displays. However, because these display system could not be created in space, anywhere and anytime; the simple solution is to wear the display. Such displays are today rather referred to as head-worn displays, but historically they have been referred to as head-mounted displays (HMDs). **Error! Reference source not found.**

Although HMDs have a great potential, such equipment prevents users from accessing its capability in normal situations. Aside that a head mounted display (HMD) shields a user from the real world, these devices require time to put on and take off, thus making it impossible to quickly switch between VR mode and real life mode. The HMD's impact on human health is not yet clear, especially when it is used for long periods of time. **Error! Reference source not found.**

## Head Coupled Displays

We should notice that the current normal displays are two-dimensional and are meant to be viewed by an observer seated directly in front of them. When the observer moves in front of the 2D display, the image displayed on the screen remains the same. But it shouldn't be the same, In order to allow the user to move off the central viewing position and still see the correct image; the displayed image needs to be updated to match the user's viewing position. [18].

So how the display is going to change the displayed image to match the user's viewing position, at the beginning we would think about an ideal 3D display (Figure 1) would emit directional light in such a way that the viewer sees different images from different viewpoints[25], such displays are most often called holographic or auto-stereoscopic Halle [26] and there have been many attempted implementations but at this time, none of them have acceptable cost, computational requirements, resolution, or viewing angle. In fact, they will not be available for at least another 20 years due to the computational requirements alone. [18]

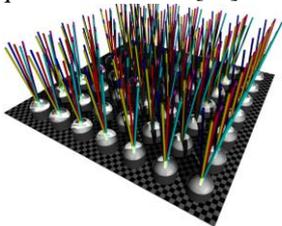


Figure 1: Ideal 3D display

There are a number of implementations exist that are called autostereoscopic displays. However, they are all limited to a small number of discrete viewing positions and distances. Examples are the Cambridge display [16] with 8 views and the commercially available SynthaGram [30] with 9 views. [31].

So to solve the problem we need to simulate these displays by restricting the number of viewers to a single viewer and rendering the scene based on that one viewer's position. Such displays are called head-coupled or head-tracked displays [27] and they primarily provide motion parallax.

When the observer moves in front of a normal 2D display, the image displayed on the screen remains the same. However, it is not seen as the same, because the surface of the display is no longer seen straight on but in perspective. The closer edge of the screen is perceived taller than the far edge, and the screen width is perceived as narrower. In order to allow the user to move off the central viewing position and still see the correct image, the displayed image needs to be updated to match the user's viewing position. This is exactly what head-coupled displays attempt to provide. [18]

The head-coupled display sometimes are called Fish Tank Virtual Reality[28], sometimes stereopsis is added (different images for left and right eye) to it, and the first implementation was described by Deering[29]. He used an ultrasonic head tracking device, a CRT monitor and stereo LCD shutter glasses. Deering described many problems and requirements that still hold. a more thorough examination of Fish Tank VR was done by Ware et al[28]. In their experiments, they found that such displays greatly increase depth determination.

## Head Tracking

In all head-coupled displays, the position of the viewer's eyes is a key parameter to the off-axis projection matrix. Eye position is obtained with a head tracking device, which can be ultrasonic[29], mechanical [28], magnetic, or optical. Optical tracking is least intrusive, but also least reliable and slowest. However, the advantage of having no head-mounted devices makes it the most appealing.

For head-coupled displays the most important head tracking requirements are robustness, precision, speed, and affordability[33], which eliminates many approaches. Almost all methods developed for head-coupled displays first find the head position, from which eye position can be estimated [31] or exactly located by finding the actual eye features in the head region.

There are many ways to perform optical head tracking with many applications, the most basic optical tracking is performed by a single static camera and can be roughly divided into global and local methods [33] [34]. Or using two Static Cameras adding stereo tracking, examples include feature based methods using epipolar lines [33], background subtraction followed by neural networks[35], and a method using infrared cameras with feature templates [36], or using a newer approach of a pan-tilt-zoom (PTZ) camera [38]. One PTZ camera can be used to cover a large space without loss of detail.

## Virtual Windows Concept

A promising new technology is proposed and developed to convert an electronic screen into a virtual window, by implementing a change in the view that takes place in the electronic screens for a given change in the viewing position of the observer. As a result of this movement parallax, not only do objects at a different distance within the view change their relative position, but also the window-view relationship changes, giving the user the illusion that he is looking through a window, while previous two-dimensional artificial windows - even when very carefully contrived- are unrealistic and soon cease to satisfy because they lack the parallax of window aperture-view [18].

The difference here in Virtual Windows technology is that it uses a real image or video rather than a virtual world or 3d image created by the computer, whereas in Virtual Reality the world is virtual and is generated by the computer, and the image is created, normally using Off-axis projection method when displayed on a head coupled display which is a rendering projection that takes into account the viewer's position and renders the correct view for that position. [29] [32].

One important study that used a static real image (not a live video) and tried to build a complete virtual window is applied by Adrijan Radikovic (2004); he called his study "A True Virtual Window", where he presented a new system using a head-coupled display and image-based rendering to simulate a photorealistic artificial window view of nature with motion parallax. And the evaluation data of the study obtained from human subjects suggest that the system prototype is a better window substitute than a static image and has significantly more positive effects on observers' moods. The test subjects judged the system prototype as a good simulation of, and acceptable replacement for, a real window, and accorded it much higher ratings for realism and preference than a static image. [18]

The same concept is tried and applied by Jonathan Clark, who published his work online. Jonathan Clark developed a system to show a recorded video rather than a static image of the scene, and he developed his work using high resolution video cameras that recorded the video of different scenes. [19]

Also the same concept of virtual windows that is produced by the head tracking is partially applied in different academic and commercial studies, as with the project done by Johnny Lee where he used a Wii-mote controller to track the head of the user and then to create a VR desktop system where the user can feel as if he is looking to a real window. [20]

### B. UGV Control Behaviors

Vehicle teleoperation consists of three basic problems: figuring out where the vehicle is, determining where it should go, and getting it there. Thus, to improve vehicle teleoperation, we need to make it easier for the operator to understand the

remote environment, to assess the situation and to make decisions.

In other words, we need to design the human-machine interface so that it maximizes information transfer while minimizing cognitive load.

Different studies used different techniques to add information to the user interface; some studies chose to use sensor fusion and sensors overlays (Combining readings from multiple sensors such as Video Camera, Stereo, Sonar and IR cameras... etc) [1] [2] [3]. While some other studies addressed the addition of Egocentric and Exocentric views so when the user look to the screen he can see from inside the vehicle and from outside the vehicle [4].

Another important information that can be added to the user screen is the orientation of the vehicle, which can help him in identifying the vehicle current state [5]. Some studies chose to display robot pose info, which is extremely useful especially with robots that can change their pose [6]

Some studies with longer distances and time delays employed virtual reality as a way of tele-operation interface [7].

also to many different smaller details of information that can be added, for instance: displaying the robot's reference frame and status, combining readings from multiple sensors, providing the ability to inspect it and automatically presenting contextually-appropriate information (e.g., showing a rear-facing camera when moving backward). While it can increase the user situational awareness, it might make the process of driving the vehicle, and this will contradict with our basic assumption in this study that decreasing the naturalness of remote control will decrease the performance of the operation.

Another important aspect of improvements that can really affect the performance of the operation is by designing a special control cockpit (the room or environment where the operator/driver sits) that makes the operation more natural and let the operator to feel more as if he is inside the vehicle.

Actually this improvement is much shared with the design and development of driving simulators where in both cases; the designer should focus on the feeling of being inside the vehicle itself by mimicking the motion of the vehicle in the cockpit itself [15]

Although this study is about teleoperation of UGVs, but there are many shared things between the cockpit of the operator and the driving simulators where they are both trying to make the user feels as if he inside a real vehicle and also driving simulators are studied extensively where their studies become largely used, allowing efficient and fast vehicle engineering vehicle design. Commercial off the-shelf systems are already available and permit experimentations with relative simulation validity. Further future works will make possible the everyday use of high fidelity driving simulators in the next years

The driving simulator has a broad range of applications. One can find driving simulators at driving schools, psychological research centers, amusement parks, car manufacturers etc. [16]

The most important step in teleoperation is using a head mounted display and a head aimed cameras that moves in the direction of operator's head, as with the studies of Massey, K. (2004), Massey, K. (2005), Massey, K. (2006). Yamauchi, B. (2006), Yamauchi, B. (2008), where they are developing technologies for immersive teleoperation and driver-assist behaviors. We should notice that immersive imagery is often the key to effective teleoperation [8].

Their immersive teleoperation system uses a head-mounted display and head-aimed cameras to provide the operator with the illusion of being in the vehicle itself. [10][11][12][13][14] Driver-assist behaviors will reduce the cognitive load on the operator by automatically avoiding obstacles while maintaining a specified heading or following a building wall or street.

They have demonstrated the immersive teleoperation on the iRobot Warrior UGV and a high-speed surrogate UGV.

Their studies are a great step in improving the remote control operation, where they have shown that head-aimed vision improves tele-operation mission performs between 200% and 400% [10], and by increasing the situational awareness of the operator they are able to extend the usefulness of small unmanned ground vehicles (UGVs) to a wider range of missions, and by reducing cognitive load on the operator, they are enabling the high-speed teleoperated control.

But the key problem with their solution is in the head-mounted displays which can make the remote operation less natural and thus reduce the effectiveness of it, also there are several problems in using Head-Mounted displays, for example a previous study found that an accommodation-vergence mismatch can create several problems for the HMD user - namely, eyestrain or visual discomfort, blurred symbology, and misperception of distance, size, depth, or speed of objects presented on the HMD, and several other problems that suggests that a further research is needed to replace this technology. [21]



Figure 2: Tele-operation using a Head-Mounted Display

		Head Mounted Displays	Head Coupled Displays
Virtual Reality			
Virtual Window	Static Image		
	Recorded Video		
	Live Video		
		<b>Our Work Is Here</b>	

Table 1: The location of our study compared to previous studies

### III. IMPLEMENTATION

#### A. Introduction

The goal of our research is to design a system that uses the virtual windows technology on the controlling Cockpit to enhance the way the driver use to control the UGV; this section provides the framework for using the virtual windows for this specific purpose.

In the literature review we can see that previous researches have designed a full virtual window [18] that is a view on a display that is as close as possible to the real view that would be seen if there was a window with the exact same dimensions and elevation as the display at the place where the scene was recorded, the difference in this research is that we need a custom virtual window that fits in the case of a controlling cockpit windows, and the driver.

We can notice the following differences required for our research:

1. The first thing is that the driver is setting in a fixed chair, so his movement is limited as he cannot step outside this place as compared to a normal virtual window where the user can move freely around the window (the display).
2. The second difference is that in our case the virtual windows should be live windows that broadcast the view from the cameras on the UGV directly to the screen display in front of the user/driver, whereas in the normal virtual windows the view is recorded from a specific place.
3. The third difference is that in our case the UGV can be moved freely to any place whereas in the normal virtual windows the scene is chosen from a specific place so the method is fine-tuned to match the characteristics of that place.
4. The fourth difference is that we need to convert three screens to a virtual windows (the front screen, and the two side screens) and the user position and orientation is different for each screen (the driver will be looking most of the time into the front screen, and he can look to the right and left screens if he turns around his head).

#### B. Supporting System

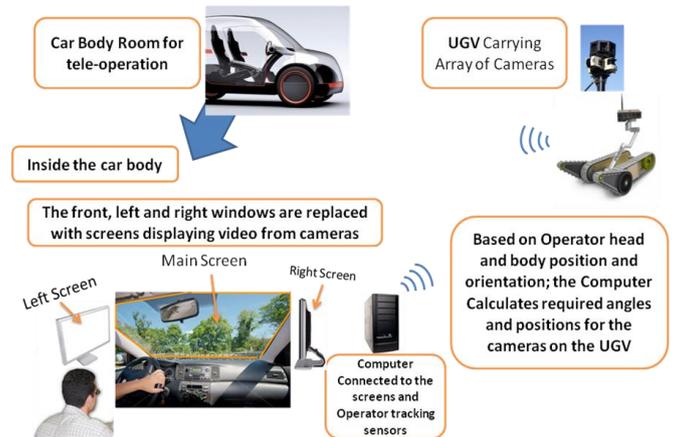


Figure 3: the supporting system design

#### The Vehicle Side

In this study, the following components will be used on the vehicle side:

- A low speed small RC car with petrol engine will be used as a small UGV with a remote controller that can be connected to a computer.
- Three wireless cameras will be mounted on the car, these wireless cameras can be rotated to any direction based on a wireless command sent by the computer.
- The three cameras will be mounted on a moveable base that can be rotated based on a wireless command, allowing a full 360 degrees movement; also each camera can be rotated up and down on its own.



Figure 4: Wireless Cameras on top of the UGV

## The Cockpit Side

In the driver side (the cockpit) the following components will be used:

- Three screens to represent the left, right and front windows of the car, they should be a high resolution screens to represent the virtual windows



Figure 5: Three screens surrounding the driver

- Head and body tracking component, which is a Camera and sensors, for instance: Natural Point TrackIR



Figure 6: Head Tracking Device

- Driving system (steering) where the driver can drive the car
- A computer connected to every other component of the system: the three screens, the tracking system, the driving system and to the transmitters of the Cameras and the vehicle.

### C. Off-Axis Projection with Live Video from Wireless Cameras

The basis of head-coupled displays is the Off-axis projection which is a rendering projection that takes into account the viewer's position and renders the correct view for that position.

In In off-axis projection the virtual viewpoint in the virtual world is aligned with the actual physical viewpoint of the user in the real world, whereas in on-axis projection (normal projection) the image projection plane is always considered parallel to the display surface[29]. The line of sight of the virtual camera is kept perpendicular to the

display by translating the camera without rotating it [32] (see Figure 7), whereas in on-axis projection (normal projection) when the observer is off the central viewing position, the virtual perspective image on the display is already seen in perspective in the real world. The compounding of perspectives results in a distorted image seen by the observer.

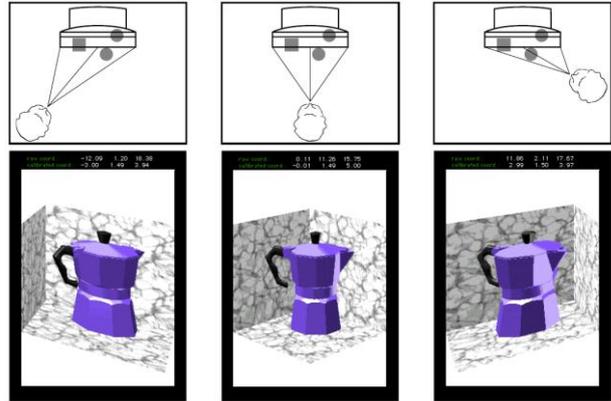


Figure 7: Off-axis projection

The off-axis projection matrix needs to be adjusted for each viewer and change with the viewpoint in order to obtain accurate images [29].

The difference in our work is that we are going to show live video from wireless cameras and project them into the screens in the driver cockpit, and the key principle here is to find the cameras right rotation angles based on the operator's head position, to achieve the off-axis projection here the rotating disc below the three wireless cameras should simply turn in the same angle of the operator perspective looking angle



Figure 8: The wireless cameras rotation angles are exactly the same match of the operator's perspective angles

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