Virtual Eye: A Sensor Based Mobile Viewer to Aid Collaborative Decision Making in Virtual Environments

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***Abstract*— Current virtual simulation techniques often include multi-user interactivity in virtual environments that can be controlled in real time. Such simulation techniques are mostly employed in virtual military training sessions and in real time gaming experiences, where users have to make more strategic decisions by analyzing the information they receive, in response to the actions of the other users in the same virtual environment. Generally, in the real world, collaborative decision making takes place when a team of people work together to control the behaviour of a single object which cannot be handled alone by an individual. A ship with its crew can be held as an example. When applying this scenario into virtually simulated environments, multiple users have to involve in representing a single object in the virtual world. These users need to obtain sufficient information about the activities in the environment that will contribute to the collaborative decision making process. Out of many sources, visual information is the most reliable source the users tend to depend on. The use of traditional static displays to obtain visual information limits the capability of providing a rich set of information about the 3D environment. Head Mounted Displays address these limitations while introducing several new problems. On the other hand, our work is focused on exploring how smart devices can be employed by a collaboratively working team of users to obtain visual information to the level beyond which a static display provides, thus aiding the process of decision making. To serve the above purpose, we propose a solution, "Virtual Eye", which uses a smart mobile device with the ability to view the visual output of the virtual world and the ability to control that view according to user's orientation changes and movements with the use of its inbuilt sensors.**

***Keywords*— Virtual reality, collaborative decision making, mobile, sensors, streaming**

I. INTRODUCTION

During the past few decades, the advancement of technology has been able to facilitate the simulation of real world scenarios in virtual 3D environments, providing users an experience equal to what they face in the real world. Multi-user interactivity is a common feature which is available in such simulated environments that model behavioural changes according to users' actions. In this context, users have to make more strategic decisions by analyzing the information they receive, in response to the actions of the other user objects in the same virtual environment. These simulation systems are mostly used in military training and in gaming sessions where the user interacts with the virtual environment in real time.

To present the user with the most realistic experience, the virtual worlds should not only model the real-world scenarios but also simulate the real-world interactions between virtual entities. To develop the idea further, a real-world situation can be taken into consideration, where a team of people is working towards achieving a common goal. In such a situation the team needs to make collaborative decisions based on the information obtained by each member of the team. If this situation is to be modelled in a virtual world, a similar experience of collaborative decision making should be provided to the users. For example, in a virtual simulation system which models a maritime environment for a ship, it should provide a real experience to the team of users who controls the virtual ship. This experience should be equal to that of an experience of a real ship crew where there are lookouts watching over for the obstacles (such as enemy boats), helmsmen navigating the ship and several other members operating on various devices providing information that aids the collaborative decision making process regarding the behaviour (i.e. navigation, firing, etc.) of the ship.

When modelling such a collaborative environment virtually, multiple-users may represent a single entity (e.g. a ship) in the virtual world as a team, where supportive users assist the other users in the team to navigate the virtual entity and to take actions on behalf of it. The assistance is offered by providing information about the activities happening in the environment. Visual information is one of the most reliable sources of gathering such supportive information. Similar work in the literature have regarded the concept of “being there” in a virtual world with the use of visual information [2] and the sense of collaboration with real people [3]. But, none of them have proposed any methods of *providing* enhanced visual information which will be used by the supportive users in a team to aid collaborative decision making.

Head Mounted Displays have succeeded in providing rich visual information of the surrounding virtual environment by changing the visual output according to the user’s angle-of-look. But in some military and gaming simulation systems, the use of Head Mounted Displays can be less preferable over the conventional static displays due to ergonomic conditions [9] as well as cost [10]. In simulation systems that use static displays, it is difficult for multiple users to interact with the virtual world more flexibly. This paper discusses the work carried out focusing on solving the problem of gathering visual information from a virtual world, beyond the limit that a static display can provide. In the succeeding section we discuss how smart mobile devices can be utilized to fulfil the task of decision making by providing the required visual information. Section 3 describes the architecture and design details of the “Virtual Eye System”, which was implemented as a proof to the concept we bring out in this paper. Furthermore, Section 4 examines the related work that has been carried out prior to this research, while section 5 concludes and presents the possible future work.

II. SMART DEVICES AIDING COLLABORATIVE DECISION MAKING IN VIRTUAL ENVIRONMENTS

A. *Importance of Information in Making Decisions*

When making decisions in virtually simulated environments, such as those that are used for training and gaming purposes, accurate and timely decision making is vital. Thus it requires sufficient and reliable information on the actions of other user-represented entities and incidents in the surrounding environment. Therefore, the reliable information gathered from various sources is important for a user to choose a course of action to be performed next.

The information can have many forms, such as visual, audio, GPS or Radar based location information. Out of these forms, people tend to rely more on visual information when taking decisions. Thus, in this context, the ways of interacting with the virtual world to obtain visual information become significantly important.

B. *Use of Smart Mobile Devices to Obtain Visual Information*

As shown in Fig.1, the use of conventional static displays to obtain a view of the virtual world to the users, limits the visual information flow from the virtual world. To address this issue, as a low cost and a flexible display, a smart mobile device can be presented as a viable solution. The display of the mobile device can accommodate the visual output of the virtual environment while using its inbuilt sensors to obtain the orientation and motion changes of the user. Hence, rather than providing a birds-eye view, a smart device can map the user into the virtual world by being his “eyesight” to the world and by reflecting his physical orientation changes effectively, providing an immersive experience.

With the capabilities described above, a mobile device can provide a rich set of visual information more flexibly within the range of a surrounded 3D sphere as shown in the Fig. 2. To facilitate this functionality as well as to test the concept, we have currently developed a system named “Virtual Eye”. Virtual Eye allows a smart mobile user to view the visual output (i.e. the virtual camera output) of a virtual world and to update the virtual camera angle according to the changes of his orientation, thus updating the current view of the virtual world. This basic model can be further developed into a virtual telescope, extending its features. In the forthcoming section the “Virtual Eye System” will be discussed in detail.

C. *Collaborative Decision Making with a Smart Mobile Device*

When several users collaboratively work as a team to control a single entity, users share information among themselves in order to make collective decisions regarding the behaviour and actions of the entity. In an example scenario of a maritime ship simulation environment, the crew should collaboratively work to control a virtual ship entity. The crew may consist of members who steer the ship, get information from other equipments such as Radar, Sonar, AIS, and lookouts who report anything they detect in the sea with the help of telescopes. The information from supporting users will be needed to the person who steers the ship to take decisions regarding the route of the ship. Such information from the supporting users is utilized by the other users in the team to take strategic decisions. This is more realistic when multiple ships are handled by multiple crews during a training session. In that situation, Virtual Eye powered mobile devices can be used by the lookouts as virtual telescopes to provide visual information regarding the other ships and obstacles in the environment, so that a trainee officer can take better decisions regarding the route of the ship.

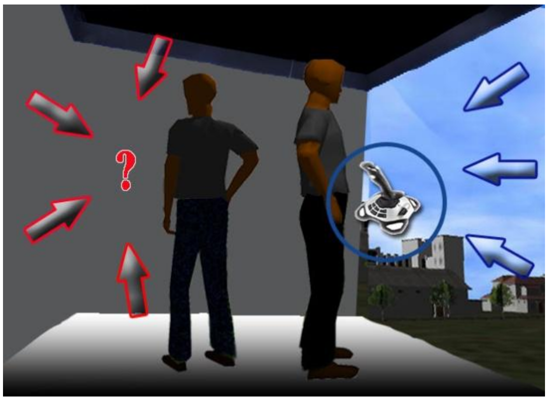

Fig. 1 Main user view which is limited by a static display

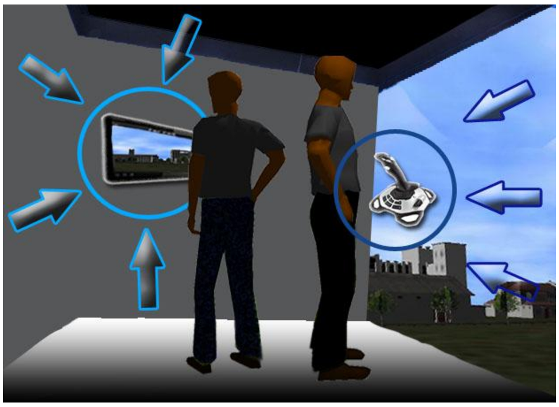

Fig. 2 Supportive user providing visual information with a smart mobile device

III. The Virtual Eye System

A. Architectural Design

The architecture of the Virtual Eye system is built upon a client-server model, bridging the client-end smart mobile device and the server-end rendering engine via a 2-way communication channel. The overview of the proposed architecture of "Virtual Eye" is presented in Fig. 3.

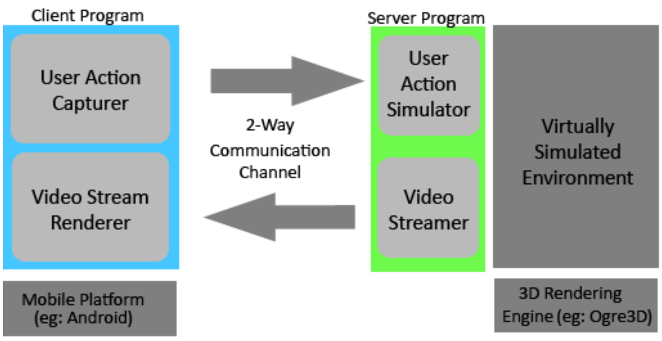

Fig. 3 Architecture of Virtual Eye

The client-end of the Virtual Eye architecture is facilitated with a smart device with motion sensing capability. In the server-end of the proposed architecture, a Virtually Simulated Environment is deployed on top of a 3D rendering engine. The server program of the Virtual Eye system, which runs on the same computer as the rendering engine, plays the role of the man-in-the-middle to facilitate the client-end interaction with this Virtually Simulated Environment. This modular nature of the server program allows the client to interact with various virtual environments interchangeably, requiring minimum modifications to the server program.

Inbuilt sensors in the smart device at the client-end, specifically the accelerometer and magnetometer sensors, are supposed to capture the orientation changes of the user from the real world. These captured data and the other user inputs are sent to the server-end, where the server program simulates them as user actions in the virtual environment. Apart from the orientation changes, the user inputs, such as zoom in/out, plays a major role in providing the functionality of a virtual telescope. According to the simulated actions of the user, an updated view of the visual output from the virtual environment is captured by the server program and streamed back to the client-end. The client-end renders this video stream and displays the telescopic view of the virtual environment. This user action simulation in the virtual environment and the accordingly updated visual output offers an immersive virtual telescopic experience that is similar to a real telescope in a real environment.

The underlying infrastructure of the 2-way communication channel, which bridges the client-end and the server-end, is facilitated by a 3G or Wi-Fi connectivity. This communication channel is capable of handling multiple client requests in parallel. To keep an effective interactivity with the virtual environment in real time, it is essential to have a ceaseless and a smooth video stream of the visual output from the virtual environment. To achieve this via the proposed 2-way communication channel, several video streaming methods and codices were considered. However given the limitations in network and smart devices in terms of network throughput and graphic rendering capability, the choice had to be an MJPEG video stream; a lightweight stream of images which can directly be displayed by the smart mobile device.

B. Realizing Real Time Motion Detection and Telescopic View

One essential feature in the Virtual Eye client is the detection of motion/orientation of the user in order to change the view point (i.e. the virtual camera angle and the position) of the virtual world. This feature provides the feeling to the user that he is actually inside the virtual environment. Inbuilt sensors on the device continuously capture motion and orientation changes. After the captured sensor readings are filtered to provide smoothness, they are sent to the server side to be simulated in the virtual world.

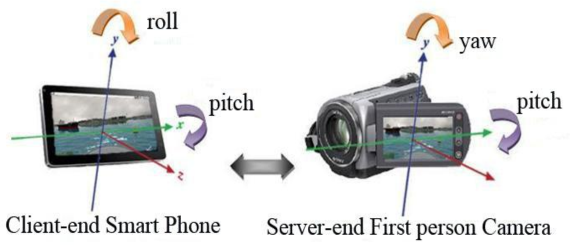

Fig. 4 Motion Mapping

As illustrated in Fig. 4, the rotation of the smart mobile device around its horizontal and vertical axes is mapped with the rotation of the first person's camera at the rendering server, around its horizontal (pitch) and vertical (yaw) axes correspondingly. The accuracy of the sensors should be high, such that the view of the virtual world should be static during the intervals where the user stays still. It is necessary to filter the jitters and the outliers to get such accurate sensor readings.

$$\text{Reading}_{old} = (\text{Reading}_{new} * \alpha) + (\text{Reading}_{old} * (1 - \alpha)) \quad (1)$$

where, $\alpha = t/(t+dT)$ and t = low pass filter's time constant.

We use the equation (1) [11], to implement a low pass filter in the client-end to omit the negligible sensor data from the sensor readings. Furthermore, the consecutive readings are being averaged to get a smoother stream of sensor readings. We believe that the accuracy of the readings will improve in the future when more powerful inbuilt sensors become available.

Another essential feature in the Virtual Eye client is to render the video stream sent from the server, which corresponds to the camera output of the virtual world. By carrying out some slight modifications to the source code of the virtual world, the camera output can be taken as a telescopic view with the zooming functionality.

"Optics" was the methodology used to obtain this telescopic view of the virtual world. In the real world we can clearly define a light path; hence we can use the focal ratio to determine how far the visual field can span. Refractor Telescopes use a convex lens as the objective to gather, bend and focus the light at the eyepiece. Equation (2) gives the magnification of a real world convex lens.

$$\text{Magnification} = \frac{\text{Telescope Focal Length}}{\text{Eyepiece Focal Length}} \quad (2)$$

But in a virtual world we cannot define a light path to implement a telescope logic using focal ratios. As mentioned earlier, the Virtual Eye rendering server is built upon a virtual first person camera. The camera is the same as its real-world analogy: it "takes a picture" of the scene in each frame from a particular vantage point. That camera has a "field of view" with near and far clipping planes. This process defines a frustum, which has the shape of a pyramid with the point chopped off, as depicted in Fig. 5 [13].

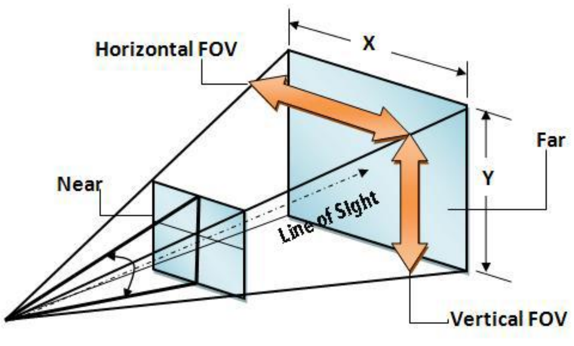

Fig. 5: Camera Frustum

Following that concept the real world optics can be brought into a virtual world using the Equation (3) [12].

$$\downarrow \text{Field of View (FOV)} = \frac{\text{Apparent FOV}}{\text{Magnification}} \uparrow \quad (3)$$

There are two ways to calculate the true field of view (FOV) in degrees from a combination of a telescope and an eyepiece. An easier method can be to divide the apparent field of view (AFOV) of the ocular by the magnification of the system. The AFOV for almost all eyepieces is provided by the manufacturer and it is easy to define the magnification as a constant factor. Using the equation (3) we can calculate the field of view of the camera according to different magnification levels. By decreasing the fields of view of the camera, we can zoom the surrounding objects in the virtual world.

C. Multi-user Interaction

The application "Virtual Eye" acts as an interface for multiple users who are interacting with the same virtual world at the same time, controlling one shared object to achieve one goal. This facility to collaboratively work with multiple users enriches the real world feeling, as all the users are interacting with the shared simulation environment as a group. Here each and every user gets their own instance of the camera in the virtual world, which can be controlled by the user according to his real world motion changes. Thus one user's behaviour in the virtual environment will not affect the other users who are interacting with the same object at the same time.

D. Applications of Virtual Eye

Real world applicable scenarios for Virtual Eye vary in many areas such as training simulations, multi-player games, virtual tour guides and etc. One such appropriate scenario is using it in the process of making strategic decisions in virtual simulated environments. In the context of multi-user environments, supportive users can assist the other users by providing information about the changes that happen in real time.

The concept being discussed so far was tested with Vidusayura; a Maritime Training Simulation System [8]. We applied Virtual Eye as the missing Nautical Telescope in Vidusayura. When it comes to the typical ship simulation training system, visual information obtainable for the main user (helmsman; the man who steers the ship) is limited due to the conventional static display available at ship simulator. Thus, the main user lacks information to make the decisions regarding his next move. But when it comes to a situation where a supportive user who has the Virtual Eye system can assist the helmsman, providing him necessarily the information about the facts that are currently unnoticed by him, it makes the decision making process more accurate and collaborative. Since the Virtual Eye system uses a separate device to operate, which does not harm the main view displayed on the screen, it was flexible to be integrated with Vidusayura with minimum modifications made to the code of the virtual world.

Although Vidusayura is a military training system, the use of Virtual Eye for the process of collaborative decision making extends beyond virtual military simulations. Another useful scenario of applying Virtual Eye is for multi-player gaming environments. As each movement of a game is imperative to not to lose the game, all the players should be aware of the visual information they are gathering from the virtual environment. Since the game controllers and static displays are physically distinct, and to view the hidden areas in the static display a controller input is necessary, the gamer has to do several tasks simultaneously before heading to the next movement. But when it comes to Virtual Eye, it is capable of providing multi-axes 360 degrees view of the scenery as well as the user input handler which can function as the game controller. Hence Virtual Eye makes it faster for a user to obtain visual information while controlling the game concurrently. This would lead to faster decision making throughout the game play.

IV. Related Work

Collaborative Virtual Environments are the most widely used training tactic at present, for the purpose of team training with a proper sense of interaction and collaboration. These systems are intended to work with individual and collaborative activities related to the user's social, intellectual and cognitive tasks [1]. Information sharing through interactions and making decisions based on the information shared, are the core of Collaborative Virtual Environments. Interactions between users can be achieved through audio and video communications such as voice, gesture and text commands. To obtain improved decision making skills, the real world should be mapped with the shared virtual environment. The notion of presence or the feeling of "being there", with the co-presence or the feeling of being "in the same place with other participants" completes that mapping process. As described further in this section, several researches had been conducted to observe the relationship between the sense of presence and decision making in dynamic environments used for collaborative training. Our goal, however, was to bring out a method of providing visual information to facilitate the aforementioned process of decision making in a Collaborative Virtual Environment.

According to the findings of a research conducted by the London University [2], the level of presence in a Collaborative Virtual Environment is positively associated with humanoid-like virtual actor that would be following the subject or the main user wherever he moved in the Virtual Environment.

Another work in the literature had been conducted with two main user groups that work separately in a Low Collaborative Virtual environment and a High Collaborative Virtual Environment [3]. Each group has been divided into two smaller sets, to observe the influence of presence and co-presence in these environments. According to the results, they have revealed that the co-presence score in the High Collaborative Virtual Environment was higher and there is a positive relation between co-presence and collaboration [3]. Edwin Blake [4] has also conducted a research to see the relationship between co-presence and the facial expression of avatars (co-users) towards the group interaction during activities.

Daniela M. Romano et al. [5] had conducted a research to inspect whether there is a relation between decision making and the notion of presence in a high risk Collaborative Virtual Environment. A well-known multi-participant desktop virtual game has been used to observe to what extent the participants feel "present" in an environment with only visual and auditory information. He believes that the construction of a shared dynamic virtual environment with similar settings of the game could be used for training of collaborative naturalistic decision making skills.

Another research context was based on the stream of sensory input, organized by its own perceiving systems to emerge the sense of being in the world [6]. One of the most important research findings, with respect to this research was that, audio feedback is perceived to be one of the most important features that engender a sense of presence while performing tasks.

Thus, various tactics have been used to improve the notion of presence and co-presence of the Collaborative Virtual Environments while performing activities. Smart mobile devices have become a primary necessity among the general population to date. Those ubiquitous computing devices posses a large potentiality to be used as devices with multi-sensory and display capabilities to provide interactivity. A group of researchers had proposed their approach [7], which uses the motion flow information to estimate the relative motion of a handheld device while interacting with a large display. The proposed interaction techniques can be further combined with many auxiliary functions and wireless services for seamless information sharing and exchange among multiple users. Virtual Eye, on the other hand, integrates the multi-user smart device interaction techniques with virtual environments to bring out a method for decision making in a collaborative, team-based environment.

V. Conclusions and Future Work

Visual information gathering in a virtualized environment with smart mobile devices has the potentiality to be a highly beneficial area. In this paper we propose the aforesaid technique to aid the process of collaborative decision making in a virtually simulated team-based environment.

Our concept can be extended to achieve the notion of presence not only by a supportive user as an information gathering device, but also by any user who can use it to gather information himself in critical environments such as high risk training simulations, virtual tour guides and gaming environments. Some of the ubiquitous computing devices can be used to model useful devices in a virtual environment, such as a telescope, compass, GPS locator, radar and etc. They can also be used as improved displays with a wider field of view and can be used to provide input to and outputs from the virtual environments with higher accuracy. Such representation of a real device in a Collaborative Virtual Environment can enhance the decision making process among a team of users. Further, the wireless capabilities in mobile devices can be used to share information among multiple subordinate users in the virtual environments such as military trainings, naval trainings and gaming environments.

Conducting a user test in the future may be helpful to evaluate users' perception when they are using Virtual Eye in a collaborative ship simulation system, in contrast to the real world maritime environment. Here, the test can be performed by providing users with several test scenarios in which collaboration among users is needed to reach their final goal. Thus the outcome can be measured on how users will react in critical decision making points that have been defined at the test scenarios.

Another user test can be performed to examine how far users experience the realistic feeling when they are using the Virtual Eye as the nautical telescope in Vidusayura, compared to a nautical telescope in a real ship.

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