Nautilus: Real-Time Interaction Between Dancers and Augmented Reality with Pixel-Cloud Avatars

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Abstract
Real-time interaction with augmented reality is a novel material for dancers and choreographers to work with on stage. Rather than focusing on a perfect synchronization between dance and music, it allows the dancers to affect their audio-visual environment and react to the change. In this paper, we report the process and outcome of a collaborative effort between art and technology that has explored this new material and resulted in the dance performance *Nautilus*. We suggest an interaction method based on a depth sensor and pixel-cloud avatars that allows the dancers to interact reliably with an augmented reality while moving freely on stage.

Author Keywords
Dance Performance ; Augmented Reality ; Human Machine Interaction ; Kinect ; Unity.

Résumé
L'interaction en temps réel avec la réalité augmentée représente un nouveau matériel avec lequel les danseurs et chorégraphes peuvent travailler pour leurs spectacles. Cela permet aux danseurs d'aller au-delà de la seule synchronisation entre musique et mouvement et amène de nouvelles opportunités comme modifier l'environnement audio-visuel et de réagir à ses changements. Dans cet article, nous présentons le processus et le résultat d'un

travail collaboratif entre art et technologie, lequel a permis d'explorer ce nouveau matériel dans le cadre du spectacle *Nautilus*. Nous suggérons une approche basée sur le tracking des corps par caméra 3D et sur des avatars composés de nuages de pixels ; cette approche permet aux danseurs d'interagir de manière fiable avec la réalité augmentée en gardant la liberté de mouvements.

Mots Clés
Danse ; Réalité Augmentée ; Interaction Homme-Machine ; Kinect ; Unity.

ACM Classification Keywords
J.5 [Arts and Humanities]: Performing arts; H.5.1 [Multimedia Information Systems]: Artificial, augmented, and virtual realities

Introduction
A dance performance can be easily considered as a multidisciplinary project. Beyond the well known combination between movements and music, a dance performance can involve a variety of audio-visual elements such as sound effects, light effects, and visual projections. These technological elements used in the production of the dance performance allow to create a specific environment, corresponding to an artistic vision, and their use is the foundation of a great interdisciplinary collaboration: a collaboration between art and technology.

A prominent example of such collaborations is the dance performance *Variations V* (1965) by John Cage and Merce Cunningham. It featured twelve 5-foot-high antennas equipped with photocells that reacted on the proximity and the shadows of the dancers to trigger sound effects based on dozens of mixed tape recorders and radios [4]. Thus, the dancers created their own sound by moving on the stage. Visual elements of the show included distorted television images by Nam June Paik and films of the dancers shot by Stan VanDerBeek during rehearsal that were projected onto a large screen in the back. This visionary performance from the 1960s can be seen as an example for interactive augmented reality, in a broad sense. The live dance was augmented with virtual elements, *viz.* the electronic sounds triggered by the sensors and the visual projection.

The mutual benefits arising from a partnership between art and technology can best be described in the words of Swedish research scientist Billy Klüver from Bell Labs, who designed the photocells for *Variations V*. He was one of the co-founders of the organization *Experiments in Art and Technology (E.A.T.)* that facilitated an encounter between the two disciplines. In 1995, Klüver explained in an interview that the *"goal from the beginning was to provide new materials for artists in the form of technology"* [1, p. 8], highlighting the fundamental benefit for artists to engage in such collaborative efforts. Regarding the scientists, he states that the *"engineer expands his vision and gets involved with problems which are not the kind of rational problems that come up in his daily routine. And the engineer becomes committed because it becomes a fascinating technological problem that nobody else would have raised"* [1, p. 9].

The past decades have brought us many great dance performances that were created in similar spirit, integrating new technology as it emerged. For a survey, we refer the reader to [2]. One of the most profound changes has been the digital revolution that has facilitated processing sensor data as well as audio-visual media by means of computers, thereby often creating digital works of art in their own right.

Real-Time Interaction: A New Material

Nowadays, with increasing computational power, it is possible to conduct a live analysis of sensor data and to create real-time computer graphics and audio based on commodity hardware. Also, most of the technological equipment can be hidden during shows when employing remote sensing or wearable sensors together with offstage computers. An example from the recent past is the dance performance *Hakanaï* (2015) by Adrien Mondot and Claire Bardainne. A dancer is surrounded by a transparent cube, on which real-time computer graphics are projected that interact with the dancer. The visualization follows physical principles and artfully combines real and virtual elements on stage.

The real-time connection between the physical and the digital world is a relatively new material for artists to work with. It differs fundamentally from a synchronization between dancers and pre-recorded media. Instead of focusing on a perfect synchronization between dance and music, or dance and visualization, it allows the dancers to improvise, to affect their environment, and to react again on the change in environment. This principle of closed-loop feedback is illustrated in Figure 1. Note that other senses of the dancers could be stimulated as well. An interface to virtual reality could also convey touch and smell, which would allow the dancer to react more intuitively on a virtual environment. But this kind of technology is still in its beginnings.

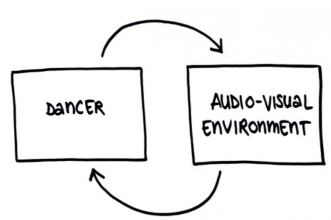

Figure 1: Real-time interaction; dancers and their audio-visual environment are in a closed feedback loop.

The Nautilus Project

In this paper, we present an explorative study on real-time interaction with augmented reality for dance performances. The project extended over one year and resulted in the performance *Nautilus* in 2016. Our aim was to explore this new material with a strong focus on the artistic point of view with the help of scientists who built prototypes based on currently available technology.

The system we have developed is based on digital avatars of the dancers in form of pixel clouds that are embedded in a virtual reality. The avatars correspond to a real-time 3D scan of the dancers with a depth sensor and are projected in exact scale on a transparent tulle (a mesh fabric) between the dancers and the spectators (*cf.* Figure 2). Both the dancers and their life-size avatars are cast in an underwater world, where they interact with plankton in the water. By changing the intensity of the stage light, we create a transition between the real and the virtual world for the spectator, thus exploring the whole spectrum of mixed reality [3].

In the following, we discuss the multidisciplinary collaboration that led to this performance, present the technical solution in more detail, describe the performance and its reception, and conclude the paper with lessons learned and an outlook to future work.

A Collaboration Between Art and Technology

An encounter between artists and scientists means to bring together two cultures that differ in language but are closely connected in the spirit of creating new things. Our experience was that this kind of collaboration has radiated a special fascination in both fields and has quickly attracted the interest of over a dozen students and professors from three universities in Switzerland, namely the University of Applied Sciences and Arts Western Switzerland (HES-SO) in Fribourg, the University of Fribourg (UniFR), and the Bern University of Arts (HKB).

From the outset, the project was guided by the artistic vision, that is science provided a service to art in form of new technology. Following this procedure, we hoped to avoid a situation where the dance performance would only be a vehicle to show off the technology.

The collaboration evolved around a small core team, the choreographer and artistic director Sara Grimm (HKB) and the technical director Andreas Fischer (HES-SO & UniFR), who worked closely together since the technology strongly influenced the artistic possibilities.

The sensor technology was explored at HES-SO by Pascal Buchs with support from Maurizio Caon, Andreas Fischer, Omar Abou-Khaled, and Elena Mugellini. The visualization, which included both visual arts and its technical implementation, was created at UniFR by Valentine Bernasconi with support from Angelika Garz and Andreas Fischer. The choreography was developed at the HKB by Sara Grimm with support from Franziska Meyer and Claudia Wagner. It was performed by five dancers from the HKB, Alina Schwitter, Eve Schütz, Marie-Louise Schneider, Mariella Surber, and Melanie Kummer.

Work Process

We developed the performance in two phases. At the beginning, the general theme of an underwater world was defined such that all teams could get started. Over a period of several months, we investigated suitable sensor technologies and designed the visualization. At the same time, the choreographer explored the theme of an underwater world with her dancers by developing cells of movement. She was repeatedly invited to the scientists' lab, where prototypes were presented to her. Finally, she selected a promising approach that was installed at the dance school.

In the second phase, which encompassed a few weeks, the prototype was explored in practice together with the dancers. The dancers played with the virtual world and developed dance sequences, which in turn resulted in new requirements for the augmented reality. It was intriguing to observe how the virtual world was transformed into something completely new during these trials. The pixel-cloud avatars, for example, were not planned but discovered by accident. Their original purpose was to serve as invisible proxies of the dancers in the virtual world to facilitate the interaction. But when we saw the avatars displayed in life-size during a trial, we were amazed by their physicality and expressive power. Eventually, they became a central part of the *Nautilus* performance.

Aligning the work processes of artists and scientists was rather demanding. As the augmented reality and the choreography are strongly linked together, they have to be changed together. Sometimes even a small change in the software creates completely new artistic possibilities. Therefore, it was important to ensure that, at some point, the augmented reality converges towards a stable design, which the artists can rely on and work with.

Towards Real-Time Interaction

One of the most crucial aspects of real-time interaction is the appropriate choice of sensors and interaction methods. At the beginning of the project, the scientists focused on real-time tracking of the dancers' skeleton, that is identifying their head, hands, feet, etc. for interacting with a virtual world, which is the standard approach. However, the choreographer rejected this solution as too restrictive. When attempted with a camera,[1] the dancers had to be in a nearly frontal position for the camera tracking to work properly; it became unstable as soon as they began to move and turn freely on stage, especially when dancing close to the floor. We have also investigated wearable sensors,[2] yet – despite being small – they felt too invasive for the dancers. Further-

[1] We tested Microsoft Kinect cameras, versions 1 and 2, with infrared-based depth sensor.

[2] Perception Neuron units with integrated gyroscope, accelerometer, and magnetometer.

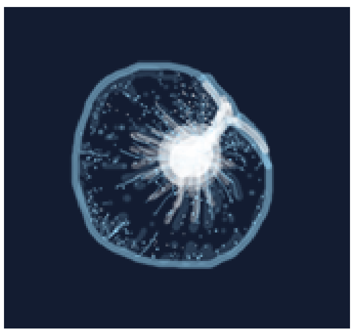

Figure 3: Drawing of a plankton.

Figure 2: Avatar (magenta) with plankton (white) in the *Nautilus* environment; projected onto a tulle that separates the dancers from the audience.

more, they were not well suited to track the exact position on stage, which at that time was already an important part of our virtual world.

To provide the dancers with the desired artistic freedom, the request of the choreographer was to take into account the entire bodies of the dancers for the augmented reality, instead of reducing them to their skeleton. It is thanks to these kind of challenges set by the artistic expectations that the scientists had to explore new approaches, which is an example for the great benefits art can have on technology.

Avatars Based on Pixel Clouds

The suggested solution is an interaction based on a depth sensor and pixel-cloud avatars as illustrated in Figure 2. It shows a dark room with a tulle between the dancer and the spectator, on which a violet avatar of the dancer is projected in life-size with a projector facing the spectator. The avatar consists of thousands of 3D pixels captured with the infrared-based depth sensor of a Kinect camera, which is positioned on the floor facing the dancer.

The avatars are embedded in a virtual environment that has been created with the Unity game development platform. They are cast in a virtual underwater world, where they are surrounded by moving plankton (see Figure 3) following physical buoyancy effects. Synchronised in real-time with the dancers, the whole body of the avatar collides with the plankton, which is the principal interaction in the *Nautilus* performance.

Technically, it has not been trivial to achieve real-time performance based on thousands of colliding pixels. In order to speed up the process, the space is tessellated with small cubes, which are activated when accumulating enough pixels. Upper and lower thresholds are considered to avoid flickering effects. When activated, point force effectors are triggered to repel the plankton, which is moving in a 2D plane. Based on the same principle of counting the number of pixels in virtual cubes, we have also defined larger areas on the stage to trigger certain effects, such as sound effects or changing the stream direction of the plankton. The runtime performance of the system was about 25 frames per second, which led to fluid movements of the avatars in close synchronization with the dancers.

Artistically, the solution based on avatars has provided the dancers with full freedom of movement. They can interact with the plankton and the virtual areas using their whole body in any pose. Even objects become part of the avatar representation when brought on stage. In order to react on their audio-visual environment, the dancers receive auditive feedback when triggering sounds and visual feedback projected on the tulle. Clearly, the auditive feedback is easier to process for the dancers, as they get only glimpses of the visualization while moving. Therefore, an external observation and guidance has been crucial for the development of the performance.

Although individual dancers are not explicitly distinguished in the tracking, their identity is clearly visible. The pixel cloud is dense enough such that even fingertip movements are observable in the virtual world. Therefore, the dance movements are also well observable when the stage lights are off and only the avatars are shown in the virtual underwater world. By adding stage light, the virtual reality disappears gradually and makes room for the real dancers.

Stage Setting

In Figure 4, our stage setting is illustrated with the tulle separating dancers and spectators. A stage of about 5m x 6m can be covered in large parts with a single Kinect camera[3] accepting occasional occlusion when one dancer is moving in front of the other. The Unity application is running on a commodity laptop offstage.[4] A wide-angle projector is facing the spectators. There is a sporadic blinding effect when a plankton moves between beamer and eye, yet this setup has the advantage that the plankton is also projected into the room of the spectators, on their clothes, the floor, and the walls, which may increase the effect of immersion. Blue stage lights are used to match the colors of the real world to the virtual world.

Although the virtual reality could have been integrated fully automatically, we decided to let someone activate the different phases of the performance manually. One of the main reasons was to let the dancers know that there is a human in control who can help if there are problems.

[3] To cover such a large stage, we needed to use Kinect version 2.
[4] We used a laptop with 2.16 GHz CPU and 8 GB RAM.

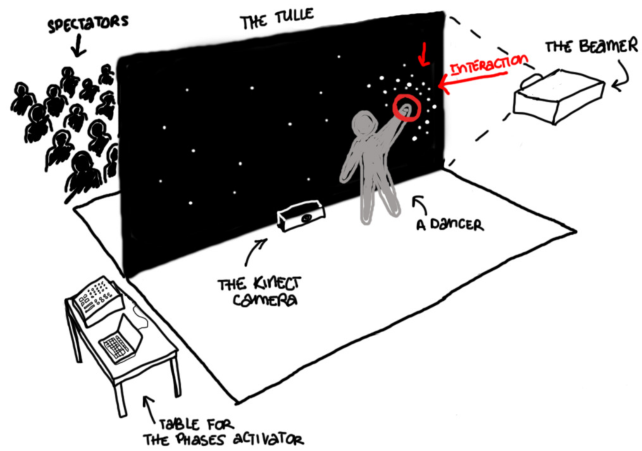

Figure 4: Stage setting.

The Performance

Named after the submarine from Jules Verne's novels, the *Nautilus* performance aims to immerse the spectators in a world deep under the sea. It explores the borders and transitions between reality and virtuality, merging them together at times to create something in-between.

The different phases of the eight-minute performance can briefly be described as follows. The show starts in a dark room. Diffuse water sounds are played without discernible rhythm and the plankton appears one by one slowly on the tulle. After some time, the dancers enter the stage from the back and their avatars perform an improvised dance amidst the plankton. The lack of meter in the music emphasizes the real-time interaction with the plankton. Gradually, the stage light is turned on and the avatars fade out, leaving the real dancers surrounded by virtual plankton. A stream begins to move the plankton and the dancers perform a synchronized dance to the composition *Mad Rush* by Philip Glass. Afterwards, the water sounds recommence and the avatars fade in again, mirrored. For a while, the dancers swim against their virtual selves. Finally, the light is gradually turned off and the avatars disappear one by one to the side, alongside with the plankton.

After the performance, the spectators have the chance to explore the *Nautilus* environment themselves. As soon as they go behind the tulle, their own avatar appears and allows them to interact and play with the plankton.

Reception

Nautilus was performed in the context of the HKB music and movement summer festival 2016 in Biel. We have distributed questionnaires after the show to obtain feedback from the spectators. 34 spectators (18 women, 16 men) with an age between 18 and 66 years returned the questionnaires. Several brief questions were answered with scores between 1 (not agree at all) and 5 (fully agree). There was also the possibility to provide general feedback, which was for the most part very positive and encouraging.

In the following, numbers in brackets indicate median scores over all answers. When asked if the virtual world or the real world were too intrusive, the answer was in both cases a clear no (1). The spectators felt that the real and the virtual world complemented each other (4). The quality of the dance movements was well visible in the virtual world (5) and the interaction between the dancers and the virtual world was understandable (4). However, the elements of the virtual reality were not convincingly similar to reality (3). This last point was also criticized in two general comments. Although the plankton moved according to physical principles, it seems that it could not fully convince as plankton movement underwater.

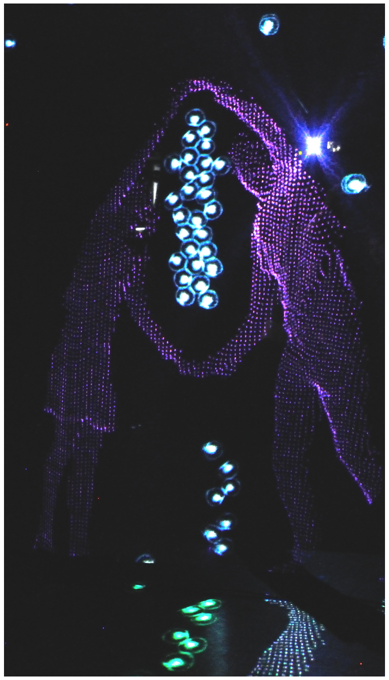

Figure 5: Two avatars catching plankton together; spectators experimenting with the *Nautilus* environment after the show.

Several spectators have tested the *Nautilus* environment after the show. Seeing how playfully they interacted with the augmented reality, exploring new effects and movements, was very interesting for us. For example, they created new forms blending the shapes of their avatars together; others started to collect the virtual plankton composing specific shapes with their avatars, as shown in Figure 5 (this culminated in a sort of game, which consisted in collecting the largest amount of plankton); others just played with their body and the space around them in order to curiously test the different reactions of the environment.

Conclusions

The collaboration between art and technology has been highly rewarding both for the artists, who could work with a new material on stage, and for the scientists, who were challenged by the artistic expectations. The suggested interaction method based on pixel-cloud avatars was quite successful and has proven to be very reliable even when multiple dancers were moving freely on stage. The spectators could become performers as well when testing the system after the show. Without the need for training, they could interact with the system using their whole body and created, among others, a sort of multiplayer game.

An important lesson learned from our multidisciplinary collaboration is that the practical work with the artists is crucial for the design of the virtual world. Some of the main elements of the *Nautilus* environment, including the pixel-cloud avatars, were not created in the scientists' lab but instead during the practical trials together with the dancers. Another lesson learned is that even small changes in the software can lead to completely new artistic possibilities. Therefore it is important to fix ideas at some point and let the artists work with a relatively stable environment.

Future work includes the development of other dance performances based on *Nautilus* by creating new virtual worlds for the avatars. Clearly, there is a wide range of artistic visions that can be developed around this technology. One of the main constraints of the current approach is the dancers' difficulty of registering their own interaction with the virtual world when they are concentrated on the dance movements and cannot watch the visualization. Therefore, we plan to add a stronger focus on auditive feedback for the dancers in future projects. With future technology, it might even become possible to feel virtual sand under one's feet and smell a virtual ocean breeze.

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