

# INSIDE:

## Using a Cubic Multisensory Controller for Interaction With a Mixed Reality Environment

Ioannis Giannios, Hellenic Open University, Greece

Dimitrios G. Margounakis, Hellenic Open University, Greece\*

### ABSTRACT

The field of electronic games is a great experimental area that contributes to the implementation of new technologies in a variety of applications. This article explores the field of mixed reality through the use of physical computing for the development of the electronic game Inside. In such an interactive environment, the physical and the virtual worlds coexist and interact with each other. A user can alter the virtual world's characteristics through a special controller designed for the game that contains electronic components that can sense real-world properties. The attention of the user is not focused only on the screen but also on the controller through which a two-way interaction is achieved. A virtual environment created by a game engine can receive messages from the controller and vice versa. Changes on the properties of the virtual world can be communicated to the controller aiming at the alteration of the characteristics of the physical world. As a result, the user experiences an immersion in an environment in which real and virtual objects coexist.

### KEYWORDS

Arduino, Augmented Reality, Immersion, Immersive Environment, Interaction, Interactive Environment, Mixed Reality, Physical Computing, Unity, Video Game, Virtual Reality, Virtual World

### INTRODUCTION

Technology increasingly assists the creation of new environments by achieving distortion, strengthening or replacement of reality. The real or physical world which we live in consists of physical objects that we can feel with all our senses. Through technology, our senses can be augmented offering the opportunities to experience new environments. In a different reality, it is not mandatory for all our senses to participate. However, the more of them participate the easier it becomes for the user to experience the illusion of immersion, that is, the feeling of experiencing something real rather than something unreal (O' Sullivan & Igoe, 2004). Human sight is the sense that can mostly be augmented since what we can perceive is what we define as real (Welch, 1978).

The term of virtual reality is often mistaken for environments not fully generated by a computer so the boundaries between different categories of such environments are somewhat blurred. Mixed reality combines knowledge from a wide variety of disciplines, like computer vision, signal processing, graphics, user interfaces and sensors (Costanza et al., 2009). Experiences that do not fully fit into the

DOI: 10.4018/IJVAR.20210701.oa1

\*Corresponding Author

This article published as an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>) which permits unrestricted use, distribution, and production in any medium, provided the author of the original work and original publication source are properly credited.

real or virtual world transform existing technologies, relationships and locations into a game platform, by expanding their structure mixing it with daily experiences (Bonsignore et al., 2012).

The aim of the game *Inside* is to familiarize the user with a mixed reality environment through a tangible interface where the input devices play the central role and the screen is a window to the virtual world. Unlike most mixed reality applications, the human sight is the one that we try to displace in an attempt to give users an illusion that blends the real and the virtual without the need to augment their sight. Gestures and physical world actions are mixed and affect the progress of the game and vice versa. That is, conditions and actions in the virtual world can affect the physical world. A special cubic multisensory controller is designed, and its purpose is to make the user immerse between the physical and the synthetic world exceeding ordinary gameplay.

## BACKGROUND

### Mixed Reality

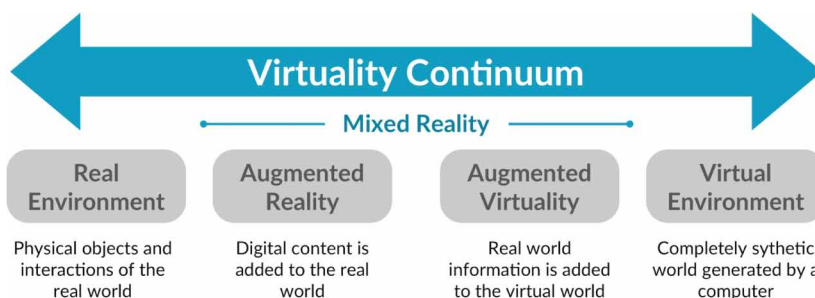
Milgram and Kishino (1994) presented the *Virtuality Continuum*, an attempt to categorize the multiple reality genres. On the one end of the continuum there is the real environment and on the other there is the virtual environment. *Mixed Reality* consists of all the reality categories between the opposites of this continuum. *Augmented Reality* is closer to the end of the real environment and *Augmented Virtuality* is closer to that of the virtual environment. This concept is illustrated in Figure 1.

Although this notion, which stems from the beginning of the 90s, is the most popular on how to define a mixed reality environment, it is not widely accepted because it is mostly focused on visual displays. Other aspects of reality can be simulated in a virtual environment like audio, motion, haptics, taste/flavor and smell (Speicher et al., 2019). Mixed reality experiences can extend beyond visual domain (Hughes et al., 2005) but the central idea remains the blend and alignment of digital and physical objects. Therefore, a mixed reality environment can be defined as an experience that is not fully contained by virtual or physical worlds (Bonsignore et al., 2012).

A mixed reality environment is a mixture of the real and the virtual in which the two worlds coexist. Augmented reality and augmented virtuality are subcategories of mixed reality, which include all these environments in which both the virtual and the real world more or less participate. Thus, the user is not fully cut off from the real world, and sounds, video, graphics, haptics and spatial data are put together serving the ultimate goal of altering the real world into a new and enhanced experience (Glover, 2018).

In this kind of environments, the characteristics of the user's reality interfaces are usually fully exploited by including types of interaction that we encounter in the real world, such as movements, gestures and speech that do not require any kind of instruction to the user (Coulton et al., 2006). The main means of interaction with the graphic elements of a system's interface are the user's hands through which the appropriate physical actions are translated by the device as commands. The user

Figure 1. The Virtuality Continuum (Milgram & Kishino, 1994)



gives these commands to the system through an interface, such as a keyboard, a mouse, a touch screen or a trackpad. Touch screens are considered to be a significant leap when it comes to humans and computers interacting since a user's actions bear more physical importance as they touch the object of interest instead of pointing at it. If we add haptics when the user operates a system, then there is no significant difference with operating a real mechanical device. Interfaces in which physical objects play a central role as both physical representations and controls for digital information are called *tangible interfaces* (Ullmer & Ishii, 2000).

The screen plays a dominant role in human-computer interaction whether is placed on a desk, held in one's hand, worn on one's head or embedded in the physical environment. Many researchers define the augmented - and therefore also the mixed reality systems - in a way that requires the use of a head-mounted display (HMD) to achieve the full immersion of the user. In an attempt to define these systems in a way that is not limited to particular technologies, like HMDs, Azuma (1997) proposed the three following characteristics.

A mixed reality system should:

- Combine the real with the virtual
- Be interactive in real time
- Take place in three dimensions

## Mixed Reality Applications

A variety of applications, which are compatible with mixed reality platforms, keep on launching. Such mixed reality systems are more affordable than ever, and everyone can enjoy them in the comfort of their own home. The majority of contemporary smartphones and tablets, as well as devices like Microsoft Kinect, Nintendo Wii, Google Daydream View, Microsoft HoloLens and Oculus Rift are only a small sample of those which support mixed reality games. Most devices are mainly HMDs (optical see-through or video see-through) or systems which connect to a monitor (usually a television set) and take advantage of data like user gestures, spatial data, posture, and speech. The games of these devices make extensive use of various techniques, like computer vision, depth information, and video detection and thus the alignment of real and virtual objects is of major importance (Gimeno et al., 2011). Real-time requirements of these systems are the cause of the gravest errors, such as the complete misalignment of different objects or misalignment between the user and their environment after a signal delay (Wursthorn et al., 2018).

An example of a mixed reality game demonstrating a tangible interface is *Scorpiodrome*. In this game, physical objects like remote controlled toy vehicles, control interactive virtual entities on a projected on a surface terrain. The vehicles go on a quest of virtual diamonds and synthetic creatures can affect the way they operate. (Metaxas et al., 2005)

Another example is the *Virtual Chemistry Lab* which suggests a method for improving teaching and implementing chemical experiments the safest way. Students can simulate a chemical experiment in a virtual lab, interacting with virtual objects, which they can see using HMDs and handle with the aid of hand controllers. (Duan et al., 2020)

In 2005, Sandor et al., presented an immersive mixed reality configuration that allows a user to reconfigure a running hybrid user interface, where information can be distributed over a variety of different, but complementary, displays. The user interacts with physical input devices and 3D objects drawn on several desktop displays. Then, a manual input device can be associated with a 3D object and the user can transform the object through it. Using an HMD the user can see the link between the displayed on the desktop monitors 3D objects and the input device, by a line that connects the two parts.

*CETA* is a mixed reality system with tangible interaction for school-aged children that was designed to enhance mathematical learning. The game is composed by a tablet, a mirror, a holder and a set of wooden blocks and the aim is to help a robot collect some screws. Using the blocks on the

table, a child must compose a number that matches the distance between the screw and the robot, as displayed on the screen of the tablet. The system detects through the mirror and the tablet's camera the actions of the child, and once they succeed, the virtual robot collects the screw. (Marichal et al., 2017)

Nevertheless, the majority of relevant projects recommend the use of a head unit or that the screen be put in a central point. Our approach differentiates from the rest of the similar games by including a specially designed controller to support the developed game. Both the controller and the game create a mixed reality environment that interacts with the user bidirectionally.

## Physical Computing

Physical computing describes the discussion between the physical and the virtual world, the conversion of one source of energy to another in the form of devices that interact with their environment through sensors (O'Sullivan & Igoe, 2004). Physical computing platforms, like *Arduino*, aim at facilitating the creation of electronic circuits and programming without requiring any prior knowledge or experience by the user (Booth et al., 2016).

These projects are usually divided into three parts: input, processing and output. Activities (input and output) can be either digital or analog. The digital ones are those that can be in two conditions (e.g. on/off) but the analog ones can bear a range of values (e.g. temperature).

Physical computing platforms consist of a microcontroller and various energy transformers. The microcontroller, which is a very simple computer, is an expert on receiving information from the sensors, manipulating basic machines and sending information to other devices. Its main use is to operate a device by using a predefined code, stored in its ROM memory that cannot be modified during its operation. (Ayala, 2005).

The energy transformers are connected to the microcontroller and can be sensors of various types that can help us detect or create changes in the characteristics of the physical world. For example, IR sensors and ultrasonic sensors can be used to sense location, while potentiometers, accelerometers and gyroscopes can be used to sense rotation, and DC motors and solenoids can be used to create motion. Haptic techniques can be implemented by force-sensitive resistors or flex sensors. A thermistor can sense temperature changes and a photoresistor can sense a change on the levels of brightness. Hybrid systems can take advantage of multiple sensors combining detection techniques in order to avoid errors or get more accurate data.

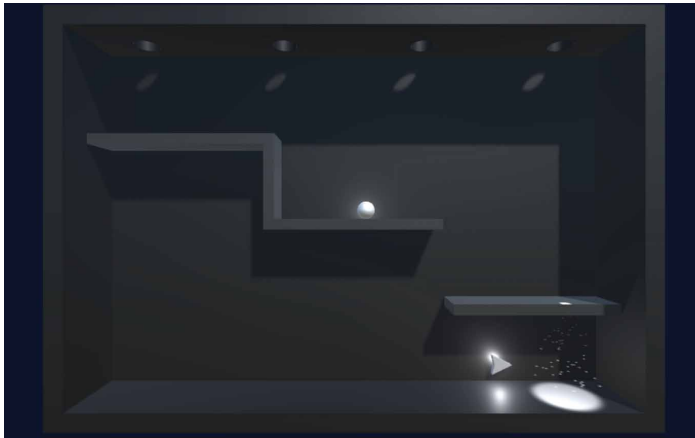
Arduino was chosen among other physical computing platforms, such as *Parallax Basic Stamp*, *MIT's Handyboard* or *Raspberry Pi*, due to its popularity in creating interactive applications that target novice users. Additionally, Arduino is highly acknowledged in the development of *internet of things* devices and is one of the most successful educational tools in S.T.E.M. (Science, Technology, Engineering and Mathematics).

A user can develop code or *sketches* and upload it to the Arduino board. Each sketch is divided into two key parts: the *setup* section, which is the initialization of the project and runs once when the device starts, and the *loop* section, which provides all the information about the project functionality and it is constantly repeated.

## GAME CONCEPT DESIGN

*Inside* is a puzzle game in which the user must lead a white sphere to a specific location of the virtual world. This finishing point is of a different color on each level. In order to have a successful outcome, the user must guide and color the sphere to signal the completion of the level. Each level is of escalating difficulty and complexity which is signified with the combination of colors and the path the sphere must follow to reach the finish line. Figure 2 shows the 1<sup>st</sup> level's white finishing point and the sphere heading to it, as pointed by arrows. The sphere can get or change its color on specific

Figure 2. Screenshot of the Inside's 1<sup>st</sup> level



points of the virtual world at which it undergoes a super-exposure to a light of the tint in which it will be painted. The users are called on to explore these points themselves, while shedding light on holes at the exterior of the controller. The location and the color of the finishing point will not be provided at the beginning of each level, meaning that the user needs to experiment with different colors until they successfully color the sphere with the finish point color of each level. Once this happens, the finish point indicated by a bright colored spotlight in the virtual world, becomes visible. The possible colors are the primary ones: red, green and blue, while combinations of these can produce even more colors at levels of greater difficulty.

While most mixed reality games focus the user's attention on the screen, whether it is an HMD or a mobile device, the presented approach stands on a different basis. The computer screen located nearby is just the window to the virtual world and not the focal point in the evolution of the game. Through the screen, the user can observe what is happening on the virtual world, without interacting with it. The whole interaction between the user and the virtual environment is implemented through a controller/box, especially designed for this game. The virtual world is shaped to give the user the impression that it is enclosed in the box object that they examine with their hands. The cubic controller functions using natural gestures by the user that provoke expected virtual world reactions. At the same time, the user can observe the result of their actions taking place inside the box through the screen.

The total control of the game is achieved exclusively through the controller so that the user can experience the illusion that the game is unfolding in the box, the inside of which can be monitored through the screen.

In order to achieve the desired functionality and user experience, the requirements we have taken into account regarding the design of the game and the controller were the following:

- The virtual world should be of a similar environment to the interior of the controller. A cubic shape was chosen.
- The complete control of the game should be done exclusively by the controller. The user must not be distracted by using keyboards or other peripherals.
- The controller must support user gestures corresponding to the functionality of the game.
- The material of the controller must be hard and sturdy.
- The user must interact with the virtual world in a bidirectional way in order for the feeling of immersion between the two worlds to be enhanced.

## IMPLEMENTATION

### Arduino (Assembly and Programming)

The elements that were used for the physical part of the game were: an Arduino UNO (rev.3) edition board and basic electronic components. More specifically:

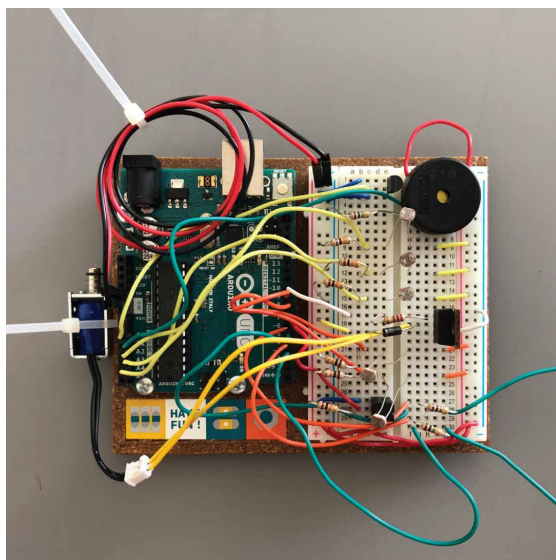
- 4 Photoresistors that can sense the amount and brightness of light on their surface.
- A tilt sensor that can tell whether its position is in normal or upside-down state.
- A piezoelectric sensor that can catch a vibration, like a user's knock.
- A thermistor that can measure temperature on its body.
- A solenoid that can produce a movement of a metal bar.

Cables, resistors, diodes and more electronic parts were used to connect the elements together and create the circuit. In addition, two touch sensors were implemented, using Paul Badger's *CapacitiveSensor* library available for use in Arduino (Badger, 2020). To keep things tidy, a breadboard was used, that is a board that allows the connection of separate parts and cables and helps avoid an overcrowding of cables. The microcontroller and the rest of the electronic parts that were combined are presented in Figure 3.

The code developed and uploaded to Arduino includes declarations of the variables and the constants, the inputs and the outputs of the board as well as their respective methods, the readings of the sensors connected to the digital or analog pins of the board, and finally the serial communication commands to send and receive messages, between the Arduino and a computer.

The four photoresistors are initialized in the setup section of the Arduino code, in which for each sensor a total amount of 10 values are collected and their average is calculated and considered to be the ambient light value. Based on this value, a threshold is calculated and indicates when a photoresistor receives light from the user or not. When a read value exceeds the threshold, a respective message is sent to the computer to alert of the existence of light.

Figure 3. Arduino board, breadboard and electronic parts combined



The value of the tilt sensor is read repeatedly on the loop section of the code to determine if the box is placed in a normal or an upside-down position. Any change in the status of the tilt sensor triggers a message through the serial to update the system of the new condition.

The piezo records the values of vibrations and when the system detects a value over the piezo threshold, the corresponding message is sent to inform the system.

The thermistor calculates the ambient temperature and a threshold is set on the setup section of the code uploaded to the board. This threshold indicates if the user affects the temperature sensor through their actions (rubbing or breathing on it). In case of a rise in temperature above the threshold, a message is sent to the computer to alert for special functionality on the game.

The touch sensor can detect the change of the electrical load and thus the human touch, since the human body carries electricity. After the implementation of these sensors, a human touch can be detected when someone touches the bare wire of the circuit. This wire can be hidden behind solid surfaces, even of non-conductive materials, like plastic or wood, while its sensitivity can be increased using conductive materials, e.g. aluminium foil (Fitzgerald & Shiloh, 2012). The values of the touch sensors are read during the execution of the program (loop section) to check if a value exceeds the threshold, meaning that the user is touching it.

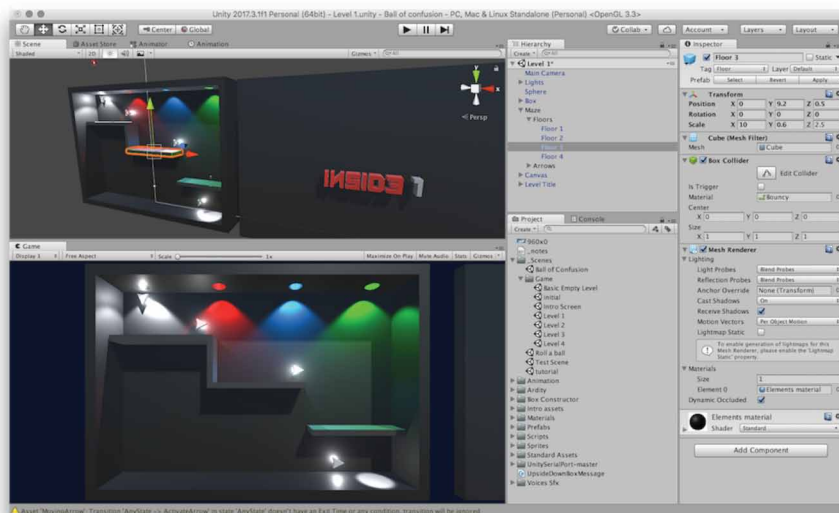
Finally, the program reads the messages that the computer may have sent through the serial to Arduino, in order to perform suitable actions, such as the electrification of the solenoid in order to perform a knock on the wooden box whenever the virtual sphere hits with a floor.

## Unity (Game Development)

Unity is a game engine platform for Mac and Windows that was created in 2005. The program is responsible for collecting all the pieces of the game's scenes, graphics and algorithms.

The initial design on Unity included a basic and simple form of a game level. In other words, a pilot was used to check the connectivity between the Arduino and a computer and achieve the functionality of the game objects. Thus, a virtual 3D environment that resembles the interior of the box/controller was designed, as shown in Figure 4. Afterwards, the necessary game objects were created and filled the interior of this virtual box, such as walls, floors, the player's character and spotlights. Each of these objects has its own properties and extra functionality can be given through

Figure 4. Creating a game level on Unity



scripts that are attached on them. These scripts can control the objects via code and have a similar structure with the Arduino sketches, including a Start() section that plays the part of the initialization of the object, and an Update() section that repeatedly executes the included code and controls the functions of the object.

Through the scripts and properties of each object, a virtual world was created with a sphere as the player's main character. This object obeys the laws of physics.

In this way, an autonomous electronic game was created that can be controlled through the keyboard. The ultimate goal is that the interaction between the user and the game takes place exclusively through the cubic controller that will send the respective commands for every action to Unity. Thus, each message sent from Arduino to Unity will be assigned to a particular key on the keyboard and the game will get full functionality via the designed controller.

The framework of the system is illustrated in Figure 5, which explains the interaction between the controller and the game.

Additional 3d objects were designed to serve as guiding support to the user. Objects like blinking arrows can appear in certain locations of the virtual environment. They provide the user with useful information in order to solve the puzzle. These hints may relate to the control of the sphere and the possible actions the users should perform, such as moving the sphere, flipping the box or illuminating a hole with the flashlight.

The finishing point consists of a bright spot on the floor, generated by a spotlight, at a different location at each level. Figure 6 shows a screenshot in which the color of the sphere gets red and an arrow indicates where the sphere should go next.

Animations were created for the game objects to fulfil aesthetic demands. More specifically, guiding arrows flicker as they move towards the pointed direction, while light gradually floods the inside of the box when a user sheds light through a hole and the sphere gets a new hue through an animation that gradually changes its color. Other than offering aesthetic value, animations also may link to events that trigger specific actions, such as a script execution or a change in an object's properties. For instance, after the successful completion of a level, an animation is activated, at the end of which an event will trigger the next level to load.

A menu consisting of three-dimensional words and lighting elements has been designed. The aforementioned objects were placed on a scene to create a central display via which the users can choose the desirable action, as shown in Figure 7. Messages that appear on screen instruct the user how to

Figure 5. Block diagram of the proposed framework that shows the interaction between the real and the virtual environment

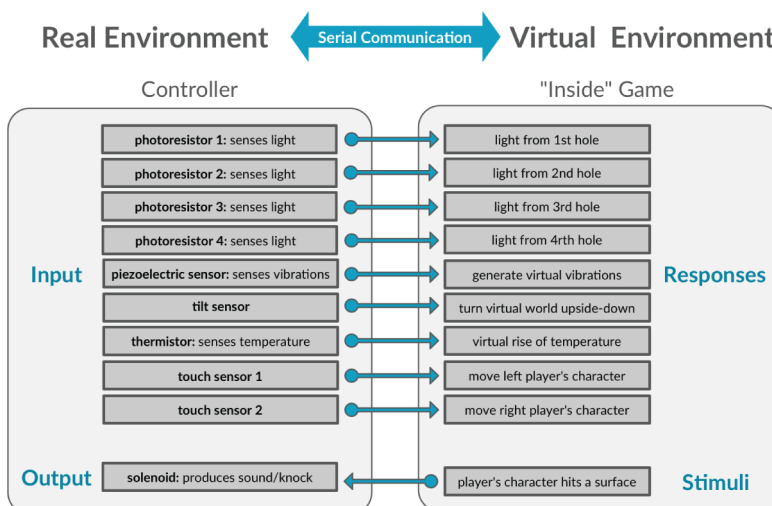
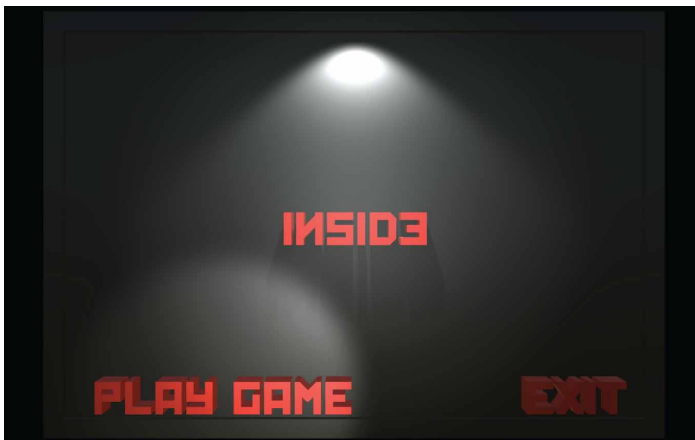




Figure 6. Screenshot of a game level where the main character is painted red and the finish point is prevalent



Figure 7. Main menu of the game



control the menu. So, as soon as the user touches the controller on the left (or right), they can choose an action (play game or exit), while using both hands they can execute the desirable action (enter).

Through the gameplay, the user is gradually instructed on how to use the possible gestures as the game progresses. For example, the first level involves as few gestures as possible and then more are added on the next levels. The fact that the physical box/controller has characteristics of the virtual box (like the material, the shape or the position of the holes), makes the instruction of the gestures even easier for the user. The ultimate goal is to give the user the opportunity to act intuitively, while being guided by virtual messages, hints and indications.

### Arduino – Unity Interface

Arduino and Unity are connected via a USB cable and the exchange of messages is possible through serial communication. One side sends a message and the other side recognizes it, reads it and performs the respective actions, depending on the content of the message. Scripts that were written for both Arduino and Unity contain all the relevant commands that make this serial communication possible.

On the Arduino, commands on the board's uploaded code open the serial communication and every message sent to Unity is executed via this serial. Similarly, if a message is received through serial, it will be read by Arduino. At every loop section cycle, there is a reading of the values of all sensors. To ensure proper functionality and avoid overflowing, the system was designed in such a way to send as many messages as necessary. Thus, duplicate messages that repeat the same values or the same piece of information are avoided. Instead, only when the system detects a change on the values of a sensor that can affect the virtual world, will it send a message that bears this information. For example, if a user touches a capacity surface, the values of the touch sensor will be above threshold, which means that a corresponding message will be sent towards Unity to inform that the user is touching the specific sensor. During this touch and while the sensor's values are above threshold, no more messages will be sent. Only when the user removes their hand and the value drops below threshold, will a corresponding message be sent. This way, the exchange of messages happens only when there is a change in the conditions thus achieving immediate response from both sides, avoiding delays due to serial overflowing because of multiple messages.

Respectively, in Unity the serial communication channel opens through a script which is responsible for sending any message regarding the changes of the game in the virtual world. Messages sent by Arduino and received by Unity through serial are processed and read so as to respond and modify the progress of the game.

### Prototype (Controller Assembly)

The controller box was constructed by wooden surfaces for convenience reasons. These surfaces were joined together, creating a cube, in which all electronic elements were placed, such as the Arduino board, the breadboard, sensors, and wiring.

Four holes, which are the points where the user should shed light to illuminate the inner virtual world, were created on the top side of the box. Photoresistors were placed inside and within close proximity to the holes trying to avoid the direct exposure of ambient light but also to be able to measure any change in the brightness in case the user sheds light into the hole. In order to avoid noise on the values due to the proximity of the photoresistors with each other, each of them was isolated from the rest using plastic caps.

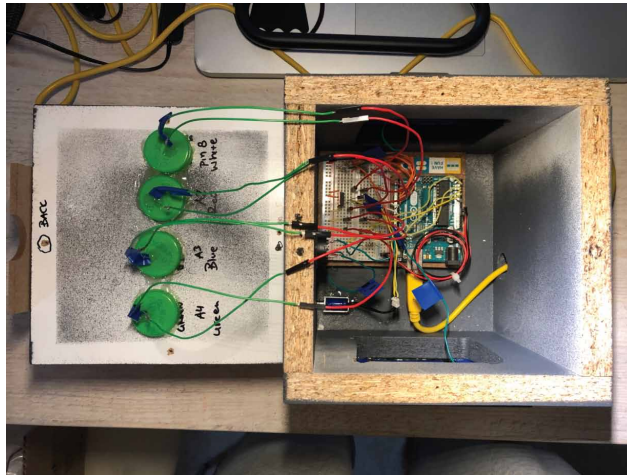
Two holes were created on opposite sides of the box through which the cables from the touch sensors found passage to the exterior of the box. Additional wooden pieces were coated with *velostat* - a conductive material similar to plastic - and were placed over the holes. The conductive material was properly placed in such a way to be in contact with the bare wires of the touch sensors and its aim is to increase the touch surface available to the user. As a result, when the user touches any of the two sides of the box, the Arduino board can sense this touch and send a message to the computer bearing this information.

The rest of the electronic elements were placed and secured inside the box so as to remain stable. The solenoid was placed in such a way that each time it receives electrical charge it causes a knock in the inner body of the box. As the virtual sphere hits the virtual floor this knock creates a vibration and a sound, which is perceived by the user and consequently creates an opposite interaction from the controller to the user. The placement of the electronics inside the box is shown in Figure 8.

The implementation of the circuit and the construction of the controller allows the following possible user gestures:

- **Touch gestures:** Touching the left or the right side of the box causes the movement of the virtual sphere to the left or to the right respectively. Simultaneous touch of both sides (left and right) can cause specific function (enter).
- **Flipping of the box:** This move enables the user to turn the virtual world upside down.
- **Lighting:** With a flashlight at their disposal, the user can illuminate specific holes on the box. Shedding light at each hole creates a different virtual glimmer of light inside the box. Each hole

Figure 8. The electronics inside the box-controller



represents a different color of light, for example the first hole produces white light, the second one red, the third one blue and the fourth one green. These holes on the physical box are at the same spot as the ones of the box in the virtual world in order to avoid confusion.

- **Vibrations / knocks:** The user can produce virtual vibrations by knocking on the exterior of the box, affecting the virtual environment. For example, when the user knocks on the box, the sphere jumps.
- **Temperature change:** The user can blow air or rub their fingers on a specific spot on the box to bring about change to the temperature. When the thermistor inside the box senses a rise on the temperature, specific actions can take place in the virtual environment, like the melting of ice.

All the above suggest actions that can enable the user to interact with the virtual environment. But interaction is also bidirectional, i.e. from the virtual world towards the user and the real world, though the controller.

Possible feedback on the system by the user is:

- **Solenoid's knock:** A solenoid located inside of the box creates a sound and a vibration when the virtual sphere hits a surface.

The implementation of the above reverse interaction was of great importance and pushes the user to greater immersion in the mix of the two worlds since a player gets used to interacting with a virtual world but not getting feedback from it.

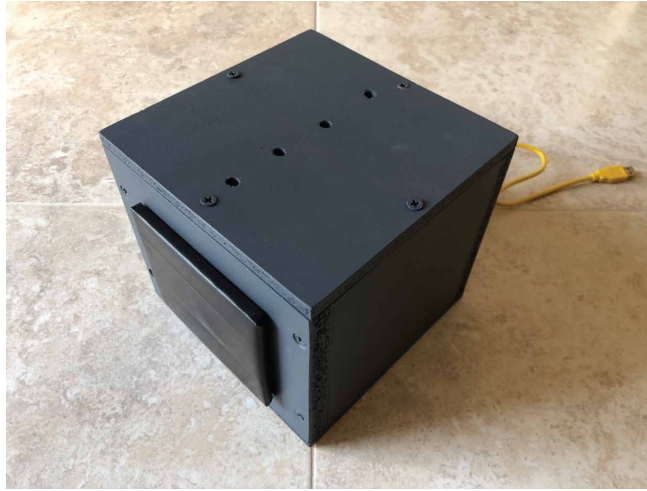
The final form of the controller is presented in Figure 9.

## EVALUATION

A primary evaluation to review the usability and the user experience of the proposed game and prototype has been executed in order to obtain useful data and initial feedback.

For the purpose of this user study, the System Usability Scale (SUS) questionnaire has been used and distributed to the participants. This questionnaire is considered to be one of the most effective questionnaires in terms of validity and reliability of the results produced (Brooke, 1996). The main reasons of the growing popularity of the SUS questionnaire in recent years are:

Figure 9. The controller of the game



- The cost of it, since it is free of charge.
- Its validity that has been established in a series of studies in both conventional software and websites, as well as other devices such as mobile phones etc.
- It produces the same or more reliable results compared to other questionnaires even with a small number of participants (Tullis & Stetson, 2004).

SUS questionnaire contains ten simple questions and the participants were asked to reflect to their answers their user experience and kind of immersion between the real and the virtual. The complete list of the questions and the structure of the SUS questionnaire can be referred to the relevant literature (Brooke, 1996). Additionally, after filling the questionnaire, each participant was interviewed in order for qualitative feedback on the prototype, as well as further impressions and suggestions, to be gained.

The sample of this primary study included 17 participants aged 22-39. No prior knowledge was required but a mere experience on video games and different kind of controllers, a characteristic that all participants satisfied.

After receiving a brief explanation on the game's hypothesis, each participant was instructed to experiment handling the controller after the start of the game. No further instructions were given on how to use the flashlight or which the full capabilities of the controller are. Each user had to discover how to navigate and progress through each of the 7 levels that were developed.

## Results

The participants of the evaluation process found it easy to use the controller and showed fluency on navigating through the game. The instructions at the beginning of the game inform the players how to navigate through the main menu, by touching right, left, or using both hands to select a command. This plain instruction proved to be enough to get the users started and to continue experimenting on the next levels.

It took around 15 minutes for each participant to successfully finish all 7 levels of the game. During the interview and after the use of the prototype, all participants showed excitement and they were willing to play again. The average score that was achieved on the SUS scale through the questionnaires was 80.25, which by conventional standards is considered to be above average and may be described as a good experience (Bangor et al., 2009). The gathered users' suggestions regarding improvements and different approaches on the prototype are listed in the next section.

## DISCUSSION AND FUTURE WORK

The evolution of technology can lead to new paths. Weaknesses and defects can be limited or even eliminated while new features can expand the utility and usability of the device.

The cubic controller is the main user's interface and the interaction between the two worlds exists. This is a *real interface* since a user's actions cause expected results in the game. Thus, shedding light to a hole can indeed produce light to the corresponding virtual hole in the virtual world and the flipping of the box can turn the virtual world upside down. This intuitive behavior makes the user's acquaintance with the controller easier and simpler. The only differentiation is the touch pad interface in which the user's touch produces an action on the virtual world which is not linked to a respective one in the natural world. This interaction, which has to do with the movement of the player's character to the left or to the right, is quite familiar even to a rookie player, and is linked to the common practice of a game in which a user presses left or right buttons to move the virtual character to the left or to the right. Therefore, even this arbitrary correlation suggests an interaction that the user can sense intuitively from the first moments playing the game without causing any confusion. What contributes to this usefulness is also the fact that the movement of the sphere keeps its consistency even when the world is upside down, meaning that touching left remains linked to the movement to the left and touching right to the right movement, as the user sees it on the screen.

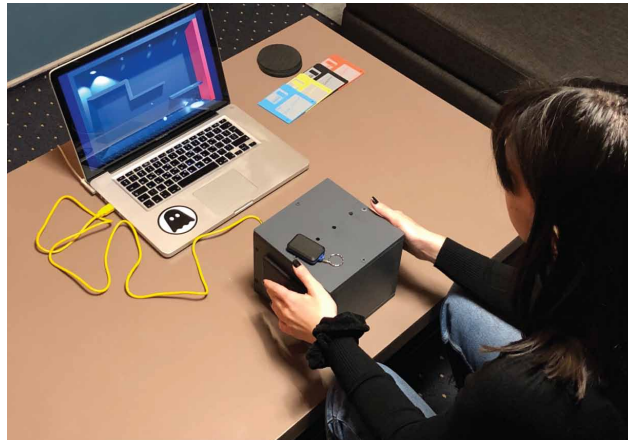
One of the advantages of the controller is the elimination of a keyboard, a mouse or any other kind of controlling device. The only device the user needs to fully operate the game is the cubic controller. Indeed, all users during the evaluation process commented that they enjoyed the fact that they only had to experiment with the box in front of them without any distractions. This enhances the user's immersion feeling in the mixed reality environment with no need of interrupting the interaction to turn to the keyboard or to any other device for additional manipulations.

One of the limitations of the device in its current form is its weight and size, as noted by user comments during the evaluation of the system. Although it gives the illusion of real-size objects existing and moving inside the box (the box size is analogous to typical laptop screen sizes), the need to use both hands to place the box upside down, lifting a load of approximately 1,5 kg might delay the game as it is proven it is not a simple task. Moreover, during the flipping of the box, the user's hands might get in contact with one of the touch sensors and result in unintentional movement of the virtual sphere. On the contrary, these are the characteristics which force the user to place the controller on a flat surface in front of them instead of holding it, something that might render the device difficult to use and might also tamper with noise readings for the inclination of the box. Figure 10 presents the proportions of the controller and a user controlling the game using the device.

The size of the controller is also a subject of review for usability reasons. In the present form, the size is not proportional to its contents and almost 80% of the interior is empty. The main reason why this is implemented that way, is simply to facilitate the fitting of all the electronic parts inside the box as well as the fact that a prototype is not a subject of scrutiny, in terms of physical dimensions and usability. Of course, we must bear in mind that the four holes on the top of the box require enough space so that when the user tries to point the flashlight at one of them, it will not shed light on its neighbors. Anyhow, replacing the material of the box and downsizing the box would change the way a user interacts with it since the controller would constantly be held in their hands without the need of placing it on a flat surface.

A key point that could be developed is the ability of the controller to detect its inclination. In the present form, a tilt sensor can make the position of box perceived through two distinct situations, normal or upside down. The use of a gyroscope and/or an accelerometer can provide us with additional data regarding three dimensions, and thus, it would be possible to detect the inclination of the box in three dimensions so that the projection of the virtual world is not based on only two states. Additionally, the virtual sphere inside the box could move into three dimensions by eliminating the two-dimensional movement that applies to the present implementation. By doing so, extra complexity to the game

Figure 10. User playing the game using the controller



levels can be added and additional increase of the feeling of immersion to the user can be achieved since the slightest inclination of the controller can also be transferred to the virtual world.

In a different approach, motors could be used inside the box to enable a real sphere to be inserted. This sphere will pop up in the virtual world and this could signify the beginning of another level. The target of this level might also be to lead the sphere to an exit that is related with a real exit on the box. When the user successfully moves the sphere out of the box in the virtual world, the actual sphere could jump out of the box in the real world as well. Obviously, consistency of the position of the entrance and exit points between real and virtual box is of utmost importance if we want to avoid confusion. On the other hand, this approach would pose more limitations on the level of creativity for the game.

Finally, to achieve portability, the controller can wirelessly connect to a computer (e.g. through Bluetooth, or WiFi) and operate on batteries. This implementation demands a microcontroller with wireless connectivity. This way, we could eliminate the limitation of keeping the controller near a computer or a monitor as well as get rid of the cables, something that would also offer greater functionality to the device.

## CONCLUSION

After the implementation of the game in its physical form (controller) as well as in software level (code development), a mixed reality environment was created, the interaction between real and virtual world being of great importance. The characteristics of the natural or reality interfaces are fully utilized, and the user interacts through gestures and actions in a real environment. Unlike most similar projects, the user's attention is not focused entirely on a screen but also in the accompanying controller through which the alignment of the physical and the virtual world is achieved. The touch of the controller causes motion in the virtual world, the use of light can affect the properties of virtual objects and the position of the box (normal or upside down) can flip the virtual world around. Additionally, the interaction between the two worlds works both ways, as events in the virtual world can change the characteristics of the real world, like the collapse of the sphere to the floor that causes a knock inside the box.

The game mainly focuses on creating the illusion/immersion that the user experiences an environment in which the virtual and the real objects coexist meaning that the virtual world unfolds within a physical object in front of them. A user's actions on this object suggest the interaction with

the virtual world and vice versa. Changes that take place in the virtual environment, like sounds and vibrations, can result in changes in the physical world. The combination of all the above stimuli is what creates a sense of immersion in a mixed reality world, rendering the boundaries between the real and the virtual loose and encouraging the user to instinctually operate the game. Finally, a mixed reality system's standards are fully met by making the game a successful example of mixed reality use in which the real and the virtual coexist, the interaction occurs in real time and in all three dimensions.

## **ACKNOWLEDGMENT**

The publisher has waived the Open Access Processing fee for this article.

## REFERENCES

- Ayala, K. J. (2005). *The 8051 microcontroller*. Cengage Learning.
- Azuma, R. T. (1997). A Survey of Augmented Reality. Presence: Teleoperators and Virtual Environments, 6(4), 355-385. doi:10.1162/pres.1997.6.4.355
- Badger, P. (2016). *Arduino*. Retrieved from Arduino Playground – CapacitiveSensor: <https://playground.arduino.cc/Main/CapacitiveSensor/>
- Bangor, A., Kortum, P., & Miller, J. (2009). Determining what individual SUS scores mean: Adding an adjective rating scale. *Journal of Usability Studies*, 4(3), 114–123.
- Bonsignore, E., Hansen, D. L., Toups, Z. O., Nacke, L. E., Salter, A., & Lutters, W. (2012). Mixed Reality Games. In *2012 ACM Conference on Computer Supported Cooperative Work (CSCW 2012)*, 11-15 February 2012 (pp. 7-8). doi:10.1145/2141512.2141517
- Booth, T., Stumpf, S., Bird, J., & Jones, S. (2016, May). Crossed wires: Investigating the problems of end-user developers in a physical computing task. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (pp. 3485-3497). ACM. doi:10.1145/2858036.2858533
- Brooke, J. (1996). SUS-A quick and dirty usability scale. *Usability Evaluation in Industry*, 189(194), 4-7.
- Costanza, E., Kunz, A., & Fjeld, M. (2009). *Mixed Reality: A Survey*. In D. Lalanne & J. Kohlas (Eds.), *Lecture Notes in Computer Science* (Vol. 5440, pp. 47–68). Springer-Verlag. doi:10.1007/978-3-642-00437-7\_3
- Coulton, P., Rashid, O., & Bamford, W. (2006). Experiencing Touch in Mobile Mixed Reality Games. *4th International Conference in Computer Game Design and Technology*.
- Duan, X., Kang, S. J., Choi, J. I., & Kim, S. K. (2020). Mixed Reality System for Virtual Chemistry Lab. *Transactions on Internet and Information Systems (Seoul)*, 14(4), 1673–1688.
- Fitzgerald, S., & Shiloh, M. (Eds.). (2012). *Arduino projects book*. Arduino LLC.
- Gimeno, J., Olanda, R., Martinez, B., & Sanchez, F. M. (2011, September). Multiuser augmented reality system for indoor exhibitions. In *IFIP Conference on Human-Computer Interaction* (pp. 576-579). Springer. doi:10.1007/978-3-642-23768-3\_86
- Glover, J. (2018). *Unity 2018 Augmented Reality Projects: Build four immersive and fun AR applications using ARKit, ARCore, and Vuforia*. Packt Publishing Ltd.
- Hughes, C. E., Stapleton, C. B., Hughes, D. E., & Smith, E. M. (2005). Mixed reality in education, entertainment, and training. *IEEE Computer Graphics and Applications*, 25(6), 24–30. doi:10.1109/MCG.2005.139 PMID:16315474
- Marichal, S., Rosales, A., Perilli, F. G., Pires, A. C., Bakala, E., Sansone, G., & Blat, J. (2017, September). Ceta: designing mixed-reality tangible interaction to enhance mathematical learning. In *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services* (pp. 1-13). doi:10.1145/3098279.3098536
- Metaxas, G., Metin, B., Schneider, J., Shapiro, G., Zhou, W., & Markopoulos, P. (2005, June). SCORPIODROME: an exploration in mixed reality social gaming for children. In *Proceedings of the 2005 ACM SIGCHI International Conference on Advances in computer entertainment technology* (pp. 229-232). doi:10.1145/1178477.1178514
- Milgram, P., & Kishino, F. (1994). A Taxonomy of Mixed Reality Visual Displays. *IEICE Transactions on Information and Systems*, E77-D(12), 1321–1329.
- O’Sullivan, D., & Igoe, T. (2004). *Physical Computing: Sensing and controlling the physical world with computers*. Thomson Course Technology PTR.
- Sandor, C., Olwal, A., Bell, B., & Feiner, S. (2005, October). Immersive mixed-reality configuration of hybrid user interfaces. In *Fourth IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR’05)* (pp. 110-113). IEEE. doi:10.1109/ISMAR.2005.37



- Speicher, M., Hall, B. D., & Nebeling, M. (2019, May). What is mixed reality? In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (pp. 1-15). ACM.
- Tullis, T. S., & Stetson, J. N. (2004, June). A comparison of questionnaires for assessing website usability. In *Usability professional association conference* (Vol. 1, pp. 1-12). Academic Press.
- Ullmer, B., & Ishii, H. (2000). Emerging frameworks for tangible user interfaces. *IBM Systems Journal*, 39(3.4), 915-931.
- Welch, R. B. (1978). *Perceptual Modification: Adapting to Altered Sensory Environments*. Academic Press Inc.
- Wursthorn, S., Coelho, A.H. & Staub, G. (2018). *Applications for Mixed Reality*. Academic Press.

*Ioannis Giannios was born in Larissa, Greece in October 1982. He holds a MEng in Civil Engineering with specialization in Structural Engineering from the National Technical University of Athens, Greece (2009) and a MSc in Information Systems from the Hellenic Open University of Patra, Greece (2019).*

*Dimitrios G. Margounakis is a computer tutor and a scientific researcher in the field of computer music. He concluded his basic studies in informatics at the Aristotle University of Thessaloniki, Greece, in 2003. He holds a Master's certificate in business informatics at the Aristotle University of Thessaloniki (2005) and a PhD in "Computer Music" at the Computer Science Department of the Aristotle University (2013). He specializes in "Languages and Interfaces for Computer Music". His published research about music visualization, digital libraries, ancient Greek music and Internet business models in the music industry have been presented in several conferences worldwide. He has served as an Adjunct Lecturer in the Department of Audio and Visual Arts of the Ionian University in Corfu, as well as the Department of Social Administration and Political Science of Democritus University of Thrace in Komotini. He is currently an Adjunct Lecturer in Science and Technology Department of Hellenic Open University, as well as the Computer Science Department of International Hellenic University in Kavala.*