Collaborative Dancing in Tele-immersive Environment

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ABSTRACT

We present a study of collaborative dancing between remote dancers in a tele-immersive environment which features 3D full and real body capturing, wide field of view, multi-display 3D rendering, and attachment free participant. We invite two professional dancers to perform collaborative dancing in the environment. The coordination requires one dancer to take the lead while the other follows by appropriate movement. Throughout the experiment, the dancers are dancing at various motion rates to evaluate how well the collaborative dancing is supported with the current technical boundary. Our important findings indicate that 1) tele-immersive environments have strong potential impact on the concept of choreography and communication of live dance performance, 2) the presence of multi-view display, real body 3D rendering, audio channel, and less intrusiveness greatly enhances the immersive and dancing experience, and 3) the level of synchronization achieved by the dancers is higher than that expected from the video rate.

Categories and Subject Descriptors

J.5 [**Computer Applications**]: Arts and Humanities—*Performing Arts*; H.5.3 [**Information Interfaces and Presentation**]: [Computer-supported Cooperative Work]

General Terms

Experimentation, Human Factors

Keywords

3D tele-immersive environment, collaboration, dance

1. INTRODUCTION

Tele-immersion is an emerging technique that enables more effective collaboration between geographically distributed users in joint activity. The strength of tele-immersion lies in its resource of shared 3D virtual space which greatly enhances the immersive experience of each participant. Several early research attempts [3, 12] have illustrated the potential in applications exemplified by virtual office and remote education where a higher level of collaboration is desirable.

Figure 1: Tele-immersive Site

In this paper, we present a study of *Collaborative Dancing* in the tele-immersive environment developed by University of Illinois at Urbana-Champaign and University of California at Berkeley. Different from previous tele-immersive systems, our tele-immersive environment features the utilization of the general Internet infrastructure and COTS-based 3D cameras with 10 or more 3D video streams provided by each connecting site. The advances in building the tele-immersive system allow us to verify the promise through user experiment across the Internet and geographical boundary.

Two professional dancers are invited to the tele-immersive environment. The environment (Figure 1) is surrounded by multiple 3D cameras. The 3D representation of the dancers is captured in real time, then streamed, and rendered in a shared virtual space. The process does not require the dancers to wear any marker or head-mounted device, which gives them the affinity to a normal dancing environment allowing continuous creative impulses. Meanwhile, our multi-display system helps the dancers to conveniently view from arbitrary angle and coordinate their body movements.

We choose to study collaborative dancing due to several considerations. First, previous tele-immersive user experiments are mostly involved with non-artistic areas. The impact of tele-immersion on collaborating artistic work has not been well-studied. Second, we want the physical activity to fully utilize the capacity of tele-immersive environ-

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ment including full body capturing, 3D spatial concept and wide field of view. Most experiments so far have been confined within the conferencing area which usually features a common virtual table with people from head to shoulder ([1, 6]). Third, we want to study the social impact of tele-immersive techniques in related domain such as how it would help people to better communicate and enrich their experience. From this respect, the collaborative dancing will give us a high level of interactivity. Fourth, for evaluation purposes we want certain flexible range of motion rate in the physical activity which the dancing can provide to us.

We have the hypothesis that the tele-immersive environment would provide a highly advanced practicing stage for collaborative dancing and have strong impact on the live dance performance including for example changing the scope people usually communicate through dancing, creating new dance performance, and in general inspiring new form of art. Our major contribution of the experiment is the evaluation of the hypothesis via the analysis of the unique view from artists. The secondary contribution is the examination of how the technical boundary would affect the performance satisfaction of the dancers. The current system is only able to track the real world with certain technical limitations such as frame rate and resolution. When streamed across the network, the 3D representation has to pass through transmission delays and jitters. These factors would conflict with the expectation of the dancers. To explore that, we design several experimental cases to let the dancers synchronize the movement at different motion rates and ask them to evaluate the state of collaboration. We will present some interesting findings reflected from their feedback. It is a challenging task to ship the tele-immersive technique out of the research lab and make it a really powerful tool for collaborative work. We hope the presented work will inspire us to further explore these issues.

2. TELE-IMMERSIVE ENVIRONMENT

The tele-immersive environment has multiple 3D camera clusters deployed at different viewpoints. We mount over 10 camera clusters to cover a wide field of view (from 120° to 360°). Each 3D camera cluster is a unit of four 2D cameras (three b/w and one color) connected to one edge computer to calculate the depth information for each pixel using trinocular stereo algorithm. All cameras are synchronized to take shots simultaneously. The 3D frames bearing the same time stamp constitute one 3D *macro-frame*.

The 3D renderer allows the viewer to select his viewpoint in a seamless fashion. It is capable of manipulating multiple objects, for example, rendering two people in one 3D space and organizing their relative distance and orientation etc. It can also duplicate people and record the 3D video for some special effect. The multi-view display is a desirable feature where the user could examine multiple views at the same time by running several renderers on different displays. The advantages include better viewing resolution and more intuitive location awareness. Currently, we apply the voice over IP protocol for the audio, mainly to let dancers easily communicate with each other for the collaboration. We are considering adding music channel as our next step.

Setting up the environment is a time-consuming task, although technically it is not that difficult. The procedure requires placing four cameras into one cluster, mounting each cluster onto the supporting frame, connecting each cluster to a computer via firewires, and some wiring job. After that, the calibration is needed to detect intrinsic parameters (the focal length, the principle point, the skew coefficient, and the distortions) and extrinsic parameters (the translation and the rotation matrices) of each camera. However, we believe that if given a tutorial, there will not be much technical difficulty involved in the process.

3. EXPERIMENT

We invite two professional dancers to perform experiment with us. First, we expect to learn via the feedback from professionals how the tele-immersive environment would influence the way they usually collaborate in dancing. Second, we want to have their judgement on the influence of technical limitations which could serve as a valueable guidance to further improve our system.

3.1 Design

Unlike the co-located dancing in the real world, distant collaborative dancing has to accommodate certain technical limitations such as frame rate and transmission delay, which makes the synchronization of movements more difficult. Therefore, the main focus is to investigate how this mismatch between the real world and the virtual world would affect the coordination between dancers. As an initial step, we let the dancers make elementary body movements in fairly common way with varying degree of motion rate: *slow* (S) - moving at the pace similar to Tai Chi or the slow motion in movies, *medium* (M) - a pace that comes naturally without having to push a speed or consciously slow down, and *fast* (F) - more driven and pushed beyond a level of comfort, like playing competitive sports.

During the experiment, one dancer takes the leadership while the other dancer picks up certain set of movement to coordinate with the leader. The overall effect to the audience is that they look more like dancing together than separately. We identify six experimental cases including *S-S*, *M-S*, *F-S*, *M-M*, *F-M*, and *F-F* (where for example *M-S* denotes the leader in medium rate and the follower in slow rate).

3.2 Results

We request both dancers to fill out a questionnaire of two parts. The first part asks them to rank various technical aspects based on their satisfaction in a scale from 1 (*unacceptable*) to 10 (*excellent*). The second part asks them to elaborate on certain issues concerning the impact of our tele-immersive environment on the art of live dance.

3.2.1 Part I – Ranking Questions

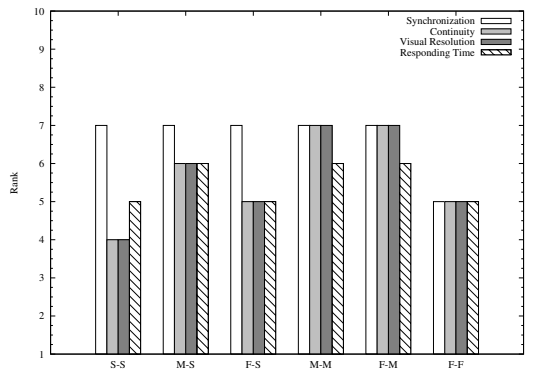
We ask the following questions for each set of experiment to reveal how the different combination of motion rates affects the response of dancers. Figure 2 summarizes the feedback of two dancers followed by the discussion.

Q1: *How do you feel about the quality of synchronization between 3D images from two sites?*

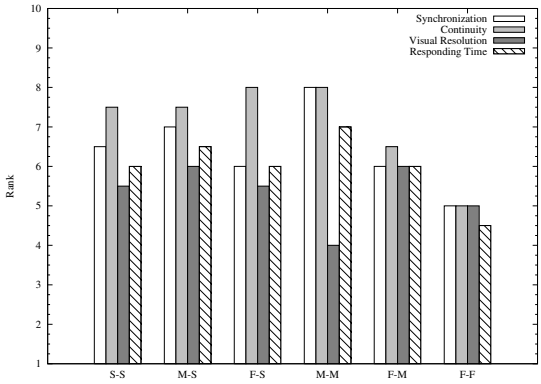
Q2: *How do you feel about the quality of continuity of dancer images?*

Q3: *How do you feel about the quality of visual resolution of dancer images?*

Q4: *How do you feel about the quality of responding time of the tele-immersion system?*



(a) Leader



(b) Follower

Figure 2: Response to Q1, Q2, Q3 and Q4

Q1: *Synchronization*
At the slow motion rate, the dancers are more satisfied with what they see and can better coordinate their movements. When they speed up to fast motion rate, the system starts to lose track of the real world. The dancers do not have the whole visual information, which distorts their coordination. The interesting thing happens when both dancers move at medium rate. At that point, the motion rate is a little beyond the capturing rate of the virtual world. However, we notice that the synchronization ranking of *M-M* is actually better than that of *S-S* (average 7.5 vs. 6.75). One dancer comments that she can easily recognize the skeleton of the other dancer which makes her fall naturally into the coordination even she cannot grasp the full detail. One possible explanation is that professional dancers assume certain pattern and rhythm in collaboration to create the aesthetic of dancing. Therefore, even though the 3D video may not keep close track of the real world at the higher motion rate, the dancers can follow synchronization to a certain extent.
Q2: *Continuity*
The satisfaction of continuity is ranked next to the synchronization (average: 6.38). There are two major factors affecting the sense of video continuity: the transport stability and the motion rate. To evaluate the former, we measure the sample of arrival time of 500 macro-frames with the fixed rate of 5 Hz. The average inter-arrival time is 0.200013 second and the sample standard deviation is 0.047 second. Compared to that, the motion rate seems to play a more important factor as reflected. It is noted that when the dancers move at fast rate (*F-F*) they both give very low rank to the continuity. Meanwhile, the slower dancer tends to feel less comfortable with the continuity as in *F-S* and *M-S* when she has more chance to observe the video.
Q3 and **Q4**: *Resolution and Responding Time*
The two dancers are not very satisfied with the resolution (average: 5.5) and the responding time (average: 5.75). In addition to poor visual effect, low resolution also makes it more difficult to seek eye contact which is an essential component for live dance. The performance bottleneck lies in the stereo algorithm. Currently, the resolution is 320×240 and the overall processing time of one macro-frame is around 210 ms. Although the delay is generally within the acceptable range for video conferencing, it is obvious that the delay requirement is higher for more interactivity of dancing.

3.2.2 Part II – Elaborating Questions

Q5: *In your opinion, what is the perceptual difference between face-to-face collaborative dancing and the virtual dancing in the tele-immersive environment?*
The first impression of both dancers is that it is a very unique and sensational experience. Both dancers indicate certain level of mental transition as they first enter into the cyberspace. One dancer comments that she becomes more focused on the intellectual part of the dancing as she is so absorbed in watching the 3D videos. The other dancer expresses a great enjoyment once she get used to the new environment and how it would encourage more collaboration.

"*... Towards the end of the experiment when we could 'play' more in the lab I felt the power of the choreography, that is the dance that we were creating together. This took some time to get used to each other's presence in the space. Compared to myself dancing alone, it was much more excited to dance with someone remotely. I really felt a connection to that other place ...*"
Q6: *How did the tele-immersion system change your choreography in collaborative dancing?*
The most important change in the choreography as reflected by the dancers is that the tele-immersive environment causes them to be concerned more with the virtual space and lose touch with the reality. One dancer comments that she feels leaving her physical body and becoming more virtual herself. As a consequence, the collaborative dancing is more grounded in time and space effort but less in weight effort. The dancers need to keep constant track of their virtual presence. In short, collaborative dancing in cyberspace calls for challenging mental adjustment to acquire a more accurate temporal and spatial awareness.
Q7: *In your opinion, what specific artistic values are created by this new form of collaborative dancing?*
The dancers are marveled by the potential impact of the tele-immersive environment as a revolutionary medium to promote the dancing art for socialization, education and entertainment purposes. First, on a global scale the technique could allow dancers from different countries and different cultures to easily communicate with each other through dancing. As the collaborative dancing requires very high level of spatial interaction among dancers, such environment can convey them an enriched experience that is simply not possible with the traditional communication mechanism. Second, remote dancing course would be made more interesting when teachers and students from different places could join the same virtual class and practice. Third, given

the platform the teacher can record the dance movement, freeze it and show the problem area when replaying it in 3D space. Compared with watching video tapes or following 3D avatars, the tele-immersive environment provides a more advanced way to practice dance.

"*... It makes me question location, migration, identity, disintegration, synchronization, travel, presence, reality and embodiment, among others ... The technology makes me move differently and see my own reality differently, see bodies in time and space in a whole new way ... This kind of set up definitely invites a new dimension in choreography and dance ...*"

Q8: *What are the limitations on your choreography due to the current equipment and technology?*

The dancers list several impediments to the creativity of the dance. First, there is not a lot of room to dance and the sweet area (a region within which the subject has its optimal 3D representation) is small. Second, we deploy two displays at each site which allow more freedom for the dancers to examine their body and movement. The dancers love this feature so much that they prefer more displays to be installed. Third, although the voice channel greatly enhances the telepresence of the remote partner, the dancers demand high-quality music track so that they could dance more vividly.

4. RELATED WORK

There have been explorations of the interaction between virtual reality and art with most influential work such as projects by Myron Krueger (Glowflow and Videoplace) in pursuit of *Artificial Reality* ([7]) to immerse the user in full and unencumbered contact with the digital world, and *Osmose* ([4]) by Char Davies et al. to study the creative potential of a dancer in movement, transformation, time and space. However, there are relatively fewer reports in the tele-immersion domain of real body and live dance performance. When we review related work based on *collaboration*, *art* (including sports), and *user experiment*, it seems that none of the work bears all three criteria. Therefore, we choose papers that have two of the three criteria.

Collaboration and Art. In [11], Schaeffer et al. present *Cube*, a virtual space that allows remote participants to engage in sport and dance activities. The users can operate avatar-based full body representation using motion capturing tools. The study shows a very high level of interactivity among participants. In [8], Meador et al. present an experimental dance performance based on similar approaches. Their works are regarded as the closest one to ours in the sense that it explores the way people interacts in the virtual space. However, the value of revealing collaborative artistic work is not so obvious. For example, although avatars could be pretty useful in sporting and gaming applications, some of the most critical human features in performing art are filtered out such as eyes and facial expression.

Collaboration and User Experiment. Mortensen et al. present a user study that investigates how two remotely located people collaborate to move a rigid virtual object in the tele-immersive environment [9]. The most important conclusions are technical weighted such as the claim that immersive interaction is supportable in the Internet2 networking. In [10], Park et al. have done an observational study on users of CAVE-based virtual environment to understand how people cooperate in the tele-immersive environment and leverage multiple perspectives to interpret multi-dimensional scientific data sets. The conclusions are concerned more about the impact of user interface including the usefulness of avatars and the necessity of sharing views.

Art and User Experiment. In [2], Chua et al. have developed a training environment for people to learn Tai Chi using avatars, virtual instructor and motion capturing. The user study is focused on the layout relationship between the virtual instructor and the student avatar, and how it would affect the learning process. In [5], Hämäläinen et al. present a martial art game system. The user study reflects on the value of the system for motivating martial arts and acrobatics training.

5. ACKNOWLEDGEMENT

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