Performance Evaluation of a Battery-Free Videogame Controller

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ABSTRACT

This paper presents our experiences in developing and evaluating a low cost videogame controller that exploits RFID backscattering for battery-free operation. Specifically, we develop a system to gather data from a paper-made device, named JoyPaper, while it interacts with a videogame console. JoyPaper is home-made device that can be built by everyone and enables consumers to playing at every moment without caring about power charging: the device is ready to work as soon as the console is on. Our experiments show that JoyPaper's performance is comparable to that of a commercial controller in terms of latency and it is able to transfer up to 1 kbps.

KEYWORDS

RFID; Backscattering; Battery free; Home entertainment.

Figure 1: Scenario.

1 INTRODUCTION

Battery power conservation has been a key objective of research on wireless networks over the past decade. A significant amount of research has addressed protocol optimization and energy harvesting with the goal of prolonging network lifetime. Especially energy harvesting has shown the ability to greatly improve the lifetime of battery-assisted devices [1]. However, it cannot guarantee power delivery in a continuous (night and day) and ubiquitous (indoor and outdoor) manner: it suites mainly applications where data need to be transmitted only a few times a hour.

More recently, there have been a few proposals for leveraging interesting developments in battery free devices. Ambient and RFID backscattering are two such techniques [2, 3]. Ambient backscattering harvests power from ambient signals including TV [4], cellular [5], and Wi-Fi [6] transmissions. The main benefit of ambient backscattering is the exploitation of existing RF signals without requiring the deployment of a dedicated device to transmit a high-power signal to nearby devices. The main limitation is that ambient RF energy is not always available — leading to reliability issues and making it suitable only for applications involving occasional (or spot) data transmission, such as money transfer between smart cards or revealing misplaced objects in a grocery store. However, more traffic demanding applications, such as videogaming (as considered in this paper), based on ambient backscattering are still lacking.

RFID is the traditional and most widely used technology that harvests power from RF signals. In RFID, the tags — battery free devices — reflect the high-power constant signal generated by the reader — a powered device — to send it their unique ID. RFID technology has impacted a variety of applications whose common required functionality is object identification — to get the unique ID associated to each tag. Indeed, identification and counting were the main functionalities so far implemented by RFID systems, as tags are very simple and resource limited devices [7]. However the range of RFID applications has recently started extending to new frontiers, enabling the development of battery-less devices more powerful than RFID identification tags. For example, RFID backscatter-based communication have been used to transmit data from low-power sensors [8].

RFID backscattering overcomes the availability limitation of ambient backscattering, allowing for a continuous RF signal in indoor environments. In turn it requires the deployment of a dedicated device (the reader) to transmit a high-power signal to tags. However, in the context of smart homes and IoT, it is quite common to have a RFID reader deployed in the environment. The use of RF-powering is also practical in the case of game controllers — the console is fixed and operates with a dedicated power infrastructure, therefore integrating a RFID reader with it is easy and not too expensive.

In this paper, we show how to realize a low-cost videogame controller, named JoyPaper, that uses RFID backscattering

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for battery-free operation (see Fig. 1). Our JoyPaper features pressure buttons and is made only of paper and sticker RFID tags.

Our key contributions are as follows:

- We describe the design and implementation of JoyPaper, a low-cost, home-made, and battery-free device based on RFID backscattering. JoyPaper leverages paperID tags [9] to devise a simple button-based videogame controller.
- We evaluate the performance of JoyPaper and demonstrate that it can handle several types of videogames, performing similarly to commercial devices.

The rest of the paper is organized as follows. Section 2 presents the related work. Section 3 describes the system design. Section 4 details our testbed and the performance evaluation of JoyPaper. Section 5 draws some conclusions.

2 RELATED WORK

To the best of our knowledge there are a few solutions in the field of battery-free devices, most of which presents how to employ the backscattering technology to realize battery free devices only from an application viewpoint, without presenting any performance evaluation.

Ambient backscattering have been exploited to develop applications that involves occasional (or spot) data transmission, such as money transfer between smart cards or revealing misplaced objects in a grocery store [2]. Hovewer, there are no proposals for devices based on ambient backscattering that implements traffic demanding applications, such as videogame controllers.

RFID backscattering has been exploited in the form of paperID tags [9] to develop interfaces on paper such as: wireless polling devices; pinwheel animations that adapt with spin speed; conducting batons; dollhouses controlled with custom RFID tags on paper interfaces, and pop-up books with embedded tags which trigger audio content. Even in these applications tags are used only to trigger sporadic commands, without the need of implementing time stringent data transfer.

Closest to our work is the work presented in [10] that leverages platforms such as the UMich Moo Computational RFID tag with on-board accelerometer to sense movements and relay this information to the reader, in order to realize a videogame controller. However no performance study has been performed to demonstrate the efficiency of the system.

3 SYSTEM DESIGN

Our system is composed of two main actors: a *JoyPaper* and a fixed *videogame console* (see Fig. 2). The JoyPaper is a wireless and battery-less videogame controller that interacts with the videogame console and supports several types of single player videogames, such as adventure, action, puzzle, and RpG. The videogame console is a fixed powered device, equipped with a RFID reader, a RFID antenna, and a server that interconnects the reader and the videogame.

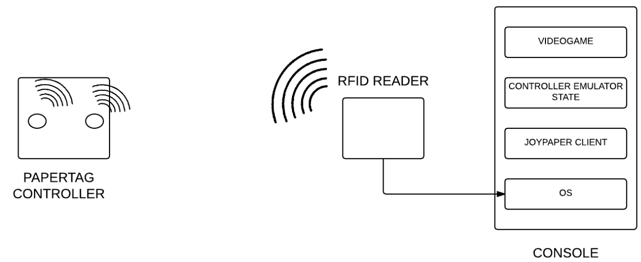

Figure 2: System architecture: The JoyPaper, a controller realized with paper tag, interacts with a videogame console equipped with a RFID reader.

JoyPaper features pressure buttons and is made only of paper and passive RFID tags. Fig. 3 depicts our prototype, which include two pressure buttons (the other buttons are represented only to show that it is possible to include multiple buttons). The key idea in the JoyPaper design is to use tags with touch-sensitive antennas that act as pressure buttons. When the user touches the antenna of a tag (see Fig. 4), the touch activates the antenna, making the tag able to communicate with the reader, which interprets the communication as a button pressure: the tag's ID indicates which button has been pressed. Otherwise, the tag is off, unable to send/receive any data.

The process for creating JoyPaper employs only paper, ultra-compact RFID tags in the form of stickers, and pens with conductive ink. Small stickers containing commercially available UHF loop integrated circuits (IC) are placed over specifically designed conductive traces (see Fig. 5), that can be easily drawn by hand using a pen filled with conductive ink (see Fig. 6). The traces capacitively couple to the existing tag antenna, providing a new antenna for the loop tag without requiring any electrical contact with the existing antenna. The resulting antenna detunes the tag sufficiently that it can no longer be read. However, if a particular traces spot (circle spot) is touched by a user finger, his body serves as ground plane, boosting the reflected signal: the antenna's continuity is restored and then tag starts to operate again (i.e., it receives a reasonable amount of energy to be activated). When touched the tag becomes an input sensor, able to send its ID to a querying reader. This allows the tags to act as sensors for user inputs, despite the fact that they are battery-less — being powered entirely by the reader — and inexpensive — the cost is only USD$0.10 per tag.

The communication protocol between JoyPaper and the reader is based on EPC gen 1 class 2 standard protocol [11]. At setup, the reader performs an interactive discovery phase to identify the tags that are on the controller and associate them to buttons (e.g., right and left buttons). To this end the reader uses the EPC `inventory` command by transmitting a `query` every 300 ms (this is the minimum time interval allowed by the EPC implementation). Tags replies by sending their Electronic Product Code Identification (EPC ID) and

Figure 3: A JoyPaper featuring two buttons, realized through paper tags.

Figure 4: Button pressure on JoyPaper.

Figure 5: Antenna.

a cyclical redundancy check (CRC). If CRC verification is successful, the tag is correctly identified. To associate tags to

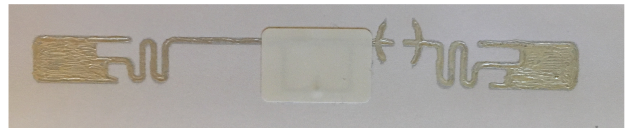

Figure 6: Tag-antenna coupling.

corresponding buttons, the user is required to press a button at time while the reader is issuing queries. If the user presses for example the right button, the tag associated with it will reply to the reader by sending its EPC ID and the reader will perform the tag-button association. Then the reader asks the user to press another button and issues again query commands to perform a new association, and so on. At the end of the discovery phase the reader has a list of present tags and corresponding associated buttons.

Then the system passes to the playing phase, in which the reader continuously queries tags to check if they are active (the user is pressing the corresponding button) or not. The EPC `access` command allows to directly query individual tags by specifying their EPC ID. If the user is touching the button related to the accessed tag, then the tag will reply to the reader — representing a button pressure — otherwise it will not receive any query and thus will remain silent. As the reader is directly querying tags (accessing them based on their ID) collisions among tags cannot happen. Even if the player is pressing two buttons at the same time, tags are accessed singularly and each tag at a time will reply to the reader. Synchronization of pressures is guaranteed by the fact that tag accesses are very fast — a tag access takes only $60ms$ — so the reader reads a tag multiple times during a finger pressure. This redundancy add also robustness against packet errors.

When the reader receives a packet from a tag it passes it to the videogame through the *JoyPaper client* and the *controller emulator state* components. The task of the JoyPaper client is to trigger reader's queries — tag inventory in the setup phase and tag access in the gaming phase. Specifically during the gaming phase, the reader continuously queries tags in circular order. If the queried tag replies (i.e., the player is pressing the corresponding button), the JoyPaper client passes the tag ID received by the reader to the controller emulator state, through a socket interface. The Controller Emulator State is in charge of producing game commands. When it receives data from the JoyPaper client it looks for the event corresponding to the received ID (e.g., left or right button pressure) in a local table and asks to the kernel of the operating system to simulate a real pressure of the corresponding button. The event of button pressure is then generated by the operating system and notified to the application level (i.e., videogame). This mechanism allows to decouple the tags' data handling from videogame logic, as the process of JoyPaper's data production is totally transparent to the application level.

4 PERFORMANCE EVALUATION

We now describe the JoyPaper capability of efficiently interacting with a videogame. We demonstrate that JoyPaper is able to satisfy the requirements of different videogames (e.g., Arcade Sports, Adventure, GdR, Simulation). Specifically, we evaluate data communication between the JoyPaper and the videogame console.

4.1 Testbed

Figure 7 depicts our testbed that is composed of three main components: the JoyPaper controller, a RFID reader, and a videogame console.

The JoyPaper is realized as described in Sec. 3, with paperID tags [9].

The reader is a low cost (less than 100$) programmable commercial reader (we used CF-RU5102), equipped with a single coil antenna and supporting the EPC C1G2 standard protocol [11], which is used in our system as core protocol in handling the communication between the reader and the controller.

The videogame console is a 17" Macbook Pro late 2012 with 8GB Ram, 2.5 GHz. The console is attached to the RFID Reader which allows to wirelessly power up the controller and exchange data according to the EPC Gen2 protocol. When the reader receives data from a tag it passes them to the videogame through the client-server architecture described in Sec. 3 and implemented in *C#*. For convenience, client and server are executed on the same host exploiting a local communication, but different hosts can also be used.

Figure 7: Testbed components

4.2 Metrics

We measure the following metrics:

Reaction time - the time between the pressure of a JoyPaper's button and the corresponding action on the videogame console.

Throughput - amount of bits received by the reader per unit of time.

Packet error rate - the fraction of incorrect packets over the total number of sent packets.

While throughput and packet error rate can be measured at the reader side (in the JoyPaper client), reaction time requires a more complex procedure due to synchronization issues between the player's action and game reaction. We cannot measure packet delay at the network layer, because we use the EPC standard communication protocol and it does not allow to insert measurement code, thus we have to measure time at the application layer (i.e., reaction time). This time then includes not only the packet delay at the network layer but also the delay incurred due to the several levels through which data passes inside the console (see Fig. 2). To measure reaction time we used a digital videocamera, framing the controller and the console monitor at the same time so as to have a unique clock to record button pressures and corresponding actions on the videogame console.

4.3 System requirements

We considered several types of videogames (adventure, action, and puzzle game) and quantified the game experience in terms of *frame rate*. Frame rate is the main factor that affects videogame performance and is usually expressed in frames per second (fps). It specifies the frequency at which the console updates the image displayed to the player, reassessing all the input received by the controller. Typical frame rate values are: i) below or equal to 30 fps for *navigating* videogames (e.g., Arcade Sports, Adventure, GdR, Simulation); and ii) equal to 60 fps for *shooting* videogames. These values show that navigating videogames are more tolerant to latency and inaccurate players' actions, as they require between 7 and 30 fps. In terms of latency this means that the controller has between 142 and 33 ms to send new data to the console. This time decreases to around 15 ms for videogames with frame rate of 60 fps.

4.4 Experimental Results

We performed several experiments with our JoyPaper and compared it to a commercial bluetooth device: a Logitech joystick per console, depicted in Fig. 8. Results on reaction time are represented in Table 1. JoyPaper takes on average $144ms$ to see the outcome of a button pressure on the videogame console. This time includes overhead in terms of transferred bit due to the use of the commands provided by the EPC standard [11] to make tag and reader communicate, which are not designed to be used in such a time stringent applications. This time decreases to $104ms$ when we use the commercial counterpart (see Table 1), which is optimized for usage with videogames.

Although the two results may appear different, the two controllers present comparable game experience when we use videogames with frame rate below or equal to 30 fps (i.e., navigating videogames). JoyPaper is able to deliver new data to the console at each frame when the frame rate is 7

Figure 8: Commercial joystick used for comparison.

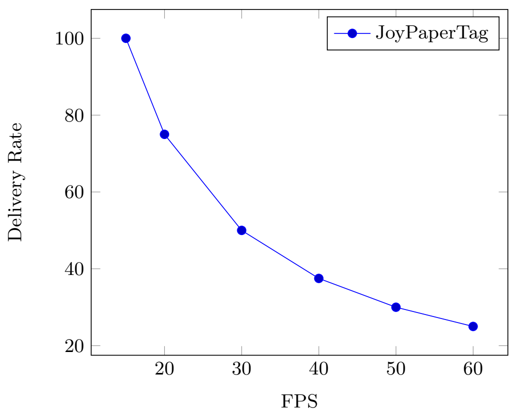

Figure 9: Delivery rate as a function of frame rate.

Device	Time	95% confidence interval
JoyPaper	144,4	(134.30 , 154.49)
Logitech	104,5	-

Table 1: Results on Reaction Time.

fps, and 75% of times when the update rate is 20 fps. This value decreases to 50% but it is still satisfiable when the update rate is 30 fps. JoyPaper cannot be used with shooting videogames (i.e., 60 fps) as the delivery rate is only 25%, too low to support shooting games.

The good performance of JoyPaper is confirmed by results on throughput that achieves over $1kbps$, with only 0.02 of packet error rate. We cannot measure these metrics for the Logitech controller because it is not programmable, but results show clearly that although our RFID reader is not very powerful and tags are made only of paper and conductive ink, we are able to achieve the same datarate of much more complex technologies, such as ambient backscattering, which in turn lack of data transfer continuity.

5 CONCLUSIONS

This paper shows how to realize a battery-less videogame controller, exploiting RFID backscattering for data transmission. Our JoyPaper is a low-cost, home- and paper-made, battery-free device that leverages paperID tags [9] to devise a simple button-based videogame controller. We use a low-cost commercial reader to interact with our JoyPaper. The communication protocol uses the commands provided by the EPC Global Standard [11], currently implemeted on commercial devices. Although the reader we used is cheap and weak and the communication protocol is not optimized for time stringent applications (it has been defined for tag inventory), our experiments show that JoyPaper is fast in sending data to the videogame (it takes only $144ms$) and guarantees also high throughput (i.e., above $1kbps$). Overall, we have shown that RFID backscattering is an effective technology for enabling wireless and battery-less control of several videogames (e.g., Arcade Sports, Adventure, GdR, Simulation).

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