Aryabrata Basu

Research Statement

"Every great advance in science has issued from a new audacity of imagination." - John Dewey, The Quest for Certainty, 1929

Origins

The year was 1993, and I was excited to visit my uncle Debabrata for he has promised to show me a Personal Computer (PC) with the original Pentium (P5 microarchitecture) microprocessor. As a third-grader, all those specifications meant little except for one aspect of PCs, which is video-games or better known as DOS-Games back then. He showed me all his collection of DOS-Games one by one, and the amazing thing about those games was the human-computer interaction of a video-gaming experience. The notion that a few keystrokes can manipulate virtual characters, vehicles, etc., in real-time still amazes me to this day. This sparked a lifelong appreciation for digital visualization via Computer Graphics. My current research interests have taken me far from those joyful days of video-gaming to creating experiential simulations of places that don't exist or hyper-realistic spaces in an effort to understand human behavior in space-time.

Motivation

Virtual Reality (VR) is the art of substituting real-world sensory information with artificial stimuli such as 3D visual imagery, spatialized sound, and force or tactile feedback and packaging it all together inside a virtual environment (VE). In 1968, Ivan Sutherland implemented the first VR system that allowed users to occupy the same space as virtual objects using wireframe graphics and an Head-mounted display (HMD). Since then, the VR community has advanced the quality of computer-generated graphics, built sensors to update the user's viewpoint (head gaze) inside the VE, and implemented high-end spatial audio playback capability. However, more recently VR systems have become more prevalent due to the adaptation of mobile communication platforms (smartphones) as immersive displays and video-gaming devices, such as gamepads, as controllers. These new generations of VR systems have enabled us to deploy highly immersive and portable virtual experiences outside of controlled laboratory settings.

There have been very few research studies that have looked into usability and acceptance of such ubiquitous VR systems by general audiences. Furthermore, the current design trends of ubiquitous VR systems do not address the core issues of VR usability, such as simulator sickness and user encumbrances, leading us to the conjecture that the majority of users may not yet accept VR systems. We take the term *immersive* in VR to refer to a VE which appears to surround the user's peripheral vision. Applications of immersive VR have developed significantly over the span of the

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last decade. From immersive molecular modeling to manifold composition visualization to evaluating travel techniques to building trust in human interactions to performing laparoscopic surgery, many research projects and applications have leveraged immersive VEs as the basis of their studies. The core of preparing any immersive VR experience falls back to drawing a VE with the perspective of the user at a fast update rate and a high resolution. The user is then able to manipulate the content of the VE by interacting with it in VR. Currently, to have an effective VR experience, the user needs to wear multiple hardware interfaces/devices.

A traditional immersive VR system deployed in a laboratory setting would include the following setup: (1) a HMD or a rear wall projected display like CAVE that displays the VE (2) a tracking system that tracks the user's physical movement mapped onto the VE. Historically, a VR setup of this sort suffers from issues of high infrastructure maintenance, poor deploy-ability, and scalability. User encumbrance issues, such as being tethered to a limited tracking area, results in a lesser range of movement for the user using the VR system. From a user experience standpoint, a higher number of hardware interfaces introduces fatigue due to increase in overall weight of the system and induces cyber-sickness resulting in decreased usability thus leaving the users with less motivation to continue having the immersive experience.

Position tracking of users in VR is limited to availability of physical space by design and it requires higher demands on infrastructure. One way to solve these issues is to facilitate user input using an array of available human interface devices (HID) including keyboards, mice, trackballs, touchscreens, joysticks, gamepads, motion detecting cameras, and webcams. Some of these HIDs have also been introduced for non-immersive video games and general computing. Due to this fact, a subset of VR users has greater familiarity than others in using these HIDs. VR experiences that utilize gamepads (controllers) to navigate VEs possibly introduce a bias towards usability among VR users previously exposed to video-gaming.

Because of the increasing prevalence of ubiquitous VR systems, we need to design and evaluate comprehensive, immersive ubiquitous VR experiences that acknowledge the existing usability bias amongst immersive VR users. Furthermore, we need to understand better how extrinsic factors play a role in affecting user performance in an immersive VR experience using such ubiquitous VR systems.

Research Philosophy

New generations of VR systems have enabled us to deploy highly immersive and portable virtual experiences outside of controlled laboratory settings. However, there have been very few research studies that have looked into usability and acceptance of such ubiquitous VR systems by the general audience. Furthermore, the design of ubiquitous VR systems does not address the core issues of VR usability such as simulator sickness and user encumbrances leading us to the conjecture that VR systems may not yet be accepted by the majority.

My dissertation discusses our work involved in the design and evaluation of both custom designed and commercially available ubiquitous VR systems, and revealed issues that may better inform future research and design.

Previous Work

My dissertation includes the following contributions:

- The Ubiquitous Collaborative Activity Virtual Environment (UCAVE), a framework conceptualized with universally accessible technology to enable untethered and portable VR experiences.

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- Designing and evaluating VR user studies in order to further evaluate ergonomic, environmental, human, and technical factors affecting users in immersive VR experiences.

- Understanding the core impact of deploying immersive VR experiences via HMD technology on user trajectory patterns (behaviors) in solving a spatial navigation problem inside VR.

Our work focused on implementing low encumbrance ubiquitous VR systems for everyone. We began to conceptualize mobile VR systems that are portable and could readily put someone into immersive VR. In our pursuit of a mobile VR design, we incorporated a light-weight HMD device connected (wired) to a smartphone to build a wearable display that one can wear quite comfortably. Once immersed, the user interacts with the content by rotating their head naturally to look around inside the VE. Such form of head-rotation based interaction is made possible by the software on the smartphone that renders each frame of the VE synced to the sensor responsible for detecting pan and tilt motion of the smartphone. We added real-time hand tracking to provide direct means of interaction inside VEs. We call this paradigm of portable VR setup "the UCAVE". The idea of personalized VEs that are shared with many users became the baseline of our design philosophy.

Next, we conducted a series of formative user studies to evaluate our UCAVE platform and gained valuable user feedback. Our first study explored the ergonomics of an immersive VR setup by studying whether the presence of a perceived tether affected user performance in immersive VR. Our findings from this study established the need for an untethered immersive VR apparatus. Once we achieved a level of sophistication in our system design, we then focused our attention on studying environmental factors by creating VEs to match indoor/outdoor real-world settings relatively. Our findings from this study showed significant difference in user performance whether the VE matched real-world environment or not. Furthermore, we noticed that a matched outdoor setting (outdoor as physical space and outdoor as the VE) seems to be the best performing setting for participants. We were encouraged by our previous results and turned our attention to human factors affecting user performance in immersive VR. We considered self-reported physical fitness as our metric for evaluating user performance. Our findings from this study showed no correlation between perceived physical competence and user performance in immersive VR. However, this study established the need to look into the gaming profile of VR users as a predictor of success in immersive VR experiences. Taking our findings from studies exploring ergonomic, environmental, and human factors, we proposed our final user study designed to examine the influence of technical factors affecting user performance in immersive VR. We aimed explicitly at exploring immersive versus non-immersive 3DUIs affecting user performance. Our findings from our final study revealed usability bias amongst participants who are also video-gamers because of their familiarity with the gamepad interface. This subset of participants solved the maze more quickly than non-gamer participants. We also found a significant statistical difference in user behavior between immersive and non-immersive VR experiences.

These findings taken together provide meaningful contributions to both users and designers in the VR community.

Research Goals

The contributions of this work have an immediate impact—immersive VR applications can be deployed in an unconstrained fashion with better accessibility to a larger population at a fraction of cost as compared to traditional VR setup.

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Reducing cybersickness
One of the current barriers to widespread acceptance of VR technology has been primarily the issue of Cybersickness. Cybersickness exhibits symptoms that parallel symptoms of classical motion sickness. I believe that having a light-weight VR apparatus such as the UCAVE system helps in solving the weight encumbrance issue. I plan to explore the variation in Cybersickness in future study design based on various configurations such as weight, the complexity of user task model, and amount of head rotation involved in an immersive VR experience.

Tracking spatial navigability
Whether or not going through an immersive virtual experience of maze navigation helps users to be better navigators of mazes is an important research question. I believe having a light-weight VR apparatus such as the UCAVE system allows users to focus more on the spatial navigation task by lessening their cognitive load due to other extrinsic factors. To be able to track the subsequent progress of users ability to navigate mazes, a longitudinal study design is needed. I plan to explore the progress of spatial navigability skill in future study design based on varying complexity of mazes ranging from easy to hard.

Reducing usability bias
I have observed in our last study that prior video-gaming experience has a dominant effect on user performance when it comes to spatial maze navigation using gamepads or game-controllers. I believe that this effect is prominent mainly due to the high familiarity of VR input device such as the game-controllers. I plan to explore other input devices which are less familiar as a gaming input device in the hope of normalizing the existing gaming bias amongst VR users.

Investigate user acceptance model
In the VR community, previous work exists that have looked into Technology Acceptance Model (TAM) and its applicability to the use of VR in clinical setting. In the light of our lasty study's findings, we plan to explore TAM towards a better understanding of user acceptance criteria for ubiquitous VR applications.

Model spatial navigability in VEs and analyze its governing dynamics
I have observed in our last study that our participant's spatial navigability predicts (to some degree) their chances of solving the maze successfully. I have been taking a deeper dive into analyzing human spatial navigability and distilling it into dynamic parameters (observed and derived). I intend to employ Neural Networks and harness the power of Machine Learning algorithms to investigate other hidden parameters to spatial trajectories. Some of the preliminary observed and derived parameters are as follows:

- Distance traveled: It is the total length of the path traveled between two positions.
- Coverage: Total number of unit cubes covered (area).
- Number of decision points reached: Total number of decision points covered in the maze.
- Positional Curvature: The signed angle of curvature between two consecutive position vectors.

- Head rotation amount: The unsigned head rotation angle between two consecutive rotation transforms.

Closing Statement

The world of Computer Graphics and Human-Computer Interaction has no shortage of challenging and hard problems. I look forward to solving some of them to shepherd public scholarship through meaningful 3D visualization and effective human-computer interaction.

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