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RobotQuest: A Robotic Game based on Projected Mixed Reality and Proximity Interaction

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***Abstract*—The appearance of video games in modern society introduced a number of modifications in the recreational and socialization habits of both youths and adults. In particular, various studies have associated the excessive use of this media with health and social problems, being the "classical" video game often a sedentary and solitary activity. The purpose of this work is to propose a possible way to deal with the above issues, which consists in exploiting a platform for robotic gaming based on consumer hardware that is being developed with the aim to reintroduce the physical and social dimensions in digital games. The proposed solution encompasses a floor-projected Mixed Reality (MR) environment, an autonomous toy robot and a set of tangible interfaces created using proximity beacons, which are combined in a robotic game concept named RobotQuest that is meant to show how to favor an engaging room-scale interaction between players and real/virtual game elements.**

***Index Terms*—Projected Mixed Reality (MR), robotic gaming, Human-Robot Interaction (HRI), Tangible User Interfaces (TUIs)**

I. Introduction

Gaming always had an historical and anthropological importance in every age and culture, being the basic form of daily entertainment. Due to technological progress, in the last years the most common types of gaming have undergone significant changes and, today, the most popular kind of recreational entertainment is represented by video games [1].

The term video game refers to every kind of game played through an audiovisual digital system [2]. Since its advent, video gaming introduced a new virtual pervasive dimension (synthesized by a computer) where the game player is an actor, paving the way for totally innovative ideas in the field of entertainment, education, etc. However, this media also influenced the habits of adults, teenagers, and children, sometimes positively, sometimes negatively.

In fact, video gaming is generally a sedentary activity, which is performed in front of screens while being seated or, at best, moving in place. Hence, differently than other kinds of games, often it does not promote exercise. Multiple studies have found correlations between the excessive use of video games and the onset of problems typical of a sedentary lifestyle, such obesity, cardio-vascular diseases, metabolic syndrome and, generally, stress and psychological issues [3], [4]. Moreover, even though multi-player gaming is getting ever more common, it exploits virtual meeting places which are not meant to foster in-presence collaborative or, in general, social activities [5].

Hence, the entertainment industry is currently focusing on the development of new game concepts exploiting both real and digital elements to favor active participation and improve socialization features. Thus, on the one hand, traditional games are being enriched with digital and social content; on the other hand, video games are trying to reintroduce the physical dimension [6]. Within this context, the goal of this paper is to propose an application scenario for a robotic game platform which shall be capable to solicit direct interactions among the players, as well as between the players and a room-scale gaming environment, thus preventing sedentary and solitary behaviors.

To reach this goal, a game concept is developed which includes the following elements:

- a robot, able to smartly play, in principle, either a companion or antagonist role (in this respect, autonomy is a necessary condition);
- a projected environment, defining the play area and including "augmented" virtual content capable to react to players' interactions;
- proximity beacons, enabling a communication between the players and the robot through real, tangible objects.

The concept was designed to be captivating and enjoyable, in order to increase confidence towards the robot (and robotic games) and offer an engaging recreational activity. Moreover, by taking into account the design principles introduced in [7], it was developed with an eye on hardware reuse, with the goal of keeping costs down. To this aim, implementation relied solely on consumer off-the-shelf components.

II. Background

In the last decade, the evolution of robotics allowed the entry of service robots in everyday's life. Robot vacuums are probably the most common type of service robots, but lawn mowers, telepresence robots and many variants of manipulation arms are today available almost to everyone. Robots have become so common to find their way also into the gaming domain, with the so-called "robotic gaming".

In [7], robotic gaming was defined as a game with a number of autonomous agents (including software, hardware and physical agents), where at least one of them is an autonomous robot and one is a person; these agents interact with each other in a possibly variable and unpredictable game environment following given rules in order to lead the user to have fun.

The authors of [7] split robotic gaming in four categories: robotic video games (virtual games where the robot is simulated, lacking any physical interaction); companion robots (with limited, in-presence interaction); real remote-controlled robots (robot is user-controlled, but lacks any form of intelligence); real programmed robots (sophisticated gaming scenarios can be envisaged, e.g., with autonomous robots playing partially or totally robotic matches, like in RoboCup [8]).

Considering the definition of robotic gaming and the above classification, the importance (and potential role) of the interaction between players and robots becomes immediately clear.

With respect to the reasons for considering interactive games involving robots, it is worth observing that the idea of exploiting human-robot interaction (HRI) in robotic gaming contexts to limit children's sedentary or asocial behaviors is documented in various works. For instance, the study in [9] focused on the effects of HRI on engagement, showed that sharing the playground between users and robot as well as the physical presence of a robot fosters users (children, in particular) to perceive the game in a more intimate way (and ultimately increases the trust towards third entities). Within the above scenario, a number of efforts have been devoted to favor the previously mentioned contamination between real and virtual elements, with the aim to further boost the player's engagement as he or she interact with the robot within its environment. Thus, Augmented Reality (AR) and Mixed Reality (MR) technologies have been used to overlap the real and virtual worlds, and generate new gaming environments where physical and digital objects coexist and interact with each other in real time [10]. In [6], the term "Phygital play" was used to refer to robotic gaming scenarios like those described above.

One of the earliest works where robots have been used together with AR environments to enable gaming applications is [11], where small mobile Do-It-Yourself robots were equipped with inexpensive light sensors for tracking purposes, while a projector allowed to create virtual paths, obstacles and battles between robots on the floor. In [12], an AR platform for robot-enabled game development based on tabletop projection and Lego Mindstorms robots is introduced. In [13], a low-cost extensible platform based on the commercial iRobot architecture is proposed to demonstrate a wide range of robotic gaming possibilities, with a focus on physical interaction with the robot in immersive environments. The platform supports projection, spatial sound, smart objects and gesture recognition. In [14], a mobile MR system for children's storytelling is presented. The system consists of a portable projector and a robot, which allow children to develop their stories in an immersive environment integrating virtual and digital spaces.

A further example is given in [15], which reports on the activities that are being carried out at TIM (the largest Italian telecommunication provider) towards the creation of a configurable cloud-based robotic gaming platform that could be used to develop various gaming experiences using one or more autonomous toy robots, different tracking technologies (based on external cameras) and a projector. Through the devised platform, any floor could be transformed in a MR-based play area, where robots' movements and players' behaviors (body poses and gestures, voice commands, etc.) could be used to create interactive gaming experiences.

III. Architecture

The game concept developed in this paper has been built upon the MR-enabled Phygital play platform presented in [15], which proved already to be flexible enough to implement a range of different games [16], [17]. However, with respect to the architecture defined in the reference work, several changes were made (revised architecture is illustrated in Fig. 1).

In particular a further interaction technology was added, by leveraging (hand-held) proximity beacons. The basic aim was to add a more physical way for the players to control/interact with the robots, besides body poses/gestures and voice commands. The added value was that these devices could be considered as a means to foster direct participation and even collaboration during the experience, being it possible for a player to move, deposit and even exchange these tangible props with other players according to some specific game objectives. The beacons used were the Estimote's ones, supporting Bluetooth Low Energy (BLE) communications. Custom cases could be 3D-printed for the beacons, to show possible meanings they could assume during the game. Furthermore, tracking sensors were moved from the external (instrumented) environment to the robot, by providing it with autonomous navigation capabilities based on the interpretation of projected content. This choice allowed to blend robot instructions into projected gaming content, thus ending up with a system much less sensitive to occlusions that may occur with multiple players moving in the play area. The shift from an exogenous to an endogenous tracking also allowed to reduce costs associated with the setup based on external cameras.

By sticking to the design principles in [7] (e.g., concerning the R^3, or *Reduce*, *Reuse* and *Recycle* philosophy), to implement the game concept a consumer-grade robot was chosen. In particular, the robot used was the Parrot's Jumping Sumo, a "mini drone" available on the market since 2015 which is equipped with two motors for ground movements (up to 7 km/h), plus a third motor to control a spring system used to make jumps up to 80 cm. The robot is endowed with a low-resolution (640×480 pixels), low-frame rate (15 fps) RGB camera facing forward. Robot motion is internally controlled by an inertial sensor. The robot has Wi-Fi connectivity for transmitting the camera feed and receiving control commands. The Jumping Sumo does not come with any specific game; rather, players are expected to drive (remotely control it) at short distance using a hand-held personal device.

Since the robot does not come equipped with BLE connectivity (required by the beacons), a board for rapid prototyping (namely, a Raspberry Pi) was mounted on the robot, and equipped with two USB plugs. The board was placed on top of the robot, powered with an external battery (front-mounted, outside the camera's field of view), and connected to two

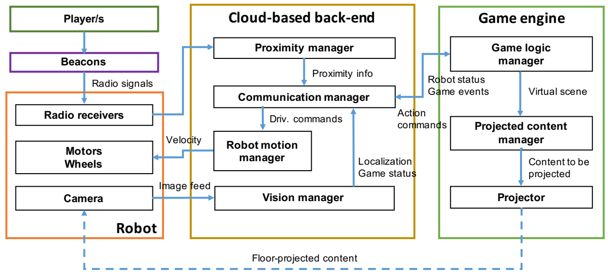


Fig. 1: Architecture of the robotic-gaming platform supporting the devised RobotQuest game concept.

BLE dongles which were used to localize the beacons through Received Signal Strength Indicator (RSSI) filtering.

By adhering to the requirements of the Phygital play platform used (which is aligned to cloud robotics principles), the Robot Operative System (ROS) was used to connect the robot to the back-end. The back-end includes services in charge to interpret image data collected by the onboard camera (which are processed using OpenCV) and transmit control commands back to the robot in order to convince the players that it was actually behaving as an autonomous agent. Communication with the robot was achieved using the ARDrone 3.0 libraries. Like in [15], the game logic and the virtual projection was managed by the Unity game engine.

IV. Game Design

By leveraging platform's capabilities, the game concept had to be capable to foster players' active collaboration in the MR gaming environment, with a robot able to move autonomously in a room-scale play area augmented with projected content. Tangible elements enabling proximity interactions could be used to let the players control both virtual and physical game elements, by positioning them close to the robot.

Various alternatives were explored (from a hide & seek game, to a robotic minesweeper, an obstacle course, etc.), by considering features to be included and limitations to live with.

RobotQuest represents the evolution of preliminary solutions considered. It is designed as a Role-Play Game (RPG), where robot and players are companions. The robot has to complete its mission by crossing a battlefield and defeating a number of enemies. To do that, it follows a path projected on the floor. At the beginning just a part of the path is shown, but it will grow during the game based on players' actions.

When the robot is placed on the path, it starts moving. As soon as it encounters an intersection it stops, waiting for an input by the players. As illustrated in Fig. 2.a, at each intersection (round), the game projects on the floor two possible enemies, each described in terms of name, abilities (attack, defenses, speed) and energy level. Possible enemies are, for instance, the *Flame Fury*, the *Icy Golem*, the *Mud Monster*, etc. Each monster can belong to one of the following categories: fire, ice, ground, electricity and water.

The robot needs to be instructed about the enemy to battle with and how to face it. Robot's actions are controlled by the players, who are provided with one or more support tools for the robot (the beacons). Possible tools are the fireball, the icing ray, the electric discharge, etc. The players choose the enemy to face at every round by positioning a beacon under either the left or right BLE receiver mounted on the robot (in a circular area projected on the floor). Each tool is effective against a particular enemy type: for instance, fire can be used against ice, ice against ground, ground against electricity, electricity against water, water agains fire, etc. Not all the tools are available, but can be obtained through so-called "combos". To get a combo tool, players need to collaborate and use more than one beacons at a time. Thus, for instance, water can be obtained by using both ice and fire tools together.

Once support tool/s is/are positioned, the path is modified in the direction of the chosen enemy. The battle begins, and the robot starts moving to simulate shoots towards the enemy and recoils (Fig. 2.b). Projected animations serve as a feedback for the players to show how the battle proceeds. Battle's outcome is determined by enemy selected and support tools chosen.

In case of a bad choice, the robot is defeated and the player looses the game. Otherwise, the robot may undergo some damages but it is allowed to proceed to the next round. To this purpose, the game logic will draw the path towards the next enemy and the robot will start moving again, repeating the game mechanics above (Fig. 2.c-d).

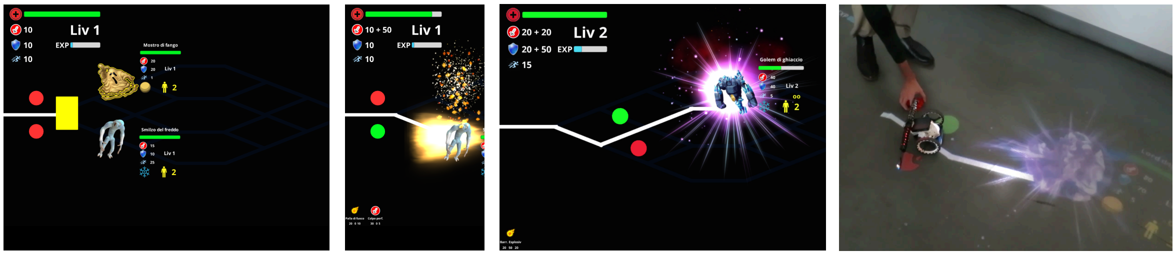
At each battle, robot's experience grows. As the game proceeds, challenges become harder. To win the game, there is a final enemy to defeat. The difficulty of the last battle is conditioned by the choices made in previous rounds. After winning the final battle, players can decide whether to terminate the game or start a new and more challenging mission. A video with gameplay is available for download[1].

V. Conclusions and Future Work

With the implemented prototype, it was possible to demonstrate that a MR Phygital play platform like that in [15] can be exploited to set up cloud robotics-based gaming scenarios capable to reach most of the objectives identified in this paper.

In particular, in RobotQuest a seamless interaction between virtual and real game elements is achieved. Digital content projected on the floor are used to display the story, but also to drive the robot (via line following, making it act as an autonomous, intelligent entity) and to augment its physical

[1] RobotQuest gameplay: https://goo.gl/3Li4Eu



(a) (b) (c) (d)

Fig. 2: Gameplay: a-c) projected path, enemies and battles, d) player placing beacons to choose enemy and use robot's tools.

behaviors (through virtual shoots and explosions that accompany its movements during the battle). The use of a RPG logic combined with proximity interaction is regarded as a means to limit players' sedentary and solitary behaviors. In fact, during the game players are requested to move in the play area to position the beacons, but also to collaborate with other players in order to build up the required support tools (through combinations of beacons). The devised solution also complies with the game design principles in [7], particularly regarding the possibility to use existing hardware and to keep costs down. By retrofitting an existing toy product, the cost of the BLE-based sensing robot is below $200 (projector excluded).

It is worth observing that many other game designs could be easily developed to tackle the issues of interest by reusing some or all of the features exploited in RobotQuest, like the presence of intersections (choices to make), enemies (obstacles to pass), support tools (players' inputs), etc. The focus could be on pure entertainment, like in this case, but also, e.g., on education (by simply changing the story and game elements). In particular, the devised solution could be ideally deployed at home or at school, where a projector may be already available.

Despite the achievements, the setup suffers from several issues, mainly related to technological limits of the employed components. For instance, due to interferences and poor processing power available onboard, data transfers on the Jumping Sumo Wi-Fi network may be delayed up to 500 ms. Moreover, the frame rate of the onboard camera could dramatically drop to 1-2 fps in case of low signal, preventing any form of real time control based on image processing. Other issues were experienced with BLE RSSI filtering, which proved to be poorly accurate in terms of distance estimation (and, hence, of localization and identification). Indeed, many of the above issues could be solved, e.g., by designing and building an *ad hoc* robot and possibly moving part of the processing on it. Nonetheless, this choice would clash with the principle of reusing as much as possible existing consumer hardware and to leverage cloud-powered resources.

Regarding future work, activities will continue on the Phygital play platform, with the goal to improve its capabilities and make it possible to devise other game concepts coping with new challenges. From a technical point of view, alternative methods to localize and track robots will be explored. New interaction modalities exploiting, e.g., other natural interfaces will be experimented. Lastly, different ways to combine physical and digital content will be tested, by using, for instance, holographic projections based on head-mounted displays.

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