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The PGIRec Software to Support the Evaluation of User-System Interaction with a Synchronous and Multi-perspective Recording System

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Abstract
Audiovisual recording is a highly relevant activity when investigating and analyzing qualitative data, both for scientific researches and for the industry. Games are a particularly challenging application for user experience and interaction evaluation, given the multitude of platforms, modes of operation, number of players and game environments that may occur through different games genres. This diversity of interaction possibilities makes it difficult for employing current audiovisual recording tools in a number of scenarios, especially considering multi-user interaction in the same or in separate environments. In this context, this paper presents an open-source recording tool, called Player-Game Interaction Recorder (PGIRec), specialized in synchronous recording of multiple sources of audio and video. The software was evaluated using brain-computer interface games in two different studies, with a total of 22 participants and over 16 hours of recorded activities using different experimental setups. The evaluation showed that the solution was stable and adaptable, since it generated audiovisual media without occurrences in different situations, with multiple audio and video sources concurrently.

Keywords: *HCI, user experience, audiovisual recording, case study, experiment, computer games.*

1 Introduction

Audiovisual recordings are valuable and important instruments, both in qualitative research and to complement quantitative analyses of scientific experiments performed in various fields of knowledge (Pasquali, 2007). The challenges and the importance of developing rigorous rules and methods to improve the capture of audiovisual recordings has been recognized since the beginning of the 1990s (Bottorff, 1994) and, for this reason, different tools have been developed to try to facilitate this this kind of data collection. Specifically in the area of Human-Computer Interaction (HCI), these recordings are used as a way to portray important situations that may occur during user-system interaction, including subtle details that may go unnoticed by the researchers at the time they occur. Garcez et al. (2011) mentions that in situations where several participants are interacting simultaneously, the audiovisual recordings must be made in order to contemplate the entire environment, since there is no way to predict when, for example, relevant conversations and behaviours may occur.

The acquisition of this type of qualitative data becomes particularly important in contexts of use that involve more contemporary forms of interaction, such as Tangible User Interface (TUI) (Ishii and Ullmer, 1997; Vasiljevic et al., 2012), gestural interaction (Correia et al., 2013), and Brain-Computer Interface (BCI) (Vidal, 1973; Ferreira et al., 2012). This acquisition becomes even more relevant due to the increasing emergence of ubiquitous computing systems, with the simultaneous use of several devices in daily activities (Furtado et al., 2014). In addition to the implementation of these new types of interfaces, effectively evaluating the interaction between users and systems are challenges that need to be overcome in order to increase the quality of use and mass dissemination of these technologies (Furtado et al., 2017).

A particular type of interactive system whose development benefits from this type of evaluation are games, which are widely explored by researchers from the Brazilian and international HCI community (Lima et al., 2018, 2019, 2021). Digital games are created by industry developers and academic researchers for different purposes. Usually, after their development, some kind of evaluation or assessment is performed regarding their use by potential players from their target audience. These evaluations may have varied goals, such as evaluating gameplay aspects or other subjective factors about the player-game interaction. To these goals, various objective data about the game can be collected via logs to better support the evaluation (e.g., game score, and time taken to finish a game match), in addition to the audiovisual recordings of the player interacting with the game environment.

In the literature we can observe works that use audiovisual recordings to help in the evaluation of the effective learning of a given "content" through the use of digital games. For example, a serious game to support Hiragana (i.e., one of the basic alphabets of the Japanese language) learning (Marciano et al., 2013) being employed in a laboratory study (Marciano et al., 2014) or *in loco,* in a real teaching-learning environment (Marciano et al., 2016). Still in the context of Japanese teaching, there are other serious games with educational focus that propose to teach the other alphabets of this language, that is, Katakana (i.e., the other basic alphabet of the Japanese language) (Marciano et al., 2015), and Kanji (i.e, the most important alphabet of the Japanese language, with over 2000 ideograms) (Marques et al., 2015a,b).

There are also works in the literature that explore new kinds of interactions and their use in the context of digital games that also use audiovisual recordings for their analysis, such as a game of chess (Vasiljevic et al., 2014) being used in a study aiming at comparing the use of the game interface via keyboard/mouse and its use via gestural interaction (Vasiljevic et al., 2016), or the study performed with a game of meteors (Miranda et al., 2013) to evaluate its gameplay using the Adjustable Interactive Rings (Miranda et al., 2010, 2011a,b), or the study performed to evaluate the gameplay and playability of an endless running game when controlled using a banana (Bento and Miranda, 2015), or even the design of an interactive sphere to be used as a game controller (Brizolara et al., 2022).

As evidenced by these examples, the audiovisual records made by recording the players using the game interface facilitates the collection and analysis of subjective data for studies with various objectives, regardless of whether the employed game is focused on entertainment or a serious game with educational purposes. The domain of digital games stands out among other interactive software in its scope of platforms, usage context, and simultaneous users, as the same game can be played on different platforms, presented in different ways, and multiple players can interact simultaneously in the same virtual environment through different interfaces. In addition to qualitative or objective investigations on player interaction, which can be performed using physical controls (e.g., keyboard, mouse and joystick), or even physiological ones (using biosignal sensors) (Ferreira et al., 2014; Vasiljevic and Miranda, 2020b), researches that also investigate the interaction between players can also be relevant in the context of games, especially in multiplayer games, both in cooperative, collaborative and competitive modes.

Given the aforementioned, the audiovisual recording of player interaction carries specific challenges, as this recording cannot always be performed with a single camera and not always the game is played by only one player, on a single device, or even in a single environment. The use of several cameras could raise the need for performing *a posteriori* editions of the multiple footages, and performing this task may entail problems, such as the lack of synchronization between the different videos collected in the resulting edited video, or the edition performed by an editor not accurately representing the objectives of the evaluation. The combination of these problems can negatively affect the qualitative analysis of the audiovisual recordings, since its effectiveness also depends on human factors associated with the processes of data collection, analysis and interpretation of the recordings (Penn-Edwards, 2012).

The importance of recording in this context therefore is evident, and thus the objective of this work is to present a solution that addresses the aforementioned issues. The main motivation for developing the software presented in this article was to provide a solution that generates a single mosaic-format video file, in real-time, from multiple perspectives (i.e., audio/video sources) collected during interaction evaluation studies with digital games. A solution with these characteristics minimizes synchronization issues amongst the different perspectives (i.e., parts) of the video and also eliminates the need for post-editing, therefore reducing bias introduced by the editor regarding the reality of facts depicted in the recording. The resulting video, thus, would assist the viewer to better interpret the cause-and-effect relationships amongst the different perspectives of the recording, including therefore all its elements, since all of them are recorded simultaneously.

To demonstrate the potential utility of the developed software, this work additionally presents an evaluation in the context of brain-computer interface games, both single-player and multiplayer. In each of these scenarios, multiple audio and video sources were used simultaneously, capturing the interaction between players with the games and with other players, showcasing the tool's potential and versatility in adapting to different experimental settings. The tool was employed in various experimental sessions to concurrently record the frontal view, side view, desktop environment, and audio of all study participants. The evaluation highlighted not only the technical feasibility of the software, but also its practical utility as a valuable tool in the research and development of player-game interaction technologies.

This paper is organized as follows: Section 2 presents related work, including other tools used currently and studies that employ them; Section 3 describes the developed software; Section 4 presents the evaluation of the solution in two experimental studies; Section 5 discusses the results obtained from the evaluation and their consequences; and Section 6 concludes the article.

2 Related work

In this section, recording tools employed in the literature to record user interaction in various contexts and with various interactive software (e.g., digital games and virtual worlds) are presented. Examples of studies that have used such tools to assist or complement experimental analysis will also be highlighted.

In the literature, four video recording tools are commonly mentioned in works and thus will be highlighted in this section: Camtasia, Morae, Ovo Solo, and Open Broadcaster Software (OBS). Camtasia by TechSmith is a proprietary software for recording webcams or operational system desktop screen, with editing functionality, for Windows and MacOS platforms. Focused on a general context of use, its main features are recording, with support for picture-in-picture, and video editing. In the gaming context, Camtasia has been used, for example, to record experiments that analyzed the interaction of children with dyslexia in serious games (Ouherrou et al., 2019a), to aid in teaching diabetes treatment using serious games (Quail et al., 2018), to investigate gender differences in performing activities within a game in a virtual environment (Martens et al., 2018), and to analyze and compare facial expressions of children with and without learning difficulties while interacting with an educational game (Ouherrou et al., 2019b).

Morae, also from TechSmith, is a recording tool for usability testing for Windows XP or later. With a proprietary license, it is possible to capture audio, video, mouse, and keyboard activity on the computer through the Morae Recorder component. It is also possible to watch and annotate videos through Morae Observer and to view and analyze videos produced through Morae Manager. In the context of games, this tool has been used, for example, to record screen and keyboard/mouse events in experiments that analyzed cognitive activities (Chuang et al., 2021) and in the usability analysis of serious games aimed at helping to quit smoking and tobacco use (Guo et al., 2020).

On the other hand, Ovo Solo, from Ovo Studios, is a proprietary video recording software for recording user interaction, and is available for Windows 7 or later. The tool allows recording of one or two webcams, the user's computer screen, and a combination of the computer screen and a webcam. Finally, the Open Broadcaster Software (OBS) is a free and open-source software for video recording and live streaming, available for Windows, MacOS, and Linux. It can record and stream audio and video from various sources, such as webcams, microphones, and computer screens, and allows for real-time mixing and editing of these sources. In the context of games, OBS has been employed, for example, to record and analyze human-human and human-AI interaction in cooperative games (Bennett et al., 2022).

In addition to the aforementioned works, there are also studies that have recorded audiovisual data without using a dedicated software for this purpose (e.g., (Vasiljevic and Miranda, 2019b)), even though qualitative analysis is a fundamental part of the experimental results. One possible factor for these cases is that most of the tools used in the literature are general-purpose systems, requiring specific adaptations for each particular use scenario. Most of them are also proprietary tools, and thus some cost for acquiring the software or licenses for its use must also be considered. The software proposed in this work, besides being free, allows the recording of different sources of audio/video in a single customized composition, without the need for any *a posteriori* video editing. The software was also developed in the context of evaluating the interaction between players and digital games, being specialized in this context compared to more general-purpose tools. Next, this recording software is presented.

3 The PGIRec software

Considering the challenges and issues related to the audiovisual recording of player(s)-game interaction, as described in Section 1, the recording software presented in this work, titled Player-Game Interaction Recorder (PGIRec), is a solution that was originally designed to aid the recording, in audio and video (A/V), of the interaction of players with digital games. However, as this situation is similar to other usage contexts, it is envisioned that this software can be used to support the recording of the interaction of other user profiles with interactive systems from other domains as well.

The software was developed using the Bash programming language, is open-source and is available for the Linux platform, being VLC[1] its only dependency. The program is free and can be employed with non-professional and consumer-grade audio/video recording devices (e.g., webcam, and smartphone or tablet's camera/microphone) which can be attached via USB ports to conventional personal computers (i.e., desktop or laptop). It should be noted that the resulting recording is limited by the resolution of the employed devices; therefore, the use of high-resolution cameras is suggested, such as High Definition (HD), Full HD (FHD) or Ultra HD (UHD), which are also known as, respectively, 720p (1280x720 pixels), 1080p (1920x1080 pixels) or 4K (3840x2160 pixels).

The software allows the composition of several A/V sources into a single "output", even while they are being recorded in real time from different audio and video devices. This "output" may be, for example, a MP4 file or a stream available through a network. In this context, **A/V sources** are audio/video streams, that may be provided from a local machine or from any remote machine/device connected through a network. Therefore, each A/V source must be available via network through an URL that uniquely identifies it.

3.1 PGIRec video masks

The **video mask**, or **Mask** for short, is the main component of the solution, as the A/V sources to the different areas of the video generated by the software are defined in this mask. A mask works as a template for a mosaic, thus being a mold that visually organizes the position of the different areas that compose a video. Each area refers to a different A/V source and has a unique identifier. The software has a set of 18 different pre-defined mask templates, although new templates can also be defined. Details of these templates, in the 16:9 format and which made possible the creation of masks in three different resolutions (i.e., HD, FHD and UHD), are presented in Tables 1 and 2. Thus, a total of 54 masks that support, in a single mask, from two to ten different A/V sources are readily available for use. It should be noticed that a pre-existing mask can also be adapted, for example, by changing the overall resolution of the video, i.e., (W)idth and (H)eight, to the 4:3 format, therefore making use of other resolutions, such as 640x480, 800x600 and 1024x768 pixels, respectively known as VGA (Video Graphics Array), SVGA (Super VGA) and XGA (Extended VGA).

Thus, in the context of this work, a video mask can be considered as a template that may guide the definition of audiovisual recordings for interaction studies with various purposes, which are available for use, and requiring only the definition of the URL for the A/V source of each area in the employed mask.

3.2 PGIRec tools

The recording software is composed of six tools. Figure 1 presents a scheme representing the relations and dependencies between these tools, and each one of them is described next.

The **PGIRec Creator** is the tool that allows the creation of new video masks, in the case where none of the 54 different masks that are available in the software meet the requirements of the study. The tool works as an assistant that guides the user in the definition of all parameters necessary to the creation of a new video mask; the tool automatically generates the file that contains the template for the video mask mosaic. Some of the information asked from the user during the use of this tool are: overall dimensions of the mask (e.g., width and height), and the dimensions of each of the A/V sources of the mask.

[1] `videolan.org`.

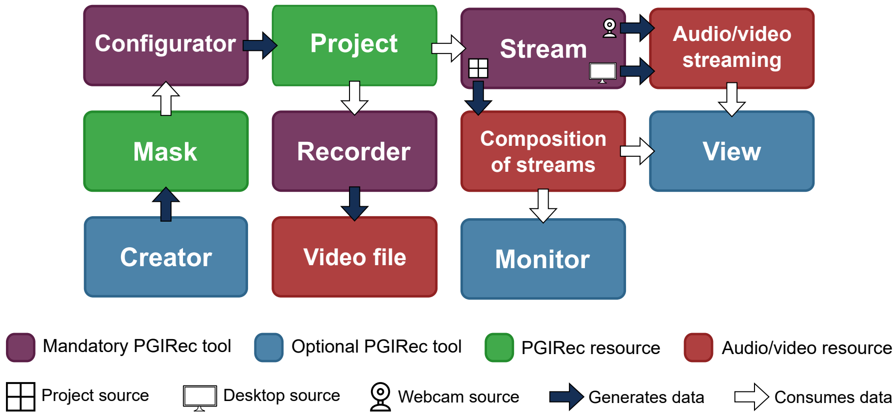


Figure 1. Relations and dependencies between the different software's tools.

The **PGIRec Configurator**, on the other hand, generates the **Project**, a PGIRec resource which supplements the mask with the IP address, the port, and the path of the resource, that is, the necessary information to use it in a specific usage context. This tool functions as a kind of assistant, guiding the user in defining these project parameters for each of the A/V sources of a pre-existing mask.

The **PGIRec Stream** is the tool that enables audio and video streaming via network (e.g., cabled or wireless) based on the Real Time Streaming Protocol (RTSP), which uses port 554 as default, and under high-efficiency video codification (HEVC/H.265), although other ports and codecs may be employed. Transmissions through this tool may be generated from the following three resources: (i) USB webcam, that is available from the Linux operational system through the path "`/dev/`" and according to the device identifier at the end of this path (e.g., "`video0`" for the first webcam, "`video1`" for the second webcam), using ports 55400 to 55409 as default; (ii) from the desktop environment (screen), using ports 55410 to 55419 as default; and (iii) from a project, which is, in practice, a composition of transmissions, using port 55420 as default.

For USB webcam transmission, it is important to mention the importance of the audio capture parameter which, if left unspecified, will not capture the device's audio channel by default. Ideally, only one A/V source in the project should have audio capture and transmission to prevent audio feedback.

In addition, it is worth to mention that the video generated in a project transmission will have the same overall dimensions of the mask used as base for the project. With the use of this tool, the A/V transmission will be available to be accessed via network through an URL that follows the pattern "`rtsp://machine:port/resource/`". Examples of URLs to the three previously mentioned resources are: USB webcam available at "`/dev/video0`", "`/dev/video1`" and "`/dev/video2`" (respectively, "`rtsp://192.168.0.1:55400/pgirec/cam0/`", "`rtsp://192.168.0.1:55401/pgirec/cam1/`" and "`rtsp://192.168.0.1:55402/pgirec/cam2/`"), desktop screen ("`rtsp://192.168.0.2:55410/pgirec/scr/`"), and project ("`rtsp://192.168.0.3:55420/pgirec/experiment/`").

The **PGIRec View** tool allows the visualization of any A/V streaming transmitted by the PGIRec Stream, be it from USB webcam, desktop environment, or project. The **PGIRec Monitor**, on the other hand, is the tool that allows to locally monitor the streaming, specifically, from projects. The PGIRec Monitor is responsible for monitoring only streams originating from the same machine, not being able to monitor remote ones. In the context of this tool, monitoring is understood as the verification of the status of the transmissions associated to a project and the local streams (e.g., from USB webcams) that comprise it, informing whenever there is a change between states, that is, whether the stream is available, has not been started, or has been interrupted.

The **PGIRec Recorder** is the tool responsible for the recording of project transmission. This tool, therefore, consumes the streaming from a project (i.e., the composition of transmissions) and writes in disk the resulting video file, regardless of whether the mask's A/V sources are from local or remote streamings. The name of the resulting file follows the pattern "`pgirec_[date]_[time].[format]`", being the date in the YYYYMMDD format and the time in the HHMMSS format (e.g., "`pgirec_20230311_031519.mp4`").

Finally, it is worth mentioning that in a practical perspective of use of the recording software, at least the three following tools, in this order of usage, should be required: (i) PGIRec Configurator, (ii) PGIRec Stream, and (iii) PGIRec Recorder. As aforementioned, the PGIRec Configurator would create the audiovisual recording project file based on a pre-existing mask, while the PGIRec Stream generates streaming from a local resource (e.g., USB webcam or desktop environment screen) or from a project, and the PGIRec Recorder storages the project streaming in disk as a single file, regardless of number of A/V sources employed in the project.

4 Evaluation

To evaluate the software presented in this work in a real context of use, two interaction studies were performed, each with a different digital game. Details about these studies, focusing on relevant aspects for this work, are presented below. The evaluations were conducted by one researcher, responsible for carrying out the experimental activity and for the audiovisual recording of the study, with written consent from the participants. Another researcher was also available to assist in the case of technical or operational faults.

Table 1. Details of the 54 masks in HD, FHD and UHD available in the PGIRec software, created from 18 different pre-defined mask templates.

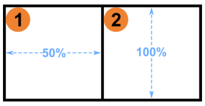
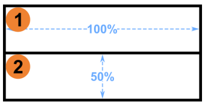
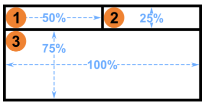
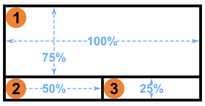
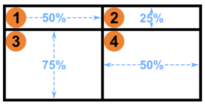
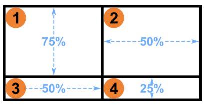
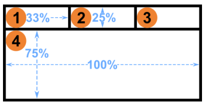
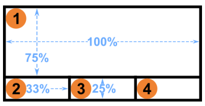
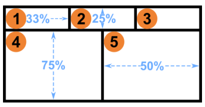
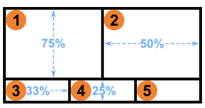
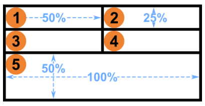
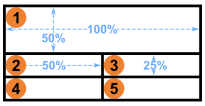
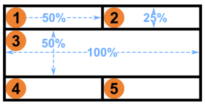
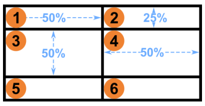
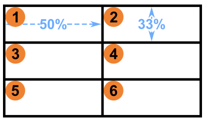
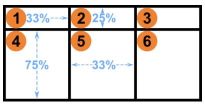
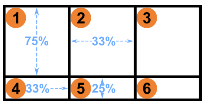
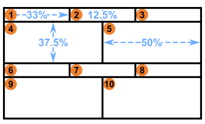
Name	Description	Relative area values (WxH)	Visual representation	Absolute area values (WxH) HD (1280x720)	FHD (1920x1080)	UHD (3840x2160)
mask02a	2 (two) A/V sources organized in a vertical layout.	(1)(2) 50%x100%.		(1)(2) 640x720.	(1)(2) 960x1080.	(1)(2) 1920x2160.
mask02b	2 (two) A/V sources organized in a horizontal layout.	(1)(2) 100%x50%.		(1)(2) 1280x360.	(1)(2) 1920x540.	(1)(2) 3840x1080.
mask03a	3 (three) A/V sources, being two located at the top and one occupying the remaining space below.	(1)(2) 50%x25%, (3) 100%x75%.		(1)(2) 640x180, (3) 1280x540.	(1)(2) 960x270, (3) 1920x810.	(1)(2) 1920x540, (3) 3840x1620.
mask03b	3 (three) A/V sources, inversion of mask03a, that is, two located at the bottom and one occupying the remaining space above.	(1) 100%x75%, (2)(3) 50%x25%.		(1) 1280x540, (2)(3) 640x180.	(1) 1920x810, (2)(3) 960x270.	(1) 3840x1620, (2)(3) 1920x540.
mask04a	4 (four) A/V sources, being two located at the top and two occupying the remaining space below.	(1)(2) 50%x25%, (3)(4) 50%x75%.		(1)(2) 640x180, (3)(4) 640x540.	(1)(2) 960x270, (3)(4) 960x810.	(1)(2) 1920x540, (3)(4) 1920x1620.
mask04b	4 (four) A/V sources, inversion of mask04a, that is, two located at the bottom and two occupying the remaining space above.	(1)(2) 50%x75%, (3)(4) 50%x25%.		(1)(2) 640x540, (3)(4) 640x180.	(1)(2) 960x810, (3)(4) 960x270.	(1)(2) 1920x1620, (3)(4) 1920x540.
mask04c	4 (four) A/V sources, being three located at the top and one occupying the remaining space below.	(1)(2)(3) 33.3%x25%, (4) 100%x75%.		(1)(2)(3) 427x180, (4) 1280x540.	(1)(2)(3) 640x270, (4) 1920x810.	(1)(2)(3) 1280x540, (4) 3840x1620.
mask04d	4 (four) A/V sources, inversion of mask04c, that is, three located at the bottom and one occupying the remaining space above.	(1) 100%x75%, (2)(3)(4) 33.3%x25%.		(1) 1280x540, (2)(3)(4) 427x180.	(1) 1920x810, (2)(3)(4) 640x270.	(1) 3840x1620, (2)(3)(4) 1280x540.
mask05a	5 (five) A/V sources, being three located at the top and two occupying the remaining space below.	(1)(2)(3) 33.3%x25%, (4)(5) 50%x75%.		(1)(2)(3) 427x180, (4)(5) 640x540.	(1)(2)(3) 640x270, (4)(5) 960x810.	(1)(2)(3) 1280x540, (4)(5) 1920x1620.
mask05b	5 (five) A/V sources, inversion of mask05a, that is, three located at the bottom and two occupying the remaining space above.	(1)(2) 50%x75%, (3)(4)(5) 33.3%x25%.		(1)(2) 640x540, (3)(4)(5) 427x180.	(1)(2) 960x810, (3)(4)(5) 640x270.	(1)(2) 1920x1620, (3)(4)(5) 1280x540.

Table 2. Details of the 54 masks in HD, FHD and UHD available in the PGIRec software, created from 18 different pre-defined mask templates (cont.).

Name	Description	Relative area values (WxH)	Visual representation	Absolute area values (WxH) HD (1280x720)	FHD (1920x1080)	UHD (3840x2160)
mask05c	5 (five) A/V sources, being four located at the upper half, and one occupying the remaining space below.	(1)(2)(3)(4) 50%x25%, (5) 100%x50%.		(1)(2)(3)(4) 640x180, (5) 1280x360.	(1)(2)(3)(4) 960x270, (5) 1920x540.	(1)(2)(3)(4) 1920x540, (5) 3840x1080.
mask05d	5 (five) A/V sources, inversion of mask05c, that is, four located at the lower half, and one occupying the remaining space above.	(1) 100%x50%, (2)(3)(4)(5) 50%x25%.		(1) 1280x360, (2)(3)(4)(5) 640x180.	(1) 1920x540, (2)(3)(4)(5) 960x270.	(1) 3840x1080, (2)(3)(4)(5) 1920x540.
mask05e	5 (five) A/V sources, being two located at the top, two at the bottom, and one occupying the remaining space at the middle.	(1)(2)(4)(5) 50%x25%, (3) 100%x50%.		(1)(2)(4)(5) 640x180, (3) 1280x360.	(1)(2)(4)(5) 960x270, (3) 1920x540.	(1)(2)(4)(5) 1920x540, (3) 3840x1080.
mask06a	6 (six) A/V sources, being two located at the top, two at the bottom, and two occupying the remaining space at the middle.	(1)(2)(5)(6) 50%x25%, (3)(4) 50%x50%.		(1)(2)(5)(6) 640x180, (3)(4) 640x360.	(1)(2)(5)(6) 960x270, (3)(4) 960x540.	(1)(2)(5)(6) 1920x540, (3)(4) 1920x1080.
mask06b	6 (six) A/V sources, being three positioned vertically at the left and three to the right, all with the same height.	(1)(2)(3)(4)(5)(6) 50%x33.3%.		(1)(2)(3)(4)(5)(6) 640x240.	(1)(2)(3)(4)(5)(6) 960x360.	(1)(2)(3)(4)(5)(6) 1920x720.
mask06c	6 (six) A/V sources, being three located at the top and three occupying the remaining space below.	(1)(2)(3) 33.3%x25%, (4)(5)(6) 33.3%x75%.		(1)(2)(3) 427x180, (4)(5)(6) 427x540.	(1)(2)(3) 640x270, (4)(5)(6) 640x810.	(1)(2)(3) 1280x540, (4)(5)(6) 1280x1620.
mask06d	6 (six) A/V sources, inversion of mask06c, that is, three located at the bottom and three occupying the remaining space above.	(1)(2)(3) 33.3%x75%, (4)(5)(6) 33.3%x25%.		(1)(2)(3) 427x540, (4)(5)(6) 427x180.	(1)(2)(3) 640x810, (4)(5)(6) 640x270.	(1)(2)(3) 1280x1620, (4)(5)(6) 1280x540.
mask10a	10 (ten) A/V sources, being three at the top, followed by two below, followed by three below them, followed by two at the bottom.	(1)(2)(3)(6)(7)(8) 33.3%x12.5%, (4)(5)(9)(10) 50%x37.5%.		(1)(2)(3)(6)(7)(8) 427x90, (4)(5)(9)(10) 640x270.	(1)(2)(3)(6)(7)(8) 640x135, (4)(5)(9)(10) 960x405.	(1)(2)(3)(6)(7)(8) 1280x270, (4)(5)(9)(10) 1920x810.

4.1 Study #1

The first study in which PGIRec was employed in practice is a controlled experimental evaluation, with a mixed within-between subjects design, which analyzed quantitative and qualitative aspects of user interaction with a neurofeedback-based game. Below is a summary of the main elements of this first study.

Game and its gameplay A single player game, called Zen Cat, in which the player must control a cat (the player's avatar in the game), which needs to rise vertically until it reaches the top of the scenario, initiating a new phase with higher difficulty. The game was developed in C++ language, using the Simple and Fast Multimedia Library (SFML) and is available for the Windows operating system. The cat is controlled through the level of meditation of the player, acquired using a brain-computer interface (Ferreira et al., 2013). As the cat "levitates" in the scenario and raises from one level to another (or "floor"), the game interface presents new visual elements, while new sounds are also played to change the player experience; a detailed description of the game is available at Vasiljevic et al. (2018b).

Participants The study involved the participation of 14 players (P1, P2, ..., P13, and P14), with thirteen male participants and one female participant, with ages ranging from 23 to 35 years old. All participants have normal or corrected vision and no auditory or cognitive impairments. Participants were initially approached verbally, and were subsequently formally invited via email. The verbal recruitment took place among students and staff of the authors' University, and suggestions for other potential participants were provided by the participants who agreed to partake in the study.

Study environment The study was conducted in a laboratory setting, consisting of an air-conditioned room, in which only one researcher and the corresponding participant were present during the execution of the experiment. Participants performed the experiment sitting in front of a desktop computer, equipped with a monitor and a front-facing camera (Figure 2, on the left). The environment was entirely artificially illuminated at the time of the experimental sessions.

Study goals To evaluate the players' interaction in a controlled experiment setup in order to verify research hypotheses related to the "manipulation" of the game's sound effects. Each subject participated in the experiment in three different days, in which one experimental session (i.e., S1, S2, and S3) was performed with each participant, which should play four game matches in these sessions; a detailed description of this experiment is available at Vasiljevic and Miranda (2019a).

Role of the audiovisual recording in the study and its focuses (as an audiovisual record) To record the player's interaction with the game interface in order to support a qualitative analysis of this interaction. The recording should capture the player from two different perspectives, i.e., a frontal and a lateral view of the participant, in addition to the game interface, as well as the audio from the game and the sounds from the environment where the experiment was conducted.

A/V sources Three, being one a machine for running the game (its desktop screen served as an A/V source), and one machine where two webcams were connected via USB ports (the other two A/V sources). Thus, to meet the requirements of this study, mask03a (cf. Table 1) was used, adapted to the 4:3 format (Figure 2, on the right). The setup represented in Figure 2 shows the arrangement of equipment in the laboratory environment where the study was conducted, along with the respective mask used to record the experimental sessions.

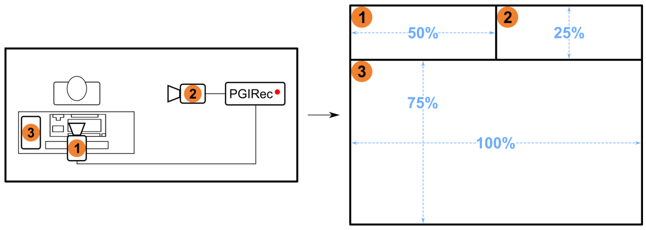


Figure 2. Arrangement of the A/V sources used in the first study: (1) front-facing camera, (2) side-facing camera, and (3) desktop screen, using mask03a adapted to the 4:3 format.

In this initial evaluation, the tools that compose the recording software worked satisfactorily, without any occurrences of errors. The software generated a total of 42 video files (i.e., one video for each experimental session of each participant), maintaining synchronization between all recording focuses. In this study, more than 14 hours of player-game interaction (14:23:28) were recorded in total, occupying 4.94 GB of disk space; the duration of the videos for each session of each participant is detailed in the graph in Figure 3.

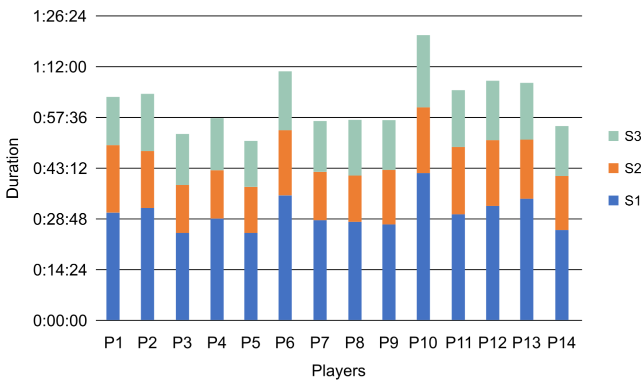


Figure 3. Duration of the experimental sessions (S*x*) of the 14 participants from Study #1.

Considering its experimental setup, the study had to be performed over a little more than two weeks in order to accommodate the schedules of both the participants and the researchers. Figure 4 presents nine examples of frames resulting from the videos recorded during this study. At the end of this study, it can be concluded that the recording software was able to satisfactorily store a good volume of audiovisual recordings of the study conducted in a setup with three A/V sources. The next study aimed at evaluating the behaviour of the software in a setup with a larger number of A/V sources.

4.2 Study #2

The second study also has a mixed within-between subjects experimental design, using a Physiological Computing system

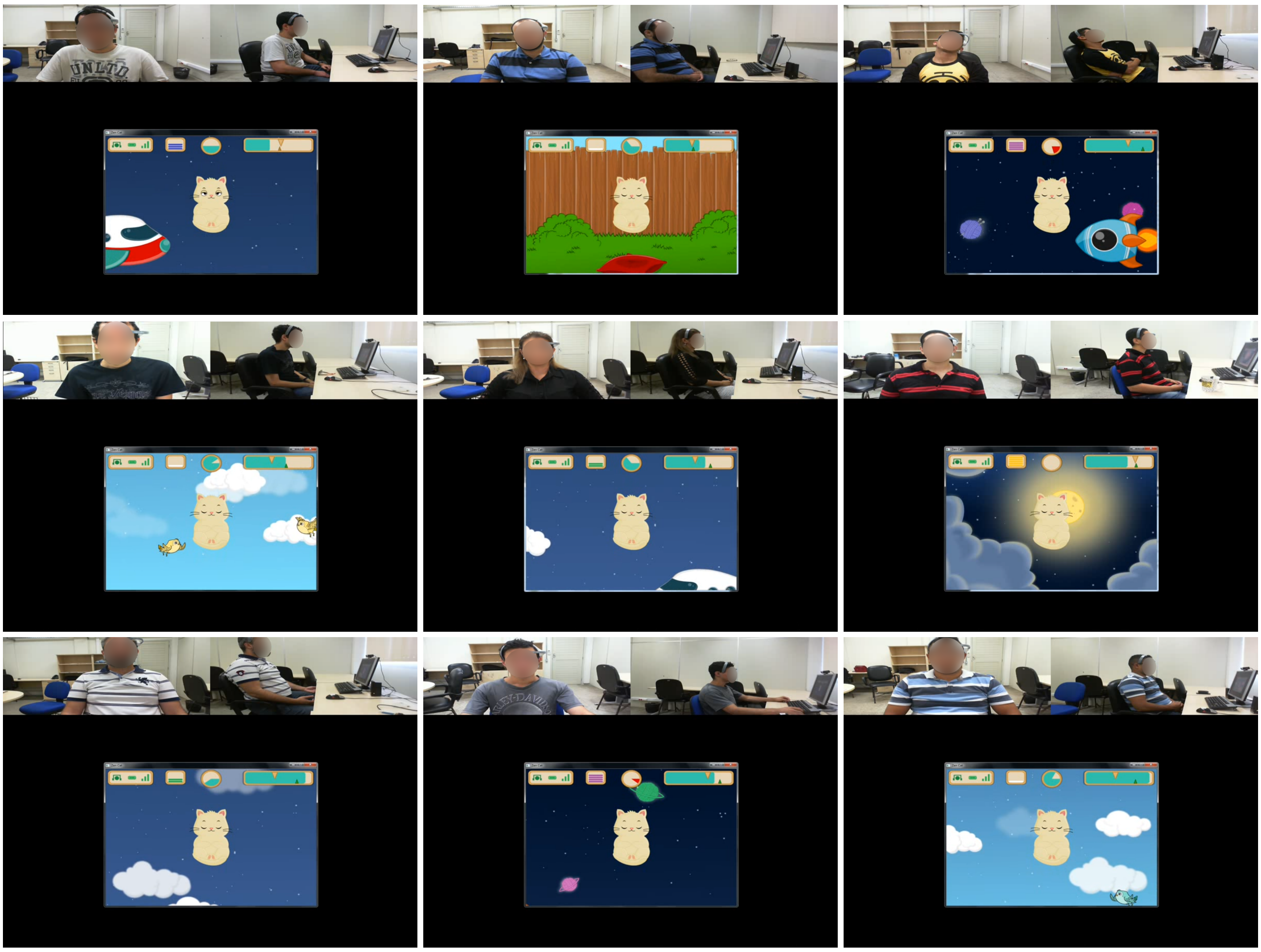


Figure 4. Examples of frames from the recorded videos (with three A/V sources under mask03a) with subjects from Study #1.

to control the game, but also investigating aspects related to the interaction between multiple players at the same time in competitive and collaborative manners in a multiplayer game. Following is a summary of the main information regarding this second study.

Game and its gameplay A multiplayer game, called Mental War, in which online players are organized into teams to participate in virtual tug-of-war competitions. The pulling force in the tug-of-war game is computed by the player's level of concentration, acquired through a brain-computer interface (Ferreira et al., 2014; Vasiljevic and Miranda, 2020a). In this game, players can act collaboratively, when playing on the same team, or competitively, when on opposite teams. Each team can be composed of up to three members, and team members can be either real players or robots (artificial intelligences within the game); a detailed description of the game is available at Vasiljevic et al. (2018a).

Participants The study was conducted with eight players (P1, P2, ..., P7, and P8), being six male and two female participants. The players were between 24 and 25 years old, without any diagnosed cognitive or sensory issues, with normal or corrected vision, and were divided into four pairs of participants. The pairs were determined by the participants themselves, who were asked to bring a companion for the experiment. In the absence of a partner, the corresponding pair was determined by their available time slot (that is, two participants without partners who were available at the same time). In total, three pairs were formed by participants who knew each other and had previously arranged to participate together, and one pair was set based on their shared availability time.

Study environment As in Study #1, this subsequent study was also performed in a laboratory setting, comprising an air-conditioned room where only one lead researcher and the pair of participants were present during the execution of the experiment. The pair performed the experiment seated in front of a desktop computer, with a monitor and a front-facing camera (Figure 5, on the left). They were positioned perpendicularly in relation to their pair, ensuring they couldn't directly see each other during the course of the game session. The environment was fully lit using artificial lighting during the experimental sessions.

Study goals To evaluate player interaction in a controlled experimental setup, in order to verify research hypotheses regarding player behaviour related to competitive and collaborative game modes. The experiment was conducted for each pair of participants in an experimental session that took place on a single day, and each pair played six matches; a detailed description of this experiment is available at Vasiljevic and Miranda (2022).

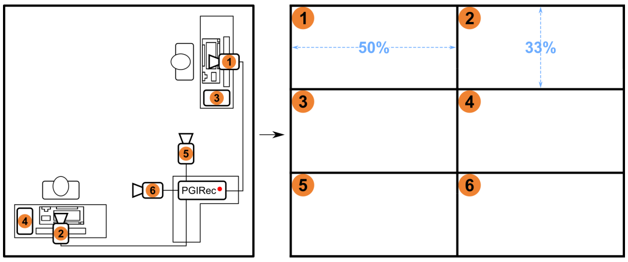


Figure 5. Arrangement of the A/V sources employed in the second study: (1)(2) front-facing cameras, (3)(4) desktops screens, and (5)(6) side-facing cameras, using mask06b adapted to the 4:3 format.

Role of the audiovisual recording in the study and its focuses (as an audiovisual record) To record the interaction of the pair of players with the game interface to support a qualitative analysis of this interaction. The recording should capture both players from two different perspectives, that is, a frontal view and a lateral view of each participant, each player's game interface, as well as the game's audio and sound ambient from where the experiment took place.

A/V sources Six, being two machines to run the game (the desktop screen of each machine was an A/V source), and one machine where four webcams were connected via USB ports (the other four A/V sources). Thus, to meet the requirements of this study, mask06b (cf. Table 2) was employed, adapted to the 4:3 format, and shown in Figure 5 (on the right) along with the experimental room layout.

In this second evaluation, the recording software was also able to capture the players' interaction with the game without any issues. In total, four video files were generated (i.e., one session video for each pair of players), maintaining synchronization between all recording sources. In this study, more than two hours of player-game interaction were recorded (2:26:34), occupying 1.06 GB of disk space; the duration of the video for each pair of participants is detailed in the graph shown in Figure 6.

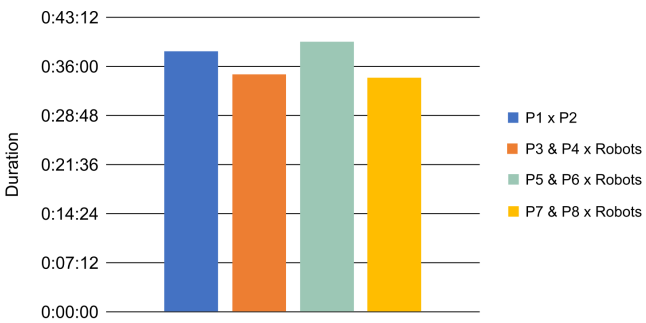


Figure 6. Duration of the experimental sessions of the four pairs of participants (P*x*) from Study #2.

Figure 7 presents four examples of frames obtained from the recordings of this study with four pairs of participants. At the end of the study, it was concluded that the PGIRec software was also able to perform the audiovisual recording of all experimental sessions without any issues, even with twice the number of A/V sources compared to the first study, that is, with six A/V sources.

5 Discussion

The use of the software in the conducted experiments allowed to verify some advantages of PGIRec in relation to other existing tools on the market. For example, the possibility of performing multiple A/V streamings from a single machine, whether from USB webcams or from desktop environments, provided flexibility in its use, which was particularly important in situations that involved the simultaneous use of several cameras and desktop recording. Additionally, the use of several A/V sources from the same or from different machines to stream a single mask, regardless of the operating system being used by the A/V sources (since the "consumption" of the mask is done by the network via RTSP), provides the solution with potential for scalability. In the studies described in the previous section, this mobility was used to ensure that the processing of the recording did not affect the performance of the machines running the games, avoiding an external factor in the experiments. While the tool was executed on Linux operational system to perform the recording process, the games and consequently the desktop streaming were executed on Windows operational system. Therefore, these characteristics differentiate the solution presented in this article from other recording tools used for research purposes presented in the literature, as commented in Section 2.

In addition to these technical aspects, the use of the tool also aided in the qualitative evaluation of the audiovisual data. The availability of different A/V sources in a mosaic, in a single synchronous video, allowed for observing and evaluating relevant events from different perspectives at the same time. For example, in the upper-top frame displayed in Figure 4, the simultaneous display of both the participant's face, posture, and game screen allowed for an analysis of the association between the participant's physical state (i.e., inclined and relaxed in the chair) and their performance in the game. In the upper-top frame of Figure 7, it is also possible to observe certain gestures of the participant (i.e., placing their hands in front of the monitor to try to concentrate better) that would not be possible if only a frontal view of the interaction was available, or that would require a post-processing step to synchronize the different perspectives of multiple videos. Although they are "isolated" events, noticing and recording these occurrences allows for a more holistic description of the users' interaction with the game, and how each action possibly influenced its outcome. In this specific case, how each participant's individual strategy influenced their levels of attention or meditation.

Another important aspect enabled by the PGIRec View tool was to verify, in real-time, any software or hardware issues that may have occurred during the experiments. For example, if any movement by the participant causes an interruption in the readings by the electroencephalography (EEG) device, it is possible to identify the problem in real-time through the game screen transmission, since it provides a visual feedback (icon) indicating whether the EEG transmission is interrupted. This prevents the problem from only being noticed after the end of the game match, thus allowing it to be resolved as soon as possible. Later, during a more detailed verification of the videos, it is possible to identify the precise moment when the error occurred and what specifically caused it.

Figure 7. Examples of frames from the recorded videos (with six A/V sources under mask06b) with subjects from Study #2.

For future versions, the software could still be complemented with additional features, such as layers of information about users and about each A/V source in text format directly over the mask, and the insertion of comments or observations using subtitle files, allowing these text information to be separated from the video files. More advanced features may also be incorporated in future versions using image processing and computer vision methods, such as automatic detection of faces and facial expressions, postures, eye tracking, and automatic speech transcription. These methods could be incorporated for use in both real-time or during post-processing in an offline manner.

5.1 Limitations

A limitation to note for the solution in its current version is streaming without the use of password protection. While this may not currently pose an issue considering a local context of use, it could be a requirement to be implemented in future versions of the solution for enhanced privacy of the audiovisual recordings collected by the software. However, measures were taken to mitigate this issue, that is, allowing the specification of an alternate port (e.g., 55400) other than the default port (i.e., 554) for availability of the streaming transmission. This flexibility is demonstrated in the examples shown in Section 3.2, where the URLs indicate transmissions via a higher port, thus making it more difficult to identify the traffic of these transmissions on a network.

6 Conclusion

This work presented the Player-Game Interaction Recorder, a recording software developed to assist the evaluation of interactions with digital games. The software is free and open-source, being flexible and scalable to be employed in the acquisition of audiovisual recordings. These features differentiate the presented solution from others employed in the literature, as described in Section 2, mainly for being a software specialized in recording multiple audiovisual perspectives of interactions in the context of games. Furthermore, the software was evaluated in two different studies, resulting in almost 17 hours of recorded experimental activity in distinct setups, demonstrating its utility and versatility.

The recording software allowed to evaluate the user interaction with these systems in a qualitative manner, through multiple perspectives, in the form of audio and video, and merged synchronously into a single multimedia file, with no need for further editing. In the specific context of the experiments described in this work, that is, games played with brain-computer interfaces, the use of PGIRec was particularly important to reveal more detailed and subjective aspects of the user interaction while playing with neurofeedback controls, since these physiological systems are usually employed in studies focusing on investigating the computational performance of signal processing algorithms, or the physiological and psychological effects of the interaction on the players, even if the system is developed as a "simple" game.

In addition, the results of this work demonstrated the potential of the software to be applied in the investigation of other, different interaction modalities, such as systems based on tangible interfaces. In this sense, although the solution is specialized for evaluating interaction with digital games, there is also the possibility of its use in other contexts, such as with non-digital games (e.g., tabletop and board games), social interaction environments in virtual reality, and even in interactions with systems controlled by voice or gestures. Considering these applications, it is noticeable the growing importance of audiovisual analysis in the context of the consumer-grade market, especially with the emergence of new physical artifacts of interaction, the metaverse, and the diffusion of ubiquitous computing at a domestic and commercial level.

As future works, we suggest performing new studies with more A/V sources, in different contexts, and with other types of digital platforms (e.g., consoles or virtual reality devices), aiming at further evaluating the scalability of the solution. In addition, as discussed in this article, it is important to evaluate the usage of post-processing methods to extract additional information in an offline manner (e.g., facial expressions and speech transcription) and, posteriorly, their use in real time, especially to verify their impact on both the system performance and, mainly, in the recording quality.

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