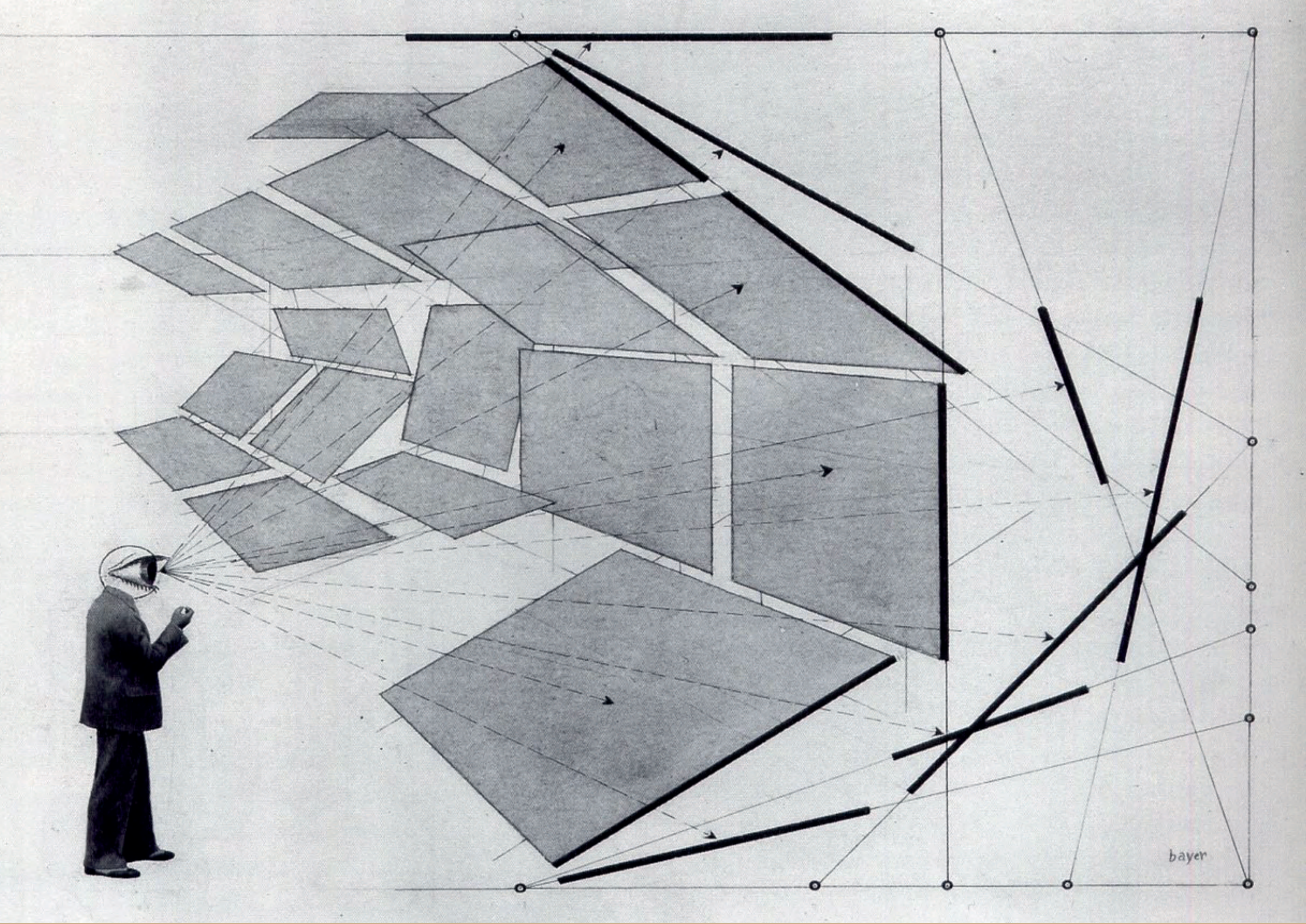

Rui Jorge Nunes Silva

Spatial Augmented Reality in Serious Games
for Cognitive Rehabilitation of the Elderly

Master's Dissertation in Electrical and Computer Engineering, supervised by
Prof. Dr. Paulo Jorge Carvalho Menezes and presented to the
Faculty of Science and Technology of the University of Coimbra

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Spatial Augmented Reality in Serious Games for Cognitive Rehabilitation of the Elderly

Rui Jorge Nunes Silva

Dissertação para obtenção do Grau de Mestre em
Engenharia Electrotécnica e de Computadores

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”It is not because things are difficult that we do not dare,

it is because we do not dare that things are difficult.”

Lucius Annaeus Seneca

Agradecimentos

Em primeiro lugar, quero expressar o meu sincero agradecimento ao meu orientador Professor Doutor Paulo Jorge Carvalho Menezes. O seu aconselhamento, orientação e suporte ajudaram-me, não só a terminar esta etapa, mas também a expandir os meus conhecimentos e a melhorar a minha análise crítica.

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A todos, o mais sincero obrigado.

Abstract

Over the years, the average life expectancy has been increasing. As a consequence, the increase in the elderly population leads to the emergence of age-related diseases. These conditions greatly impact the autonomy and, therefore, the quality of life of the elderly since there is a reduction in motor and cognitive capacities. It is known that there are therapies that can help prevent or delay the onset of cognitive and motor deficits. However, most of these are based on repetitions, which can cause a lack of motivation. For the therapy to have the best possible effect, the literature shows that it is necessary to develop therapeutic tools that balance repetitions, effectiveness, and keep the user motivated. Thus, the possibility of creating a platform that allows the development of serious games based on Spatial Augmented Reality (SAR) arose. SAR was thought of as a good solution since it uses physical space and objects to create its interaction, and, in this manner, it is more adaptable to audiences with various deficits. In line with the reality of the increase in average life expectancy and the reduction in capacities resulting from it, it was considered pertinent that the platform's development should be aimed at the elderly population. Hence, it was proposed to develop two Serious Games (SGs) in order to test the platform to be created, which can contribute positively to the involvement in therapies. In addition, it is hoped that this application will be adaptable to serve various objectives and not only what will be addressed throughout this dissertation. The creation of the two SGs based on SAR, with the possibility of being adapted to the user, had the approval of a superior educational technician. It should be noted that the application in a real context is central to being able to understand if the games are adapted to the real needs of each patient and to make the necessary changes. Therefore, this intervention is presented as future work, both for elderly people with cognitive deficits and those who do not have diagnosed deficits. It is also suggested the development of other

games using SAR and the inclusion of Dynamic Difficulty Adjustment (DDA).

Keywords

Spatial Augmented Reality, Serious Games, Cognitive Rehabilitation, Interactive Environments, Elder Care

Resumo

Ao longo dos anos a esperança média de vida tem vindo a aumentar. Como consequência, o aumento da população idosa leva ao surgimento de doenças relacionadas com a velhice. Estas doenças têm um grande impacto na autonomia e, por conseguinte, na qualidade de vida dos idosos, uma vez que existe uma redução das capacidades motoras e cognitivas. Sabe-se que existem terapias que podem ajudar a prevenir ou a atrasar o aparecimento de défices cognitivos e motores. No entanto, a maioria destas são baseadas em repetições o que pode desencadear falta de motivação. Para que a terapia tenha o melhor efeito possível, a literatura mostra que é necessário elaborar ferramentas terapêuticas que equilibrem as repetições e a eficácia e, também, que mantenham o utilizador motivado. Surgiu assim a possibilidade de ser elaborada uma plataforma que permita o desenvolvimento de jogos sérios baseados em realidade aumentada espacial (RAE). Pensou-se na RAE, uma vez que utiliza o espaço e objectos físicos para fazer a interação e, desta forma, se torna mais adaptável aos públicos com diversos défices. Aleando à realidade do aumento crescente da esperança média de vida e à reducação das capacidades que daí advém, considerou-se pertinente que o desenvolvimento da plataforma descrita acima fosse direccionada à população idosa. Assim, propôs-se a elaboração de dois jogos sérios com o objectivo de testar a plataforma a desenvolver, jogos estes que contribuam de forma positiva para o envolvimento nas terapias. Para além disso, ambiciona-se que esta aplicação seja adaptável para servir vários objectivos e não só o que será abordado ao longo desta dissertação. A criação dos dois jogos sérios baseados em REA, com a possibilidade de serem adaptados ao utilizador, teve a aprovação de uma técnica superior de educação. De salientar que a aplicação em contexto real é fulcral para que se consiga perceber se os jogos são adaptados às necessidades reais de cada um e para fazer as alterações necessárias. Assim, apresenta-se como trabalho futuro esta intervenção, tanto a idosos com défices cognitivos como a idosos que não tenham défices diagnosticados. Para além disso, sugere-se o desenvolvimento de outros jogos utilizando REA e a inclusão

de mecanismos de ajuste dinâmico de dificuldades automáticos.

Palavras-Chave

Realidade Aumentada Espacial; Jogos Sérios; Reabilitação Cognitiva; Ambientes Interactivos; Assistência a Idosos

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Acronyms

AAL Ambient Assisted Living. 5

AD Alzheimer's Disease. 5

AR Augmented Reality. 13

CT Cognitive Therapy. 2, 3, 32, 49, 50

DDA Dynamic Difficulty Adjustment. 56

DoF Degrees of Freedom. 37

FOV Field of View. 35

HMD Head-Mounted Displays. 3

IPS Interaction Planar Surface. 33, 41, 42, 50, 52–54

IRP Individualized Rehabilitation Plan. 2, 11

MMSE Mini-Mental State Examination. 10, 11

MR Mixed Reality. 13

NCDs Neurocognitive Disorders. 10, 13, 55

OS Operative Systems. 32

QoL Quality of Life. 10

SAR Spatial Augmented Reality. 3–7, 15, 17, 24, 25, 31–34, 49, 50, 52–56

SGs Serious Games. 3, 12, 32, 33, 39, 47, 49, 56

SL Structured Light. 24, 27, 28

TBI Traumatic Brain Injury. 10, 55

UI User Interface. 5

VR Virtual Reality. 13

Contents

Chapter 1

Introduction

Within this M. Sc. Dissertation, it was studied the development of spatial augmented reality-based serious games to create tools for cognitive rehabilitation therapy for the elderly. In this section, the motivation for this work is introduced by summarising how the current world demographic has caused a high demand for cognitive rehabilitation tools, and it is explained how spatial augmented reality can contribute for creating solutions for this problem. Afterwards, the primary objectives and key contributions aspired for this work are described, and the structure of the complete document is stated.

1.1 Context and Motivation

The global average for longevity was twenty-nine years old at the end of the 1850s. In the past year, it reached its peak value of seventy-three years old [6]. Current pandemic circumstances have been affecting global health, but despite the harsh consequences and strict safety measures we face in our day to day lives, everything indicates that this tumultuous period will come to an end, and that longevity will resume its ascending trend. In 2004, a United Nations' report comprised the world's health and lifestyle indicators to weave predictions about longevity: global life expectancy is said to surpass 100 years by 2300 [7]. This three digits number transmits confidence in the rate at which science has been progressing and also implies how the average human age will increase. This is not a new trend, since the average population of most countries has become older over the years, as the increase in longevity is accompanied by the decline in the birth rate.

Thus, elders represent a growing demographic with preeminent health needs, which must be answered for by health care services. These needs are unavoidable to our human nature, as senescence originates health problems that can condition the autonomy and well-being of the elder citizen by impairing the execution of daily tasks, affecting their quality of life [8–10].

Such conditions, often referred to as age-related diseases, can affect multiple areas of functioning. Neurodegenerative diseases such as Alzheimer's and Parkinson's, and traumatic accidents such as strokes, considered constituents of this disease group, can cause motor and cognitive functions to become severely impaired.

The surge of these predicaments is on the rise, the lack of responses to support cures, coping mechanisms, and rehabilitation strategies, concerns the professionals working with this demographic. It has become clear that, currently, the best solution is to combine multiple areas where research has showed results to preserve autonomy for as long as possible, to assure some quality of life. Often, elders undergo simultaneous approaches which can be medical, pharmaceutical and therapeutic. It is also customary to incentive lifestyle changes to help to cope with the symptoms and even to prevent them from happening in the first place.

When elders contract these diseases, certain aspects of their behaviour changes, mainly due to impairments of their cognitive capacities. The impairments in cognition can be reflected in areas such as attention span, memory, decision making, orientation and language [11]. As a consequence of the limited progress in the study of these diseases, the mentioned multi-area approaches are much more preventive than restorative. Hence, it is proven that these interventions benefit from being applied in an early stage of the condition, delaying the evolution of the disease and guaranteeing the quality of life for more years [12–16]. So, as soon as these symptoms start to appear, it is important to report them to doctors and caregivers [17, 18].

Cognitive therapy can play a crucial role to counteract these diseases, especially in the early to medium stages of progression. To diagnose the cognitive skills of the elder, specialists in neuropsychology map their neuropsychological profile [19–21]. Afterwards, an Individualized Rehabilitation Plan (IRP) for cognitive therapy Cognitive Therapy (CT) is delineated. The IRP consists in a series of restorative and compensatory therapeutic activities which include exercises to stimulate the affected areas of the brain, and strategies to help to cope with the affected faculties in everyday tasks, aiming at ensuring autonomy for as long as possible.

To encourage the (re)learning process, cognitive exercises used in therapy demand consistent repetitions with slight variations of the same activities [22]. The repetitive nature of the exercises and the inability to accomplish some tasks can often lead to frustration, tediousness, lack of motivation, and even the abandonment of therapy [12]. To lessen the burden of the intrinsic characteristics of these activities, engagement approaches such as *gamification* can promote the entertainment of the user, which is proven to lead to more effective therapy sessions [23]. Thus, it is common the use of Serious Games (SGs) in a therapeutic context.

SGs are video games that promote the (re)/learning process of a specific skill where the entertainment of its player is not its primary aim. Cognitive therapy often uses these type of games to provide targeted stimuli for the elderly. Depending on the stage of development of the disease, they can help in sustaining executive functions including visual processing, working memory, attention, language, and verbal communication.

In the CT area, the tools used regularly comprise board-, card-, and computer-based games which can be designed to attain therapeutic objectives. Using these games, subjects can exercise cognitive competencies while trying to entertain and motivate patients through engagement techniques [24–27]. Recent works have explored emerging technologies such as virtual, augmented and mixed reality (VR, AR, MR) in the rehabilitation area, intending to bring new therapeutic tools, with a focus in engagement and adaptability [28–32].

New technological approaches can create interesting possibilities and even improve the effectiveness of therapy. However, () and conventional () use Head-Mounted Displays (HMD) or other auxiliary devices which may lead to discomfort and rejection by some people, especially those who are using them in a therapeutic scenario. More ecologic approaches can be achieved when using Spatial Augmented Reality (SAR) principles, integrating, in a naturalistic way, computer-generated graphics within the users' own physical space, by the use of projection mapping techniques [33]. For these reasons, the creation of interactive serious games based in SAR can create new opportunities to improve the effectiveness of therapy.

1.2 Objectives

The paradigm exposed in the previous section revealed the necessity to explore alternative solutions for cognitive therapy tools within the elder demographic. The primary objective of this work is the implementation of a solution based in spatial agumented reality, that supports the creation of interactive therapeutic games. To improve the effectiveness of cognitive therapy, the system should prevent the shortcomings of traditional methods by using appropriate game design principles, by focusing on user engagement, by fostering the adaptability, customization and personalization of games, and by creating additional features that aid therapists' work.

This system should constitute a platform to be used in clinical environments but also, dependent on the user condition, to be used somewhat autonomously in homes, therapy centres, assisted living centres, etc.. To do this, it is necessary to provide a structure for multiple therapists to provide their several patients with the correct prescribed exercises and to track users' progress during the several sessions.

Reflecting on these statements, the principal objectives of the system are to:

- Build an expandable platform that allows the development of SAR-based serious games for the cognitive rehabilitation for elders;
- Develop one or more games to test the application of the platform;
- Promote the creation of useful therapeutic tools through the use of SAR environments which can enhance therapy effectiveness;
- Provide features to facilitate the work of the therapist through tracking and automation;
- Use the functionality of a computer-generated interactive environment to create adaptable, and customizable games focused on the individual user;
- To be portable and deployable to suit its use in several scenarios.

1.3 Related Work

A research was made to comprehend the current state of research in SAR based serious games for elderly cognitive rehabilitation. The following summarises the bibliographical research performed.

Given the specificity, few articles were found on this exact area, so the scope of research was widened: there were analyzed projects which made use of projection-based serious games for motor rehabilitation [34, 35], vr based cognitive rehabilitation serious games [36–38], traditional serious games for cognitive training in age-related diseases [37, 39–42], and a SAR based Ambient Assisted Living (AAL) system for elders [43]. These projects provided valuable information which supported the development of this work.

In the following paragraphs, it will be summarised the works that were found to be the closest to the area of work of this thesis.

In [39], a group of researchers implemented a traditional serious game directed for patients suffering from Alzheimer's Disease (AD). The intention of their work was to promote accurate challenge demands for each individual user, favouring adaptability and maximising the level of *flow* stage gameplay to enhance the effectiveness of training. These adjustments were made by recognising cognitive performance indicators (such as scores and achievements) and adapting game parameters to guide better experiences for the user during gameplay. The research claims that positive rewards in-game translate to better and more effective therapy.

The research in [44] compared two social tabletop games for its use with senior citizens: a traditional static board game and an adapted version of a SAR based game. By questioning groups of elders after each gaming session, they concluded that senior citizens found the spatial augmented reality approach to be more immersive and engaging. These results indicate that elders' gaming experiences can benefit from the use of well-adapted SAR based approaches.

Researchers in [45] stressed that age-related conditions can affect the ability for elders to manipulate a computer mouse, which favours the use of more natural alternatives to interact with computer-based environments. To test a workable solution, they developed a tabletop assistive User Interface (UI) for elders, based in spatial augmented reality. The result was a prototype interface that gives the user the options to consult medication schedules, to place calls, see their calendar and watch media through the use of projections. Interaction is made by using the finger or a marker with retro-reflective material.

CogARC project [46] developed an augmented reality tool for cognitive screening and training for people with dementia. This tool comprises several cognitive mini-games where the objects of the game are tangible cubes which are ”augmented” through their observation in a tablet. This work achieved good results in the quantitative screening of cognitive capacities, and concluded that systems such as these have to focus in specific factors to avoid non-intuitive flaws: system errors conduced patients to feel confusion, uncertainty and tension, so the system must be robust. Games must have an iterative design nature to increase adaptability (subsequent adjustments to user performance and progress). There must be given important attention to the interaction medium, as the use of an auxiliary device (tablet) caused some issues in perceiving depth and gameplay functioning. They also underlined the importance of including game mechanics like competition, feedback, rewards, and challenges in order to increase elderly players motivation and entertainment.

The research portrayed in [47] shows a projection-based interface that allows healthcare professionals to stimulate people with dementia through the use of music and reminiscence therapy. According to their study, the use of music produces very interesting cognitive results for people with dementia, triggering past memories and emotions. This implementation focused on customization and their results showed that the overall use of personalized music withdrew stress and pressure from the game challenges which lead to better in-game performance. Therapists involved in testing found the whole system very appealing, useful, and demonstrated interest in using it to work with their patients.

1.4 Key Contributions

Taking into account the state-of-the art included in the research (exposed in the previous section), the work developed in this dissertation focuses on building a platform that facilitates the creation of serious games based in SAR to work on the cognitive rehabilitation of elders. This platform will provide features that favour natural interaction, adaptability, customisation, and scalability.

1.5 Document Structure

The chapters that provide structure to this document are ordered as follows:

- **Chapter 1** presents the context and motivations for this study and analyses other similar works;
- **Chapter 2** describes the areas of cognition, how age-related conditions can impair these areas, what are the traditional methods used in therapy to rehabilitate those functions, and describes how game design methods can improve therapy;
- **Chapter 3** characterises the components of a SAR system from a computer vision standpoint and presents the implementation of calibration methods for the camera and the projector;
- **Chapter 4** explains the proposed system by outlining how it can project and map virtual environments into cards to create interactive card and board games based in SAR;
- **Chapter 5** depicts two developed games that were built using the proposed system to attest to its functionality and application;
- **Chapter 6** discusses the obtained results, drawing conclusions from the resulting system and presents future work suggestions to incentive the explanation of this project.

Chapter 2

Background Knowledge

This section summarises the background knowledge acquired from the made research, which substantiates the work developed in the next chapters.

2.1 Cognition and Cognitive Areas

According to APA's Dictionary of Psychology [48], cognition is defined as "all forms of knowing and awareness, such as perceiving, conceiving, remembering, reasoning, judging, imagining, and problem-solving.". These capacities are essential to our survival and overall interaction with the surrounding world, and without them we would not be capable of converting sensory experiences into new knowledge.

Six fundamental domains define cognitive function [49]:

- Executive function;
- Learning and memory;
- Perceptual-motor function;
- Language;
- Complex attention;
- Social Cognition.

Cognitive processes, given their intricate abstract nature and importance, are studied in many fields such as neuroscience, psychology, psychiatry, and even linguistics. A variety of aspects can affect the quality of these processes, being that the principal factors are genetics and previous experiences.

Aspects of the human cognition are still unknown today, but previous research concluded that some controllable aspects can improve cognition: regular physical exercise, diet and social, and intellectual stimulation [50–52].

2.2 Cognitive Impairments

Cognitive impairments may be at fault when a person has difficulty using one of the refereed cognitive functions [11]. Frequent signals of cognitive impairment are memory loss, inability to learn, lack of attention, and erroneous decision making[10].

In an initial state, these signals surge subtly, where one person can still be able to cope with everyday tasks. With the advancement of cognitive damaging diseases, these can be transformed into severe symptoms which may cause complete loss of autonomy and deteriorate Quality of Life (QoL) [8, 53]. As opposed to inborn conditions (which were not analysed in this work), environmental factors can cause the acquisition of cognitive deficits, specifically Traumatic Brain Injury (TBI) and Neurocognitive Disorders (NCDs). The diseases can be classified as of their stage of progression as mild (mild cognitive impairment) or major (dementia) based on the severity of the affected capacities [49].

Cognitive impairing diseases can be neurodegenerative, the most common being Alzheimer's, and Parkinson's disease; and of a traumatic nature such as TBI and strokes [54]. Strokes can lead to vascular dementia, which reduces the supply of blood to the brain provoking cognitive impairments. Anxiety, mood and psychotic disorders can also create cognitive impairments, being that those are often mild and reversible. As found in many studies, the common denominator and the major risk factor for these conditions is ageing [10], which causes the elderly demographic to be the most affect group by a large margin.

The evaluation of the cognitive impact of these diseases is made by measuring the cognitive capacities of the patient, commonly through a 30-point questionnaire designated as Mini-Mental State Examination (MMSE) [20, 55]. They use this test in clinical and research settings, often allied with a medical examination. The result of the test estimates the stage of development of the disease and determines the affected areas. The same patient is asked to repeat the test periodically to keep track of the evolution of his condition.

Based on the diagnosis and evaluation of the patient cognitive state, a multi-area intervention protocol is established [19]. Being that these diseases are chronic in their nature, this intervention is not a cure. Instead, they combine a series of pharmaceuticals and therapies that aim at delaying the progress of the disease and to find coping strategies to circumvent affected areas to guarantee the most autonomy level to the patient.

2.3 Cognitive Therapy

Cognitive therapy has been an essential part of the therapeutic intervention in patients in the initial and medium stages of progression of neurocognitive diseases [16]. The research concluded that the brain loses its plasticity with ageing [56], and this process is accelerated by the degenerative nature of cognitive affecting diseases [13]. It is imperative to diagnose and assess patients as early as the first symptoms arise. After inquiring about the state of impairment with MMSE questionnaire, or others, a neuropsychologist can trace the neuropsychological profile of the patient.

From this profile, an therapeutic cognitive rehabilitation plan is created which focuses on providing therapeutic fitted to the patient's needs [12]. At this moment, it is very important to inform families and caregivers of the results of the evaluation and diagnosis. This way, they can comprehend the struggles and limitations of the patient, accompanying the therapeutic intervention, and help him cope with everyday tasks in a manner that favours their autonomy.

The IRP is made up of restorative and compensatory therapeutic exercises which stimulate the most affected areas of the brain [21]. The therapeutic tasks tend to simulate everyday tasks in order to transport mechanisms (re)/learned in therapy to everyday activities [53, 57, 58].

As in all learning processes, the exercises used in therapy are often very repetitive [22], which can induce tediousness and lack of motivation . The challenge level is often frustrating given that patients are asked to face and work on their limitations. These two factor together can create poor results and low effectiveness in therapy and sometimes even the abandonment of the intervention [23]. This can also worsen the apathetic and depressive state that patients of these diseases commonly have.

So, research reveals that to enhance therapeutic effectiveness, the developers of therapeutic tools have to focus on including the following factors: maintaining an acceptable challenge threshold that induces evolution in users' performance, lessen frustration, and enhance motivation levels; and using game design mechanics to reduce the impact of repetition, improving engagement and entertainment as it is proven that engagement is a very important factor for increasing therapy effectiveness [23].

It is also very important for the therapist to keep track of the development of the evolution of the patient through the systematic reassessment of his cognitive capacities. This is done to estimate the effectiveness of given therapy and to adapt future therapeutic sessions [12].

2.4 Serious Games

SGs are computer-based games which focus on being instructive and pedagogical through simulation approaches [25, 27]. Contrary to traditional video games, they focus on promoting learning experiences first and the entertainment factor comes second [24, 26]. They are used in a wide range of areas given their proven result in transferring knowledge in a more immersive and interactive manner: E.g. defence, education and health.

The use of these games is proven beneficial since it uses the concept of *gamification* on important everyday problems [58]. Gamification elements on these games include purposeful goals represented as game rules, objectives, difficulties and levels, and respond to players' performance through the use of scores, achievements and times, etc.. When desired, competition incentive can be implemented to encourage the betterment of user's performance through the use of principles such as leader-boards.

The use of game's principles in SGs design, when conjugated with a clear and defined therapeutic purpose, has proven to enhance engagement and entertainment of its users [57]. This keeps high motivation levels in players and allows the learning experience to be more effective.

As refereed in Chapter 1, recent works have created SGs in the domain of cognitive training.

These works focused on providing better engagement in therapy through the use of new technologies and virtual environments such as VR, AR and MR, and obtained satisfactory results [5, 28, 30–32].

2.5 Serious Games Design for Cognitive Therapies

As it is aspired to build useful and therapeutic serious games, the design part of the development process is one of the central components.

First, it has to be established a concise cognitive therapy purpose, declaring on the particular deficits it will work on enhancing. In second, the game concept should be defined. A failure-preventive way to create a valid concept is to base the game in tools already being used in a therapeutic context. This method benefits from the familiarity that users already have with used tools and assures that it will be appropriate for therapeutic use. After looking at traditional therapeutic games, the developer can introduce additional features and technologies, creating an updated version of the game.

Neurocognitive Disorders can cause varied symptoms, even to patients affected by the same condition [10]. This highlights the importance of looking at each patient as a separate case, with individual characteristics. The therapy sessions have to accommodate this consideration. The search for therapeutic tools that can adapt to correspond to each patient needs can be an arduous task, hence the high demand for alternative solutions referenced in Chapter 1.

Modern tools aspire to provide solutions to this problem by taking advantage of new technologies [5, 28, 30–32]. Their functionalities can enable the development of features targeting the adaptability, customisation and personalization of the therapeutic games [23, 59]. This allows creating functionality-rich environments that can provide many degrees of adjustment in the elements of the game, such that therapy readjusts to each patient performance and evolution.

Besides better adaptability, personalization features can trigger more emotional and personable gameplay, which can generate better engagement and motivation levels [59]. This can be done by including elements of the user's life, such as personal objects, recognisable faces or places, and familiar sounds, creating a scenario of *reminiscence* therapy [48].

To captivate players by interacting with the game, the interface should also provide sound feedback to maximise the stimulation of the game, and given that music and sound memory is very long-lasting even in persons with severe dementia [47].

The *gamification* elements described in the previous section can serve other very important function in their therapeutic use: tracking and testing the cognitive capacities of its user. E.g. the therapist specifies a game, a difficulty level, and other game parameters for a therapeutic session. Afterwards, by evaluating the attained score and execution time, it is possible to establish a measure of performance or recovery level. This allows the therapist to adapt to the next sessions of therapy more accurately.

Given that elders will probably use these games, they are most likely unfamiliar with video-games and computer-generated environments. So it is important to keep the interaction with the system natural, robust and simple.

The entire system should cause a cycle of playing, providing feedback to the user, portraying performance through game mechanics and delivering them to therapists to allow the adaptation of the game with *gamification* parameters [23]. This results in therapy sessions iterations, that will consecutively adapt to the patient's condition (Figure 2.1).

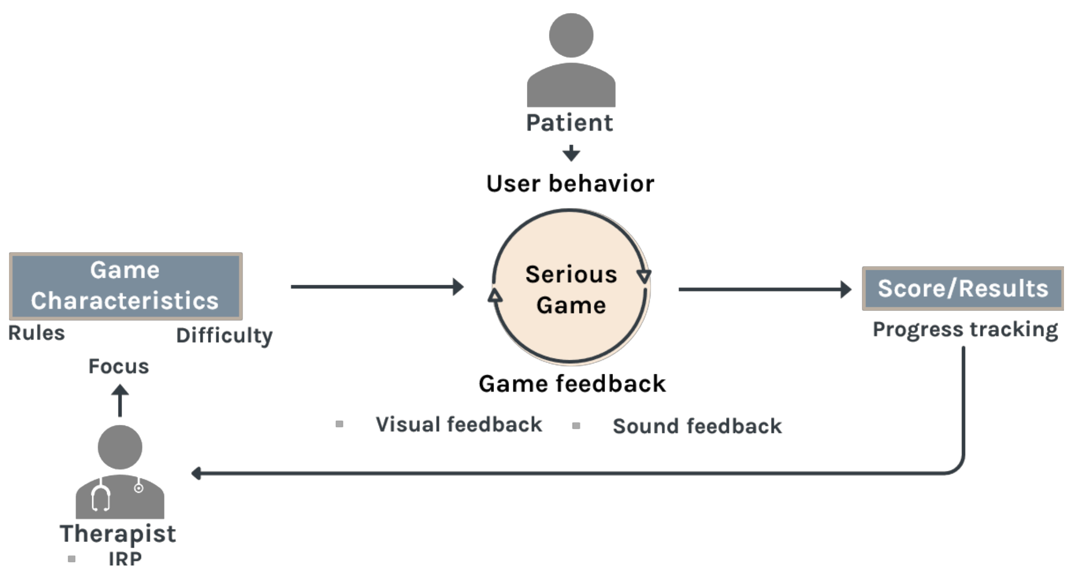


Figure 2.1: SGs' iterative cycle

2.6 Spatial Augmented Reality

Spatial Augmented Reality, also known as projection-based augmented reality, consists of a computer-generated environment that overlays real surfaces to change their appearances or to create illusions of virtual objects [33]. This platform is frequently used in public events as an entertainment tool by using buildings or objects as projection screens. Its use can create optical illusions such as changes in dimensions and give the impression of movement onto static objects (an example of a projection-mapping spectacle ”A Luz do Jogo & UC: Uma História de Luz” in University of Coimbra can be seen in Figure 2.2). These configurations have become more prevalent in recent years due to projectors becoming less expensive and due to the overall increase in usability of augmented reality in various fields. SAR-based applications have also been used in areas such as health, design, reconstruction, and precision and shape measuring.

To map projections to buildings or objects, it is usually made beforehand a 3D recreation of the surfaces. Then, the visual scenes can be created and adapted to each surface accordingly. If the projection scenes do not react to changes in the environment, this type of installation is defined as static projection-mapping. It is also possible to create interactive projection-mapping environments if the projections can change according to users' or objects' movement. A conventional interactive setup consists of a video-projector and a camera that captures the projective environment's changes.

Figure 2.2: Example of video mapping [1]

Chapter 3

Camera and Projector Calibration

In general, interactive SAR interfaces rely on computer vision methods to fulfill their functions. Therefore, to create installations within this medium, it is necessary to comprehend the mathematical fundamentals behind the elements of the system, which are the camera and the projector. In this section there will also be analyzed methods for the calibration of the system elements

3.1 Camera

The camera frames will portray the changes that occur in the projective frustum. Therefore, to guarantee that the captured frames' data contains an accurate representation of the real world, it is needed to perform camera calibration. By calibrating the camera, one can obtain its lens and sensor's characteristics, position and orientation concerning the world. These characteristics can be divided into two types of parameters: the intrinsic parameters and the extrinsic parameters. These parameters make up the mathematical models described in the next sections.

3.1.1 Pinhole Camera Model

$$sm' = K\,[I \mid 0] \begin{bmatrix} R & t \\ 0 & 1 \end{bmatrix} M' \Leftrightarrow \tag{3.1}$$

$$
\begin{gathered}
\mathrm{sm}' = \mathrm{K}[\mathrm{R}|\mathrm{t}]\mathrm{M}' \Leftrightarrow \\
s\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}
\end{gathered} \tag{3.2}
$$

A camera can be represented by the pinhole model illustrated in Figure 3.1. This model, demonstrated in Equations 3.1 and 3.2, describes how a world point M' is projected into the camera point m' through the influence of the camera matrix K[R|t] (using homogeneous coordinates and within the scale factor s) [60]. The parameters of this model are described as follows.

- **Intrinsic Parameters (*K*)**:
  They describe the internal characteristics of the camera and remain static if the focal distance or lens are not changed. The following characteristics constitute the intrinsic matrix ***K***:
  - **Focal distance f_x, f_y**: is the distance between the lens and the image sensor, measured in pixels from the camera pinhole to the principal point. For an ideal pinhole camera, $f_x = f_y = f$, as illustrated in Figure 3.1, in practice, they can have slightly different values due to flaws in the sensor, lens aberrations or the use of a *anamorphic* lens format;
  - **Principal point (c_x,c_y)**: is the point defined by the interception of the orthogonal line that goes from the pinhole of the camera to the image plane. This line is called the optical axis of the camera. This point corresponds to the projective center and for an ideal pinhole camera, it is located at the center of the image plane. For a real camera it can have small offsets in its location due to tangential distortion or lens aberrations.
- **Extrinsic Parameters [*R*|*t*]**:
  They describe the position and orientation of the camera concerning the world scene, and are divided as:
  - **Rotation matrix, *R***: is the direction of the world-axes in camera coordinates;

– **Translation vector, *t*:** is the location of the origin point of the world in camera coordinate system.

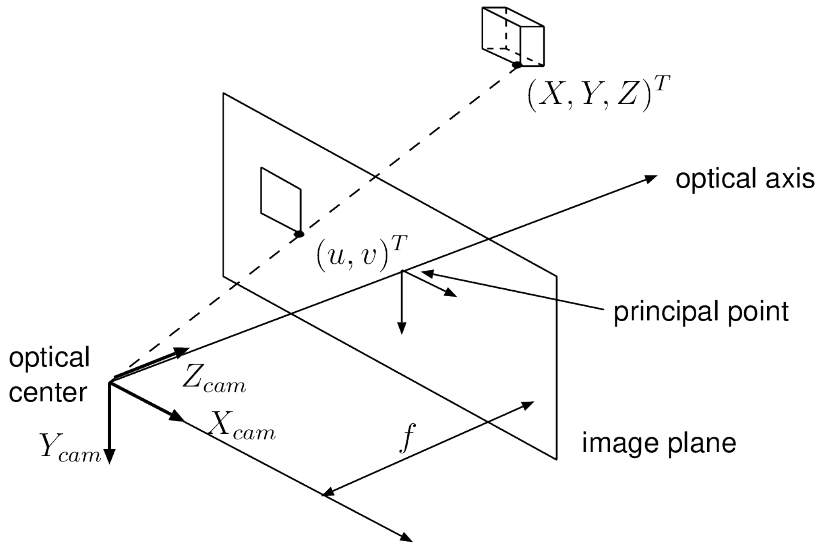


Figure 3.1: Ideal pinhole camera model [2]

3.1.2 Distortion Coefficients

Despite the simplicity of the pinhole model in describing the protective transformation that occurs on a camera, real-world lenses usually produce distortions which make the projection of a world point (X,Y,Z) into the camera plane (u,v) non-linear. Therefore, to enhance the estimation of the camera model, it is necessary to take into consideration these non-linear distortions. In Equation 3.3 it is demonstrated how the pinhole camera model describes a projection point. In Equation 3.4 it is described how this model can be extended to account for distortion coefficients.

$$\begin{gathered}
\begin{bmatrix} x \\ y \\ z \end{bmatrix} = R \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + t \\
x' = x/z \\
y' = y/z \\
u = f_x * x' + c_x \\
v = f_y * y' + c_y
\end{gathered} \tag{3.3}$$

$$
\begin{gathered}
x'' = x' \frac{1+k_1 r^2 + k_2 r^4 + k_3 r^6}{1+k_4 r^2 + k_5 r^4 + k_6 r^6} + 2 p_1 x' y' + p_2 \\
y'' = y' \frac{1+k_1 r^2 + k_2 r^4 + k_3 r^6}{1+k_4 r^2 + k_5 r^4 + k_6 r^6} + p_1 \left(r^2 + 2 y^2 \right) + 2 p_2 x' y' \\
\text{where } r^2 = x'^2 + y'^2 \\
u = f_x * x'' + c_x \\
v = f_y * y'' + c_y
\end{gathered}
\tag{3.4}
$$

This **distortion coefficients** are described as follows:

- **Radial distortions $k_1, k_2, k_3, k_4, k_5, k_6$:** which cause straight lines in the world to be represented by curves in the camera image plane. The radial distortion is usually higher as we get close to the image edge due to the radial distance being greater. Wide-angle lenses are heavily affected by this type of distortion. We can see an example of this type of distortion in Figure 3.2;

- **Tangential distortions p_1, p_2:** they occur when the lens and the camera image plane are not parallel. A illustration of how this issue is caused is present in figure 3.3.

Radial distortions are usually more prevalent in real-world cameras and its impact is more noticeable in the distortion of images than tangential distortion. We can consider higher-order coefficients for each of the components but, according to the studied sources [61], these are sufficiently reliable to estimate the camera model.

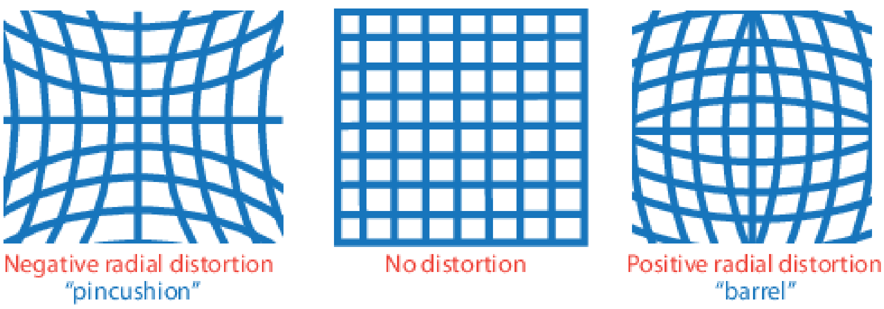


Figure 3.2: Depiction of radial distortion seen in straight lines [3]

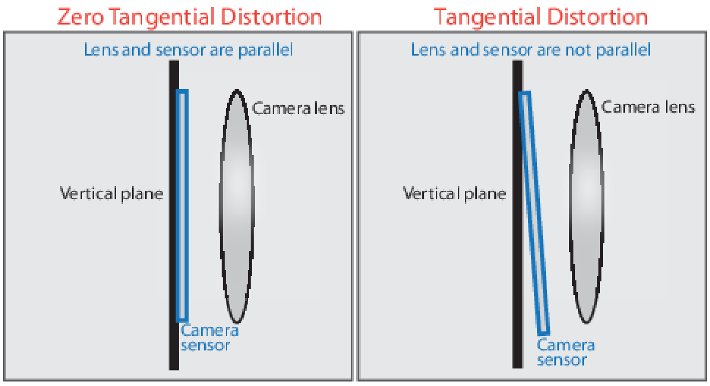


Figure 3.3: Illustration of how tangential distortion occurs [3]

3.1.3 Camera Calibration

To define the previously described camera matrix, it is needed to estimate its parameters. Along the years there have been proposed a series of methods for computing camera calibration. For every method it is required some type of known correspondence between the world and the camera image plane. Most common solutions to establish this correspondences, require the use of a pattern which allows the accurate detection of its features. There can be seen examples of frequently used patterns in Figure 3.4. E.g. in a regular chessboard (left image of Figure 3.4), we can manually measure the position of the corners in real world units and identify the same points in an image captured by a camera of that same pattern, in pixel coordinates. By knowing the position of a given corner in the world, and in the camera frame, a correspondence can be established.

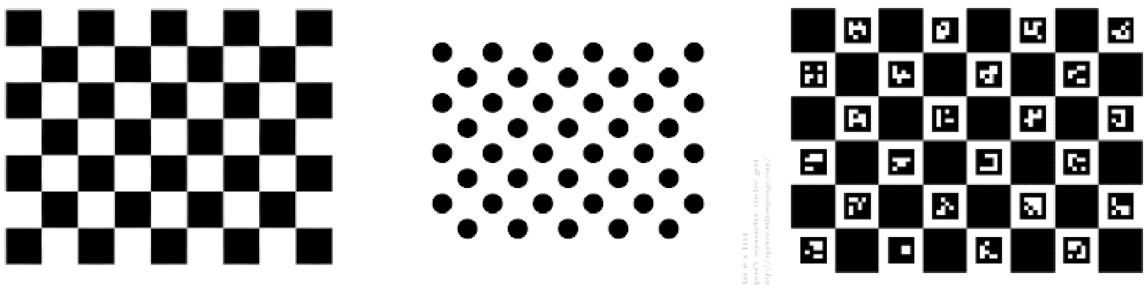


Figure 3.4: Examples of calibration patterns used for camera calibration

One of the most frequent methods used to perform camera calibration was introduced by Zhang in [62]. This method utilizes a planar chessboard pattern in order to establish correspondence between the camera image plane and the world coordinates. This correspondence is obtained through the capture of images of the pattern in a variety of poses. The captures can be made with a static camera, where the pattern pose changes or with a static pattern where a camera pose changes (it is required at least two different poses). With this correspondences its possible to estimate the intrinsic and extrinsic parameters of the camera as well as its radial distortion coefficients, as described in section 3.1.2. The algorithmic procedure of this method is described in detail in [62]. For the sake of brevity, a summary of this algorithm is described in the following steps:

1. Estimate the homography relation between the world and camera for each pose using the location of the pattern's corners;

2. Determine the intrinsic and extrinsic parameters from the resulting homographies using closed-form solution;

3. Estimate radial distortions using linear least-squares fitting, minimizing the projection error;

4. Refine all parameters by minimizing the total projection error.

Given that this method does not require the use of complex calibration objects such as orthogonal pattern planes (as in gold standard method proposed in [60]), and it is not necessary for the camera to move as in [63], the method is easily applicable for different types of use cases. In this sense, this method was chosen for the camera calibration task. There are several guides, documents and tools available that make use of this method and that expedite the task of calibrating a camera. Here, the functions provided by *OpenCV* library [64] and the single camera calibration toolkit provided by *Matlab* [65] are used.

3.1.3.A Application and Results: Zhang's Method

A camera calibration procedure was made, using Zhang's method [62], to obtain the characteristic matrix of the camera used in this work. A simple application was built to capture pattern poses, to detect its features and to obtain the calibration results. The output of this process was a camera matrix with mean reprojection error of 0.14 pixels. In Figure 3.5 there is presented a diagram of the extrinsic parameters, which illustrates the variety of the used poses. The group of Figures 3.6 presents an original pose capture, the same image with the distortion corrections applied (by using the resulting camera matrix), and the difference between the two frames, colored in yellow.

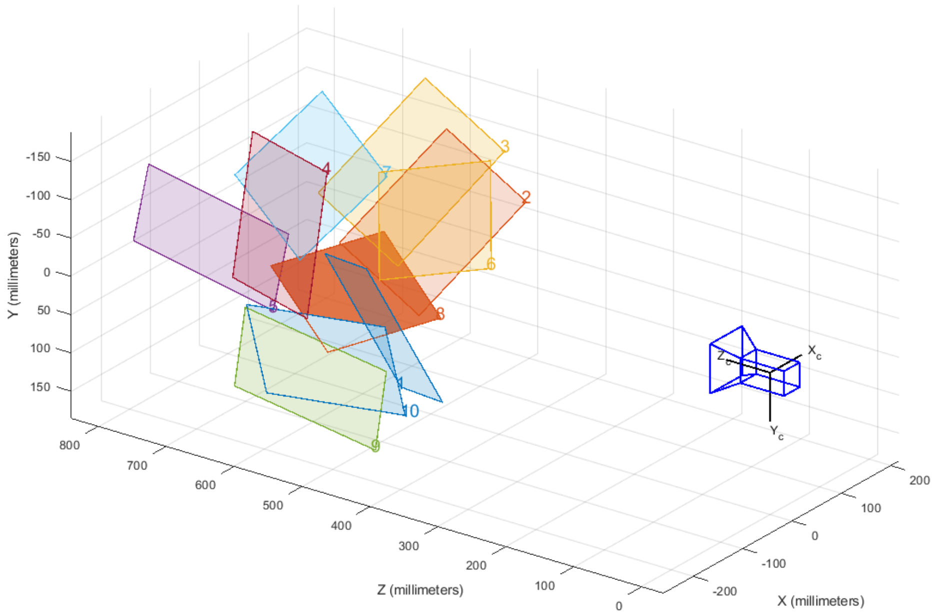
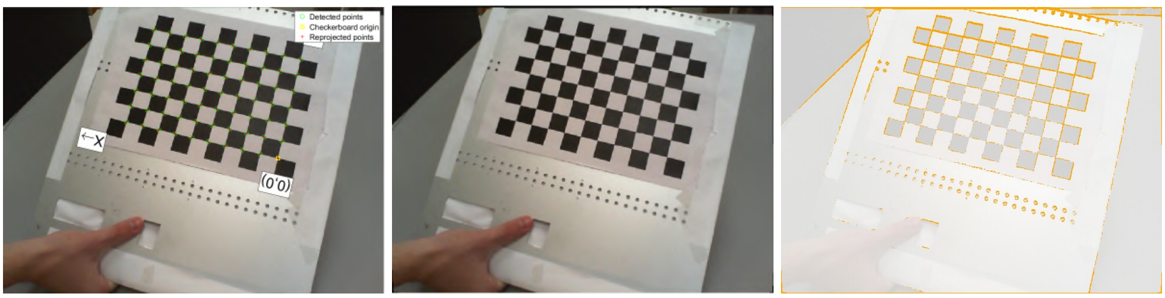


Figure 3.5: Camera-centered Extrinsic Poses Representation



(a) (b) (c)

Figure 3.6: (a) Original Pose Capture; (b) Undistorted Image; (c) Difference between the two images.

3.2 Projector

A projector can be depicted as the inverse of a camera (Figure 3.7), so it is possible to describe the projection of a point in its image plane to a point in the world where it projects by using the same mathematical models as for the camera. Thus, the projector model is composed by the same parameters as described in Section 3.1. However, due to the peculiarity of the projector not being able to capture images, calibrating a projector is a more complex task as it always requires the use of an auxiliary camera to retrieve fundamental data for the calibration.

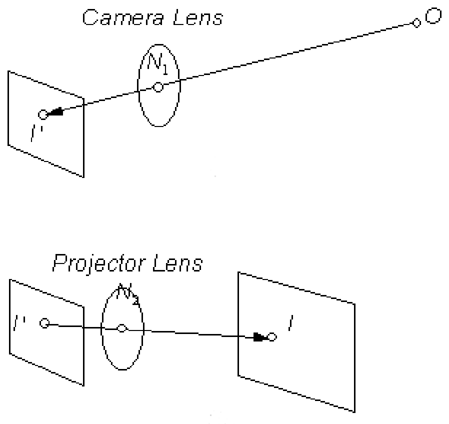


Figure 3.7: Projector as inverse of a camera [4]

3.2.1 Projector Calibration

To explore the area of projector calibration within this work, there was developed a calibration method based in the use of global planar homographies, which disregards the non-linear distortions of the projector. There was also tested the use of an already available software tool, designated scan3d capture, which makes use of Structured Light (SL) encoding and local homographies to map camera coordinates to projector coordinates. This last method results in a model that includes non-linear distortions of the projector and provides an additional tool to perform 3d scanning with the SAR setup. The objective of this subsection is to compare the results in accuracy from considering or not the non-linear distortions introduced by the projector lens.

3.2.1.A Application and Results: Global Homography Method

It is important to understand that, inversely to a camera, the world measurements of a projected pattern's features are not known, and change depending on the relative pose between the projector and the projection surface. However, the corresponding measurements in the projector image plane (the digital image of the pattern being projected) are known and will remain static during the calibration process.

As a homography matrix relates two images of the same planar surface in space, it is possible to use a calibration plane where a projected chessboard will be overlaid, to estimate the homography matrix between the projector and the camera $H_{c \to p}$. This matrix is estimated by using the correspondence between the locations of the pattern's corners in the camera and projector's frames. As the developed SAR interface also makes use of homographies to perform a calibration step, this projective relation is explained in more detail in the next chapter (section 4.5).

Resorting to the identified properties, a method was designed to make possible the use of the same strategies as in camera calibration to calibrate a projector.

This method uses two distinct chessboard patterns: a physical pattern fixed in a flat calibration board (planar surface where metric is known) and a projected pattern that overlays onto this board when the printed pattern is covered. The global homography method is described in the following sequential steps, which repeat for at least two poses of the calibration board:

1. Projected Pattern:
   (a) Detect projected chessboard corners' locations in camera frame;
   (b) Find the homography matrix $H_{c \to p}$ through the correspondence between the locations of the projector pattern's corners in the camera and the projector frames.
2. Printed Pattern:
   (a) Detect printed chessboard corners' locations in camera frame;
   (b) Transform each corner location in the camera frame to the projector frame by using the homography matrix $H_{c \to p}$ found in step 1.(a).

By using the resulting corresponding locations of the printed pattern's corners in the world and projector planes, it is possible to calibrate a projector using Zhang's method, as described in section 3.1.3. As the positions of this corners are also known in the camera frame it is also possible to perform extrinsic stereo calibration of the camera and projector.

A test projector calibration was made using this method which resulted in a projector matrix with mean reprojection error of 0.54 pixels. The stereo calibration resulted in a mean reprojection error of 0.49 pixels.

In Figure 3.8 it is presented a diagram of the extrinsics of the camera and projector pair for each pose. The group of Figures 3.9 presents one of the captured poses with its perspective rectified to create a synthetic view of the projector (in camera resolution), and the same image fitted into the original camera capture.

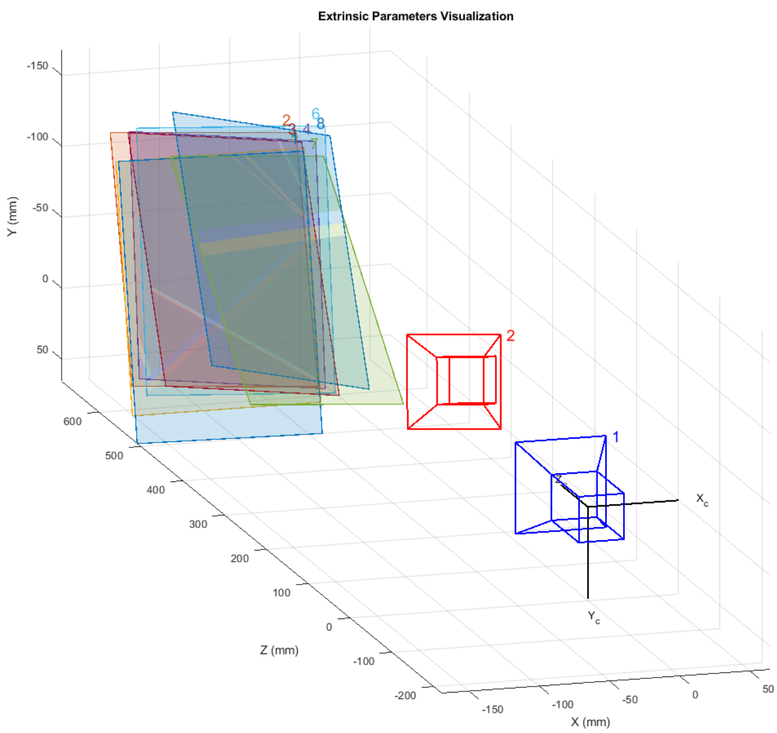
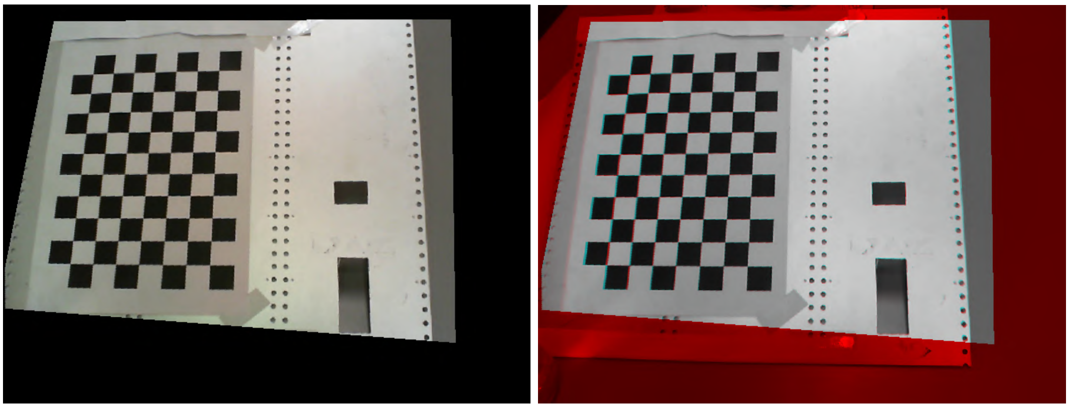


Figure 3.8: Camera and Projector Extrinsics



(a) (b)

Figure 3.9: (a) Synthetic Projector View; (b) Synthetic Projector View Fitted in Source Camera Capture.

3.2.1.B Application and Results: Scan3d Capture

To comprehend the use of structured light encoding and the concept of local homographies as an alternative method for projector calibration, the scan3d capture program was studied. This software was tested and its results are reflected in this subsection. The application serves as proof of concept for the article [66].

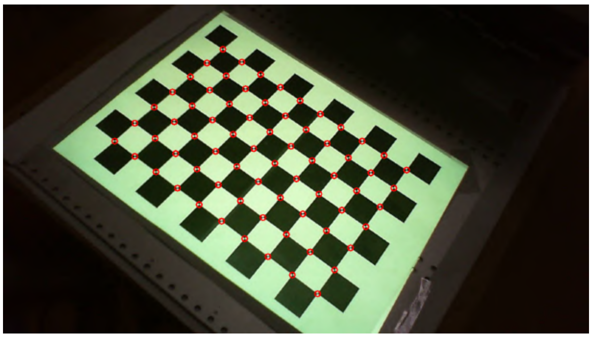
As the name suggests, this calibration method intends to be accurate enough so its results enable the camera-projector pair to perform 3d scanning by using SL techniques. As opposed to the previous method, the projector model considered here includes radial and tangential distortion components in order to enhance the estimation of the projection of a point from the projector image onto the world.

The following steps synthesize how the algorithm works, and have to be repeated for at least two poses of the calibration board:

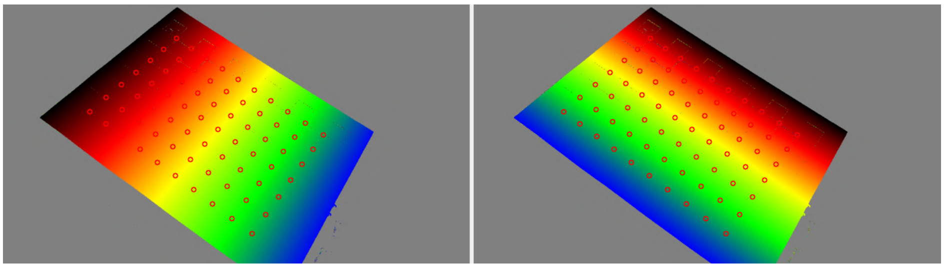
1. Detect chessboard corners' location in the camera frame with fully illuminated pattern (Figure 3.10a);
2. Project structured-light patterns over the calibration board and retrieve global and direct light components;
3. Decode structured-light patterns into projector row and column correspondences (considering light components) (Figures 3.10b and 3.11);
4. Compute local homographies at each corner location (e.g. considering area of 47x47 pixels) using the cameras' corners locations from step 1 and the projectors corners location from step 3;
5. Translate corner locations (step 1) from camera to projector coordinates using local homographies obtained in step 4.

By using the correspondence between the camera and projector's pattern location resulting from this process, it is possible to use Zhang's method to find the camera's and projector's intrinsic matrix, as well as to estimate the stereo extrinsic parameters of the pair. By following this steps through the use of the scan3d capture application, it was obtained a projector matrix with a mean reprojection error of 0.14 pixels and a stereo calibration with a mean reprojection error of 0.23 pixels. In Figure 3.10a it is shown one of the camera frames captured with the detected pattern features. In Figures 3.10b it is represented the encoding of the grey pattern which results in the projector view of Figure 3.11.

From these results it can be concluded that, as expected, by using a method that can estimate the non-linear distortions of the projector, it is possible to obtain a more accurate calibration (this method provided almost four times more accurate calibration than the described in section 3.2.1.A). This demonstrates that lens distortions have to be taken into account to



(a) Chessboard corners detection



(b) Decoded gray pattern where same colour represents pixels in the same column (left image) and in the same row (right image)

Figure 3.10

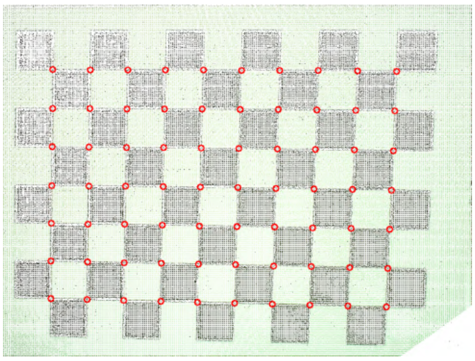
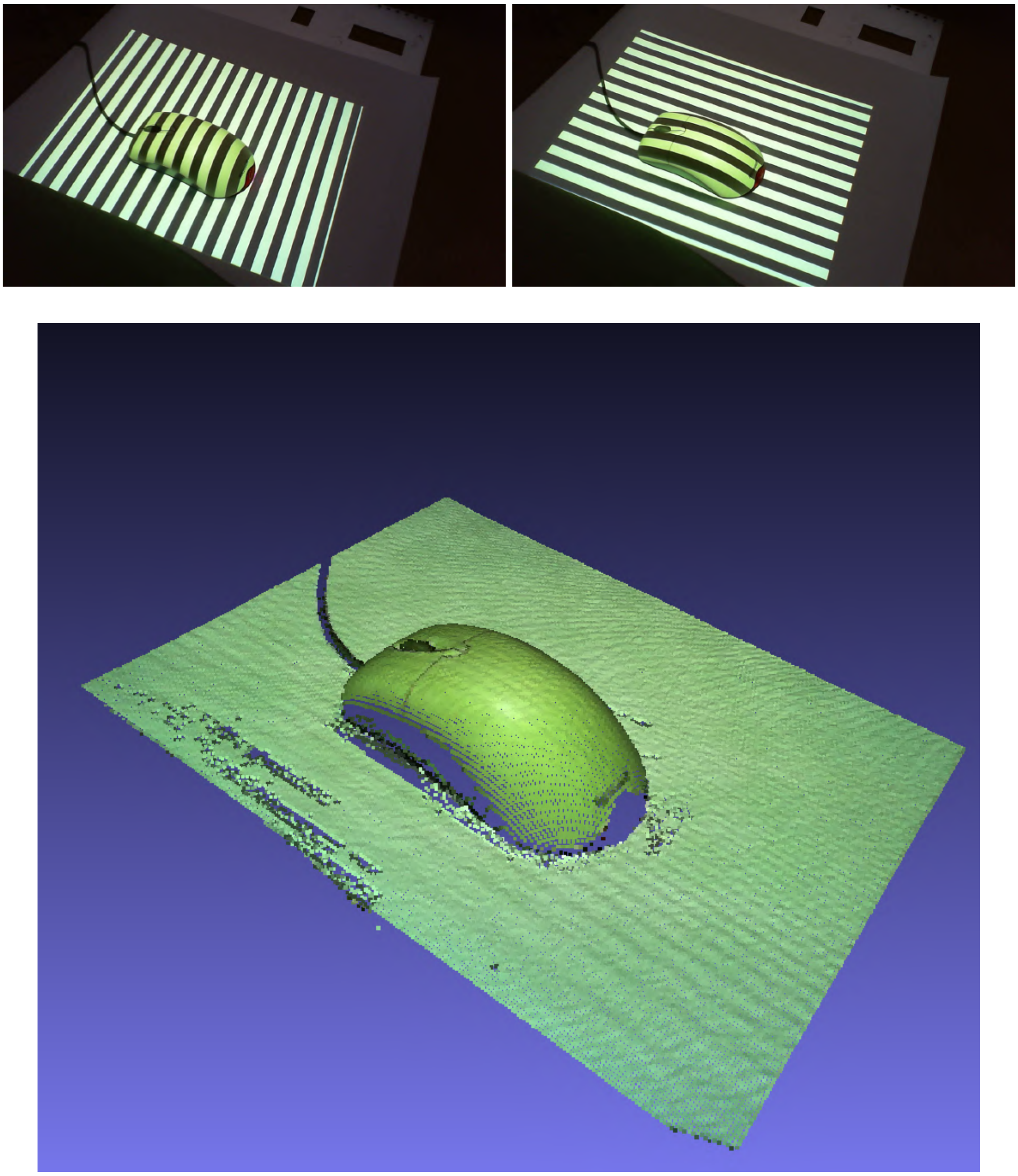


Figure 3.11: Generated Projector Viewpoint

calibrate the projector accurately when the use case demands precision (such as 3d scanning). To test the precision of the calibration results it was used the 3d scanning functionality of the program. A computer mouse was scanned with the SL system, which produced the point cloud presented in Figure 3.12.



(a)

Figure 3.12: 3D Scanning Process of a Computer Mouse

Chapter 4

Proposed System

4.1 Problem statement

As described in Chapters 1 and 2, age-associated diseases can cause cognitive decline. These capacities are necessary to guarantee the autonomy of elderly and to maintain their quality of life. One of the fundamental interventions that helps prevent cognitive decay is cognitive therapy. As shown in the referenced chapters, serious games can be an important therapeutic tool, and for this reason, there have been made significant efforts to apply new technologies to this area to further enhance the effectiveness of therapy. The objective of this work is to create new games for cognitive therapy by using a SAR-based interface.

This chapter will present the idealized system that intends to meet the established objectives in Chapter 1.

To create useful therapeutic tools, there should be examined where current methods can fall short. In the research made, there were identified frequent culprit factors in therapeutic exercises, that can negatively impact the effectiveness of therapy, delaying the progression of the patient, and creating difficulties in the therapists' work. These factors are:

- Repetitiveness - repetitive exercises can cause a sense of tediousness, which can decrease the motivation of the patient;
- Frustration - the struggle in challenging exercises can be frustrating. This is proven to lead patients to abandon therapy;

- Adaptability - a wide variety of conditions can affect patients in unique ways. If a tool is not sufficiently adaptable, it is difficult for therapists to correctly adjust exercises to cater to patients' needs.

- Dispersion of the therapist's role - therapists employ a significant amount of time encouraging patients in order to maintain their motivation. This can cause the focus of therapy to be diverted from processes such as tracking performance.

Having these aspects in mind, the target of the system should be to replicate the cognitive exercises already in use, with complementary features that minimize the flaws identified. This can be done by creating a better approach that meets the needs of the patients, and facilitates the work of the therapist. Assuring that these goals are met, is to ensure that therapy will be more effective.

4.2 System Requirements

Requirement	Property	Description
1	Entertaining	Improve the entertainment ability of the SGs.
2	Adaptability	Adaptable to patients' conditions, stages of development of their diseases, and their performance evolution.
3	Accessibility	Avoid the use of complex User Interface design and control schemes.
4	Customizable	Tools to customize SGs content for different patients.
5	Scalability	Allow the built structure to facilitate the development of other SGs in SAR.
6	Certification	Support the approach to cognitive exercises in tools which are validated in the CT field.
7	Portability	Easily deployable and adaptable to different types of setups and Operative Systems (OS).
8	Intuitive	Promote natural interaction through the use of the SAR environment.

Table 4.1: Non-functional requirements of the system

By taking into account the aspects denoted in the sections 2.5 and 4.1, by analyzing the related work described in section 1.3, and by targeting the objectives set in chapter 1, there were delineated the requirements for a system that promotes the creation of serious games for cognitive therapy. The established requirements are reunited in Tables 4.2 and 4.1. This tables separate functional requirements, which defines the essential features of the system,

Requirement	Description
1	Identify user.
2	Provide prescribed SGs with recommended parameters automatically.
3	Track user performance.
4	Provide visual and sound feedback.
5	Avoid the use of keyboards and mouse for user interaction.
6	Provide therapists with a platform showing user evolution.
7	Provide parameters of adjustment for game rules, objectives and difficulties.
8	Accommodate ways to personalize games for its user.

Table 4.2: Functional requirements of the system

from non-functional requirements, which specify how the system should deliver those features to the user.

4.3 Solution Concept - Spatial Augmented Reality Cards Framework

After the requirements were established, a concept for a SAR-based solution was created.

In the researched tools for CT, it was found that card-, and board-based games are used very frequently due to the cognitive stimulus they provide. Since it is intended to substantiate the system implementation on validated tools, it was decided to implement a card-based SAR framework.

The goal of this concept is to replicate the gameplay of traditional card games and to provide additional features that can enhance engagement and effectiveness in a therapeutic context. A deck of specially crafted cards will be placed on a surface inside the projection frustum, that here is defined as Interaction Planar Surface (IPS). The cards' locations are tracked and projections are superimposed over them to create the illusion of virtual objects registered to physical surfaces.

The framework should comprise primitives which support the development of SAR-based Serious Games with cards. By transferring time-consuming tasks such as card tracking, projection-mapping, and performance tracking to ready-made software structures, that can effectively lessen the burden of implementing SAR applications and expedite their development process.

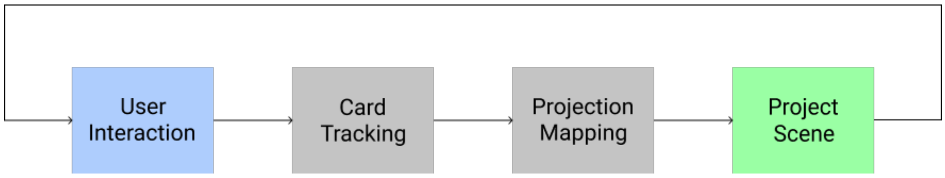


Figure 4.1: System Pipeline

This pipeline of the system can be described in four sequential steps:

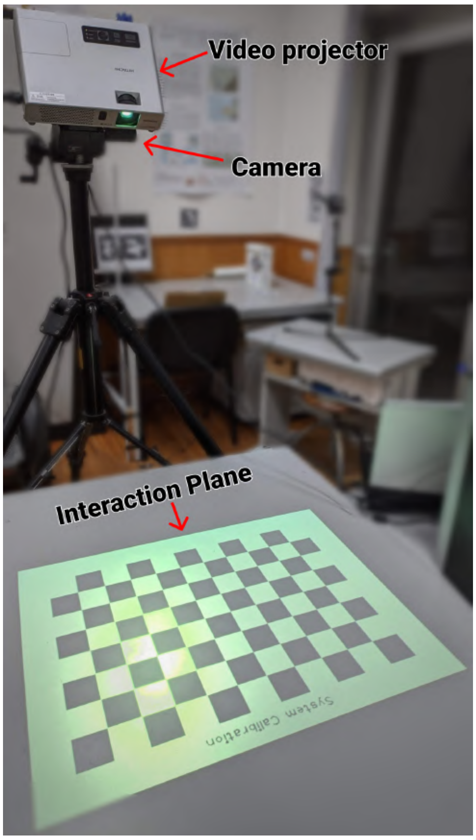
1. The user interacts with the cards in the projective environment;
2. A camera captures frames that encompass the changes caused by his interaction (tracking process);
3. The system receives the camera frames and decodes them into intelligible data inputs;
4. The system interprets the inputs and generates new images accordingly (mapping process);
5. The projector overlays the new images onto the cards.

To promote natural interaction with the environment, the system should carry out this sequence in a cyclical fashion. The more robust and accurate the tracking and mapping processes are, the better will be the visual registration to the cards. For this process to be viable, the cards' position have to be tracked in the camera frames, and projections must be generated accordingly to the physical space where the virtual environment overlays. The next sections will explain each step of this pipeline.

4.4 System Setup

The elements of a conventional SAR system are: the user projective space, the camera, and the projector.

When setting up a SAR interface, the area where the projections are made has to be selected. The framework is adaptable to several flat surfaces (e.g. table, wall, ground), but as the focus of this implementation is on replicating card game experiences, a table will be chosen as the projection surface. Then, the projector position and orientation needs to be defined. The pose and the characteristics of the projector (resolution, focal length, throw ratio, throw distance, brightness) will limit the area of projection: its orientation and the distance between the optical center of the projector and the table will limit the area of projection. The angle between them will create a keystone distortion of the projector image, which can be corrected manually in some projectors or automatically in the application. The last element of the setup is the camera. The pose of the camera must guarantee that its Field of View (FOV) covers the entire area of projection and not much more (in order to get rid of unnecessary noise when tracking). Its resolution and sharpness must be reliable enough to allow the distinction of features in the area of projections. The setup utilized to develop this work is shown in Figure 4.2.



(a)

(b)

Figure 4.2: Setup - Whole System (a), and Camera and Projector Close Up (b)

4.5 System Calibration

To enable the projection-mapping part of this framework, it is needed to estimate the projective relations between the components of the system. To find this relation it is imperative to perform a calibration procedure. Since the two methods studied in Section 3.2 are complex and time-consuming, for this framework to be easily deployable, a simpler calibration method was designed.

The camera frame, projector frame and projection surface can be modelled as planes in space, which share representations of the same planar surface (projector image). Therefore, the calibration process should result in defining the projective transformations between them.

To map a world point $(X,Y,Z,1)$ (in meters) to a image plane $(\tilde{u},\tilde{v},\tilde{w})$ (in pixels), using homogeneous coordinates, an alternative representation of the camera model used in section 3.1 is used (without taking non-linear distortions into account) (Equation 4.1) where the focal lengths are $f_x = \frac{1}{\rho_u}$ and $f_y = \frac{1}{\rho_v}$, γ is the skew factor and (u_0, v_0) is the principal point. The model is composed by the intrinsic matrix K, which defines the intrinsic parameters of the camera (focal length, image sensor format, and principal point), and the extrinsic matrix E, that describes its position and orientation in world coordinates. Multiplying the two, the result is the camera matrix C.

$$\begin{pmatrix} \tilde{u} \\ \tilde{v} \\ \tilde{w} \end{pmatrix} = \underbrace{\underbrace{\begin{pmatrix} \frac{1}{\rho_u} & \gamma & u_0 \\ 0 & \frac{1}{\rho_v} & v_0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix}}_{\mathbf{K}} \overbrace{\begin{pmatrix} \mathbf{R} & t \\ \mathbf{0}_{1\times 3} & 1 \end{pmatrix}^{-1}}^{E}}_{\mathbf{C}} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} \tag{4.1}$$

In this computation, the scale factor is arbitrary as it does not influence the result: if both $\tilde{u}, \tilde{v}$ and $\tilde{w}$ are scaled by λ, when converting back to Cartesian coordinates, the $lambda$ is canceled (Equations 4.2, 4.3). This allows the simplification of the operation, as it fixes a value in the camera matrix (C_{34} is fixed to 1 in Equation 4.4).

$$\begin{pmatrix} \tilde{u} \\ \tilde{v} \\ \tilde{w} \end{pmatrix} = \lambda \begin{pmatrix} C_{11} & C_{12} & C_{13} & C_{14} \\ C_{21} & C_{22} & C_{23} & C_{24} \\ C_{31} & C_{32} & C_{33} & C_{34} \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} \tag{4.2}$$

$$u = \frac{\tilde{u}}{\tilde{w}}, v = \frac{\tilde{v}}{\tilde{w}} \tag{4.3}$$

$$\begin{pmatrix} \tilde{u} \\ \tilde{v} \\ \tilde{w} \end{pmatrix} = \begin{pmatrix} C_{11} & C_{12} & C_{13} & C_{14} \\ C_{21} & C_{22} & C_{23} & C_{24} \\ C_{31} & C_{32} & C_{33} & 1 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} \tag{4.4}$$

The estimation can be simplified further, as the choice of the world coordinate system is arbitrary: if the world coordinate system is placed in the plane itself, with the Z axis orthogonal to it, then every plane points will have coordinate $Z = 0$. This allows the elimination of the Z column in the camera matrix. The result is a three by three matrix defined as a planar homography (Equation 4.5).

$$\begin{pmatrix} \tilde{u} \\ \tilde{v} \\ \tilde{w} \end{pmatrix} = \begin{pmatrix} H_{11} & H_{12} & H_{13} \\ H_{21} & H_{22} & H_{23} \\ H_{31} & H_{32} & 1 \end{pmatrix} \begin{pmatrix} X \\ Y \\ 1 \end{pmatrix} \tag{4.5}$$

The homography matrix has 8 Degrees of Freedom (DoF), meaning that to estimate it, it is required to find the coordinates of at least four points in the world and their correspondents in the image plane. The more point matches found, the better the estimation will be.

With the theoretical aspects covered, it is possible to design a calibration process for the system. Since the relations between the system planes can be modelled as projective transformations, the relationship between each pair is given by a homography matrix (Equation 4.5). These relations are portrayed in Figure 4.3. In fact, to perform the tracking and mapping steps, it is only needed to define the homography matrix between the projector and the camera frames ($H_{c \to p}$). To find the matrix $H_{c \to p}$, one has to project a pattern that facilitates the retrieval of the coordinates of its features. A chessboard pattern was chosen for this effect since its use is simple, robust, and frequent in calibration tasks.

The built calibration procedure goes as follows:

1. A chessboard image with the projector's resolution is created and its corner's coordinates are detected (illustrated in Figure 4.4).

2. The chessboard is projected over the projective surface and its corners are detected in the camera frame;

3. By having the coordinates of both camera's and projector's corresponding corners, in their respective frames, the homography matrix ($H_{c \to p}$) can be found.

Now that the projective transformation between camera and projector frames is defined, it is possible to proceed to the tracking and mapping steps.

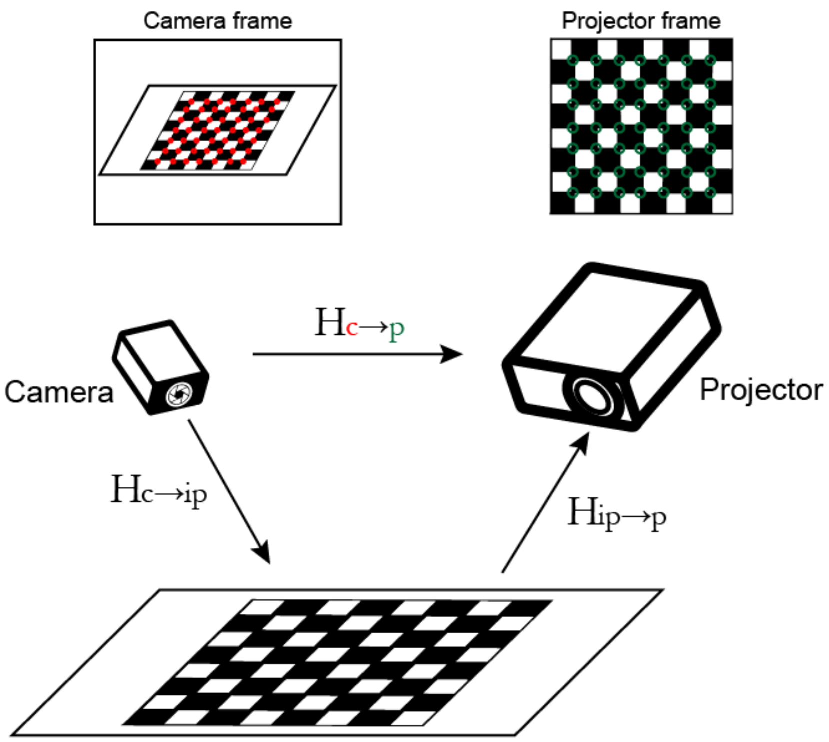
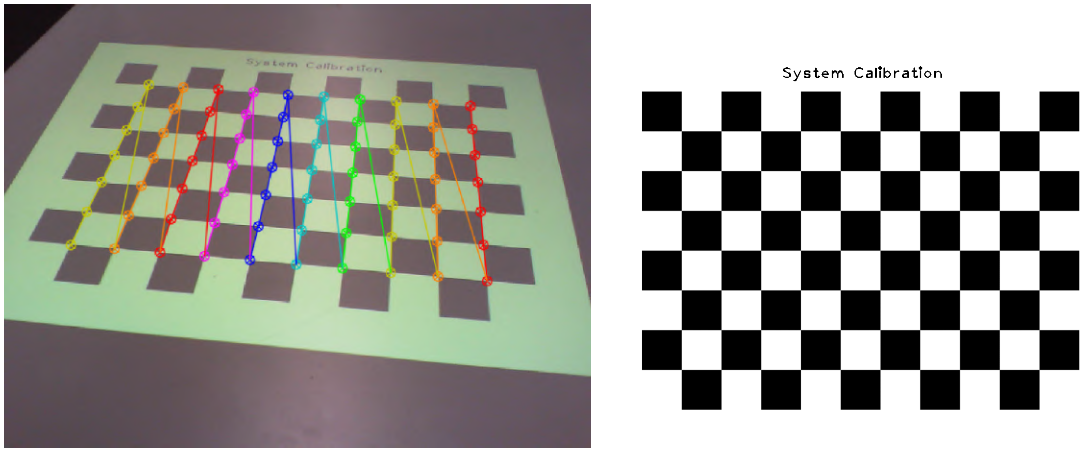


Figure 4.3: System Calibration - Homography relations between planes.



(a) (b)

Figure 4.4: Calibration Frame: (a) camera, (b) projector

4.6 Tracking

Users will interact with the SGs by moving cards in the projective surface, so it is needed to track cards' positions in the camera frames. To guarantee smooth interaction, the tracking process needs to be fast and robust. Thus, when designing the cards, it was chosen to include ArUco's fiducial markers into them [67]. This library provides primitives to locate markers on an image. An example of the markers used is presented in Figure 4.5.

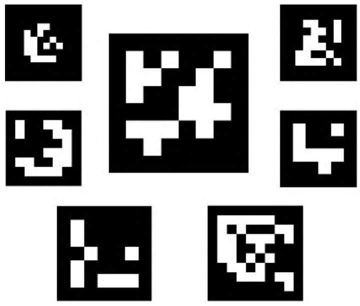


Figure 4.5: Different types of ArUco Markers

A mock-up for the cards was designed after the following description: the cards have one active side and one decorative side; the active side is divided into two halves: the bottom part, where a marker is placed, and the upper part, that is blank to allow the projections of images onto it. Therefore, markers' size and projection space is dependant of the card size, so the cards should be sufficiently big to allow the visibility of markers and projected images for several types of setup configurations. Each card has a different marker (with a different id) to allow unique identification. The mock-up is observable in Figure 4.6.

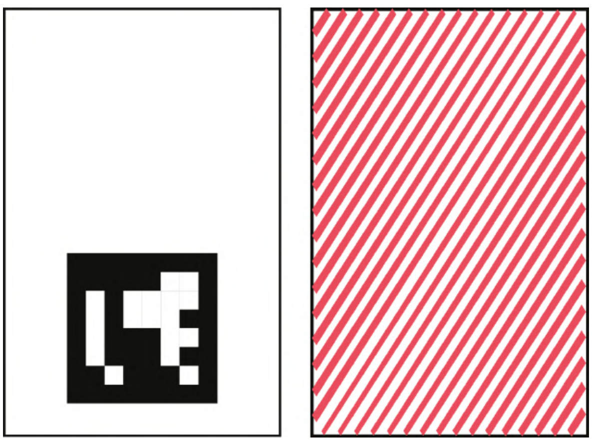


Figure 4.6: Card Concept Design

The mock-up was followed to create physical cards with the following measurements: 18.5cm of height and 12 cm of length, and the markers used have 6 cm of length. The tracking of the built cards was tested and the results satisfy the intended purpose (Figure 4.7).

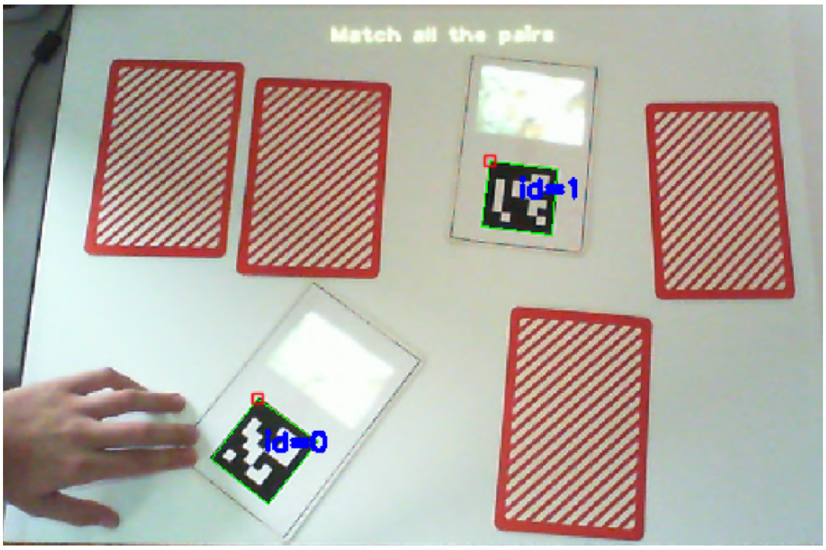


Figure 4.7: Card Marker Detection

When tracking the markers, corner coordinates can suffer small variations even if the card is still. If the system updates its projection mapping directly from these coordinates, the result can be a very unstable image. To solve this issue, the center location of each marker is saved and compared with the corresponding one on new frames. The centers are calculated from the coordinates of the markers corners, number 0 and 3, as shown in equation 4.6. The distance between the old and new location is calculated to decide if the projection relative to that card needs to update or not (equation 4.7). The projection updates if this distance is bigger than a user-definable threshold (the value can be dependent on the environmental conditions and the requirements of each game).

$$C_x = \frac{X_{c0} + X_{c3}}{2} \qquad C_y = \frac{Y_{c0} + Y_{c3}}{2} \tag{4.6}$$

$$d = \sqrt{(C_{x_{current}} - C_{x_{old}})^2 + (C_{y_{current}} - C_{y_{old}})^2} \tag{4.7}$$

It is worth noting that, if the user occludes a card marker while interacting with the system, the projection in the respective card is omitted during occlusion and reinstated when the marker is detected again.

Using this configuration, tracking each card position, in the camera frames, can be made with reference to the pixel location of the markers' corners. Knowing the locations, it is possible to proceed to the next step, that is the projection mapping onto the blank half of the active space of each card.

4.7 Mapping

Now that the location of the cards in the camera frame is known, we want to be able to project onto them in the Interaction Planar Surface. To achieve this effect, their locations in the projector frame has to be found as well, and the images of each card have to be adapted to account for the projective transformation between the projector's frame and the projective surface.

Hence, the process of projection mapping can be divided into three steps: first, obtaining the cards' location in the projector frame; second, fitting the images intended to be projected for the blank space in a flat card's image and placing them properly; lastly, applying a projective transformation to the images and positioning them in their correct location on the projector frame, so that when projected, they lay flat in the cards as if they were printed onto them.

For the first step, the location of the markers in the camera frame have to be transferred to the projector frame. This can be done by multiplying the coordinates of each marker's corner with the homography $H_{c \to p}$ found in the calibration step, as in Equations 4.5 and 4.8. The result is the corresponding coordinates in the projector frame.

$$\mathbf{P}_{cam} \simeq \mathbf{H_{c \to p}} \mathbf{P}_{proj} \tag{4.8}$$

Afterwards, it is needed to create the digital images with each of the cards' desired appearance. A blank image with the same size as the cards is used as a base. In the blank image, the area where a virtual object should be placed is delimited (inside the empty upper half of the active side of the card), the object is scaled to fit this area, and it is placed in its center. The fitting process must guarantee the use of several sizes of images, so the resizing of the object must keep the original ratio between width and height (as in Equations 4.9, 4.10, 4.11, 4.12). The fitting process is represented in Figure 4.9.

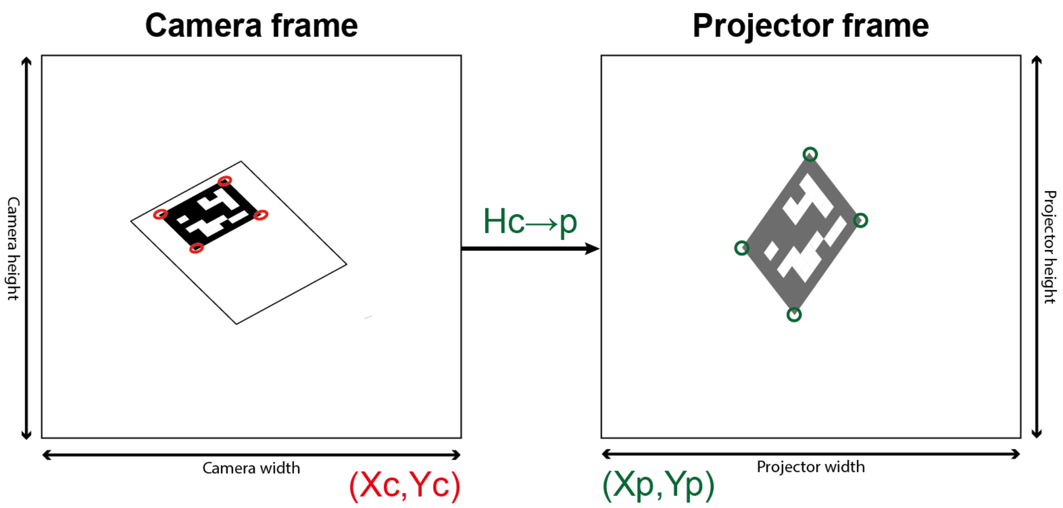


Figure 4.8: Marker location in projector frame

$$a = \min\left(\frac{width_{PA}}{width_{OI}}, \frac{height_{PA}}{height_{OI}}\right) \tag{4.9}$$

$$t_x = \left(\frac{Width_{SI}}{2} - \frac{Width_{PA}}{2}\right) + \left(\frac{Width_{PA}}{2} - \frac{width_{ScI}}{2}\right) \tag{4.10}$$

$$t_y = \left(\frac{Height_{SI}}{2} - \frac{Height_{PA}}{2}\right) + \left(\frac{Height_{PA}}{2} - \frac{Height_{ScI}}{2}\right) \tag{4.11}$$

$$\begin{bmatrix} a & 0 & t_x \\ 0 & a & t_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} \tag{4.12}$$

Lastly, it is needed to rectify the perspective of the card image so that it overlays correctly when projected into the IPS. The projective relations between the elements of the system are used once again: the corners' coordinates of each marker are known in the projector frame, thus, using the source image of a flat card's active side (true to world size), we can find the marker's world coordinates. With the four corresponding corners, a homography matrix can be found $H_{si \to p}$ (Equation 4.13). Multiplying the points in the card image by this matrix results in a projective transformation that rectifies its perspective in the projector frame, such that when projected over the respective card in the Interaction Planar Surface, it looks like the image is flat and registered to it.

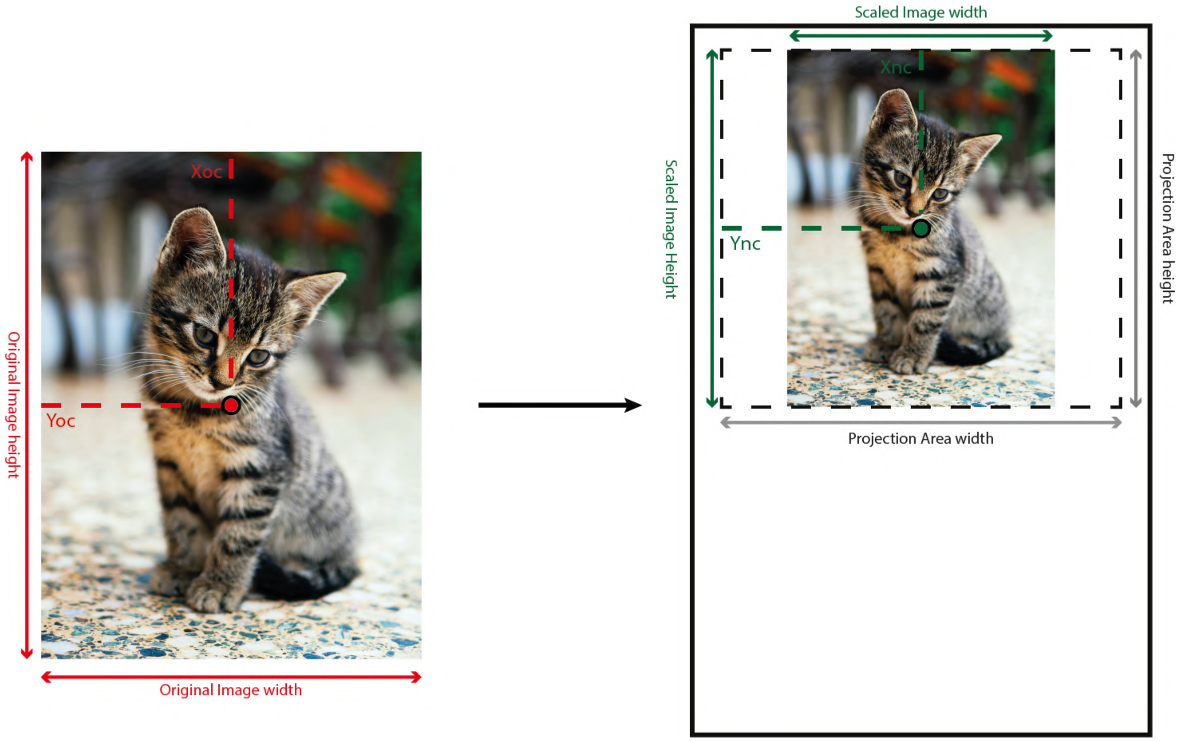


Figure 4.9: Fitting Process. Image taken from Unsplash website

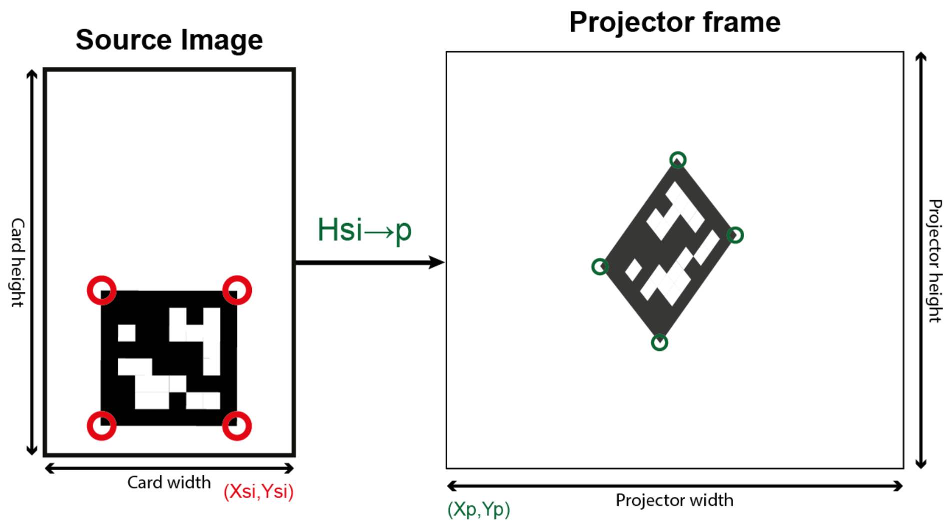


Figure 4.10: Homography transformation between source image and projector frame

$$\mathbf{P}_{si} \simeq \mathbf{H}_{\mathbf{si}\rightarrow\mathbf{p}}\mathbf{P}_{proj} \tag{4.13}$$

After replicating these steps for all the visible cards, an image, with the projector resolution, is created: this image is composed of all of the cards' images, each one with their perspective rectified and in their correct location. This image is sent to the projector, which overlays it over the cards in the projective surface.

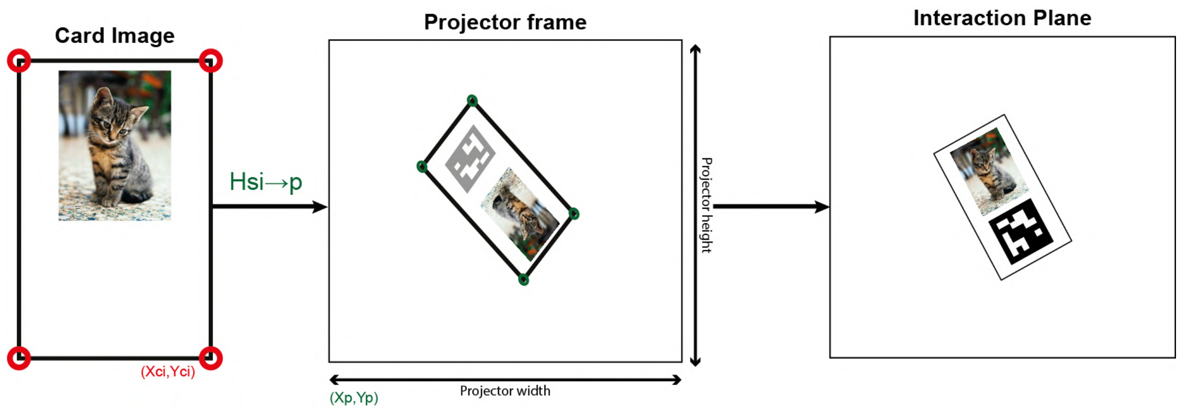


Figure 4.11: Perspective Rectification of source image

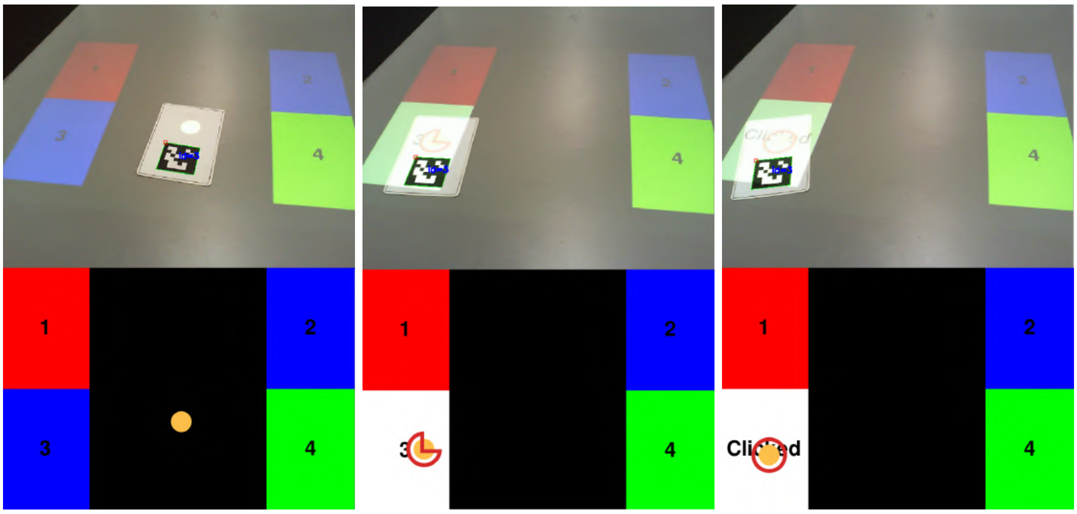
4.8 Interaction

One of the fundamental requirements for the framework is to create an intuitive and simple interface.

The games can be designed to account for the card control and even take advantage of the cards features (by using more than one card, utilizing their physical format or unique id). Given that the manual change of parameters and option selections might be needed for this use case, it is necessary to include some type of interface where the interaction is somewhat analogous to traditional game menus.

To allow the use of menus with buttons, a method was implemented to allow the card to behave like a computer mouse. The first card seen when a menu is presented is identified as a mouse card. Afterwards, a pointer is projected in the upper half of the active side of the card. In a menu, buttons are projected onto the user surface. A binary mask for each button and the card is created to allow the detection of button clicks. When the user hovers a button with the mouse card, the colour of the button changes and a timer is started. If the mouse card remains intersecting the same button for an interval, a click signal is transmitted - the respective button was clicked. During this time, the image of the pointer changes to portray the passing of time as a loading circle (Figure 4.12). This process is shown in Figure 4.13, where the above images are the camera frame, and underneath are the projector frames. This process applies to many types of use cases and satisfies the requirement in a way that the keyboard and mouse are not needed.

Figure 4.12: Loading clock icons



(a) (b) (c)

Figure 4.13: Pointer Card - Pointer Card (a), Pointer Loading (b), Pointer Clicked (c)

4.9 Performance Tracking

The performance of a patient in a game helps to identify his cognitive impairments and demonstrates how he is evolving cognitively in a sequence of therapeutic sessions. Thus, it can be very useful for therapists if a therapeutic tool records and presents patient's performance in a discernible way.

Therapists prescribe games and parameters according to each patient cognitive capacities. These recommendations can be translated to known game mechanics, such as objectives, levels, difficulties, etc. (input parameters). While participating in a game session, variables such as scores, counters, achievements, points, time, etc. convey patient performance (output variables). This variables are saved and sent to the therapist for posterior analysis.

The output variables describe how the patient did in achieving the game's objective. E.g. high scores signify that the user was able to follow the rules of the game, accomplishing the purposed tasks - which can be an indicator that the difficulty used is adequate or perhaps too easy for that specific user; low scores mean that the player did not understood the rules of the game or was not able to accomplish the prescribed tasks because its cognitive capacities do not allow it. In this case, it could mean that the parameters are not adequate for that specific patient. The time the player took to finish a game, level or task can also portray the performance of the player: if he took to long to achieve a goal, this could indicate that the challenge level is too high and that the patient is struggling to perform the game tasks. If he was able to reach said goals in a small amount of time, this could mean that the objectives are too easy for the player. Indicators such as number of interactions with a given object in game can translate their game habits and the strategy used to accomplish the proposed tasks. An abandonment indicator is also important to include in game: if the player stops interacting with the game, being by leaving the game running without performing any tasks or by exiting the game without accomplishing the set objectives, could mean that his level of interest is low or that he became frustrated with the game.

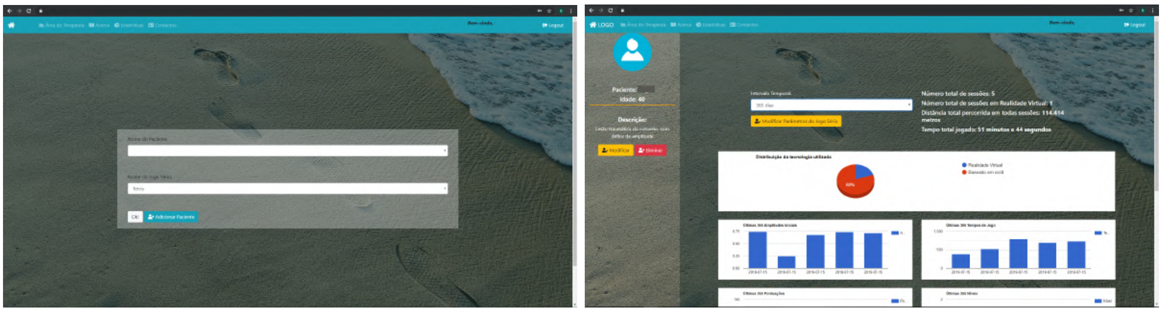
One way or another, by observing the results of each game session, the therapist can readjust game parameters so that the next therapy session is fitted and adapted to each patient needs. If their performance has low results, the game mechanics should be simplified so that the next session is adequate to his capacities. If their performance has medium results, the game parameters should not need much adjustment as the game mechanics are adequate for the patient. Lastly, if the results are good, this could mean that the game is too easy and the parameters should be adjusted to keep the challenge and entertainment factor of the game and incite the evolution of patient capacities.

4.10 Back-End Support

To facilitate the delivery of the right therapeutic games and parameters for each elder, and to provide tracking of patient's performance, the framework was integrated into a therapy serious games performance analysis web platform developed in [5].

Therapist can store the recommended games and parameters for future therapeutic sessions according to each patient needs. When the user logs in to the platform, the recommended parameters are downloaded from the database. After the gaming session, the data related to their performances is submitted to this database so it can be analyzed posteriorly by his therapist.

A website gives therapists access to the data stored in the database so they can analyze patient performance and adjust their games and parameters. The website allows a therapist to login and to choose which one of his patients profile he wants to see. When the patient is chosen the data related to its therapeutic sessions is presented in a format of graphs. This is presented in (Figure 4.14).



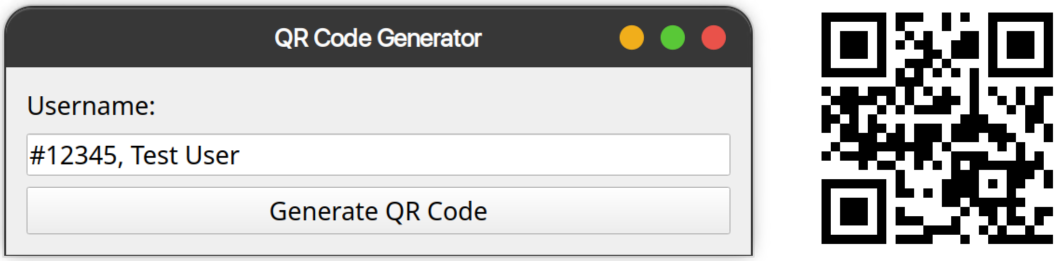
(a) (b)

Figure 4.14: Login authentication of therapist (a), and patient performance data (b). Created in [5].

4.11 User Identification

The keyboard and mouse are not utilized to interact with the system, so the insertion of credentials to identify the user has to be done differently. To circumvent this handicap, there was created a method that uses the camera of the system to identify the user in a matter that is even simpler than inserting the username with a keyboard. The method comprises a QR code generator with a graphical user interface, and a QR code reader (Figures 4.15a and 4.16).

In the act of creating a patient profile, the therapist generates a unique QR code using the created tool (Figure 4.15a). The generated QR code contains the patient's username followed by their ID. This code is provided to the patient so he can identify himself to use the system (Figure 4.16). This QR code reader is intended to integrate into the beginning of the SGs. When the game are initialized, a message is projected into the projection surface for the user to present his QR Code. The user shows his identification card to the camera, the marker is detected and the user is identified. After this identification process, the user-specific parameters (recommended by the therapists) are downloaded from the database and the game starts with these parameters defined.



(a) (b)

Figure 4.15: (a) QR Code Generator GUI;(b) Generated QR Code for ”Test User”

Figure 4.16: User Identification: QR Code Reader

Chapter 5

Developed Games

5.1 Developed Games

In this chapter, there will be described two SGs for different areas of Cognitive Therapy. These games aim at accomplishing the role of useful therapy tools by following the requirements stressed throughout this thesis, and make use of the proposed SAR-based framework, described in Chapter 4, to show its functionality and attest its applicability.

As mentioned in Chapter 2, the conceptual nature of these games was based on already validated therapeutic tools. More features were added in order to provide more adaptability to the patients' needs, to create a more pleasant and engaging experience and to track the performance of the player through the use of *gamification* metrics (score, difficulty, time, etc.).

To expedite the development of the games, the Pygame library was used [68]. This library provides primitives that facilitate the development of multi-platform games.

Both games follow the same pipeline:

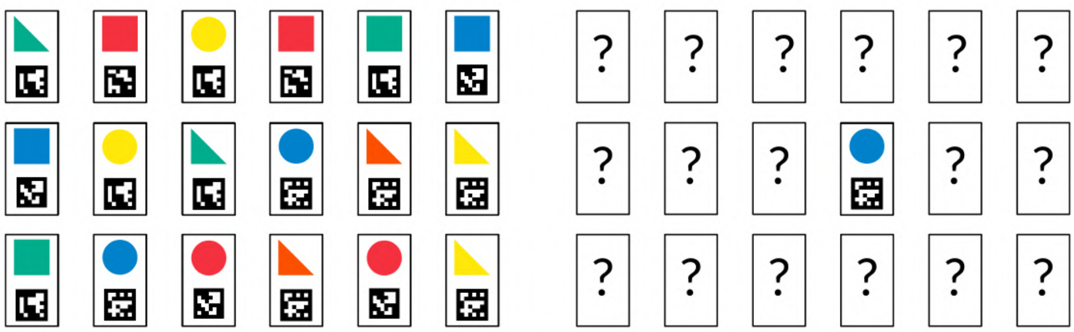
1. **System Initiated**;
2. **System calibration** - to discover the relation between the elements of the setup, as portrayed in section 4.5;
3. **User Identification** - where the user presents its card id to the camera to login (as in section 4.11)

4. **Gameplay Stage** - where the user plays a session of the game with the recommended parameters;

5. **End of Game Session** - which has three options of ending: game completed, game over or game abandoned.

5.2 SAR Memory Cards

The use of memory card games is verified and commonly used as a tool for CT [69], so it was decided to build an enhanced version using SAR.



(a) (b)

Figure 5.1: Memory Game Stages 1 - (a) Initial stage where all cards are facing up; (b) First card flipped (Find matching pair stage)

The patient starts with all the cards facing down on a table (IPS) and has to find all the matching pairs (Figure 5.1a). The player flips cards up one at the time trying to find a pair (Figure 5.1b), if it is a wrong pair, the last two cards have to be flipped down again (Figure 5.2b), if the pair is correct, the cards remain face up and the player can proceed to find the next pair (Figure 5.2a). This process repeats until all the pairs are found (Figure 5.2c). The game is adaptable in the following ways:

- The number of cards is dynamic: the more cards, the harder is the game;
- The images that appear on cards can be completely customized: this allows to build many types of games. E.g. cards appear with pictures of places, colours, animals, fruits, vegetables, familiar faces, emotions, and the patient has to find matching pairs;

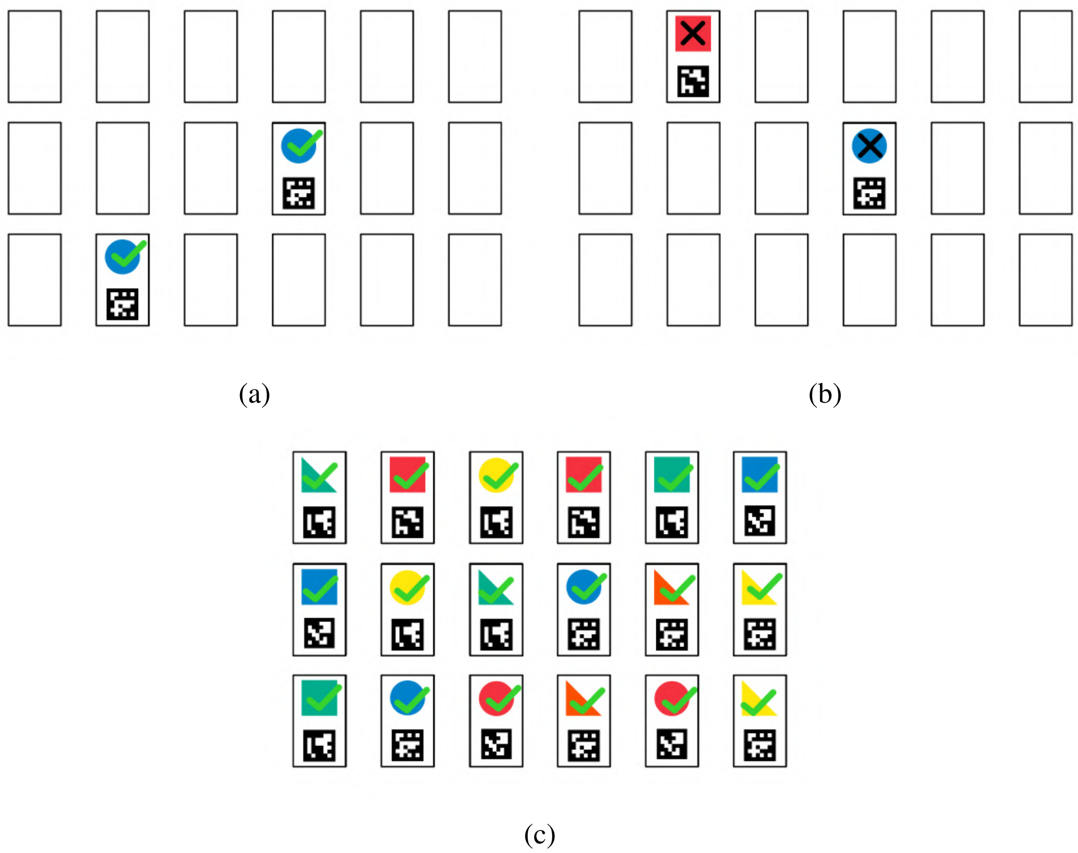


Figure 5.2: Memory Game Stages 2 - (a) right pair found (check mark icon over matching cards); (b) wrong pair (x mark over unmatched cards); (c) all pairs found (game won)

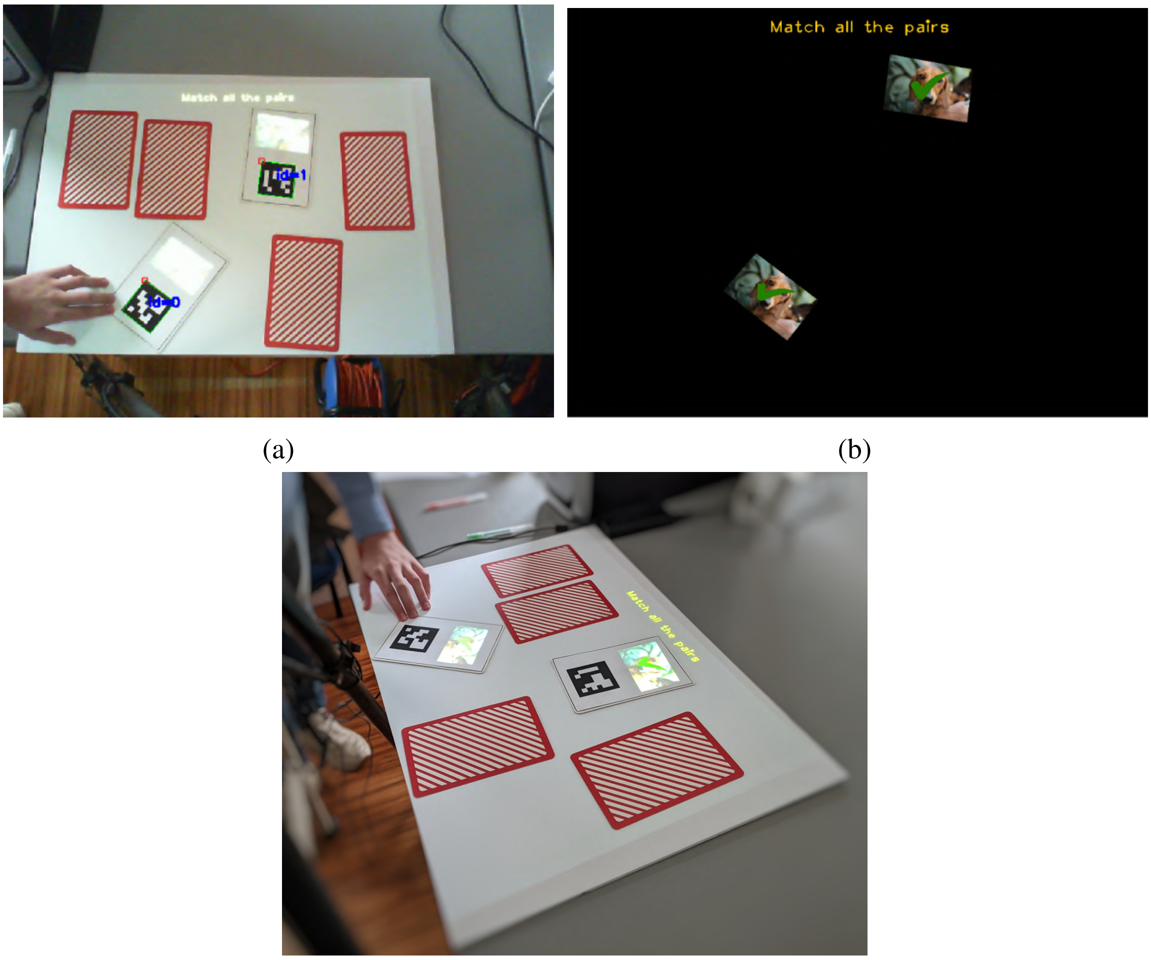
cards appear with names of familiars or personal objects, and the players have to find the card with the corresponding image;

- The game also has an option for providing initial help, where the player sees which images are on each card before turning them down.

While the player interacts with the game, the interface provides positive and negative feedback in the form of visuals and sound.

When the game ends (all pairs found), a celebratory screen is shown with the player's score. The score embodies the number of cards (the more is better) and time of completion (less is better) used in that session.

The images, the number of cards and help mode should be controlled by the therapist. After finishing a CT session, the scores, time, and number of tries are sent to the database for posterior analysis. A demonstration of this SG is showed in Figure 5.3.



(a) (b)

(c)

Figure 5.3: SAR Memory Demonstration (setup's element perspectives) - (a) Camera Frame; (b) Projector Frame; (c) IPS Photography

5.3 SAR Pong

Pong was one of the first video-games created, and, from an early stage, its application for cognitive rehabilitation was studied. This helped to introduce the concept of SG for CT [70].

The objective of the game is to score goals, throwing the ball through the defence line of the other player while defending our line by bouncing the ball back with the paddle. The game starts with the ball in the middle of the field and goes into a random direction, the ball is reset to this position after a goal. A SAR implementation of the game was developed using the framework, where the player controls its paddle position by moving the card vertically in the IPS (an illustration of the game concept is shown in Figure 5.4).

The game-play focuses on the attention span, reaction speed and spatial awareness of its patients as it forces the patient to watch, react and predict the trajectory of the ball. The

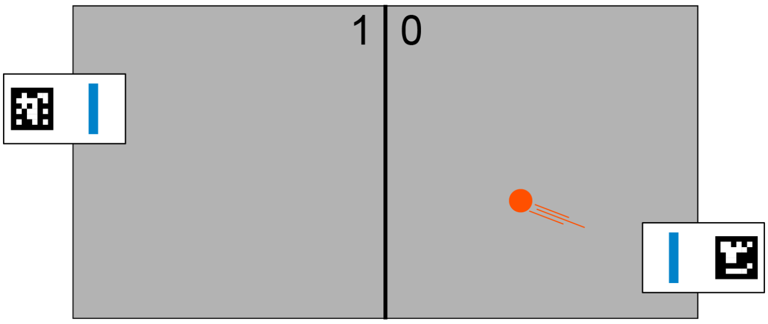


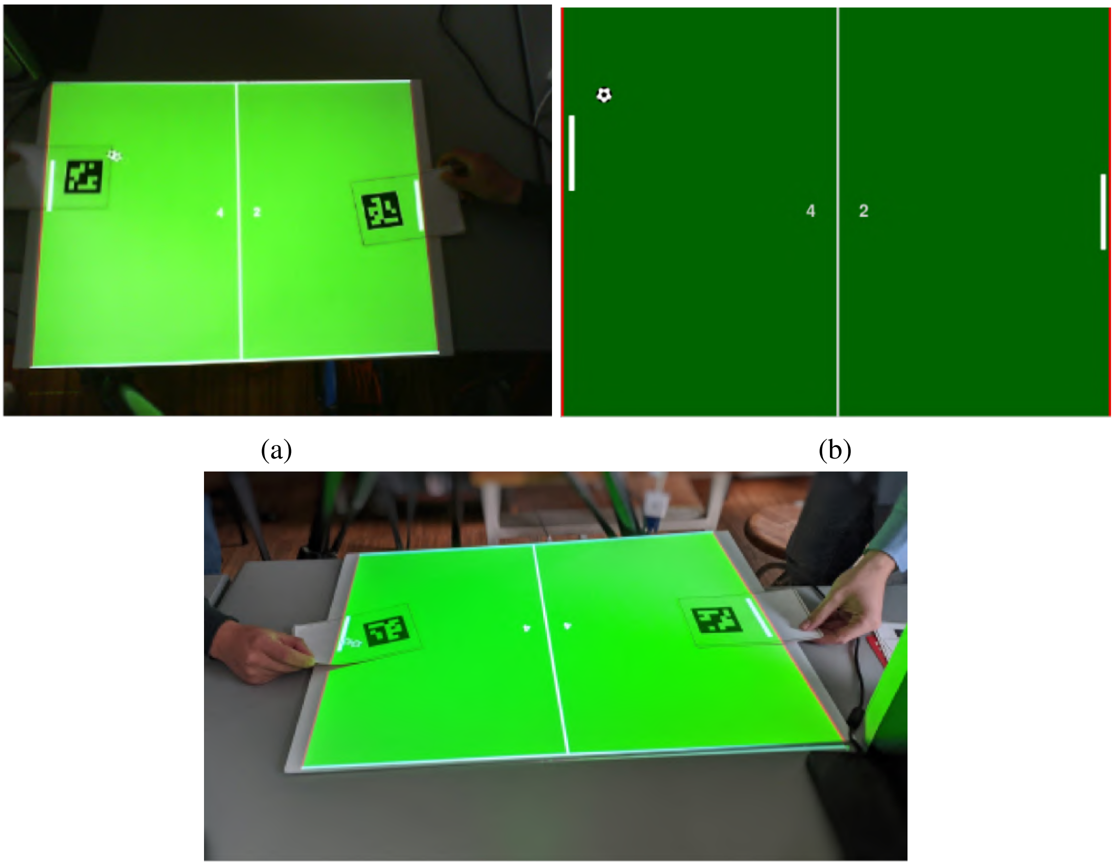
Figure 5.4: SAR Pong Game Concept

game can be played alone or with another player (being the therapist, caregiver or family member/friend). While playing alone, the game engine will take over player 2's paddle and compete with the patient. Multiplayer mode can be an incentive to play since it can be engaging for the patient to be accompanied while doing therapy.

The therapist can set the following adaptation factors:

- Game mode: solo or multiplayer;
- Velocity: the velocity of the ball;
- Bounce dynamics: simple or complex;
- Duration of the game: points or time required to win the match.

The game provides distinct visual and sound feedback of the bounces in the walls, paddles, when there is a goal and when a match is won. The score, the author of the goal and winner of the match is presented in the IPS in textual form. At the end of a match, the scores, duration, and number of paddle hits are sent to the platform so they can be analyzed. A demonstration of this game is showed in Figure 5.5.



(a) (b)

(c)

Figure 5.5: SAR Pong Demonstration (setup's element perspectives) - (a) Camera Frame; (b) Projector Frame; (c) IPS Photography

Chapter 6

Conclusion and Future Work

In this thesis, it was set the goal to develop serious SAR-based games that serve as cognitive rehabilitation tools for the elderly. The need to create an instrument for this age group arose from the natural increase in average life expectancy that has been noted over the years. Elderly people are living longer and, inevitably, they will be facing losses of some capacities that can lead to the development of cognitive deficits.

Therefore, to expedite the process of creating new tools for this problematic, a framework was created to serve as foundation for the development of card-based serious games in the SAR environment. The target for this games is cognitive rehabilitation, as to prevent the evolution of cognitive deficits associated with TBI and NCDs. With the platform created, two games were developed: a game that allows the users to train memory denominated SAR Memory. Which has a particularity: it is possible to customize the projections to represent familiar images (family, places, objects, etc.). The other game, SAR Pong, aims to train the user's attention span and reaction speed.

These two games, when using SAR, become captivating and immersive for the elderly. This hopefully can make the therapy performed with them, to have better engagement. Besides this, the games were integrated into a back-end platform composed of a website and database. The records of each user performance are saved for therapists to monitor the evolution of their patients efficiently, and to adjust the parameters of future sessions. This platform, given its flexibility, allows other games to be created for different purposes easily. By seeing the results presented in this dissertation, it can be said that the objectives of this work were fulfilled. This work was intended to be validated with the target audience in order to understand if the developed tools can positively impact the engagement and effectiveness of therapy for the elderly. Unfortunately, with the current situation of the covid-19 pandemic, it was not possible to put that into practice, since the organizations that support elderly care have suspended all visits and activities. In order to try to circumvent this obstacle, a superior educational technician was contacted to try to understand if what we built would be in accordance with the possible needs of the target audience. The feedback received was positive, and the game's adaptability characteristic was highlighted as an essential feature. That is, in the specialist's point of view, therapeutic activities should always take into account the needs of patients and, as far as possible, be elaborated with their inputs. In addition, the fact that it is possible to adopt the personal elements of each patient increases the probability of success of the therapeutic activity. The fact that all scores are automatically saved, was said to facilitate the therapist's work and, therefore, the necessary adjustments will be much easier and faster to apply. However, in her opinion, the validation with the target audience becomes crucial to understand what the impact on users is and how it can improve therapy. By analyzing the perspective of the specialist, there were defined objectives for future work. There should be validated the application in real therapeutic context of the games developed, and the collection of respective information. It would also be interesting to test the application with elders who do not have diagnosed cognitive deficits to understand if they have any impact in enhancing cognitive functions. In this sense, it would be interesting to conduct a longitudinal study in which a group of elderly people would be monitored over time. During which, these games would be used to see if they have any impact or even help prevent cognitive deficits. Other interesting additional feature would be the inclusion of Dynamic Difficulty Adjustment (DDA) mechanisms, to automate the difficulty parameters adjustment, facilitating the work of the therapist.

If in one hand it was created an adaptable platform for game development based in SAR and two games that use its functionality, on the other hand, it would have been good to have a clear sense of its impact on cognitive therapies. Only then would it be possible to have a complete sense of accomplishment. However, this dissertation will hopefully be useful for the fields of SAR and SGs, and can help pave the way for future works in this area.

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Appendix A

GRAPP 2021 Conference Submission

SAR-ACT: A Spatial Augmented Reality Approach to Cognitive Therapy

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Keywords: Interactive Environments, Spatial Augmented Reality, Cognitive Therapy, Elderly Care, Serious Games

Abstract: It is predicted that longevity will keep increasing in the forthcoming centuries. Thus, the elder demographic will grow, and the surge of age-related diseases will become more prevalent. These conditions can affect autonomy and affect the quality of life by reducing cognitive and motor capacities. While medical interventions have been progressing, preventive and restorative therapies remain an essential part of the rehabilitation process. Consequently, there is a high demand for tools that can help enhance the effectiveness of therapy. This work proposes a spatial augmented reality framework for creating card-based serious games for cognitive therapy. The objectives of the project are: to use this technology to facilitate the adaptability and personalization of serious games, to create an engaging tool that helps mitigate frustration in therapy, and to help therapists to keep track of patients' progress to adapt future sessions. Two serious games were developed to test the applicability of the framework. An analysis of the work was made by a specialist that concluded it had accomplished the desired objectives and that it has promising results for future validation in cognitive therapy.

1 INTRODUCTION

Since the middle of the XIX century, longevity around the world has increased at an exceptional rate, evolving from the global average of 29 to 73 years old (in 2019) (Max Roser and Ritchie, 2013). According to United Nations' predictions, life expectancy is going to surpass 100 years by 2300 (United Nations Department of Economic and Social Affairs of the United Nations, 2004). This data gives assurance that the world's health will continue its ascending trend, but also warns us that the population will get considerably older. While it is positive news that people will have longer-lasting lives, it raises a question on how will the quality of these lives be (Drewnowski et al., 2003), (Robine et al., 2009). Age-related health issues will surge with senescence. These conditions can occur in multiples ways affecting motor and cognitive skills, and if we do not work on trying to improve our approach to them, whether being with lifestyle changes, medically, pharmaceutically and therapeutically, then longer lives will not translate to healthy lives (Jaul and Barron, 2017). The surge of neurodegenerative Alzheimer's or Parkinson's disease and traumatic complications such as strokes cause cognition to decay. They can significantly impair the execution of daily tasks, causing elders to lose autonomy and, consequently, their quality of life (Galvin, 2006), (Larson et al., 1992), (Mioshi et al., 2007).

Cognitive impairments can manifest themselves in various areas such as attention span, memory, judgment, decision making, logic and abstract thinking, orientation, and language (Glisky, 2019). When patients manifest symptoms of cognitive decay, it is crucial to diagnose their condition and evaluate their cognitive skills early to counteract the potential evolution of the disease (Albert et al., 2011), (Svenningsson et al., 2012). Usually, specialists in areas such as neuropsychology, map a neuropsychological profile by performing examinations to evaluate the patient's cognitive skills (Harvey, 2012), (Morris et al., 2000), (Yi and Belkonen, 2011). Following this assessment, they usually establish an individualized rehabilitation plan (IRP) for cognitive therapy (CT). This data can also help doctors identify the disease and its stage of development, and to prescribe appropriate pharmaceuticals. The IRP should result in a series of restorative and compensatory therapeutic activities that can help the elder rehabilitate functions or delay the development of the disease.

It is well established that therapies should start as early as possible, before the brain loses its plas-

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ticity, especially with the progression of neurodegenerative diseases (Choi and Twamley, 2013), (Clare and Woods, 2004), (Clare et al., 2019), (Loewenstein et al., 2004), (Niu et al., 2010). IRPs should include tasks that stimulate the brain in the affected areas and delay cognitive decline. They should propose methods to cope with areas where faculties are limited, promoting strategies for enduring plausible advances of the disease, ensuring patient's autonomy for as long as possible.

Serious Games (SGs) can play the necessary therapeutic roles by providing stimuli that aim at sustaining executive functions, including visual processing, working memory, attention, language, and verbal communication. Board-, card-, and computer-based activities can be designed purposely to attain these therapeutic goals while simultaneously trying to engage the patients through the exploration of game principles (Kueider et al., 2012; Lamb et al., 2018; Peretz et al., 2011; Rocha et al., 2015). Recent works have explored emerging technologies such as virtual, augmented and mixed reality (VR, AR, MR) in this area, intending to bring new tools to the path of CT (Ferreira and Menezes, 2020a; Ferreira and Menezes, 2020b; Gamberini et al., 2009; Grealy et al., 1999; Kirner and Kirner, 2011).

While VR and AR offer great possibilities, the use of head-mounted devices may lead to discomfort and rejection by some people. More ecologic approaches may be achieved with the use of Spatial Augmented Reality (SAR) principles, integrating, in a naturalistic way, computer-generated graphics with the users' own physical space, by the use of video mapping techniques (Bimber and Raskar, 2005). Using it, existing objects can be hidden, highlighted, or have their appearance modified to fulfill the game's objectives.

This work comes inline with the above and proposes a framework to support the development of SAR-based Serious Games for cognitive stimulation.

1.1 Paper structure

The remainder of this paper is organized as follows: Section II presents an overview of the research conducted in more conventional and recent works in the area of SGs for CT; section III describes a summary of the process for designing an SG for CT, the challenges and requirements that are taken into account for outlining its development, and illustrates the framework concept, its development and implementation; section IV demonstrates the SGs built, describes their functioning, and their areas of application. Section V comprises an overview of a specialist that corroborates the developed works. A conclusion is made for the potential of the concepts presented, through an objective analysis of the framework and respective SGs built, comparing them with current and emerging tools for CT in section VI. In this section its also made clear the intention of future work on this platform.

2 Serious Games and Cognitive Therapies

Cognitive exercises frequently simulate everyday challenges by using various and specific tools (Faria et al., 2016), (Kurz et al., 2009). These tools can provide stimulus that help patients to relearn the use of their lost or degrading abilities. As for every learning process, it requires consistent repetitions with slight variations of the same activities (Jeffrey A. Kleim and Jones, 2008). The repetitive nature of the exercises and the slow recovery often lead to frustration and tediousness. Therefore patients can become unmotivated and unwilling to keep up with therapies.

Unsurprisingly, CT's effectiveness is affected by the patient's capacity to endure his assigned exercises (Choi and Twamley, 2013). The main obstacle in developing tools for CT resides in finding two balances: keeping an acceptable challenge threshold that induces evolution in players performance while not being frustrating enough to demotivate, and using mechanisms in game design to lessen the impact of repetition in therapeutic tasks, keeping the player engaged and entertained (Burke et al., 2009). By maintaining the patient engaged, these tools will help the therapist become free to focus on other aspects, such as assessing performance evolution and planning the subsequent exercises. Through the fulfilment of these objectives, the role of a therapeutic tool is then accomplished, and its application will promote the effectiveness of the IRP.

The design of the SG for CT, for the reasons detailed above, is a crucial stage of development. When idealising a game, the developer should focus on one or more of the cognitive deficits it will address. To ensure development will result in useful tools, a strategy may be to base the project on already existing and certified tools for the intended therapeutic purpose. Then, new creative outlooks can be added through new technologies while keeping the target at the requirements.

Since the patients' conditions can be varied, their IRPs can be considerably different even for the same diseases. It can be challenging for therapists to find tools that adapt to each specific patient's needs. By taking advantage of modern tools, when designing an SG, one should concentrate on adaptability, customisation, and personalisation (Burke et al., 2009; Faria et al., 2018). The bigger the granularity of the changeable elements of the SG is, the easier it will be to adapt to different IRPs, and the more will it suit each patient's performance and evolution (Burke et al., 2009; Tong et al., 2014). With specific personalisation of the game, by including components of the patient's life, like personal objects, or recognisable faces or places, one can assure that the player will gain some level of ownership over the therapeutic activities and, this way, achieve higher levels of engagement and motivation (Faria et al., 2018).

The concept of SGs as therapeutic tools also proposes the *gamification* of therapy to achieve better entertainment, engagement, motivation, and a sense of progression. The developer should adopt elements from traditional game principles like score, time, difficulty, and levels. These components can also help adapt the game to the player and translate their performance while doing therapy. For example, the therapist can specify a game, its difficulty level, and other parameters for a patient to play during a therapy session. Afterward, by analysing the attained score and execution time, it is possible to infer about performance and/or recovery. This way, the SG promotes changeable iterations of therapy sessions that will consecutively adapt to the patient's condition.

To keep players captivated while interacting with the game, the interface may provide visual and audio stimulus, but their inclusion must be carefully analysed to make sure they enable the intended goals. Therefore, a cycle of playing, giving feedback, analysing performance, and adapting the game is critical to keep in mind the objectives while establishing the game design, as portrayed in Figure 1. To allow every type of person to use it, the game should be flexible and customisable as much as possible. To this end, it is important to avoid complex control schemes and dynamics that would be hard to tune or adapt by the therapist or caregiver.

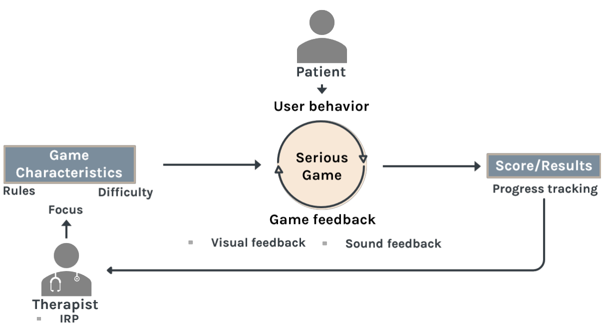


Figure 1: SGs' iterative cycle

3 Proposing a SAR-Based Framework for CT

From the above, and approaching the available technological solutions for developing tools supporting cognitive therapies, spatial augmented reality appears as an interesting candidate. Contrary to other technologies, in SAR interfaces the user can benefit from a wide field of view, and the interaction with the environment can be made through the handling of physical objects. Since elderly citizens are most likely not used to computer interfaces, SAR can present a valid alternative by replacing accessories like keyboards, computer mice, HMDs, smartphones or tablets with real objects that are more familiar to the user. This particular factor highlighted a great opportunity: to upgrade the use of common therapeutic card games with SAR.

By creating a framework that enables and expedites the creation of projection-based serious games for cognitive therapy for elders, developers can focus on creating engaging, customizable, and adaptive environments to enhance therapy effectiveness. This idea led to the solution proposed in this document, for which the next section presents the concept and identified requirements.

3.1 Concept and Requirements

By using a contemporary outlook at a familiar task, patients can become more captivated in therapy. Considering they are already used to these objects and their manoeuvrability, their adaptation process to the game should be more straightforward. Ideally, by providing stated benefits, both cognitive stimuli and therapy efficiency can be improved.

The interaction of the SAR Cards Framework works in the following way:

1. The user will manipulate cards in the projection area;
2. Cards' locations are tracked by the system;
3. Projections are adapted based on card locations and game rules/objectives;
4. Interface provides visual and sound feedback based on player performance;
5. When the session ends, the player score/performance is recorded.

A global overview of the SAR Card framework functionality can be seen in Figure 2.

Given the overall concept of the framework and the design considerations stated in the previous sections, the following requirements were defined for the development of the framework:

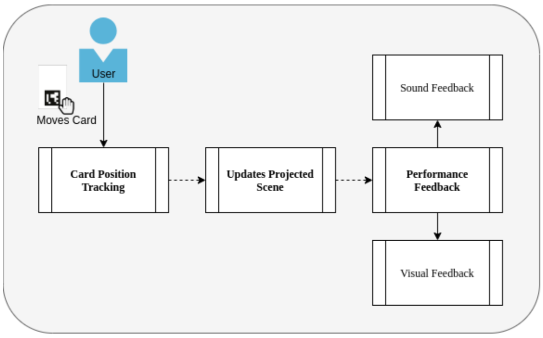


Figure 2: Framework functional overview

- User manipulation of the cards should be analogous to traditional card games;
- The framework must provide ways to measure user performance in several parameters to encourage self-improvement and for the therapist to analyze;
- Player interactions with the system are made exclusively with cards;
- Inclusion of functionalities to enhance adaption to the player's needs;
- Deliver visual and sound feedback to signal if the user is doing well;
- The system should be flexible and expansible to promote the development of several types of SGs.

3.2 Implementation

The basic elements required to build a SAR system are a camera and a video projector. By inquiring about the logistical aspects of an installation of this kind, it was concluded that it is frequent for therapy centres and assisted living facilities to already own these devices for other purposes, which facilitates the deployment of the system at reduced cost.
To create the illusion of virtual images registered to physical cards, the following run-time steps are required:

1. Obtain card's location in the camera's frame (tracking stage);
2. Translate their locations to the projector's frame;
3. Adapt the corresponding images for skewness (mapping stage);
4. Generate a frame of adapted images in their locations;
5. Project over the cards in the area of the game, here defined as the interaction plane (IP).

Firstly, a calibration step is made to retrieve the relationship between three planar surfaces: the camera frame, the interaction planar surface (IPS) and the projector frame. This calibration process consists in capturing the projection of a chessboard pattern onto the IPS from the camera's point of view (POV).

It was chosen to use a chessboard pattern due to its regular geometry that allows robust and accurate feature extraction. OpenCV library was used to extract the position of the corners in the camera's and projector's frames (OpenCV, 2015), and use it to establish a correspondence between projector and camera frames. This correspondence is obtained in a compact form as a homography matrix. This relationship also encompasses the relation of both of them with the IPS. A diagram of the projective transformations is presented in Figure 3. With these relations defined, for every point in the physical IPS delimited by the projection area, it is possible to find its approximate projection on both the frames of the projector and camera.

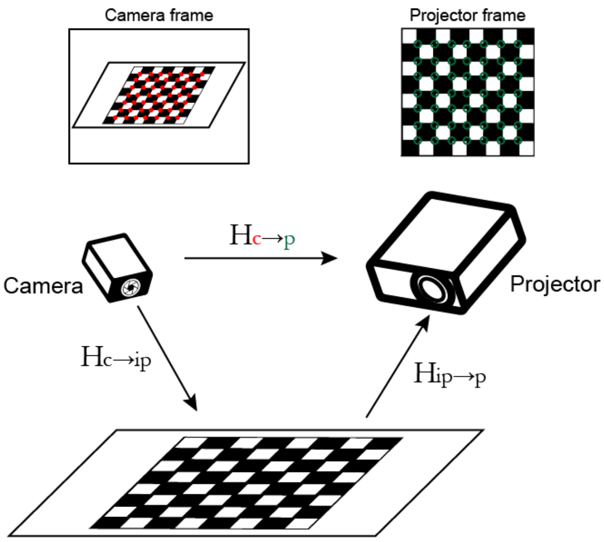


Figure 3: Homographies between planar surfaces

To track the locations of the cards in the game environment in a quick and flexibe manner, each of them received fiducial markers. For the sake of simplicity the fiducial markers choice fell on ARUco (**?**; Romero-Ramirez et al., 2018) as their support is readily available on OpenCV. The cards besides the markers have a substantial a blank area which is used for the projection of images as described hereafter.

The overall process cycle is as follows:

1. Track cards marker corners positions (X_c, Y_c) in the camera's frame;
2. Transform corners positions to the projector's frame (X_p, Y_p) (using the matrix $H_{c \to p}$ obtained in the calibration stage);
3. Find the perspective transformation between each

marker's corners of a flat source image of a card (in pixels) and the correspondent corners in the projector's frame;

4. Warp the image to be projected respecting the found perspective transformation matrix;
5. Add it to the projector's frame in its correct position.

The result will be an overlay image projected onto the cards disposed on the IPS. This enables that the projection be perfectly adapted to any moving a card, even if is tilted. The projection of the image on a specific card is only stopped if its marker becomes obstructed in the camera view. The setup used to implement the SAR environment can be observed in Figure 4. Figure 5 shows a diagram of the complete processing pipeline.

Figure 4: Setup used to implement SAR SGs

4 DEVELOPED GAMES

To demonstrate the applicability of the framework, two SGs were implemented. These games were based on established therapeutic tools, and several features were added to cater to patient's needs, while the performance of the player was tracked through the use of game metrics such as score, difficulty and time. The games were integrated into a web platform (composed by a database and a website), to provide therapists with a straightforward way to check on the performance development of each patient's case and decide how to adapt the next therapeutic tasks.

4.1 SAR Cards Memory Game

Memory card-based games are frequently used as a tool for CT (Muragaki et al., 2006). Hence, it was decided to build an enhanced version using SAR.

The patient starts with all the cards facing down on a table (IPS) and has to find all the matching pairs. The player flips cards up one at the time trying to find a pair, if it is a wrong pair, the last two cards have to be flipped down again, if the pair is correct, the cards remain face-up, and the player can proceed to find the next pair. This process os repeated until all the pairs are found. The game is adaptable in the following ways:

- The number of cards is dynamic: the more cards, the harder is the game;
- The images that appear on cards can be completely customized: this allows to build many types of games. E.g. cards appear with pictures of places, colours, animals, fruits, vegetables, familiar faces, emotions, and the patient has to find matching pairs; cards appear with names of familiars or personal objects, and the players have to find the card with the corresponding image;
- The game also has an option for providing initial help, where the player sees which images are on each card before turning them down.

While the player interacts with the game, the interface provides positive and negative feedback in the form of visuals and sound.

When the game ends (all pairs found), a celebratory screen is shown with the player's score. The score embodies the number of cards (the more is better) and time of completion (less is better) used in that session.

The images, the number of cards and help mode should be controlled by the therapist. After finishing a CT session, the scores, time, and number of tries are sent to the web platform for posterior analysis. A demonstration of this SG is showed in Figure 6.

4.2 SAR Cards Pong Game:

Pong was one of the first video-games created, and, from an early stage, its application for cognitive rehabilitation was studied. This study helped to introduce the concept of SGs for CT (Lynch, 1982).

The objective of the game is to score goals, throwing the ball through the defence line of the other player while defending our line by bouncing the ball back with the paddle. The game starts with the ball in the middle of the field and goes into a random direction, the ball is reset to this position after a goal. A SAR implementation of the game was developed using the framework, where the player controls its paddle position by moving the card vertically in the IPS.

The game-play focuses on the attention span, reaction speed and spatial awareness of its patients as it

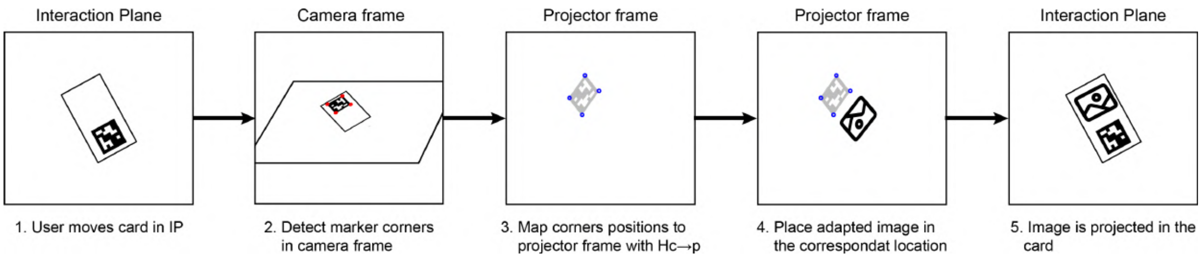


Figure 5: SAR Cards Framework pipeline

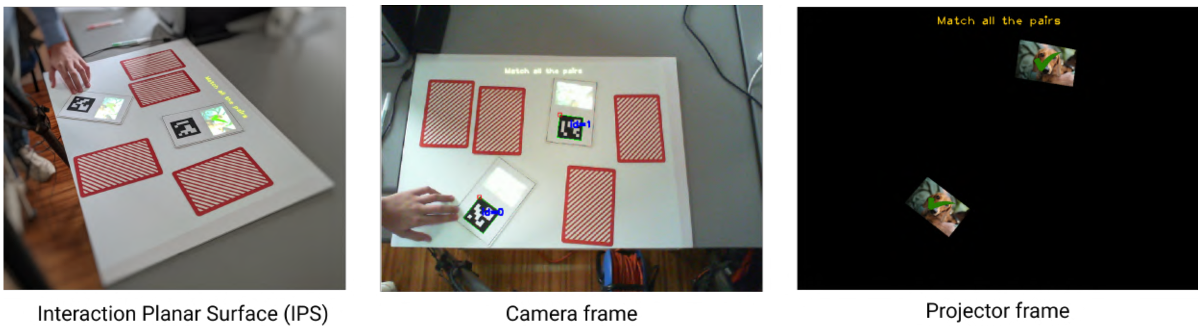


Figure 6: SAR Cards Memory Game demonstration

forces the patient to watch, react and predict the trajectory of the ball. The game can be played alone or with another player (being the therapist, caregiver or family member/friend). While playing alone, the Artificial Intelligence (AI) will take over player 2's paddle and compete with the patient. Multiplayer mode can be an incentive to play since it can be engaging for the patient to be accompanied while doing therapy.

The therapist can set the following adaptation factors:

- Game mode: solo or multiplayer;
- Velocity: the velocity of the ball;
- Bounce dynamics: simple or complex;
- Duration of the game: points or time required to win the match.

The game provides distinct visual and sound feedback of the bounces in the walls, paddles, when there is a goal and when a match is won. The score, the author of the goal and winner of the match, is presented on the IPS in textual form. At the end of a match, the scores, duration, and number of paddle hits are sent to the platform so they can be analyzed. A demonstration of this SG is showed in Figure 7.

4.3 Patient Performance Interface

The games were integrated into a therapy SG performance analysis web platform developed in (Omitted, 2019). This platform allows us to download the right therapy parameters for the right patient and upload the results of each session. The results are presented with graphs comparing sessions for more accessible analysis (Figure 8).

5 ANALYSIS

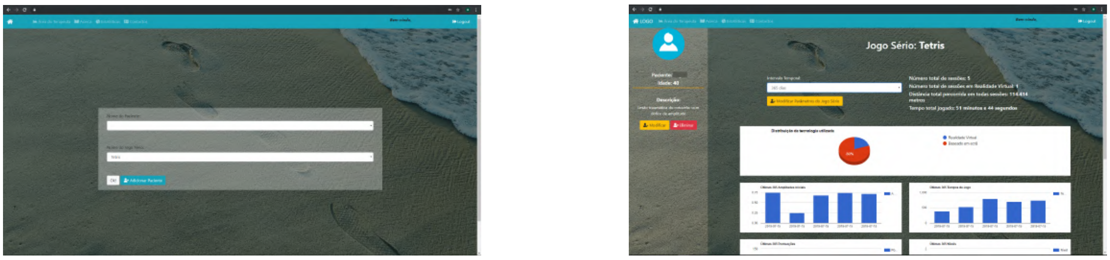
The design principles, requirements, framework, and the SGs for CT developed were reviewed during and after the development process by a Superior Education Technician. The demonstrated results received positive feedback. The reviewer considered that the objectives set for this work were accomplished from the point of view of the therapist. In her opinion, the SGs created with the framework show promising features that can possibly help in the effectiveness of CT. Thus, there should be made experiments with patients in a real therapeutic environment to test the effectiveness of this SGs. By her perspective, only with real patient-therapist experience, we will gather information to adapt the SGs to elders' needs.

6 CONCLUSION AND FUTURE WORK

In this paper, we took from the traditional games used to train cognition in CT and added features to enhance adaptability, personalization, engagement and performance tracking. These features were implemented

Interaction Planar Surface (IPS) Camera frame Projector frame

Figure 7: Pong game demonstration



(a) (b)

Figure 8: Login authentication of therapist (a), and patient performance data (b). Created in (Omitted, 2019).

through the use of SAR. This technology requires only a video-projector, a camera, and makes use of the familiar physical space of its user. By only using these components we highlight the benefits of this type of system when comparing it with more expensive or cumbersome methods like AR or VR. It was developed a framework that makes use of SAR for creating SGs to facilitate cognitive stimulus. The target audience was older adults that suffer from cognitive impairments. Two SGs with different cognition targets were built to test the framework application. The games were analysed by a specialist who gave a positive feedback and reinforced the idea that these games need to be tested with patients in a real-world context. This feedback assures us that our work reveals promising results to create new CT tools. The next step will be to study its impact on a small group of patients to confirm if these benefits translate to more effective therapy. It will also be interesting to study if non-cognitive-deficient elders can benefit from this type of tool.

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