A Study of Collaborative Dancing in Tele-immersive Environments

Zhenyu Yang, Bin Yu, Wanmin Wu, Klara Nahrstedt
University of Illinois at Urbana-Champaign
Department of Computer Science
SC, 201 N. Goodwin, Urbana, IL 61801
{zyang2, klara}@uiuc.edu

Ross Diankov, Ruzena Bajscy
University of California at Berkeley
Department of EECS
253 Cory Hall, Berkeley, CA 94720
{bajcsy}@eecs.berkeley.edu

Abstract

We first present the tele-immersive environments developed jointly by University of Illinois at Urbana-Champaign and University of California at Berkeley. The environment features 3D full and real body capturing, wide field of view, multi-display 3D rendering, and attachment free participant. We then describe a study of collaborative dancing between remotely located dancers in the shared virtual space. Two professional dancers are invited to the tele-immersive site of each university. As a preliminary experiment, we let the dancers perform elementary body movements and coordinate their dancing. The coordination requires one dancer to take the lead while the other follows her by appropriate movements. During 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-display system, 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.

Keywords

3D tele-immersive environments, collaboration, dance

1 Introduction

Tele-immersion is an emerging technology that would allow more effective collaboration of remote users in joint activity such as training of Tai Chi movement, dancing, or assistance in physical therapy than the traditional video conferencing system ([10]). The strength of tele-immersion lies in its resource of a shared virtual space that enhances the immersive experience of each participant. Several early research attempts ([3, 12, 5]) have illustrated the potential of tele-immersion in applications exemplified by virtual office, tele-medicine, dancing and remote education where a higher level of collaboration is desirable. The previous tele-immersive systems differ from each other either by the connectivity of the distributed sites (e.g., using high speed and leased lines) or the quality and number of video streams (e.g., 2D video, small number of streams and views) or media (e.g., using graphic avatars instead of real video).

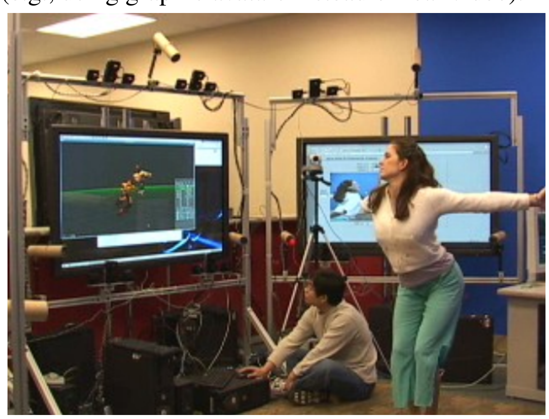


Figure 1. Tele-immersive Environment

In this paper, we introduce the tele-immersive environment built by the research team of University of Illinois at Urbana-Champaign and University of California at Berkeley. As a comparison, our tele-immersive system uses Internet2 network connectivity and COTS-based 3D cameras with 10 or more video streams provided by each connecting site. The advances in building the tele-immersive system allow us to verify the promises through the user experiment across the geographical boundary. We then present the study of *Collaborative Dancing* in the tele-immersive environment. For the experiment, we invite two professional dancers to each site of the two university labs. Figure 1 shows one of the dancers performs dancing while checking the presence of her and her partner in the 3D virtual space.

The tele-immersive environment employs multiple 3D cameras to capture the real 3D representation of the dancers from a wide field of view. The capturing process does not require the dancers to wear markers or head-mounted devices, which gives them the affinity to a normal dancing environment. Meanwhile, our multi-display 3D rendering system helps the dancers to conveniently view from an arbitrary angle and coordinate their body movements. Thus, it creates an illusion that the dancers are dancing in the same physical location. Figure 2 shows the snapshot of two dancers rendered in the virtual space.

Figure 2. Collaborative Dancing in 3D Space

We choose to study collaborative dancing due to several considerations. First, previous tele-immersive user experiments are mostly involved with non-artistic area. The impact of tele-immersion on collaborating artistic work has not been well-studied. Our exploration will extend the state of research into a very important area. Second, we want the physical activity to fully utilize the capacity of tele-immersive environments including for example, full body capturing, 3D spatial concept and wide field of view. Most experiments so far have been confined within the conferencing area. For example, they usually feature a common virtual table with people from head to shoulder (e.g., [1, 5]). Third, the tele-immersive environment is in its nature a communication medium. Therefore, we want to study the social impact of tele-immersive techniques in related domain such as how it would help people to better communicate with each other and how it would enrich their experience. From this respect, the collaborative dancing will provide us with higher level of interactivity than other activities such as Tai Chi. Fourth, for evaluation purposes as justified later on, we want certain range of motion rate in the physical activity. That is, the performer can create his/her movement at various speeds instead of one speed. The dancing art can provide us with such flexibility.

We have the hypothesis that the tele-immersive environment would provide a highly advanced practicing stage for collaborative dancing and have strong impacts on the live dance performance including changing the scope people usually communicate through dancing, creating new dance forms, and in general inspiring new forms of art. Our major contribution of the experiment is the evaluation of such hypothesis via the cooperation with artists and to analyze the tele-immersion system through their unique view. As manifested in later sections, the discoveries are very revealing and encouraging.

The secondary contribution is the examination of how the technical boundary would affect the performance satisfaction of the dancers. The current tele-immersive environment is only able to track the real world with certain limitations of frame rate, resolution, and other processing costs. When streamed across the network layer, the 3D representation has to pass through with transmission delays and jitters. These factors would conflict with the expectation of the dancers when they perform the dance. To explore that, we design various experimental cases to let the dancers synchronize their movement at different motion rates. We then ask the dancers to evaluate the state of collaboration in the virtual space. 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 and make it a really powerful tool for collaborative work. As we have learned from the study, the challenge is not totally from a technical sense. The experience of working in the virtual space is always different from that in the physical world no matter how the fidelity of 3D audio and video is maintained. Meanwhile, it may also give us a whole new space for creativity as some of the rules can be broken in the virtual space. We hope the presented work will inspire us to further explore those issues.

The paper is organized as follows. Section 2 introduces the tele-immersive environment. Section 3 describes in detail the collaborative dancing experiment. Section 4 discusses related work. Section 5 concludes the paper.

2 Tele-immersive Environment

The tele-immersive environment is a multimedia room with multiple cameras and displays. Within it, the 3D model of the object is captured and rendered in a shared virtual 3D space along with remote users to cast a common sense of an immersive experience. Behind that, the environment is a highly sophisticated system which is responsible for capturing, streaming, and rendering 3D models in real time.

2.1 System View

Figure 3 illustrates an overview of the tele-immersion architecture which features a multi-layer design consisting of the *application layer*, the *service middleware layer*, and the underlying transport layer. The task of application layer is to manipulate the multi-camera/display system for end users including synchronizing 3D cameras for reconstruction, routing 3D video streams onto multiple displays, and rendering the 3D scene from arbitrary user viewpoints. The service middleware layer provides services including the 3D video content adaptation and compression, and the coordination of 3D cameras for bandwidth management and streaming control.

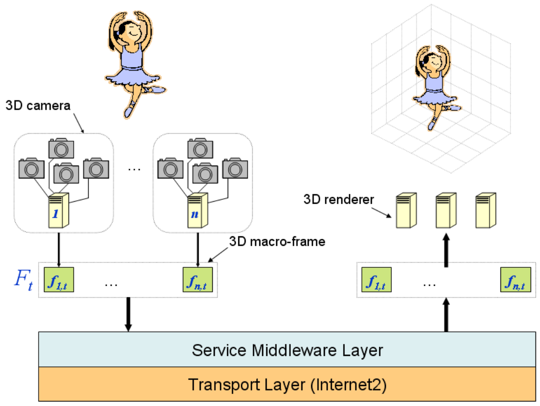


Figure 3. System Architecture

There are multiple 3D cameras deployed at different viewpoints around the scene. Each 3D camera is a unit of four 2D cameras (one color camera plus three black/white cameras) connected to an edge computer. The edge computer performs an image-based trinocular stereo algorithm ([8]) to compute the depth information of the object. The advantage of the multi-camera array is the coverage of large field of view, which provides more freedom of view selection to the user. With the accurate calibration, the view change can be rendered in a seamless fashion, offering a better quality than that of 2D camera array.

All cameras are synchronized to take shots at the same time instant. The 3D frames bearing the same timestamp constitute one 3D *macro-frame*. Once the macro-frame is ready, it is forwarded to the service gateways for compression and streaming. Upon the receipt of one macro-frame, it is decompressed and sent to the multi-display rendering system where it is rendered in 3D virtual space. The multi-display rendering system allows the user to watch from different views simultaneously, which is a desirable feature of the 3D rendering system. The rendering program could manipulate multiple views in one display. However, for optimal visual quality it is preferrable to render each view onto one dedicated display.

The 3D rendering system allows the user to select his preferrable viewpoint in a seamless fashion. It is capable of incorporating 3D models from different tele-immersion sites. For example, it can render two people together in one 3D space, organizing their relative distance, position and facial orientation. It can duplicate people to have some special effect. It can also record the 3D video and replay it later on. Thus, it provides the ability for a dancer to dance with a pre-recorded video, which could serve as a training and rehearsing platform as well.

2.2 User View

Figure 4 shows the tele-immersive site of the two universities. When the user enters the environment, his 3D model is reconstructed and rendered in a virtual 3D space. The rendering system is capable of loading pre-scanned virtual environment such as a theater stage. For that, the physical background of the user is segmented first. To facilitate that, we create the background using consistent color (blue or green) to reduce the lightening noise.

We use a carpet of 6×6 square feet to indicate the capture region covered by the 3D camera array. The carpet reduces the noise reflected from the floor as well. During the experiment, the dancer is suggested to restrict her motion scope within the carpet. We mount 10 to 12 3D camera clusters around the room in two rows of different height (three feet and six feet) with a wide field of view (from 120° to 360°). Thus, the upper and lower body of the dancer will be covered when she is on the carpet. To improve the effectiveness of the stereo algorithm, there are several infrared emitters that shed a pattern of line stripes onto the subject.

For the 3D rendering system, we use two configurations. At one site, we utilize several plasma displays where the user can manipulate his view using keyboard and mouse. At the other site, we utilize dual projectors for stereoscopic video where the user needs to wear stereo goggles.

Currently, we apply the voice over IP protocol for the audio channel. The purpose is mainly to let people in the environment easily communicate with each other for the collaboration. The voice is picked up by wireless headset to reduce the echoing effect. In addition, we prepare sound track at each site and synchronize the play back of the music during the dance experiment.

3 Experiment

We invite two professional dancers (one professor and one graduate student from the dance department of each university) to perform experiment with us. There are two major goals we hope to achieve. First, we expect to learn via the feedback from them how the tele-immersive environment would revolutionaize 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 improve our system.

3.1 Design

Although there is a wide range of design choices for choreographing the collaborative dance, some design choices may not be feasible in the tele-immersive environment. Unlike the co-located dancing in the real world, in distant collaborative dancing the 3D model is captured at certain rate while the dancers may move at different rate. When the 3D video is streamed across the network layer, it would experience variation of delay and jitter which may

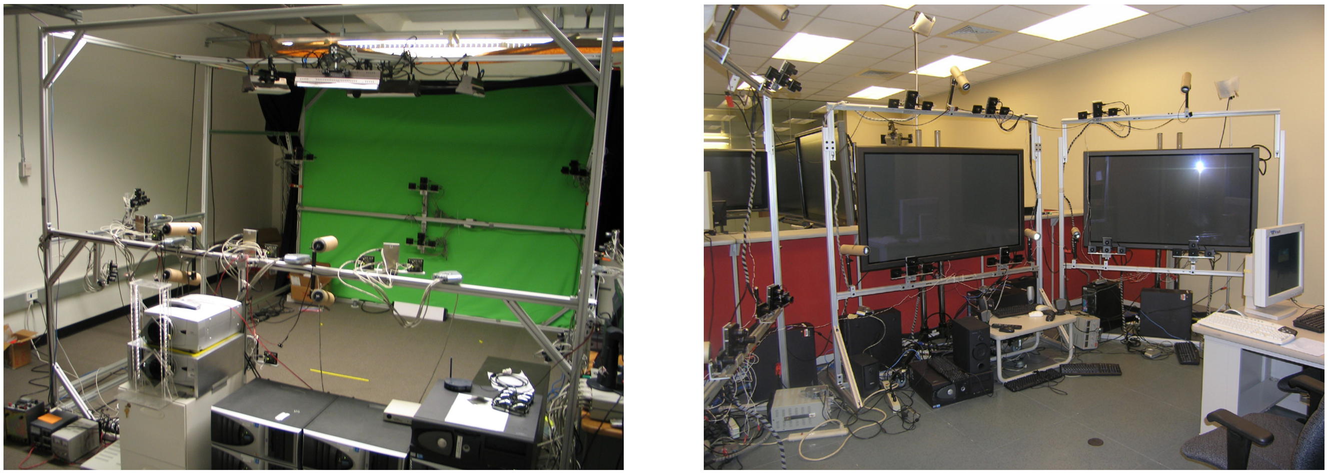


Figure 4. Tele-immersive Sites

make the synchronization of movements even more difficult. Therefore, our main focus is to investigate how this mismatch between the real world and the virtual world would affect the coordination between dancers.

As a first step, we let the dancers make elementary body movements that they will perform in fairly common way with varying degree of motion rate as defined in Table 1. In pilot experiments of local capturing and rendering, we notice that the mismatch becomes obvious when we move at medium and fast rates.

Table 1. Dancer Motion Rate

Rate	Definition
slow	moving at the pace similar to Tai Chi or the slow motion in movies
medium	walking, a pace that comes naturally without having to push a speed or consciously slow down
fast	more driven and pushed beyond a level of comfortable moving, like playing competitive sports

The dance has more of an improvising sense but we ask the dancers to collaborate in their movement as much as possible. At the beginning, one dancer (leader) takes the role of leadership. When she changes her dancing movement, the other dancer (follower) will pick up certain set of movement in a correspondent way to coordinate with the leader. The overall effect to the audience is that they look more like dancing together than separately. Meanwhile, the dancers also have a feeling of how well they collaborate with each other.

We have in this case three types of rate: the physical dancer motion rate of two dancers r_a and r_b, and the digital video rate r_v (including the time cost of capturing, processing and rendering) at both sites. The experiment will reveal to us how the dancers react under the scenarios where (1) r_a, r_b and r_v match, (2) r_a and r_b match but not r_v, and (3) r_a, r_b and r_v do not match. Following that, we identify six sets of experiments: (*S*-*S*) both dancers in slow rate, (*M*-*S*) leader in medium rate and follower in slow rate, (*F*-*S*) leader in fast rate and follower in slow rate, (*M*-*M*) both dancers in medium rate, (*F*-*M*) leader in fast rate and follower in medium rate, and (*F*-*F*) both dancers in fast rate.

3.2 Results

We run each set of experiment for around two minutes. There is a short timeout in between when we prepare for the next experiment. The total experiment elapses around one hour. At the end of the experiment, we request both dancers to fill out a questionnaire which is organized into three parts. The first part asks them to rank various technical aspects of the system 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 environments on the art of live dancing. The final part asks them to summarize on desirable features and improvements, and to give general comments.

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.

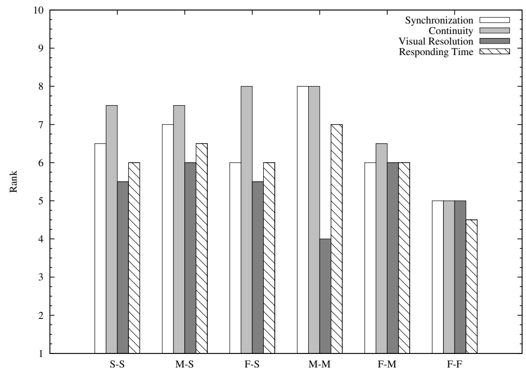
Q1: *How do you feel about the quality of synchronization between 3D images from two sites?*

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

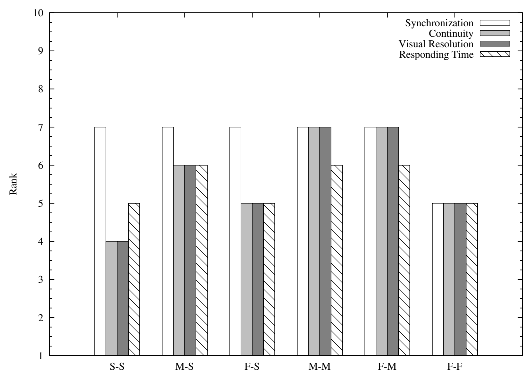
Q3: *How do you feel about the quality of visual resolution of dancer images?*

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

Figure 5 summarizes the feedback of two dancers from which we gain the following findings. The upper figure is the leader and the lower figure is the follower.



(a) Leader



(b) Follower

Figure 5. Response to Q1, Q2, Q3 and Q4

Q1: *Synchronization*

The two dancers are pretty satisfied with the synchronization in almost all testing cases except for the case of *F-F*. When they perform collaborative dancing, the dancers expect that the video rate could capture the physical rate the same way as they would observe in the real world. However, this does not always hold in the 3D virtual space. Only at the slow motion rate will the digital technology be able to match the rate of physical change and give the dancers an approximately correct view of the real world. In this case, the dancers are more satisfied with what they see and can better coordinate their motions. When the dancers speed up to fast motion rate, the digital video rate lacks behind the physical motion rate and the system starts to lose track of the real world. In this case, the dancers do not see everything and it may distort their coordination since they do not have the whole visual information of where their partner is at certain time. The coordination is also hindered by the synchronization problems, i.e., the faster the dancers move the worse the synchronization becomes and at some point the dancers may not truly coordinate with each other but fall back to an individual dance and observe what is happening on the screen. This is also clear as the video shows that in case of *F-F* they start to overlap in the virtual space and in real world it would mean that they step on each other.

The most 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), which is quite to our surprise. 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 their collaborative work to create the aesthetic of dancing. Based on that, a well-trained dancer could apply her expertise to predict the movement of other dancers and interact accordingly. Therefore, even though the 3D video cannot keep close track of the real world at the higher motion rate, the dancers can follow synchronization to certain extent.

When the dancers move at different speeds, we see a better consideration/coordination from the slower dancer (follower) as in cases of *F-S* and *F-M*. Since the slower dancer has time to watch what is happening in the cyberspace, it may be avoided that the faster moving dancer gets into the dance space of the slower dancer. This is interesting since it comes to the slower moving dancer to do the coordination among the various rates between physical world and the virtual world instead of the leader.

Q2: *Continuity*

The satisfaction of continuity is ranked by the dancers next to the synchronization (average: 6.38). There are two major factors which affect the sense of video continuity: the network layer and the motion rate. When we stream the 3D video stream at the fixed sendering rate of 5 Hz (i.e., period of 200 ms), the average inter-arrival time is 0.200013 second and the sample standard deviation is 0.047 second. More than half of the inter-arrival times is less than or equal to 0.2 second and the buffering mechanism is used to hold early arriving frames which brings the jitter to an acceptable level. On the other hand, the motion rate seems to play a more important factor as reflected from the experiment. It is noted that when the dancers move at fast rate (*F-F*) they both give very low rank to the continuity. In such case, the motion cannot be fully captured by the virtual space which makes the 3D video seem less continuous. Meanwhile, the slower dancer tends to feel less comfortable with the continuity as in *F-S* and *M-S* when she (as a follower) has more chance to observe the 3D 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 (an essential component for live dancing) as noted by the dancers in the feedback. — "... *there is no direct eye contact with the other performer,* *a foreign concept to live performance ...*"

The performance bottleneck lies in the 3D stereo algorithm. Currently, the resolution of each 3D frame is 320×240 pixels. The average 3D reconstruction time is 157.3 ms. The overall processing time of one macro-frame is around 210 ms including compression, transmission, decompression and rendering. 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. From the hardware point of view, the camera cluster can support up to 640×480 pixels resolution at the video rate of 15 Hz, still indicating a large space of improvement. However, more software and hardware acceleration techniques need to be explored which is our next challenging goal of upgrading the tele-immersive system.

3.2.2 Part II – Elaborating Questions

The elaborating questions ask for the dancer's opinion about the potential impact of the tele-immersive environment on live and collaborative dance performance.

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 collaborative dancing in the tele-immersive environment gives them a very unique and sensational experience compared with the dancing in traditional settings. 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 instead of her physical body as she is so absorbed in watching the 3D videos. The other dancer expresses an 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 establish. Maybe it had to do with getting used to each others presence in the space. Compared to myself dancing alone in the lab, it was much more vivid and fun to dance with someone remotely. I really felt a connection to that other place ...*"

We observe that there are two important reasons why dancing in the tele-immersive environments arouses such dramatic feeling of the dancers. The first one lies in the very fact that they could communicate via dancing with a remote person, which is totally different from the way that dancing is usually organized and performed. At the beginning, the dancers do not have a prepared mind-set for the change. The second one is due to the advent of 3D free viewpoint video that the dancer can directly watch herself and her partner at any time from any arbitrary angle without the need of turning her head or body. In practicing dance, the dancers need to be constantly aware of her pose and movement. From this aspect, the tele-immersive environment provides them with a much more powerful feedback channel than traditional training methods such as dancing in front of mirrors or under the supervision of a trainer. Another important point lies in the value of audio channel which greatly enhances the tele-presence of the remote partner as one dancer emphasizes. — "*... When her voice was added and we could communicate through speech this greatly enhanced her presence ...*"

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. For example, one dancer comments that she needs to pay special attention not to "*crush*" into each other.

In short, collaborative dancing in cyberspace calls for challenging mental adjustment to acquire a more accurate temporal and spatial awareness. Further more, the dancers need to keep constant track of their virtual presence. — "*... Towards the end we attempted virtual touch. I found this very important and viscerally charged. I knew that she wasn't there but she was 'there' in a way and this was very powerful. There was a tenderness, lightness and delicacy in the touch, being careful to dance together. So this was a change from how I normally partner with people. Again the 'weight' effort wasn't there. There was a 'direct' attention to space, to the pixels of her (the other dancer) virtual presence ...*"

Q7: *In your opinion, what specific artistic values are created by this new form of collaborative dancing?*

The artistic values can be categoried into two parts according to the feedback from the dancers: *a)* the impact on the traditional dance, and *b)* the inspiration of a new venue for collaboration and choreography in 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. The feedbacks are summarized into several points. First, on a global scale the technique could allow professional dancers from different countries and different cultures to ignore geographical boundaries and easily communicate with each other through dancing. As the collaborative dancing requires very high level of spatial interaction among dancers, the tele-immersive environment can convey them an enriched experience that is simply not possible with traditional communication methods such as 2D video conferencing. Second, remote dancing class will 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 dancing movement, freeze it and show the problem area when replaying it in 3D space. Compared with dancing through watching video tapes or following 3D avatars, the tele-immersive environment provides a more advanced way of practicing dance.

As to the impact on the new form of collaborative dancing, both dancers admit that the experience of dancing in the tele-immersive space has inspired them to consider in a creative sense and enriched their usual view of dancing art. — "*... 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 ...*"

One dancer comments that the tele-immersive environment makes her consider *an entirely new relationship* with the other dancers and with the audience. The dancer expresses the concern of how to coordinate her focus as she is handling a solo and duet at the same time and how to maintain the contact with the audience. — "*... It is interesting and exciting challenge to create work where one can watch the same movement as a solo and duet simultaneously ... There is a choice for where the dancer chooses to look while dancing. She can either look at the screen showing the two in cyber space and choose to relate to the other dancer this way, or ignore it and focus on her own movement ... there is no direct contact with the audience, a foreign concept to live performance ...*"

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. The first one is related to the physical space, that 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. Some portion of the space is also taken by cameras, computers and cables. The second one is related to the multi-view display system. Currently, we deploy two displays at each site which allow more freedom for the dancers to examine their body and movement from any arbitrary viewpoint at any time. The dancers love this feature so much that they prefer more displays to be installed.

3.2.3 Part III – Summarizing Questions

We first ask the dancer to rank the features and improvements according to desirability in a scale of 1 (weakest) to 10 (strongest), followed by questions for general comments.

Q9: *Please rank the most desirable features/improvements including: (1) lower response time, (2) sharper visual quality, (3) synchronized music between the two sites, (4) synchronization between 3D video rendering of local and remote dancers, (5) automatically changing view perspectives such as simulated moving surrounding camera, and (6) multiple views of the 3D scene*

The ranking is shown in Figure 6. Among these, the dancers show strong interest in enhancing the synchronized music and the multi-view system.

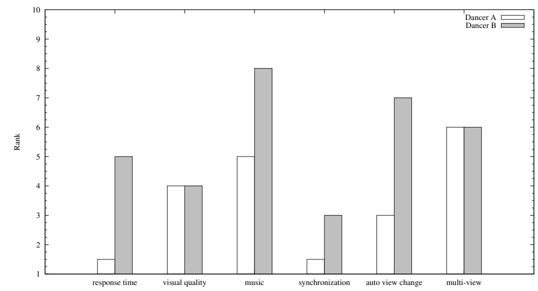


Figure 6. Ranking of Features/Improvments

Q10: *Are there any other general comments about the technology and artistic impact?*

The dancers express the wish of continuing the experiment with more realistic dance performance (e.g., with choreography). One dancer comments that she prefers less intrusiveness of the environment so that the artist can focus on the creative work. The other dancer indicates that the visual quality is not as important as having multiple views in allowing full understanding of the partner.

4 Related Work

We review related work based on: *collaboration*, *art* (including sports etc.), and *user experiment*. None of the work we have found so far bears all three criteria. Therefore, we choose papers that bear two of the three criteria.

Collaboration and Art. In [11], Schaeffer et al. present a software system that allows remote participants to engage in sport and dance activities. Inside the virtual space (*Cube*), the users can operate their full body avatar-based representation using motion capturing tools. The study shows a very high level of interactivity among participants. In [6], 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 arts 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 [7]. The most important conclusions are technical weighted such as the claim that immersive interaction is supportable in the Internet2 networking. In [9], 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 [4], 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 conclusion

In conclusion, our preliminary evidence suggests that the dancers can tolerate a certain level of mismatch between the physical motion rate and the video capturing rate in synchronizing their movement. So far, we have no knowledge of whether such inconsistency would influence the performance of the dancers from an aesthetic sense. Therefore, we plan to continue the experiment with choreographed dance for further evaluation.

The multi-display system is proved to be very useful for rendering 3D models where multiple displays are installed with each showing a different view of the scene. It extends the function of mirrors which the dancers usually rely on for practicing purposes. Given a set of interesting views, the multi-view system can arrange the display layout in an intelligent way. However, currently a testing staff is needed to assist the dancer in manipulating views. We intend to introduce detection channels for an automatic view selection.

In addition to the *traditional* challenges such as improving the resolution (eye contact) and response time (interactiveness), the experiment opens up new ones including a better user interface with less personnels and intrusiveness, and a larger dancing space. We will continue on addressing these issues to increase the quality of dancing interaction.

Most importantly, we are encouraged to find that collaborative dancing is a very promising application for the tele-immersive system and its potential impact needs to be further explored. We believe the research will reveal to us a better understanding of how the tele-immersive environment affects the way people interact with each other in collaborative work. The information will help us improve the design and implementation to promote its application in other social, artistic and educational domains.

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