Real-time Projection Mapping for Flexible Objects in Musical Stages

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Abstract

This paper describes our efforts in developing real-time projection mapping system, effective technique available in the performance by combining costume and digital technology. Our system can project and align images on the surface of moving actor's costume by applying augmented reality based on projection mapping, and the images can change frequently during the performance. Therefore, this result can not only describe a particular character effectively, but also offer visual experience to audiences. We explain our result obtained by rehearsing the scenes[†] applying our techniques in the real stage set installed in a wide theater.

Keyword : Projection mapping, Flexible shape, Dynamic objects, Real-time masking, Performance arts

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[†] The scene is a part of the performance, Korean original musical ‘Turandot’, that produced by DIMF(Daegu International Musical Festival) in Korea. It derived some idea from the opera ‘Turandot’, but it shows a wholly different story, music, and choreography. This paper indicates a part of various performing techniques for the musical.

1 Introduction

In contemporary performing art areas, such as play, dancing, and musical, numerous attempts have been made to shift away from existing analog esthetics to new paradigm fused with digital technology. In fact, this convergence of performing arts and high technology is natural phenomenon, which dates back to decades ago. Since a genre called performance emerged, dramatic and aesthetic potential of new technology has been realized and applied to the area. The technology applied to the performance enhances space of stage and an actor's body, and helps audiences understand the intention of the performance [1]. Furthermore, it draws the audiences by offering extraordinary experience. However, simply applying technology to performance does not guarantee the success for creative and spectacular practices.

Key point of the convergence is that technology should harmonize with the objects optimized for the performance, such as a stage set, props, costume, lighting, without damaging its story [2]. More importantly, the convergence should be realized by performance, not technology. Because excessive exposure of technology disturbs audiences' concentration, we have to keep in mind that its indiscriminate abuse of technology may lower the quality of the performance.

In this paper, we propose an approach, named Real-time Projection Mapping System, to meet the key point described above, illustrated in Fig. 1. The purpose of our research is to develop an effective performance technique which can be applied to the performance practically by combining costume with digital technology. The costume is an important component of a performance, which reflects the actor’s character in it. Real-time Projection Mapping System can change texture, patterns, and images on moving actor's costume frequently by using projection-based augmented reality (AR) techniques during the performance. The result was able not only to express specific character effectively, but also to provide interesting visual experience for the audience.

2 Related Works and Motivation

2.1 Projection-based Augmented Reality

Projection-based AR is described as video projection technique, which can extend and reinforce visual data by throwing images on the surface of 3D objects or space; this belongs to Spatial Augmented Reality in a broad sense [3, 4]. Using projection-based AR, it is easy to implement graphical representation that ordinary lighting techniques cannot express. Unlike general lighting technique, the technique can project high-definition image or video, and change the object shape visually with the flow of time. Therefore, it can show visual images dynamically. This combination of imagery and real-object allows the audiences to recognize visually extended space. In addition, unlike conventional highly equipment-dependent AR which is restricting audience's body, this technique can advantage to improve their immersion. These advantages are requirements for better audiences' experience in the performance [5, 6]. In media art field, the projection-based AR is called Projection Mapping; which covers smaller field than the Projection-based AR.

2.2 Projection Mapping on Moving Objects

Projection mapping is a technique which causes optical illusion by analyzing three-dimensional object, projecting images, and then precisely aligning them. This technique is being widely used in various fields such as façade of building, plastic objet, and also in the performing art field. In these cases, it usually projects the images onto fixed objects by using manual alignment between the objects and projected images. On the other hand, there are a lot of recent researches trying to perform projection onto dynamic objects with automatic alignment, but these researches are applicable only to limited shapes and movement of objects, requiring huge computation for image alignment [7]. This causes latency until the image is aligned with 3D objects. The more latency, the slower the movement of projected image following the movement of object, consequently, it generates a visual error, which reduces the immersion of audiences [8, 9].

2.3 Feature of Costumes in Our System

When projection mapping is applied to performing art, its purpose is augmenting the exterior of object or the interior environments in the theater, such as a set and objects in the stage. Unfortunately, we were unable to apply the existing method due to the characteristics of costume as follows.

Flexible shape. 'Flexible shape' is a shape like actor's costume. The existing techniques can be applied only to the surface of 3D solid objects, such as polyhedrons, cylinders, or spheres. In general, the shape of stage objects may be complex or atypical, but they are not flexible. However, flexible objects have silhouettes which are difficult to predict, and their shapes change frequently. Besides, if part of the costume is covered by occluding objects, the existing method cannot be applied.

Dynamic object. Similarly, when projection mapping is applied to dynamic object whose position is moving or shape is changing, this work also causes difficult problems. For example, when the actor performs simple movements like moving from side to side or lifting arms, it is difficult to apply projection mapping even in this easy case. To solve these problems, there have been various attempts; such as, showing the effect like projection mapping by merging certain pre-set motions with video contents through many exercises [10], or synchronizing preprogrammed robot's movement with video contents [11]. However, it is evident that the actor cannot perform the given motion according to the scenario exactly robot during live performance.

3 Real-time Projection Mapping System

The problems discussed in chapter 2 are factors degrading performance quality by distracting the attention of the audience. Thus, we implemented Real-time Projection Mapping System using a masking technique, so that the images are automatically projected and aligned onto the dynamic object and actor's costume with flexible shape in real-time. The process of the system is as follows: 1) Tracking varying actor's silhouette, 2) Creating synthetic images by masking the silhouette and then compositing with video, 3) Aligning generated images with actor's costume on stage through the projection.

3.1 Hardware Configuration

Fig. 1 abstracts the hardware configuration of real-time projection mapping system. The main apparatuses of this system are composed of infrared(IR) camera and IR light equipment for the extraction of precise and natural actor’s silhouette; computing device with graphics processing for rapid and effective image processing, masking images creation, and video contents synchronization; a high-lumens projector to project the images onto the surface of the actor's costume.

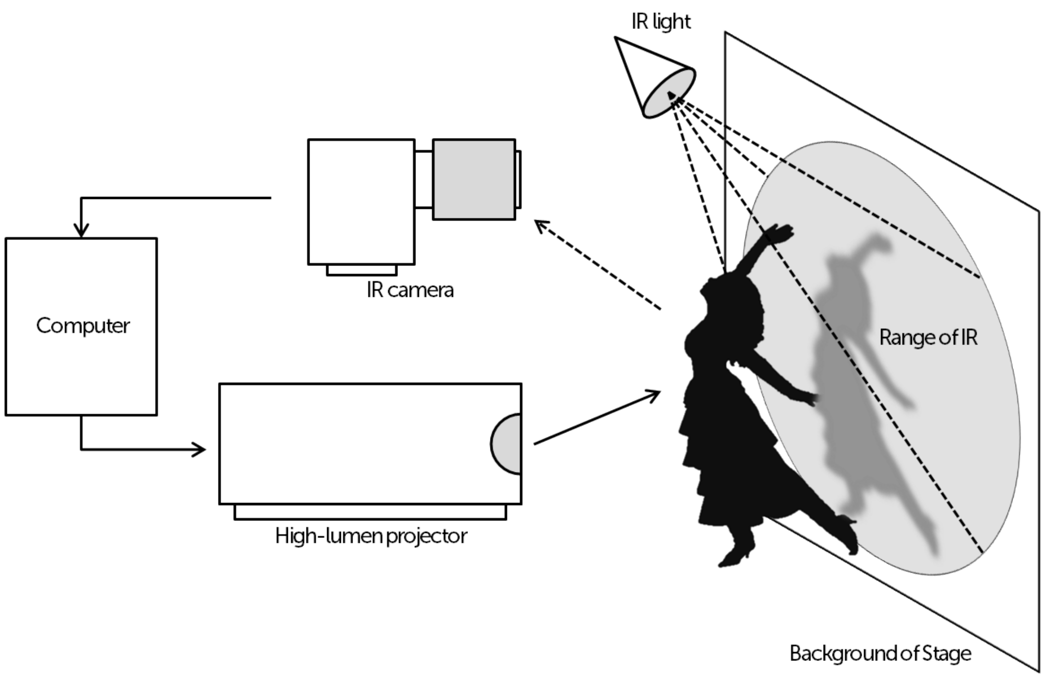

Fig. 1. The hardware configuration of real-time projection mapping system

There have been previous attempts using depth camera, like Kinect from Microsoft, to extract dynamic object silhouette with flexible shape. This equipment can easily extract the masking image, with the help of the depth data in space. To produce high-quality result, the center line of the projector lamp and IR camera lens have to be set up as parallel and close as possible. However, in case of depth-camera, its effective-range is too short to be used in a big theater. To solve the problem, we used IR camera device with zoom function in order to capture the actor in large space as well. Capturing only particular area reflecting IR light, the IR camera is effective to separate the background and the actor precisely.

3.2 Projection Mapping based on Real-time Masking

The purpose of Real-time masking technique is to project the images onto the certain part or the rest of the scene without delay. For instance, when we would like to augment an actor or his costume surface using projection mapping, we can select only his silhouette area excluding any other part, then project with exact alignment. While this masking technique needs less computation (as compared with 3D object tracking such as [7]), it is able to show relatively high quality result. In other words, it can respond rapidly to the actor's movement and align precisely. We perform the process illustrated Fig. 2 to generate the masking images of the silhouette from IR camera and to merge the images with video contents made in advance.

Fig. 2. Steps of our system process

First, an actor is captured at certain position by IR camera, with IR light projected over a wide range in the back side of the stage. Then, the masking image is generated from the silhouette by using binarization, morphology, and Gaussian blurring of the captured images. Finally, the masking images are combined with the frames of video contents. This process is presented in Fig. 2. These steps of the process are performed on GPU which enables parallel operation and computational speed-up. As a result, it can reduce time latency a lot in image processing.

3.3 Precise Calibration of Mapping

In order to handle unexpected problems directly on the stage, we made real-time mapping application with several adjustment functions. And, this can be used for quick and effective set up before the performance. This application is designed to deal with various problems happening under physical environment, lighting condition, or projector position, in the theater. In addition, it includes various functions which can directly control the parameters of image processing in real-time. The functions can be grouped into three categories.

- Mask adjustment: adjusting brightness value of IR camera according to the lighting condition and modifying the parameter for morphology and blurring to extract accurate and natural actor's silhouette.
- Projection transform: adjusting the size and the location of projected image to minimize the errors of mapping in the case that it is hard to select optimal projector position because of the theater condition.
- ROI area exclusion: excluding the unnecessary area from the projection when the projection mapping is applied to the actor in live performance.

4 Implementation and Result

We selected a theater, and installed stage set, stage objects, and the real-time projection mapping system, as illustrated in Fig. 3.

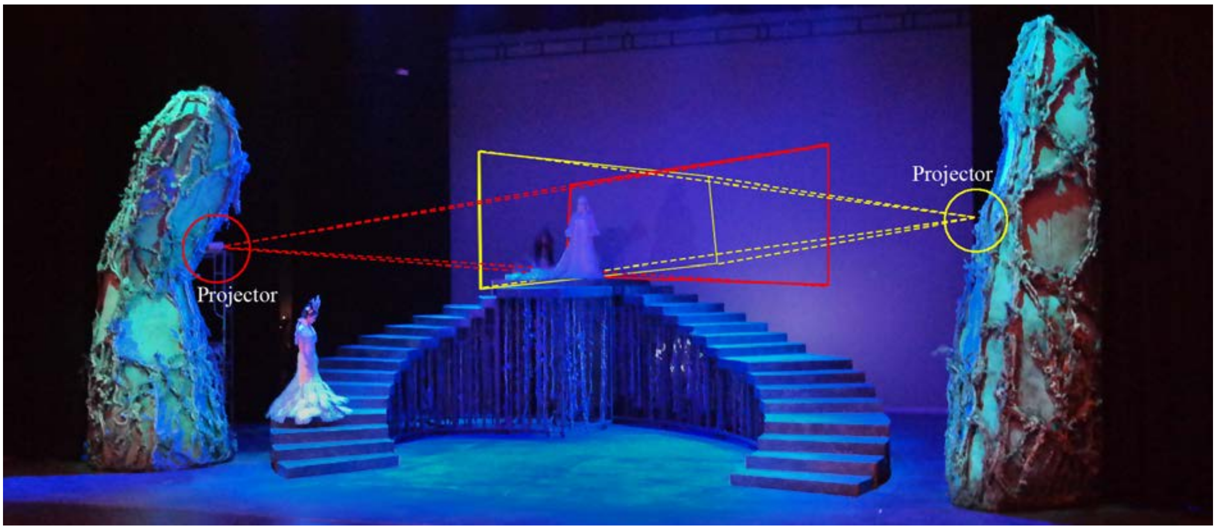

Fig. 3. Installation of stage set, stage objects, and the real-time projection mapping system

Then, particular musical scenes applying our system were rehearsed. In this scene, two characters appeared, and one's dress was augmented to look like a ghost decorated by our system. Although the actress kept moving frequently, the images were projected onto and combined with her dress accurately in real-time, as shown in Fig. 4.

Fig. 4. Projection mapping on moving actress in real-time

To find out how fast our system can respond to the actor's movement, we checked the required time to align processed images with the actor's silhouette. Initially, while the actor was not moving, we aligned the images with the actor's costume. Then, the particular scene was rehearsed according to the planned direction while recording with a camera in front of the stage. Finally, the recorded video was analyzed. In the recording, we selected a portion with the largest actor's movement. When the actor stopped moving, we counted the frames until the images were aligned with the actor's costume.

With this method, the result presented that the images are aligned exactly after 5 frames; which means that approximately 0.167 seconds latency occurred. If we calculate the aligning time for all the frames in the scene, our system shows lower average latency. Our system was tested on a PC with Intel core i7-3770 3.50GHz CPU, NVIDIA GTX680 GPU, 16GB RAM; Point Grey FIREFLY® MV IR camera; and EPSON EB-G5950 high-lumen projector.

5 Limitation

The limitation of this result is that the experimentation of our system is optimized to express the ghost in the scene of the musical. If the actor performs any extreme movements, such as running, jumping, or swinging arms, the visual errors may be more exposed to the audience due to larger latency. In addition, when the actor moves out of the projection area, the images cannot be projected onto her silhouette. Nevertheless, the experts in the musical field gave the positive response that we can show a spectacle of the scene satisfying our intention under limited environment.

6 Conclusion and Future Work

In this paper, we presented the performance technique and real-time projection mapping system, which can be used effectively by merging performance suit and digital technology in performance. Additionally, we equipped sets for the performance in the theater, and showed the result implemented our system. Our research started in order to provide interesting visual experience to audiences. Our system augments dynamic object with flexible shape, which is actor's costume surface, and can change the images according to the narrative of a play in real-time. The mapping result of high quality is obtained from the application that corrects errors generated in the process of projection mapping on stage.

In the future, our plan is to improve the performance of our system further to be performed robustly as well as the performances of multiple genres or various scenes. In order to improve our system further, in the viewpoint of reducing the aligning latency, we are going to optimizing the GPU based algorithm and now researching the technique that generates the composed image beforehand at the calculated position by expecting an actor's future movement from the previous frames.

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