Real-Time Dynamic Digital Scenography: An Electronic Opera as a Use Case

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Abstract. In scenography, digital media has been increasingly used to design richer and more immersive experiences, for example, using video mapping or holographic projection. However, such technologies may sometimes collide with the natural (and sometimes unavoidable) improvisation moments of live interpretation. Thus, to ensure the control of these effects, large technical teams are often needed in the production of such events, which may become unfeasible in smaller size productions with smaller budgets. To test possible solutions to this problem, we endorsed the creation of an interactive low-budget scenario for the electronic opera *TMIE, Standing on the Threshold of the Outside World*, by the composer Carlos Alberto Augusto. To accomplish that, image projection techniques are combined with software to create scenarios that are capable of dynamically changing during the opera and interact with artists in real-time. This paper presents some of the experiments done so far, such as a set of interactive digital effects automatically controlled using computer vision, and simple software to manually control or time the sequence of effects during the show. Then, we discuss the potential of these techniques aimed at enabling the generation of atypical graphic solutions for live shows, as well as the practicality of having a user interface to easily manage the entry and exit times of each of the developed scenarios.

Keywords: Scenography · Computer vision · Interaction

1 Introduction

In performing and scenic arts, scenography seeks to visually organise the action's space to create a more immersive relationship between the scene and the audience [19]. The theatres' sets are traditionally built using physical and tangible materials. However, the recent technological advances promoted the democratisation of digital media, allowing the exploration of novel ways of acting. More and more, nowadays playwrights and directors begin to create, design and/or stage

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artworks exploring such technologies, making the use of digital special effects become increasingly frequent in contemporary scenic arts. The result is theatre plays capable of promoting more engaging and immersive relationships between the performers and the set, as well as between these and the audience. Most popular technologies include Video Mapping, Holography, Augmented Reality (AR), Virtual Reality, Physical Computing (PC) and Computer Vision (CV).

However, due to the natural characteristics of theatre plays, *e.g.* improvisation or chance events, the control of the special effects is, typically, a complex and time-consuming task that involves multiple technicians from various disciplinary fields, such as Sound Design, Light Design, Architecture, Graphic Design, *etc.*. These circumstances may still hinder the wider use of these techniques, namely in productions with smaller budgets. In that sense, this work seeks (I) to explore techniques from computer vision and video projection to create and apply digital special effects that autonomously react and interact with actors, and (II) to develop software to easily manage the employment of these special effects during the play.

In this project, the developed techniques are designed to be employed in the scenography of the electronic opera *TMIE, Standing on the Threshold of the Outside World*, written by the composer Carlos Alberto Augusto. In this play, the stories and realities of two deaf female characters are presented by the alternating discourses of two female singers and a male singer with the aid of an electronic soundtrack. We designed and developed a different environment of visual effects for each character, according to their characteristics and experiences in the play.

To facilitate the usage of such special effects, we developed software for controlling these effects. This software may be operated in two ways: (I) manually (*i.e.* one technician may activate/deactivate the effect); and (II) automatically (*i.e.* the effects are synchronised with certain events in an automatic manner). Also, the software is designed as a multipurpose system, allowing the development and inclusion of new effects, the blending between the existing effects, and the adaptation of the video projections. This way, it allows their use in other contexts, enabling the fulfilment of the requirements of other spaces and plays.

The remainder of this paper is organised as follows. Section 2 presents related work focusing on (I) digital effects to live shows and (II) existing software to create and handle these effects. Section 3 briefly introduces the opera understudy, *TMIE*. Section 4 describes our approach to the development of the present system and the visual effects. Finally, Sect. 5 draws the conclusions and points to the future work.

2 Related Work

Recent technological advances have allowed the exploration of new possibilities for the design of sets, which can now be fully or partially built with digital artefacts as in the virtual set of *The Jew of Malta* by Art + Com in 2002 [38] where projection is used to create a new layer of story interpretation. Since

this story centres on the oscillating thoughts and postures of the various actors, this new and more readable layer of the libretto's deconstructed narration is developed through technology. For this, the actors' white costumes are used as a projection surface so that we can visualise the characters' thoughts and beliefs directly on their bodies. For example, one character's influence over another reveals itself in the fusion of their designed outfits. This is achieved with the use of an image recognition system that identifies the actors' silhouettes in real-time. From the contours of these silhouettes, virtual masks are created, later textured and projected onto the actors (see Fig. 1).

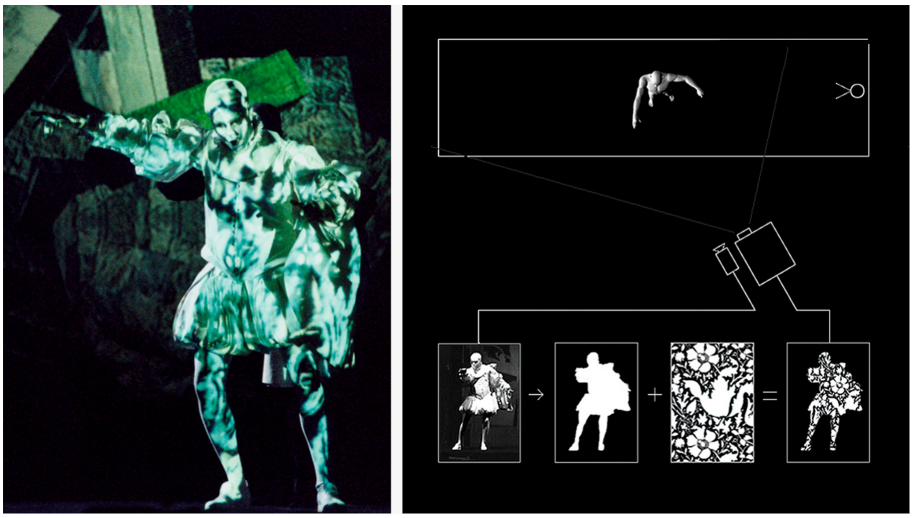

Fig. 1. Virtual Scenography *The Jew of Malta*, Art + Com, 2002. © Art + Com

The introduction of these new digital visual effects also allowed, for example, (I) the creation of more complex plots using computer simulations to visualise and test scenographic spaces [20], (II) the design of dynamic, interactive and moving scenarios through video projections or video mapping on the surrounding space, the scenic objects/props and even over the actors [32,37,42], (III) the creation of interactive and holographic scenic elements [3,32], (IV) the automatisation of the movement of physical scenarios [10], and (V) the creation of hybrid scenarios built both with real objects and virtual elements, using AR techniques [3].

More specifically in the context of Opera, we see this concept of interactivity in the work *Amazonas*, from 2010 [40], where actors interact on stage with a multi-touch table. In this case, a surface was used to influence the projected setting, therefore, the audience is able to easily follow the actors' interaction with the environment. The difference is that every live performance is different in speed, expression as well as audience's reaction. This often causes moments of improvisation or even some sections that are ignored by the actors, which

makes it difficult for all the movements to be precise enough to appear real to the audience. Thus, this type of interaction becomes more realistic and natural in the eyes of the public. The use of this multi-touch table, and the interaction that comes from it, provided actors with new forms of interaction on stage. Also, they allow presenting information more naturally since the interactive exhibition is integrated with the piece.

In the context of this work, we are interested in exploring dynamic, interactive and even autonomous techniques that enhance the interaction between performers and the public and, at the same time, that may handle the unpredictability of theatrical plays. In this context, PC and CV techniques are often used to detect/recognise objects, people and sounds, and to generate audiovisual content [16] as one may see in works made using *Chordata Motion* [6], an open-source motion capture system. Also, it is possible to observe the use of sensors, such as gyroscopes, accelerometers or depth sensors (*e.g.* Microsoft Kinect), to detect and recognise the movements of performers in the three-dimensional space and, subsequently, use the gathered data to manipulate, in real-time, images projected onto the scene, like in the dance performance *Programming & Music* [13].

Several scenographic works make use of the aforementioned technologies to create more immersive performances. For example, this may be identified in the performance *8* [11], which tells a story through dance, music and dynamic scenography. In the scenario of this performance, video projections are made over mobile physical elements, in real-time. To do this, an intelligent system named *BlackTrax* [7] is used to track objects and people.

Levitation [34] is another performance that makes use of video projections and a tracking system, based on Unity Development [35], to give the illusion that the dancer is floating. To do that, the projections on the stage are automatically adapted to the dancer's movements. *Video Mapping Dance Show* [5] and *2047 Apologue I* [39] are other examples of works where artists are placed around visual projections that respond to their movements in real-time.

Furthermore, in live shows, it is still possible to complement the projected effects with other types of visual effects. Examples of this are the shows *Al Janoub Stadium* [23] and *U2 – Experience + Innocence Tour 2018* [9], which combine projections with live-action, holography, light, laser effects, sound effects and pyrotechnics, to make the environment the most immersive as possible.

With the increasing possibilities in building scenarios, there has been a growing need for more complex and capable tools. Nowadays, there are already several different tools that may be used to help the development of digital and even interactive scenarios for real-time applications, many of those without requiring the need to code. *MadMapper* [18] is an advanced tool that allows the mapping of video and light through a highly complete user interface. *Resolume* [29] is a VJing software with a modular node-based interface to create effects, mixers and video generators. *TouchDesigner* [8] consists of a visual programming system that can be applied, not only in the development of video-mapping effects but also in the creation of user interfaces, virtual reality applications, managing hardware, among other tasks. *Ventuz* [36] is a production and design environ-

ment that allows the creation of animated and interactive content using mainly, but not only, simple drag-and-drop actions. *Lumo Play* [17] allows one to create interactive floors, walls, digital signs and touchscreens by using any projector and their own hardware. Finally, *Smode* [33] allows the real-time composition and visualisation of interactive content in a simulated 3D stage. Although all these solutions may facilitate the development of digital effects, many of these tools are proprietary software and most require a considerable learning curve until the users gain the necessary ease to create ideas from scratch.

Nevertheless, for creating video mapping installations, there are also available easy-to-use and open source tools. For example, for interactivity one may use Processing [27], an easy-to-use multipurpose framework, based in Java, that was specially created for artists and designers. Regarding the mapping task, also in Processing, we refer to the SurfaceMapperGUI library [14], which allows the mapping of complex shapes but only works on an old version of Processing (1.5.1), and the Keystone library [43], which allows the use of rectangular surfaces only, but can still be a helpful tool. Furthermore, there is software such as MapMap [2] or Visution MAPIO [31], which may be useful for allowing the mapping of Processing sketches in real-time. The shortcomings are that Visution MAPIO development for macOS has been suspended and MapMap's integration with Processing seems not to be working properly, at least in macOS BigSur (used by our research team).

3 *TMIE*

*TMIE, Standing on the Threshold of the Outside World*is an electronic opera in four acts written by the Portuguese composer Carlos Alberto Augusto. A version for a sole soprano was premiered, in 2016, at O'culto da Ajuda (Lisbon, Portugal). The *libretto* is mainly based on the books *Wired for Sound* by Beverly Biderman (1998) [4] and *Miss Leavitt's Stars* by George Johnson [15], and complemented with excerpts from other texts, namely the *Fragments* by Empedocles [12] and poetry by Antero de Quental [28]. In this presentation, one single performer played all the roles with the support of a pre-recorded electronic orchestra and video sets.

The opera's plot is supported by three characters: Messier (soloist), Selena (soloist); and Coryphaeus (choir). Messier is a deaf woman who is always discovering her innermost self through the experience of listening. This character was inspired by the author of the book Wired for Sound [4], Beverly Biderman, who suffers from profound deafness. She gives a personal account of her life before and after a cochlear implant, the first effective artificial sensory organ.

Selena is a goddess who roams the skies in a silver horse-drawn cart. She was inspired by Henrietta Leavitt, the first female astronomer who also suffered from profound hearing loss. During the 19th century, Henrietta volunteered at Harvard where she developed tools that later helped Edwin Hubble calculate the distance between galaxies.

On the other hand, Coryphaeus is a philosopher studying the stories of the other two characters on the stage. This way, he has the role to mediate between

them, clarifying their common ground. This character was inspired by Empedocles, a Greek philosopher who studied and created the first theory of the ear and hearing, the act of listening.

The play of this opera consists of personal reflections presented in an irregularly altered manner, by the characters. These reflections share the theme of the audition (or lack thereof). Nevertheless, the speeches are sometimes not directly related to each other, nor they are not conversations between characters.

In the context of this work, we are working with the same plot as the one presented in 2016 (see Fig. 2). However, instead of the plot being performed by one solo singer, each role will be played by a different singer.

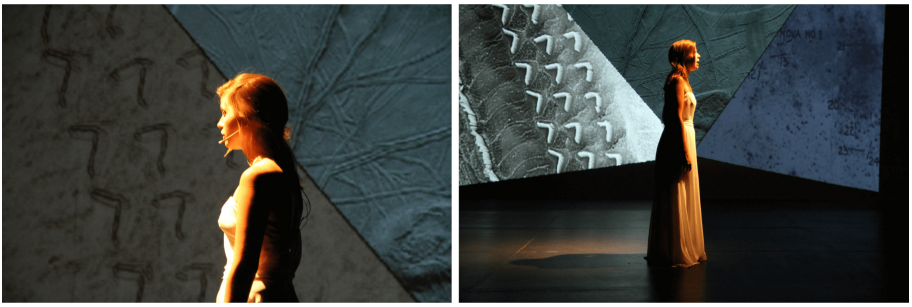

Fig. 2. Video snapshots of the premiere of *TMIE*, in 2016, at O'culto da Ajuda (Lisbon, Portugal). A full record of the opera may be visualised at https://youtu.be/3kogIlnBrfE

4 Approach

The present system plays a set of special effects to be employed in the scenography of the electronic opera *TMIE*. This project still is a work in progress, so, the opera's presentation, where this system will be introduced, is in the production stage. Nonetheless, at this moment, the system can create a set of real-time digital special effects that fulfil most of the requirements of the present opera. Also, this system can be set up without the need for large technical necessities or considerable budgets. In that sense, our current approach is focused on two developing stages: (I) the creation of real-time digital effects that automatically gather data from the stage, especially using CV techniques, and do translate these data into visuals; and (II) the development of software to set up and control the employment of effects. The following subsections will comprehensively describe each stage.

4.1 Digital Real-Time Effects

In the first stage, a set of different experiments were accomplished to read the stage environment and automatically gather data from it, and to subsequently

generate visuals that translate these data into visuals. These experiments were developed by employing different technological possibilities. For instance, we have tried CV algorithms and libraries, such as PoseNet [25], U-Net [1], BodyPix [26], FaceAPI [21] or OpenCV [24] to assess the viability of using such techniques in a stage environment. Preliminary experiments using these algorithms were performed in Javascript using the *ML5* [22] and the *P5.js* [41] libraries. The final version of the system has been developed in Java using the Processing library [27]. Figure 3 displays some outputs of the referred preliminary experiments.

Fig. 3. Preliminary experiments on the development of real-time interactive effects to be projected on stage over artists. (a) Scenographic elements automatically following the artist's eyes/face, using the ML5 implementation of the PoseNet algorithm; (b) Scenographic elements automatically following the artist's arm, using the ML5 implementation of the PoseNet algorithm; (c) Scenographic elements automatically mapped over the artists' body, using the ML5 implementation of the U-NET algorithm.

After accessing the viability of the aforementioned technologies, and respecting the preferences of the opera's author, we started to propose scenarios/effects that would conceptually match the plot of the opera. This way, a different digital scenario environment was developed for each of the characters according to their characteristics, experiences and speech.

Selena, the astronomer, has an obvious connection with the stars. For that reason, a background pattern of stars (white circles over black background) was created. By timing the different moments and/or bypassing in the amplitude analysis of the character's miked voice (a decision left to the author), this scenario may change according to the different moments of the dialogue, varying in size, movement and colour (inverting brightness). By inverting colours and getting black stars over a white background, the scenario stops from representing a stared sky to become a representation of the negative sky scans that were part of an old technique used by astronomers to study the sky. These scans are referred to by Selena in her speech, creating a conceptual connection between the character and both the positive and negative versions of the effect (see Fig. 4). A demonstration video may be accessed at https://vimeo.com/642489858.

Messier's dialogues refer to her life experience before and after losing her hearing. To demonstrate the different moments of this evolution, a background made of dynamic luminous paths was created. These are created from moving overlapping circles that randomly change direction and which size varies with

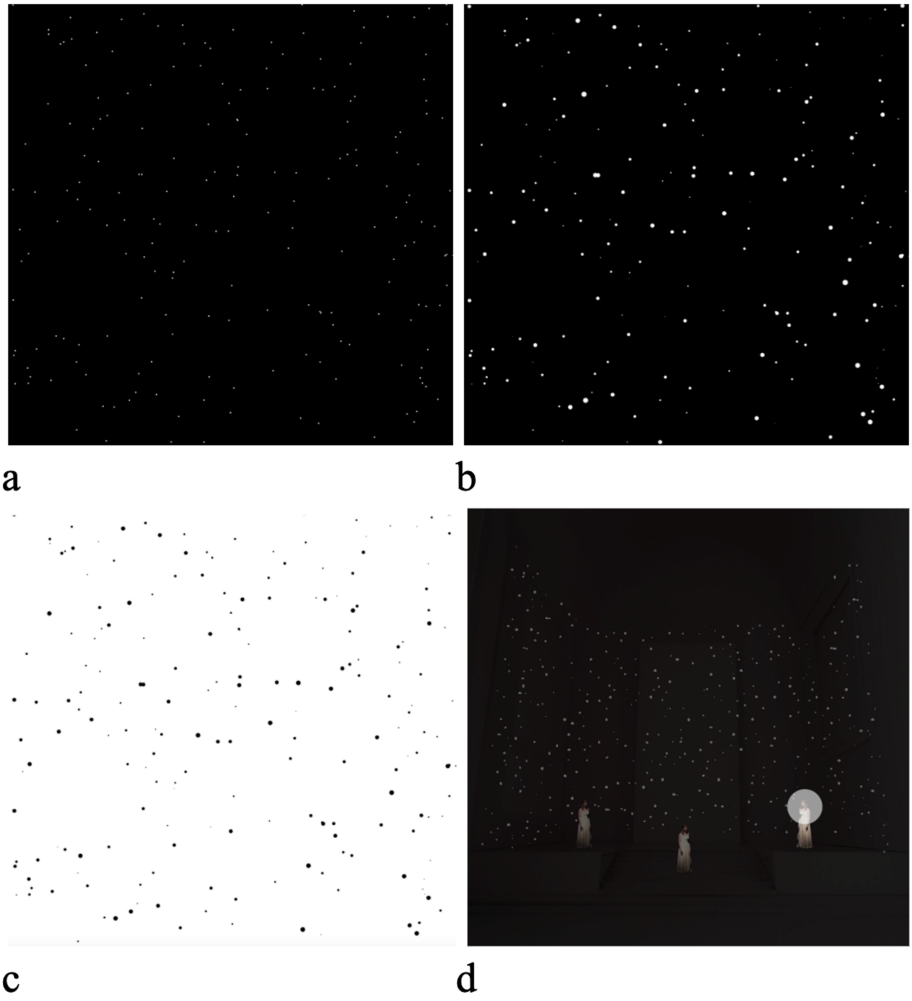

Fig. 4. Examples of different states of the environment developed for the character Selena, to be applied in the form of a background video projection: (a) small white stars over black background; (b) bigger white stars over black background; (c) black stars over white background; (d) example of application on real space.

their speed. Thus, their graphic appearance may conceptually resemble electrical impulses, neuron connections or the character's hearing connections to the world. While performing, the rays may be growing forward or backwards according to the respective moments of the characters' lives that are being referred to in the speech (see Fig. 5). To accomplish that, the two versions of this effect (forward or backwards) are to be timed in the software, yet other interactive features may be added later on. For example, speeding up the growth of the rays according to the character's movements (the more the faster), conceptually relating to her

efforts/action to improve her hearing and thus understanding of the world. A demonstration video may be accessed at https://vimeo.com/642490592.

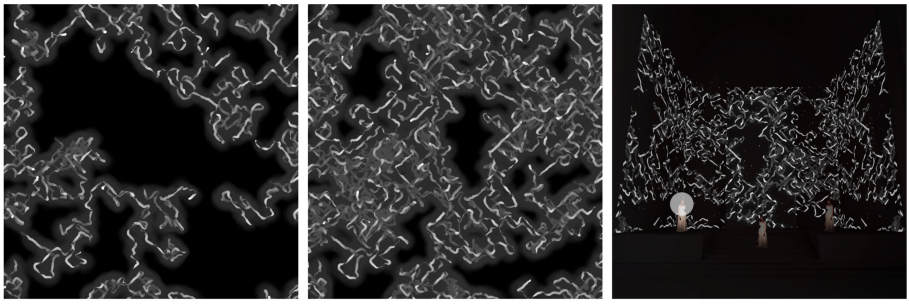

Fig. 5. (a, b) Examples of different states of the scenario/effect developed for the character Messier (white light paths over black background), to be applied in the form of a background projection; (c) example of application in a mock-up.

In addition to the environments created specifically for these two characters, all the three characters are accompanied by a light focus that follows their faces during their speeches (see Fig. 6). Coryphaeus, whose role is to clarify the connection between the remaining two, makes use of the focus effect only, which ends up being the means of connection between the three characters. This effect was ideally designed to function in the form of a hologram [30] and may take the form of different shapes or colours. Nevertheless, the effect may also be implemented as a simple projection (similarly to the aforementioned effects) or an automated mechanic light focus. To create the effect, a face detection algorithm was used to detect and follow the artist's face. When detected, a shape is drawn over the detected face with a size adapted to it. A demonstration video may be accessed at https://vimeo.com/642489151.

4.2 Controlling Software

In order to facilitate the activation and control of the developed scenarios, a controlling software was developed to allow the visual effects to be sequenced and to automatically start and stop. The fundamental objective of the proposed software is that a single technician can set up and easily control or automate a set of digital effects. For the software to be dynamic and adapt to different contexts and works, it was designed, so, it allows the introduction (or removal) of new scenarios, each implemented as a different "object" with a respective method "draw" that will draw over a given video projection display. The draw functions of the respective effects must be queued in a switch inside the draw function of the main program. Thereafter, one may automatically call the next

Fig. 6. Examples of different states of the scenario/effect developed for the character Coryphaeus, to be applied in the form of a hologram, a simple projection over the artists and background, or using an automated light focus.

effect in the queue by clicking the right arrow key or by setting the respective start and stop times.

The controlling software also enables the adaptation of the output to the architecture characteristics of the stage space. Thus, when necessary, the user can resize and distort the projection mask by using only the mouse and keyboard to move the vertices of the projection mask and, consequently, keystone the projection.

Lastly, the software was designed to allow simultaneous projections, in the case of being needed multiple projectors to cover all the space.

5 Discussion and Conclusions

In the design of digital scenarios and real-time scenographic effects, one may identify a growing use of digital media that has been allowing the development of richer and more immersive experiences for the audience. However, in live shows, unplanned or improvised artists actions are a constant reality, making it difficult to ensure the control of the audiovisual effects in real-time. Thus, it is often necessary to involve large technical teams to accomplish these kinds of tasks and, for this reason, in small productions with low budgets, the wider use of these techniques may become impractical.

However, based on our current observation, we believe that the use of real-time visual effects during theatre plays will enable the generation of more engaging scenarios. These effects not only enable the development of more immersive experiences but also can add a new layer of interpretation, which can aid in a better understanding of the plot.

In this paper, we have presented preliminary work on the development of solutions to surpass the problem of dealing with the real-time generation of visual effects. First, by developing a set of digital real-time dynamic and interactive visual effects and, secondly, by developing proper software to set up and easily

control the sequence of effects intended. Furthermore, as a case of study, we designed and developed digital scenography for the electronic opera *TMIE*. The designs must be implemented using simple video-mapping projections. Also, as to complement, holograms [30] or light focus may be added.

Although this work is still in a preliminary phase, our experiences demonstrated to be practicable (at least so far in the implementation phase) and flexible enough to create a multitude of graphic solutions. In that sense, so far, the indicators suggest that our solution may solve the problem, bringing the desired interactivity to the studied opera without the need for a high budget or a large technical team.

Future work will focus on (I) developing a user interface to be added to the controlling software, namely to enable the user to define the entry and exit times of each visual effect, and to improve its usability, (II) developing more visual effects and scenarios environments to the opera *TMIE*; and (III) evaluating the effects and software in a real context, during the rehearsals and live shows of the studied opera.

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