RFID Toolkit for Customizable Game Controlling

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***Abstract*—This study introduces a customizable passive radio frequency identification (RFID) toolkit supporting bodily movements as well as hiding, showing, or touching objects as gaming inputs (controlling activities). The established toolkit is functional without onboard power sources, making its implementation into clothing, walls, floors, and any self-made game controllers simple and cost-effective. We developed gaming scenarios connecting the physical world to gaming. To play a game, players in the clothing-based scenario can move different parts of their body, such as their arms and legs, whereas players in the floor- and wall-based scenarios can move their bodies right or left in the gaming space. On the other hand, object-based scenarios allow any object to be turned into a game controller. In practical testing, the percentages for average correct input detection, non-detection, and false input were 77%, 14%, and 9%, respectively, which is promising. However, there were a few challenges in detectability and reliability, which must be solved for the next prototype iteration.**

Keywords— Customized game controllers, Games, Passive UHF RFID, RFID toolkit

I. Introduction

As game controllers have developed, new types of interactions between the player and the game have become possible. Versatile technologies have been used to capture bodily movements to control games, e.g., an inertial sensor when lifting the arm [1], wrist, and forearm [2] to control the movement in the game and a depth camera to capture players' bodily movements [3]. However, these solutions require complex and expensive electronics systems.

The simple, battery-free nature of radio frequency identification (RFID) technology makes it a potential answer for the above-mentioned challenge, enabling ubiquitous gaming environments: A basic RFID system allows digitizing any object for game interaction [4], for playing a sound, or showing graphical feedback [5]. Especially RFID-controlled games have been developed for children with special needs, e.g., learning disabilities [6], attention-deficit/hyperactivity disorder [7], and Down syndrome [8]. Moreover, RFID tags have been used as wearables to interact with a game, such as the Runner and Chaser game, where an RFID reader was integrated into the chaser's glove [9]; in bodily movement-controlled physiotherapy, an RFID tag was integrated into clothing to control a boat in a game [10]. Similarly, RFID has been used for dice [11], chessboard [12], and card games [13] and to determine the location and orientation of game objects in tabletop games [14]. Players wearing passive RFID tags on their feet have been tracked by an interactive floor [15]. Due to their portability, mobile RFID readers have an advantage over fixed readers in games [16]. For example, a game that uses an RFID-based mobile device to project relevant data on a wall [17], and a mobile phone to interact with an augmented toy that had RFID tags attached to it [18]. Finally, a mixed-reality game, a novelized version of PACMAN, was played outdoors using an RFID-enabled mobile phone by scanning tags attached to various locations in a park [19].

In this paper, the established RFID toolkit for customizable game controlling provides a system that 1. Allows defining various interaction modalities with games, e.g., embodied interaction and tangible interaction, 2. Contains a simple logic that people can easily use without coding or electrical assembly knowledge, 3. Relies on passive ultra-high frequency (UHF) RFID technology without needing any complex sensors or systems.

II. RFID Toolkit Software

The RFID toolkit software uses the ThingMagic Mercury API, enabling continuous reading from ThingMagic M6 RFID reader. Previously, a self-created software was used for a music player by blocking and unblocking tags from a reader for a specific amount of time [20] and as "a control interface" on clothing and furniture to run home appliances as an on/off switch [21]. In this study, the created software is turned into a software for customizable game controlling.

Fig. 1 shows the working principle of the created system. The bodily movement detection is based on passive UHF RFID tags that are shown to the reader antenna (unblocked) or blocked from the reader antenna (i.e., on/off type of input) for a set time. For example, showing the right arm (with a tag attached) will result in tag detection and output being triggered. Likewise, bodily movements can block or unblock an object with a tag attached to it, triggering an output.

Fig. 2 illustrates the key components of the created RFID toolkit software. In Settings, users can configure Internet Protocol (IP) and power transmitted from the reader antenna (from 1000 to 27000, i.e., from 1 dBm to 27 dBm). Increasing or decreasing the power affects the read ranges of RFID tags. The second component is Database. As the software uses digital outputs, e.g., showing images (.png format), playing audio (.wav format), and sending keystrokes in the active game (it can be the alphabet, number, arrows, or a special key on the keyboard); the database stores the files and links a unique tag ID to a specific file. There is a dropdown menu where the user can see the existing files in the database and link that file to a tag, as well as simply copy and paste any file into the database folder to appear in the dropdown menu.

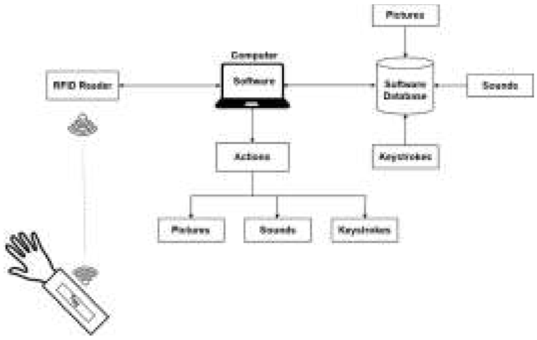

Fig. 1. Working principle of the developed system

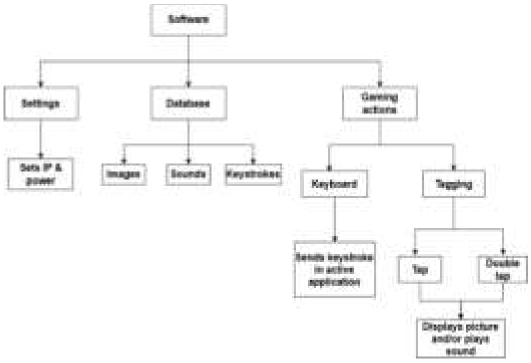

Fig. 2. Components of RFID toolkit software

The third component is Gaming Actions (including Keyboard Action and Tagging Action) functioning by blocking and/or unblocking a specific RFID tag from the reader for a predetermined amount of time to activate the connected outputs. We call this time the "interval between the same tag". Thus, this function allows each tag to be recognized only once within the "interval between the same tag," e.g., 500 ms. Depending on the game, users can choose how long they want to block or unblock the tag before the output. Keyboard Action uses the SendKeys Class, which supports a variety of keys, including single keyboard characters like A, B, or C; numerals; special keys like Enter and Tab; the up, down, right, and left arrows; and shortcuts like CTRL + C. Some games require only one keyboard key to be pressed, while others require the key to be pressed continuously, indicating that some games are more input-sensitive than others. This can be an issue when playing video games. However, using the SendKey Class, we can increase the sensitivity of the key that is pressed by specifying repeating keys in the database. For example, when acceleration is pressed in a car game, the car should keep moving forward. This can be accomplished by inserting {UP 40} into the database, indicating that the software will press the UP key 40 times for a single input of tag detection. Thus, the car moves smoothly, and we may say we matched the sensitivity of the key for that game. If there is only a single {UP} in the database for the tag input, the car moves very slowly and jerkily or not at all. The Tagging Action allows the user to tag any physical object with an RFID tag and block or unblock it once (tap) or twice (double tap) within a certain period to produce audio and/or visual output. The user can choose whether the output should be sound or image by ticking the box and setting the time in milliseconds for tap and double tap. For example, if one tag is detected twice within 500 ms-1200 ms, it is a double tap; if only once, it is a tap; and 0 ms to 500 ms will be counted as nothing because the user must block the tag for at least 500 ms.

Fig. 3. Single player: Playing Subway Surfer by moving left (first picture from the left), right (second), and jumping (third). Multi-player: playing Soccer Legends 2021 (Crazy Games), player 2 kicking the ball while player 1 moves backward (fourth)

III. Example Gaming Scenarios

The following game scenario exemplifications describe the developed RFID toolkit's potential. ThingMagic M6 reader is utilized at the European frequency range with a circular polarization reader antenna. SMARTRAC belt RFID wet inlay (Monza R6) passive UHF RFID tags are used in all scenarios. Three gaming modes are presented: 1) clothing-based, 2) wall- and floor-based, and 3) object-based.

A. Clothing-based gaming

Clothing-based gaming lets users attach passive UHF RFID tags to their clothing and use bodily movements (movements that make the tag readable for the RFID reader antenna, i.e., unblocking) to create gaming actions. The reader antenna is 150 cm away from the user, power is set to 22 dBm. First, one player plays Subway Surfer. Tags are placed on the user's forearms and leg (below the knee), as Fig. 3 shows. The user moves the gaming character to the right and left by moving their right and left arms, respectively, and lifting their leg for a jump. Next, two players play Soccer Legends 2021 (Crazy Games). The user's right and left arm movements correspond to the forward and backward movements of the football player, respectively. Leg movements are used to kick the ball. Fig. 3 shows a player kicking a ball with a tag in his leg, while another player moves backward.

Several games demand the player to change something (e.g., character clothing) or take something (e.g., character weapon) specific to the game. RFID toolkit allows, e.g., that the user can change into a pink sock in the game by wearing a pink sock with a tag. Fig. 4 shows how tags are attached to a sock, gloves, and a beanie. When the user wears the socks (making the attached RFID tag unblocked, i.e., readable for the RFID reader), it sends the keystroke to change the gaming element, i.e., changing the game character's socks. One player wears the beanie and gloves, while sitting and standing, and repeatedly takes them on and off to see the connected output on a screen.

Fig. 4. Connecting the clothing in the physical world to a game by tagging these articles of clothing with RFID tags

TABLE I. RESULTS OF TESTING THE RFID TOOLKIT IN THE INTRODUCED GAMING SCENARIOS

Scenario	Game	Output in game		Detected		Non-detected		False input	
Clothing-based gaming	Subway Surfer	Right		69%		26%		5%	
		Left		80%		13%		7%	
		Jump		89%		11%		0%	
		Average (%)		79%		17%		4%	
	Soccer Legends 2021(Crazy Games)	**Players (P)**		**P1**	**P2**	**P1**	**P2**	**P1**	**P2**
		Forward		76%	81%	22%	18%	2%	1%
		Backward		45%	39%	18%	7%	37%	54%
		Kick		39%	43%	32%	36%	29%	21%
		Average (%)		53%	55%	24%	20%	23%	25%
	Wearing clothing (standing & sitting setups)	Standing	Cap	50%		50%		0%	
			Gloves	100%		0%		0%	
		Sitting	Cap	100%		0%		0%	
			Gloves	100%		0%		0%	
		Average (%)		88%		12%		0%	
Floor-based & wall-based gaming	Floor (Ball and Wall game)	Right		79%		8%		13%	
		Left		72%		12%		16%	
		Average (%)		76%		10%		14%	
	Wall (Snow petrol- Crazy Games)	Right		67%		29%		4%	
		Left		77%		7%		16%	
		Average (%)		71%		19%		10%	
Object-based gaming	Madalin Cars Multiplayer (Crazy Games)	Right		67%		33%		0%	
		Left		86%		14%		0%	
		Acceleration		90%		5%		5%	
		Brake		66%		12%		22%	
		Average (%)		77%		16%		7%	
	Doll	Tapping		Tap	Double tap	Tap	Double tap	Tap	Double tap
		Head		100%	100%	0%	0%	0%	0%
		Right arm		100%	82%	0%	9%	0%	9%
		Left arm		100%	100%	0%	0%	0%	0%
		Right leg		100%	67%	0%	17%	0%	16%
		Left leg		100%	100%	0%	0%	0%	0%
		Average (%)		100%	90%	0%	5%	0%	5%
	All	Average (%)		77%		14%		9%	

B. Floor- and wall-based gaming

Floor- and wall-based gaming allow users to attach RFID tags to the floor and/or wall to make gaming actions by using bodily movements to block the tag on the wall or floor from the RFID reader. Here, the reader antenna is 200 cm away from the wall and floor tags. The power level is set to 24 dBm. Fig. 5 shows how the tags are attached to the wall in the wall-based game and the floor in the floor-based game. One player plays Snow Petrol (Crazy Games) in a wall-based game and Ball and Wall in a floor-based game. In these games, the player moves right or left to control the motion of the gaming element right or left, respectively.

Fig. 5. Test setup for wall-based (top left) and floor-based (bottom left) game; Playing a wall-based game by moving right and left (middle); and blocking a floor tag to move the gaming character right or left (right)

C. Object-based gaming

Object-based gaming employs RFID tags to connect any existing physical object to a game. Here, we present two types of object-based gaming: a car game and a doll game. For the car game, Fig. 6 shows two tags attached to the created foam steering, one at the brake pedal, and another at the accelerator pedal. When the user rotates the steering to the right, the left tag will be unblocked to the reader. The accelerator and brake pads have tags right below the pedal that become blocked when the user presses the pedal, which will then create the output. Here, the RFID reader antenna is 120 cm away from the tags, power is set to 19 dBm. Fig. 6 demonstrates a car game in action, showing the user playing Madalin Cars Multiplayer (Crazy Games).

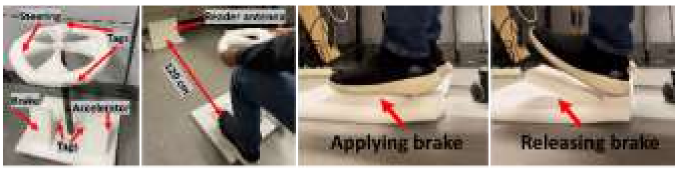

Fig. 6. Developed foam steering, brake pedal, and accelerator pedal for a car game with tags (the first picture from left); a participant plays the game (second); applying brake (third); and releasing brake (fourth)

Next, a handmade doll has tags inside both hands and legs and one tag on the head, as Fig. 7 shows. The situation card is taken from an existing empathy game [22], in which the doll has a "fever and a sore leg". Here, one user touches the doll's head once (interval between the same tag is set to 1000 ms), the display shows where the doll is touched, and the doll says she has a fever. When the user presses the doll's head twice within 3000 milliseconds, the doll says she feels good. Similarly, when the user touches the doll's right leg, the doll says she has leg pain, but when the user presses the leg twice, she says she feels good. Here, the RFID reader faces the doll from the top; the distance between the reader and the doll on a table is 120 cm, while output power is 19 dBm.

Fig. 7. Created empathetic doll with RFID tags (left); user touches the head, and the doll says she has a fever (middle); doll game testing setup (right)

IV. PRACTICAL TESTING

The parameters "interval between the same tag" and "repeating key" differ in each gaming scenario since some games require only a single press to move the character, while others require continual pressing. These game parameters were discovered through trial and error.

Two players tested the system. Each game was played for ten minutes. We recorded videos of the player movements and the game screen and analyzed the action detection and related outputs. If the gaming action results in the desired output in the game, it is considered a successful detection. If the gaming action results in no output, it is considered non-detection. If the action, which may or may not be detected, leads to detecting another tag in the game, this is considered false input. Table I presents the results of this practical testing. The average detection, non-detection, and false input were 77%, 14%, and 9%, respectively.

As Table I shows, the average detection rate in clothing is 79% for a single player and 54% for two players, as the other player's body interferes with the RFID tag signals of the other players' RFID tags. A larger gaming area might improve the result. Standing cap detection is 50% when wearing clothing and 100% with other standing/sitting scenarios. Because the reader was facing the user's torso and when the user was wearing a cap, the tag was not directly in front of the reader antenna, possibly resulting in non-detection. The average detection rate for floor, wall, and object-based games was 76%, 71%, and 77%, respectively. In the doll game, single tap detection was 100%, while double tap detection was 90%. Non-detection may have occurred if the user did not block the tag properly or underestimated the time, and when the user blocks one tag, they may unintentionally block another as well.

V. CONCLUSION

A battery-free RFID toolkit with specific software has been developed, allowing users to build a customized physical gaming world that can be linked to any digital game. The developed gaming scenarios connect the physical world, e.g., clothing, floor, wall, and various kinds of objects, to versatile games. Users can use their creativity to develop personalized input, output, and customizable game controllers. The initial results can be considered promising, but considering the discovered faults of the toolkit is the next step. We will especially focus on studying the use of different types of RFID tags and tag placements. Our plan is to improve the robustness of the system by using multiple antennas in optimized placements.

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