Body and Gesture Tracking, Representation and Analysis: Implications for HCI, Human Motor Function & Virtual Human Action

1. Research Team

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2. Statement of Project Goals

This User Centered Sciences (UCS) area has multiple projects with unique goals. These involve:

- Gestural HCI – This project aims to design, develop and evaluate a hand gesture based language for enhancing human computer interaction across multiple media formats and display systems in collaboration with the IMSC 2020 Classroom Research Theme. The research in this area will also have impact on user interface components across a wide spectrum of IMSC research areas.

- Vision-Based Tracking – This project aims to create a vision-based tracking system in collaboration with Prof. Ram Nevatia and Prof. Isaac Cohen that could be used for tracking, representing and quantifying human motor performance. Advances in vision-based tracking technology could form the basis for the capture and recognition of human action required for the creation of multimodal HCI options that utilize gestural behavior. This technology could also have significant impact on applications that target gait analysis and motor rehabilitation.

- Body Gesture and the Expression of Emotional State in Virtual Human Representations – This project aims to investigate human capacity to decode the communication delivered via body action in virtual human representations (avatars/agents). Previously, IMSC UCS research has examined the factors that contribute to successful detection, by human users, of emotional facial expressions conveyed by avatars actuated using Performance Driven Facial Animation [1]. The current work has expanded to investigate similar issues for full body non-verbal expression of emotion.

The knowledge gained from these projects will drive the integration of UCS methodologies in the design, development and evaluation of IMS that incorporates gestural interaction with both standard magnetic tracking and vision-based systems. This work could also have wider generalizable value for creating the enabling technology required for development of multimodal and perceptual user interfaces (PUIs). The goal here is to replace current human-computer input modalities, such as mouse, keyboard, or cumbersome tracking devices and data gloves, with multimodal interaction and PUI approaches to produce an immersive, coupled visual and audio environment. The ultimate interface may be one which leverages human natural abilities, as well as our tendency to interact with technology in a social manner, in order to model human-computer interaction after human-human interaction. Recent discussions on the incremental value of PUIs over traditional GUIs suggest that more sophisticated forms of bi-directional interaction between a computational device and the human user has the potential to produce a more naturalistic engagement between these two complex “systems”. This enhanced engagement is anticipated to lead to better HCI for a wider range of users across age, gender, ability levels and across media types.

3. Project Role in Support of IMSC Strategic Plan

As the underlying enabling EE/CS technologies continue to evolve and allow us to create more useful and usable Integrated Media Systems (IMS), a continuing challenge involves the design of innovative and more naturalistic user interfaces. As well, the development of computational devices that have the capacity to sense human user facial and gestural actions (from which user state inferences are made) and use of this information to support better interaction and engagement between a user and IMS scenarios is a desirable goal that is in line with the IMSC mission. Advances in our capacity to track, represent and analyze human motor action will also serve to drive IMSC application development that could have significant positive impact on society via applications designed to address motor training and rehabilitation. Further, the “populating” of these environments with believable virtual human representations is a desirable goal for enhancing user “presence” for a variety of IMS interaction and communication purposes. Whether virtual humans represent real humans in real time or are programmed entities with some level of artificial intelligence (agents), the incorporation of “believable” virtual human representations into IMS, that both look and *act* like real people, is a vital research direction across the IMSC strategic plan.

4. Discussion of Methodology Used

Multiple methodologies have been employed across the projects in this area. For the Gestural HCI project, we conducted an informal evaluation that involved the observation of naturalistic gesture commands emitted by 38 users. The sample that was observed comprised of 18 male and 20 female participants with ages ranging from 19 to 68. Users were presented with 31 stimulus slides that contained screen captures across 4 different media types and requested users to “Use what you feel is the best hand gesture for signaling” a certain common command (Figure 1). Twenty-one common commands were selected to represent HCI activities that are typically performed in normal practice using a mouse and keyboard. User gestures were noted and following the standard administration of the stimuli, users went through the commands with the investigator and discussed the rationale for their chosen gestures.

Figure 1. Examples of Stimuli for Naturalistic Gesture Study

This provided a wealth of initial material to initially guide our development of a hand gesture interactional language that will be tested more formally with users wearing six degree of freedom tracked sensor gloves. The user issues to be investigated in this research will require a series of controlled studies that target many factors related to the usability and usefulness of our evolving gesture-based HCI language. Such factors include: learn-ability, throughput, fatigue, preference, media types, scale of display, commands, age/gender and the relative value of gesture behavior compared to voice interaction for certain commands.

The programming of these gestural commands is currently being done in collaboration with Prof. Cyrus Shahabi's laboratory and one of the primary IMSC research areas that has driven this work is the 2020Classroom project headed up by Prof. Chris Kyriakakis. In support of this research area, UCS has formulated a series of design questions to guide future application research development in the area of education. These questions combine elements of a cost/benefit analysis with a user-centered design perspective that serves to highlight key issues in advanced educational IMS design. These are briefly summarized in abbreviated form:

Can the same objective be accomplished using a simpler approach?
An initial task and requirements analysis is the first step to justifying that a given IMS application can serve a useful purpose beyond what currently exists with traditional educational methodologies. This is an area that can be addressed with the use of heuristic evaluation methods with expert educators, perhaps using focus group and survey methods.

How well do the current IMS assets fit the needs of the educational task or objective?
While similar to the first question, this step requires true collaborative interdisciplinary efforts to integrate the expert domain-specific knowledge of both educators and IMS technology specialists. This stage requires the development of an initial set of procedures that can be tested with users during the next step in the design process.

How well does the IMS approach match the needs and characteristics of BOTH the targeted educator and student user group?
This involves a series of tight, short heuristic and formative evaluation cycles conducted on basic components of the system. Consideration of user characteristics in this fashion is now standard practice in IMS development [2]. A clear example of the effectiveness of this approach in promoting usability (and learning) can be seen in the thoughtful work of Brown et al. [3]

incorporating input from tutors and students with severe learning disabilities in the design of life skill IMS training scenarios.

Will target users be able to navigate and interact within the system in an effective manner?
The challenge here is to make interaction and navigation within IMS educational environments as seamless, intuitive and naturalistic as possible. This challenge is particularly relevant since in order for users to be in a position to ultimately benefit from an IMS application (usefulness), they must be capable of learning how to navigate and interact with objects and processes within the IMS environment. Even if a user is capable of using an interface system at a primitive level, the extra non-automatic effort required to navigate and interact can serve as a distraction and limit success in achieving the targeted educational objective. In this regard, Psotka [4] hypothesizes that facilitation of a "single egocenter" found in highly immersive interfaces serves to reduce "cognitive overhead" and thereby enhance information access and learning.

What is the potential for side effects due to interaction with the system?
The potential for adverse side effects due to extended use of IMS needs to be considered for both ethical and functional reasons. Simple negative effects might involve eyestrain and repetitive motion stress injuries. Perceptual aftereffects, nausea and disturbances of balance and orientation have been reported with some populations using 3D interactive virtual reality systems [5] and vigilance for such symptom occurrence should be a standard component of the IMS design and development evaluation process.

What are the best metrics for determining the usefulness (effectiveness/efficiency) of the system for targeting educational objectives?
The determination of the "usefulness" of a given IMS educational system is subject to many concerns. It should likely be assumed that success in addressing the educational objectives for specific user groups is an empirical process governed by a healthy mix of theory, psychometrics, philosophy and, for better or worse, economics! Final summative evaluation is usually employed to directly test the usefulness of an "evolved" IMS system. Many metrics exist for this across a range of levels of analysis (i.e. learn-ability, throughput, transfer of training, motivational factors, etc).

The UCS component of the Vision-Based Tracking project (in collaboration with Prof. Isaac Cohen and Prof. Ram Nevatia) has recently commenced with the submission of an NSF ITR proposal and with the building of a proof of concept virtual environment that uses magnetic tracking for concept demonstration and benchmarking of existing technology for comparison purposes with a future vision-based system. The increasing use of video sensors in daily life environments is motivated by the importance of visual sensing of human activity. While security systems have been the major driving application, vast spectrums of new topics have emerged, such as computer-aided training, multimodal interaction and post-trauma rehabilitation.

In this research effort we are beginning a research program to use visual sensing of 3D body motion and its analysis for improving the rehabilitation process for motor impairments. An essential part of the rehabilitation process for physical dysfunction is the remediation of motor deficits in order to improve the functional ability of the patient and to enable him or her to live as independently as possible. Conventional therapy focuses on muscle strengthening, increasing joint range of motion and improving balance reactions. One of the major challenges facing clinicians in rehabilitation is identifying intervention tools that are effective, motivating, and that promote transfer of the ability to function in the "real" world. However, traditional therapies employ intervention tools that tend to be tedious, monotonous and provide little opportunity for grading the level of difficulty. Recent efforts incorporate a single camera "fixed-plane" vision-based approaches have appeared in the literature in this area and have shown promise. These applications use a single camera vision-based tracking system that produces a representation of the user embedded within a two dimensional flat screen display environment where they can interact with graphical objects (Figure 2)

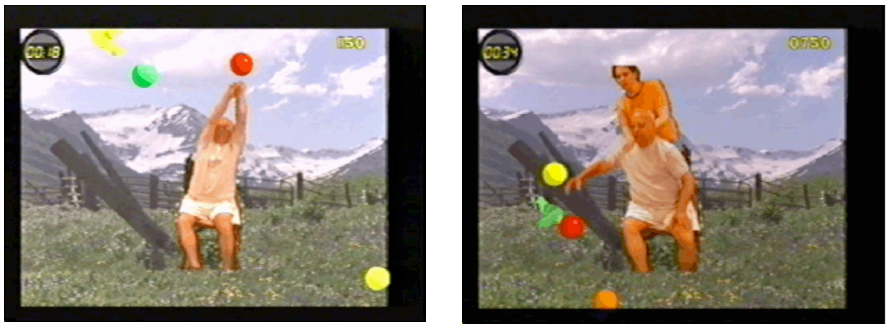

Figure 2: Illustration of a single camera vision-based virtual environment used for post-trauma rehabilitation. On the left, a stroke patient uses his intact left arm to attain full passive range of motion at the wrist, elbow and shoulder joints of his impaired right arm. On the right, a therapist is providing proximal counter resistance and support to his left shoulder thereby enabling the patient to initiate active movement of the impaired upper extremity.

Such existing systems have significant limitations; quantifying and understanding 3D body motion from a single visual system is inaccurate since only 2D projection of the body motion is captured by the camera. Moreover, approximately one-third of the body joints are nearly unobservable due to motion ambiguities and self-occlusion. Multiple views are therefore required to quantify, disambiguate and identify the 3D human body motion. Within this context, our goal is to use multiple video sensors to accurately detect and track 3D body motion, identify body postures and recognize user gestures.

The advantage of visual sensing, compared to magnetic trackers, is that it allows the patient to move freely during sessions with an occupational therapist. This provides a better understanding of the patient's range of motion, movement speed, muscle strength, endurance, dexterity and accuracy. We have created a network of collaborators within three major centers of occupational therapy (i.e., Haifa University, University of Ottawa, Kessler Medical Rehabilitation Research Center). These centers currently use the 2D vision-based approach, and are limited by these systems with regards to providing accurate 3D body motion measurements. These collaborative centers will conduct the clinical evaluation of the vision-based body motion tracking system that we develop, and will integrate the 3D body measurements obtained during the study into efficient and systematic motor training applications. The clinical trials to be carried out by our collaborators are to be funded through their own channels. Thus far, at IMSC we have created a magnetic tracking, proof of concept system to begin user testing and to explore issues for scenario development. As we commence initial user centered trials with this system, we will concurrently address the scientific problems related to the visual sensing of 3D body motion from video sensors. Our vision-based body representation, motion estimation and tracking system will be demonstrated in two test applications. These applications will focus on the tracking, representation and measurement of full body motor performance in normal users, and persons with disabilities who have motor impairments. Our aim is to develop two direct vision-based test applications: non-immersive and immersive. The test applications will serve to drive and demonstrate the underlying vision-based tracking technology science, while serving to create cost-effective tools that could fundamentally advance the existing standard of care for motor assessment and rehabilitation. If successful, these applications could have considerable impact on the ultimate health, employability and quality of life of persons with these types of disabling conditions, in a manner that could significantly reduce healthcare costs. As well, these applications will serve as ideal test beds for evolving the underlying vision-based tracking technology needed for the development of multimodal interaction and PUI test applications.

Test application 1 (TA1) – This non-immersive application will use our vision-based tracking system as a tool for quantifying head, trunk and limb kinematics in users while they are performing conventional physical and occupational therapy rehabilitation intervention (e.g. gait assessment and training for fall prevention).
Test application 2 (TA2) – This immersive application will integrate our vision-based tracking system with a head mounted display (HMD) device. Within this system, users' motor movement in all three planes will be tracked. Relevant body areas will be represented in the HMD while users undergo motor therapy by interacting with scenario content within a "game-based" virtual environment (VE).

In both test applications, standard kinematics and functional outcome measures for motor movement assessment will consist of range of motion, muscle strength, endurance, dexterity, movement speed, "smoothness" and accuracy, body stability and additional measures gathered via focus groups with expert rehabilitation professionals. In this research effort we propose to address the problem of deriving an accurate body representation and recognizing body gestures from a set of video sensors. Dynamic scene analysis will be performed at different resolutions, according to the desired level of description. We consider a hierarchical set of features, describing the human body shape and its motion, for recognizing specific patterns of body motion. In our approach, human gestures are divided into a number of states, during which a certain pattern of similar motion or similar human shape configuration is observed. These states describe a simple event (*e.g.* "walking towards something"), a posture (*e.g.* "standing") or a basic gesture (*e.g.* "waiving" or "pointing"). The characterization of these states is prone to error, as the visual sensing of humans is inherently noisy. This is primarily due to: the illumination/texture dependency of blob-based motion detection, the segmentation of these blobs into objects/humans and the tracking of the moving objects across time. The temporal boundaries between various states describing a pattern of activity are not easy to identify, as there is no clear distinction as to when a specific state starts or terminates. Also, for a given pattern of activity, its recognition is challenged by substantial variation in the duration or by multiple pauses.

We will investigate the use of new 3D shape descriptors for identifying human body postures and for characterizing the patients' gestures as temporal transitions across various postures. The use of an articulated body model will describe accurately the location of body joints and their temporal variations. These temporal profiles will provide accurate 3D measures of body parts and the kinematics enabling motor movement assessment. Also, these profiles will provide the base for an efficient representation of body gestures in terms of elementary motion or temporal transition between identified postures.

Collaboration with the clinical research partners allows us to develop the tracking software with insight derived from the clinical experience of the limitations of the existing tools. Comparative clinical trials will be performed with existing systems and with our 3D body tracking and gesture recognition system. Working under the design requirements needed for populations with motor impairments will drive the enabling technology development which will have generalizability to system development with unimpaired populations for general 3D user interface applications.

Finally, the Body Gesture and the Expression of Emotional State in Virtual Human Representations project uses the Vicon motion tracking system at the USC Zemeckis Center to capture trained actors who are expressing dynamic body postures and gestures that implicitly communicate emotional states. The body actions captured in this system are rendered as "faceless" animated characters using 3D projection technology and are presented to research subjects who attempt to decode the nature of the emotional expressions. These test scenarios consist of a text-based description of the context in which pairs of these animated characters will be interacting. Selective emphasis cues will be provided to research subjects guiding them to observe the action of one of the figures for ratings of the animated characters state. No verbal or facial cues will be presented to subjects in an effort to isolate specific body gesture communication efficacy.

Actors have been trained to perform the actions described above via collaboration with Prof. Sharon Carnicke, Assistant Dean of the USC School of Theatre. We anticipate that this methodology, expanded from the early non-verbal communication literature [6], and the subsequent stimuli generated will serve to drive a series of studies that will later involve factorial combinations of body, face and verbal cues delivered to subjects. This research is expected to advance knowledge on the relative communicative value of multiple inputs for creating believable virtual human representations. As well, data on human judgment capacity for this type of communication can serve as the basis for the longer-term goal of creating PUI systems that can perform similar functions in an automated fashion.

5. Short Description of Achievements in Previous Years

Most of these projects are new regarding UCS involvement. Previous achievements by the groups we are collaborating with on the Gestural HCI and the Vision Based Tracking projects are available on their specific technical project reports found elsewhere in this volume. The initial work on facial action (PDFA) decoding in humans was a precursor for our UCS interest in the Body Gesture and Expression of Emotional State area. That work resulted in published research on our methodology and results from the PDFA project [1]. As well, an IMSC website includes the paper and the actual facial action stimuli [8]. This website was created for better dissemination and comprehension of our findings since the uniqueness and complexity of the data presented in the paper are difficult to interpret by a reader without visual inspection of the video and animation stimuli (linked to results) on which it is based.

5a. Detail of Accomplishments During the Past Year

• Gestural HCI –Initial user testing was conducted with results feeding into the design of hand actions for the gesture language that we are creating in support of the 2020Classroom project. Creation of gestures, user evaluation with tracked gloves and iterative redesign of gestures based on user results and technology limitations are ongoing.
• Vision-Based Tracking – A proof of concept magnetically tracked hand movement VR scenario was created and initial user evaluation of the system is ongoing. An NSF ITR was submitted to support the technical development of the system. Collaborations with leading international rehabilitation centers have been formalized and tasks/requirements analysis has begun with these groups to guide system design. Also, collaboration with USC School of Fine Arts students who are taking an Art and Technology course (co-taught by UCS investigator Prof. Rizzo) for the design of compelling graphics-based game-like scenarios to be used in these applications has been formalized as class projects within the course structure.
• Body Gesture and the Expression of Emotional State in Virtual Human Representations – The methodology for this project has been formalized after painstaking analysis of the non-verbal communication literature for best practices and via extensive viewing of taped "improv" interactions using professional actors. Actors from the USC School of Theatre have been trained on the key gestures for use in the study and Vicon motion capture of these actions is in progress. Rendering and post-production of the animated characters to be used in the study will be done in April 2003 and the initial formal decoding study will commence in May 2003.

6. Other Relevant Work Being Conducted and How this Project is Different

• Gestural HCI – While the field of multimodal interaction with computers has been quite active over the last few years, we were unable to locate an existing gesture-based language that met our requirements for the 2020 Classroom project. Our requirements are based on developing a one-handed set of commands that have fast learn-ability (for novice users) while promoting efficient throughput (efficiency with expert users) that will scale across a wide range of media types and display systems. Also our methodology is designed for evolving this work in the future to evaluate the comparative value of hand gestures relative to facial and voice inputs to produce an empirically based comprehensive multimodal system.
• Vision-Based Tracking – recent efforts that incorporate simple single camera "fixed-plane" vision-based approaches have appeared in the literature in this area, and have shown promise [8-10]. These applications have used a single camera vision-based tracking system that produces a representation of the user embedded within a two-dimensional flat screen display environment. The users can interact with graphical objects as depicted in Figure 2 in this environment. The origins of this work can be traced back to Krueger's [11] seminal "Videoplace" application in the early 1970s, where it was observed that humans were compelled to interact with graphic objects displayed in this format. In the early 1990s, the Vivid Group [12] designed and marketed a series of single camera vision-based applications as location-based arcade entertainment systems. Known as the Gesture Xtreme VR System, it uses a blue backdrop and a chroma key to separate the user's image from the background. This system has now come to be embraced by motor rehabilitation specialists as a research and clinical tool for the treatment of motor impairments.

Our system would allow for 3D movement tracking and quantification in Test Application 1. In Test Application 2, first person, 3D interaction within a HMD, in which vision-based capture of body movement and position would be tracked and displayed in a natural fashion, will be supported. Advances on existing technology in this project includes:

3D interaction – In TA1, we will build a vision-based system where users' movements may be tracked and quantified in 3D space as they performed full body exercises. For example, this functionality would allow for elderly persons at risk for falls to practice balance and ambulation skills in various real, obstacle-laden environments (while wearing a safety harness). Our system could track and quantify locomotor impairments in naturalistic 3D assessment scenarios that could guide the administration of specific prophylactic muscle training (also monitored using the system), thereby reducing the risk of falls in this highly vulnerable population. The 3D tracking technology would allow for measurement of motor performance without the 2D constraint that exists with current single camera vision-based systems. For Test Application 2, users' full body activity could be tracked to support 3D interaction with virtual objects in a VE using a HMD. This would create a variety of graded testing and training conditions that would not be possible using physical stimuli in the real world. As well, depth perception is a key element for rehabilitation of target-specific body action. Hence, the provision for naturalistic depth characteristics that are similar to those found in the 'real world' would be an advantage that our 3D vision-based system would have over existing approaches.

First person interaction – For TA2 using a HMD, users would have more naturalistic first person interaction with the active stimuli. This is in contrast to the mirror image approach described in the application above. While users may make the translation to the mirrored interaction method found in existing single camera systems, such reversed training may be less likely to transfer or generalize to the real world's first person perspective. This transfer of training issue was noted as far back as 1903, when E.L. Thorndike formulated the "identical elements" theory (superior transfer of training occurs with increased similarity between training tasks and actual criterion targets) [13]. Also, Osgood [14] reported 46 years later that a "Similarity paradox" occurs when highly specific simulation training results in learning that needs to be unlearned as the criterion task changes (commonly referred to as *Negative Transfer*). As well, mirror reversal studies in humans indicate a lag in perceptual re-adaptation when humans wear prisms for a period of time that invert their visual field [15]. Our approach would eliminate this potential problem via structuring the interaction in the first person perspective.

Integration of naturalistic head movement to track objects – In our TA2, users would be able to interact with stimuli that appear from all directions in the 3D space, instead of only with the limited face-forward direction that is currently available with existing single camera systems. This is highly significant in that the integration of head movement within any upper body "eye-hand" or full body targeted movement rehabilitation task is essential for the training to match the demands of the real world needed to support transfer of training.

Portability and Cost Effectiveness – We intend to create a system that would deliver our TA1 and TA2 scenarios via a basic PC with 2-3 low-cost cameras. Our tracking method would also not require a "blue screen". The current Vivid system requires a dedicated room with a blue screen and costs in excess of $10,000. Our system would be designed to be half the cost, and will allow for portability such that mobile units could be used in patient rooms and possibly as part of a home-based, tele-rehabilitation method.

Development and evaluation of the system in collaboration with established researchers using the single camera Vivid System – Our collaboration with the clinical research partners at the University of Haifa, Israel and with University of Ottawa, who have done a good bulk of the existing rehabilitation research with the Vivid Gesture Xtreme system, and with the Kessler Medical Rehabilitation Research Center in the USA, are significant assets for developing the TAs with the aid of expert heuristic input. This will allow us develop the tracking software with the insight derived from clinical experience of the limitations of the existing system and to later run comparative clinical trials with both systems. This development will include collaborative input on the design process from our clinical partners and iterative user-centered design trials during the first two years with elderly volunteers from the USC School of Gerontology. It may also include persons with neurological dysfunction that are available via the UCS (Rizzo) affiliation with the School of Gerontology.

• Body Gesture and the Expression of Emotional State in Virtual Human Representations – The uniqueness of this research is based on its use of previous decoding methodology developed at IMSC [1], its use of the Vicon tracking system and on the integration of extensively trained actors to produce the stimuli that will be presented to human judges.

7. Plan for the Next Year

• Gestural HCI – We will continue user testing needed to iteratively evolve the language for various 2020Classroom applications. Other application areas will be explored and tested. Commencement of evaluation research will compare value of hand gestures relative to facial and voice inputs to produce an empirically based comprehensive HCI system. Exploration of vision-based tracking integration to replace current tracked glove solution will be done.
• Vision-Based Tracking – We will focus on developing and evaluating the performances of the vision-based algorithms within specific TA1 and TA2 scenarios. The evaluation of the accuracy of the vision-based body motion estimation will be performed by using magnetic sensors and optical markers for comparison studies. Our collaborators will provide input for the design of scenarios of interest for the applications TA1 and TA2.
• Body Gesture and the Expression of Emotional State in Virtual Human Representations – We intend to complete the first round of decoding studies with human raters. Knowledge gained in this round will be incorporated into the next study to expand our library of gestural behaviors that underlie non-verbal expression of emotion. This knowledge will also support our development of PUI technology.

8. Expected Milestones and Deliverables

We plan to continue our system development in this area and produce:

- User studies with the first generation gesture language for the Gestural HCI project.
- Initiate integration of gesture language into selected 2020Classroom media applications and begin user testing across a range of display systems.
- User study with magnetic tracked interaction scenario for range of motion testing for the Vision-Based tracking project.

- Compare first generation vision-based tracking system with magnetic system on same environment as in #3.
- Create a number of scenarios with collaborative input that integrates gaming features into the interactional format for future testing of vision-based system.
- Complete 1st Body Gesture and the Expression of Emotional State in Virtual Human
- Representations decoding study.
- Publish and present results from this research.

9. Member Company Benefits

If found to be usable and useful, the knowledge generated by these tools and methods will offer better ways for users to interact with information technology, whether operating on basic tasks or in more complex immersive environments, and could be of value for IMSC corporate sponsors.

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