E-Playground: Simultaneous Identification of Multi-players in Educational Physical Games Using Low-cost RFID

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ABSTRACT

We propose a design for an affordable interactive floor, and an accompanied software architecture for developing multi-player educational games. The floor uses passive RFID technology for robust tracking of the position and the identity of the students during play. The tracking results could be used to monitor and analyse the performances of individual students. A prototype was implemented using off-the-shelf electronics and thus it could be adopted in schools or community clubs with declined budget. To evaluate the latency and the scalability of the design, an analytical model and its empirical validation are presented.

CCS Concepts

•**Human-centered computing** → **Human computer interaction (HCI); Interaction devices;** *Interaction techniques;* Collaborative interaction;

Keywords

Edutainment; Educational Games; Interactive Floors; RFID

1. INTRODUCTION

The education system in Egypt faces urgent challenges such as the crowdedness in the classrooms, and the focus on memorisation for examination rather than the skills required by the labour market (e.g., collaboration and teamwork) [1]. Further, physical education is often overlooked. Only 50.9% of the young Egyptians (10 -17 year olds) practice regular physical activities [2]. In [3], we argued that educational games have the potential to improve the learning experience in the Egyptian schools. We proposed an e-learning management system that uses educational games (Figure 1) to connect learning inside and outside the classroom. Educational games are argued to have many educational benefits [4] such as engaging the students using various game mechanics (e.g., badges and leaderboards). Game design could allow for tracking the students' performances over time. Using appropriate analysis techniques, inferences could be made about students' progress and common mistakes. Teachers use the feedback about the students' performances to plan their lessons around the students' needs.

The presented research focuses on multi-player educational games to teach the students communication and collaboration skills, which are basic in the 21^{st} century. Drawing upon the classic Egyptian playground games, we propose an interactive floor that supports multi-player games.

We present the hardware design and evaluate its performance analytically and empirically. The design achieves real-time positioning and identification of simultaneous students using passive Radio Frequency Identification (RFID). It uses commodity hardware so it could be adopted in schools with declined budget. A software architecture is proposed to support game development for the floor.

2. RELATED WORK

This section reviews the various technologies that were introduced to support floor interaction.

2.1 Vision-Based Interactive Floors

In [5], Grønbæk *et al.,* proposed a tracking system, which uses four video cameras that are placed $3m$ under the floor. The cameras capture the pictures of the floor to detect limb contact points that are used by the system to infer the movement on the floor. Luzardo *et al.* [6] proposed an interactive floor that uses floor projection to display real-time reactions (*e.g.,* water ripples) of the users' feet steps. The tracking camera is mounted on the ceiling, and used to capture the picture of the floor. The shape of the moving user is detected and used to estimate the user's position.

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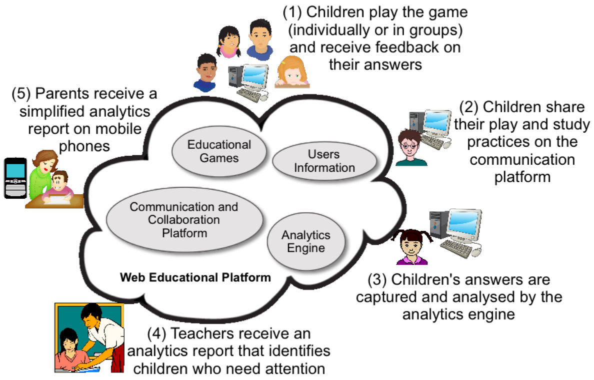

Figure 1: An e-learning management system, figure replicated from [3]

2.2 Sensor-Based Interactive Floors

Sensor floors use force or pressure sensors to track the pressure of the moving individuals.

Z-tiles are tiles assembled to build an interactive dance floor [7] and [8]. A Z-tile has 20 force sensitive resistors on its surface, especially designed with a mixture of silicon rubber and carbon granules. The user's pressure pattern on the tile is used to detect her position.

2.3 Wireless Sensor Networks Localisation

Wireless modules such as ZigBee, Bluetooth, and Wi-Fi could be used to locate and identify objects indoors. Wireless modules are portable and easily embedded in objects such as mobile devices. The Received Signal Strength (RSS) technique is used to estimate the location of the tracked object. Wireless Sensor Networks (WSN) are used mostly for positioning in large indoor areas (*e.g.,* hospitals and schools).

Reichenbach and Timmermann [9] used a combination of RSS measurements and the weighted centroid localisation technique for indoor localisation. Weighted centroid localisation depends on the existent sensor nodes and the beacon nodes with known positions (*e.g.,* GPS nodes). The system reduces the effect of RSS variation by sending the signal at two different frequencies and using two antennas, one for each frequency. Lim *et al.* [10] used a smart antenna that receives the signal from a mobile target (wireless access point), measures its signal strength, and passes this information to a client PC (a reader). The system uses three readers to read the signal from the mobile target. The readers estimate the angle and the strength of the arrived signals. A data server triangulates the data from the three readers to detect the position of the mobile target. Experiments showed that the most frequent errors between the estimated location and the actual location happen at distances $2m$ and that the proposed system can achieve a resolution of $1m$ with a probability of error 0.179. Kaemarungsi *et al.* [11] proposed a localisation system that consists of anchor or reference nodes, a locating gateway node that is connected to PC, and a mobile or tracking node. The localisation is based on two phases. During the offline phase, the system measures and collects RSS by placing a mobile node at various locations. The system stores these values to compare them with the values collected in the online phase. The tracked node is located according to the nearest RSS.

2.4 Using RFID for Indoor Localisation

RFID readers can operate at several frequencies; microwave, Ultra High Frequency (UHF), High Frequency (HF), and Low Frequency (LF). Microwave RFID readers operate at 2.45 GHz and have a reading range up to one meter. UHF RFID readers operate from 860 MHz to 960MHz with a reading range up to five meters. HF RFID readers operate at 13.56 MHz, and its reading range is up to one meter. LF RFID readers operates at frequency $<$ 135 KHz and its reading range is $<$ 0.5 meter [12]. As the frequency range increases, the data rates get larger. The microwave readers have the fastest data rates while LF readers have the slowest data rates. Nonetheless, operating at high frequencies increases the impact of environmental factors on the reading accuracy. Microwave and UHF RFID readers are affected by metal and wet surfaces, while LF RFID readers are not affected by those factors.

RFID tags could be either passive tags or active tags. Active RFID tags read data from a wide range of frequencies compared to passive tags. Passive RFID tags are cheaper, and do not require an external power source.

Ni *et al.* [13] proposed a localisation system that locates and identifies people using active UHF RFID and RSS measurements. The system locates the tags by matching their RSS with neighbour reference tags. The average error in the position estimation is $1m$ using four readers. Moreover, the system spends about one minute each time to scan eight power levels to estimate the signal strength of the tags. Such error range and latency are not accepted in real-time interactive games.

Zhu *et al.* [14] proposed a system to track a mobile UHF RFID reader. The system uses reference passive tags inside the room (mounted on the floor and the ceiling) with preknown coordinates. The user carries the RFID reader. The tags that are detected by the reader are called the activated tags. The localisation is based on identifying the circle, centred by the reader, that contains the activated tags. The localisation process takes six seconds.

Scherhaufl *et al.* [15] introduced a passive UHF tag localisation technique. A multichannel reader generates a continuous wave. The RFID reader generates a continuous wave and the tag reflects the signal to the reader, which receives it on multiple channels. The tag location is identified by calculating the arrival phase of the reflected signal, and the length of the signal path.

Savochkin *et al.* [16] used passive RFID tags and a UHF RFID reader for 2-D positioning. The system defines the antenna interrogation zone or the zone in which any tag can be detected. The system estimates the positioning zone by calculating the intersection of the interrogation zones of the antennas that receive response signals from the tag.

Yang *et al.* [17] proposed tracking mobile COTS RFID tags by detecting the phase of the received signal. The user carries the mobile tag, and the reader measures the phase difference between the transmitted and the received signal and uses it to estimate the tag position. The system handles two cases; the controllable case, where the tag has a constant speed and a known track, and the uncontrollable case, where the track and the velocity are unknown in advance.

2.5 Indoor Localisation – Visible Light Communication

Using white Light Emitting Diodes (LEDs) technology for indoor localisation has been attracting increasing attention recently. LEDs offer high data rates, are simple to install, and have the lowest cost among the other discussed sensors. Yang *et al.* [18] proposed a 3-D localisation method algorithm that uses RSS indication. Three LEDs are mounted on the ceiling, and a receiver LED is carried by the tracked target. Simulation results showed that the system achieves localisation with a $3cm$ error for one receiver. Nadeem *et al.* [19] proposed a 3-D localisation system using white LEDs. LEDs transmitters are mounted on the ceiling of the room, one of them is the reference LED. Each LED transmits at a different frequency. The receiver is a photodiode and a circuit contains a band pass filter, frequency down converter, and the positioning algorithm. The position is calculated by solving simultaneous equations based on the phase difference. Simulation results showed that the mean localisation error is $1mm$ in a $5m \times 5m \times 3m$ for one receiver.

3. HARDWARE DESIGN FOR THE POSITIONING AND IDENTIFICATION SYSTEM

Our choice for the technology is influenced by the requirements for the multi-player educational games and the target users (*i.e.,* primary school students). Tracking the students using vision or weight sensors frees the students from wearing tracking devices. Environmental conditions (*e.g.,* ambient light and shadows) affect the accuracy of the vision-based identification systems. Moreover, precise vision tracking of multiple persons is possible only if every person limits her movement to a pre-defined area on the floor, which might limit the possible game designs.

Force sensors are resilient to environmental factors, but less accurate in distinguishing individual students of similar weight or footstep patterns. WSN, RFID, or LEDs could distinguish the students as the sensors could send and/or receive identification data.

We use passive RFID tags as they are affordable, lightweight, and do not require external power sources. Therefore, they could be worn in a foot band. RSS-based positioning is influenced by environmental factors such as temperature, height of the sensor, the type of antenna, and the flow of human traffic. We thus use a proximity-based identification, where the location of the RFID reader is used to indicate the student's position

3.1 Floor Design

The floor is divided into N tiles. The students wear RFID tags in their feet, the tag is read by an RFID detection circuit embedded underneath the tile. The tile's dimension in our implementation is $50cm \times 50cm$. The system identifies the student's position or the tile number under which the RFID detection circuit resides (proximity based identification). To report students' positions at a fine-grain level, more than one reader could be installed under each tile. The system consists of one master circuit, and slave circuits that are embedded underneath each floor tile, as shown in Figure 2.

The master circuit is connected to the PC via a USB port and wirelessly to the N RFID detection circuits embedded under the floor tiles. It is responsible for managing the communication between the slave circuits and the PC. The master circuit includes a low-cost wireless module (nRF24L01 [20]), a USB to Universal Asynchronous serial Receiver and Transmitter (UART) converter, and a low-cost micro-controller (ATMEL ATmega8 [21]). The nRF24l01 module has high speed communication air data rates up to $2Mbps$ with low power operation (*i.e.,* $11.3mA$ Tx current and $13.5mA$ RX current), and its communication range is up to $60m$. The communication between nRFn24L01 and the PC is done using the Serial Peripheral Interface (SPI). We used a USB to UART converter because of the unavailability of USB to SPI converters in our local market at that time. The ATMEL ATmega8 micro-controller, which has the two communications peripherals, SPI and UART, is used to bridge the communication between the PC and the nRF24L01 wireless module. The nRF24L01 was configured using an open source firmware [22].

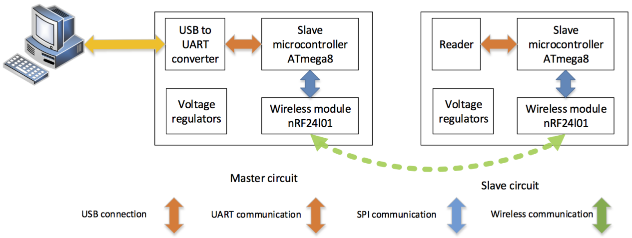

Figure 2: A schematic diagram for the master and one slave circuit.

The slave circuit (RFID detection circuit) includes a passive RFID reader, a micro-controller (ATMEL ATmega8), and a wireless module (nRF24L01). The circuit is responsible for reading the ID of the RFID tag and sending its data wirelessly to the master circuit along with the tile number.

The main component in the detection circuit is the RFID reader of the tag ID. We use the RDM6300 module [23], which is an affordable LF passive RFID reader (about $6). RDM6300 sends an RF signal to the tag and receives back the reflected signal including its identification number. The module sends and receives the signals using an external loop antenna made of copper coil and operates around 125 KHz. The antenna dimensions are $2.5cm \times 3cm$.

3.2 Reference Communication Model

The master and slave circuits perform two concurrent operations. The slave circuits detect the tag ID (if present on the tile), and store the ID along with the tile number (from 1 to N) in the slave micro-controller. The operation is performed periodically. The master circuit collects the read data from all slave circuits, and forwards it to the PC as follows. For each tile, the PC sends the number of the tile to the master micro-controller, which forwards it to the corresponding slave micro-controller via the wireless modules. The slave uploads the data back to the master circuit, which forwards it to the PC. We consider this as our *Reference Communication Model*, and evaluate its performance in Section 5.

4. SOFTWARE ARCHITECTURE

We propose a software architecture to develop games for the introduced floor design. The architecture consists of

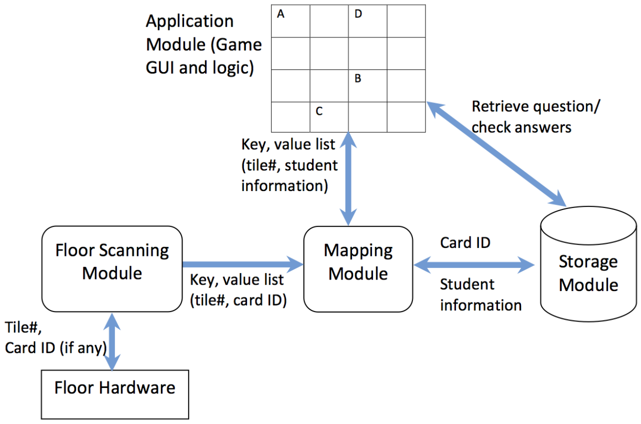

Figure 3: The software architecture of the proposed system.

four main modules as shown in Figure 3. The *floor scanning module* is responsible for scanning the floor to update the students' positions. The *storage module* consists of a database for storing students' information including their assigned RFID tag IDs. The *mapping module* communicates with the database to map the tag IDs to students' information. The *application module* includes the game logic, mechanics, and interface. The game graphical user interface (GUI) shows the floor as a board divided into blocks corresponding to the floor tiles. The students' positions and names are shown on the blocks on which they stand.

The *floor scanning module* communicates with the floor hardware via a serial port. The communication is based on a JAVA event-driven library that writes the data (tile number) on the serial port, and listens for an event that is triggered once the data is available for read on the port. The event is triggered when the hardware responds with the ID of the tag placed on the requested tile, zeros if no card is placed, or an error code if communication error happens. Scanning all the floor tiles represents a cycle. After each cycle completion, a key/value list of tile numbers as keys and tag IDs as values is constructed, the list is used to update the game user interface. The *mapping module* is responsible for mapping the tag IDs to students' information. It communicates with the database, queries the required data and constructs a key/value list of tile numbers as keys and students' names as value, to update the game interface and internal state. The floor could support various multi-player gaming scenarios as introduced in [3].

5. PERFORMANCE EVALUATION

We devise an analytical model to describe the latency of the hardware design. We then validate the model with the empirical results for a 12-tile prototype.

5.1 Hardware Latency

The system has one master circuit and N slave circuits, each has one antenna that reads the tag ID when placed on the tile. We compute the time taken in scanning the floor for the *Reference Communication Model*, described in Section 3, where the PC scans the tiles sequentially to obtain the tag IDs if present on the tiles.

Initially all the wireless transceivers are in the receiver (RX) mode (*i.e.,* listening to the RF channel). After switching the transceiver mode RX-to-TX or TX-to-RX, there is a standby delay ($T_{stby} = 130\mu sec$) before the data is processed.

The first operation is updating the slave micro-controller with the RFID reading via the antenna. The tag reading time (T_{reader}) depends on the decoding time, which varies from one RFID reader to another. The RDM6300 RFID reader has 100 $msec$ decoding time.

$$T_{reader} = 100(msec) \tag{1}$$

In the second concurrent operation, the master circuit read the data from the slave circuits as follows. The PC sends one byte to the master micro-controller via UART at baud rate R_1. The byte contains the address of the tile ($1 \leq$ address $\leq N$) that should send the data to the PC. The data is either the tag ID, if present on the tile, zeros if no tag is detected, or an error code in case of communication error. UART adds start and stop bits for each byte.

$$T_{add} = \frac{10}{R_1}(sec) \tag{2}$$

The master micro-controller sends the buffer (B_{cont}) that contains W payload bytes and 9-bit nRF24L01 configurations bits to the master transceiver (master wireless module). The communication between the master micro-controller and the master transceiver uses SPI with baud rate R_2.

$$T_{cont} = \frac{B_{cont}}{R_2}(sec); B_{cont} = (8 \times W + 9) \tag{3}$$

The master transceiver sends the air buffer (B_{air}), which contains one preamble byte, five address bytes, W payload bytes, 9-bit configuration, and one CRC byte to the slave transceiver (slave wireless module). nRF24L01 offers two air data frequencies (R_{air}); 1 $Mbps$ or 2 $Mbps$.

$$T_{air} = \frac{B_{air}}{R_{air}}(sec); B_{air} = (8 \times (1 + 5 + W + 1) + 9) \tag{4}$$

The slave transceiver sends an acknowledgement to the master transceiver after a standby delay T_{stby}. The acknowledgment buffer length and transmission time is similar to the B_{air} buffer. $T_{ack} = T_{air}$ The slave transceiver forwards the W payload bytes to the slave micro-controller via SPI at baud rate R_2.

$$T_{fwd} = \frac{8 \times W}{R_2}(sec) \tag{5}$$

The slave micro-controller sends the data to the master micro-controller with the same sequence of events described above. The master micro-controller uploads the W payload buffer (B_{write}) to the PC via UART at baud rate R_1. UART adds start and stop bits for each byte.

$$T_{write} = \frac{10 \times W}{R_1}(sec) \tag{6}$$

$T_{scan-one-tile}$ is the time in $msec$ between sending the address to the tile and receiving the tile's data is computed by the following equation (assuming all times are converted to $msec$).

$$T_{add} + 2 \times (T_{cont} + T_{air} + T_{fwd} + T_{ack} + 2 \times T_{stby}) + T_{write} \tag{7}$$

The scanning time for N tiles is then calculated as follows.

$$T_{scan} = N \times T_{scan-one-tile}(msec) \tag{8}$$

When $T_{scan} < T_{reader}$, the PC may scan each tile more than once during decoding time, which will result in collecting replicated data since T_{reader} is the minimum time by which the reader can obtain a new reading. When $T_{scan} = T_{reader}$, the PC will scan each tile exactly once during decoding time. When $T_{scan} > T_{reader}$, the PC will miss actual readings from the tiles, in this case the sequential reading model should be substituted by parallel scanning for the tiles (*i.e.,* using more than one master circuit, each is responsible for $M < N$ tiles).

5.2 Empirical Results

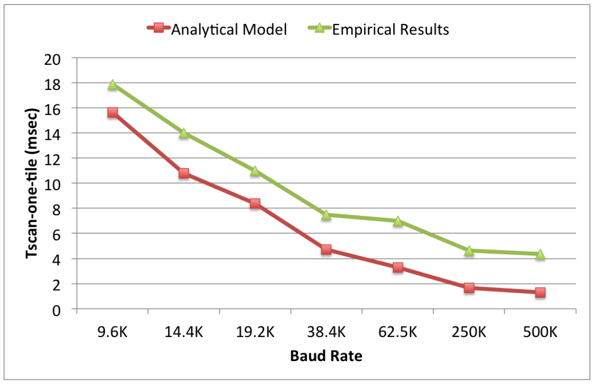

Figure 4: $T_{scan-one-tile}$ Empirical vs. analytical results for different baud rates (R_1).

Figure 4 shows the empirical and the analytical values for $T_{scan-one-tile}$ at different baud rates (Eq. 7). The difference between the empirical and the analytical results is almost constant with a mean 2.947 and 95% confidence interval [2.606, 3.288]. Since Eq. 7 was only concerned with the communication time, we attributed the difference between the empirical and the analytical results to the processing time the PC takes to open the serial port, and process the received data. We modified the $T_{scan-one-tile}$ (Eq. 9), and T_{scan} (Eq. 10) to reflect such change. $T_{PC-serial-comm}$ is set to the mean value 2.947. This value is obtained empirically, and will vary according to the PC hardware specifications and the implementation of the port listener.

$$T_{scan-one-tile-mod} = T_{scan-one-tile} + T_{PC-serial-comm}(msec) \tag{9}$$

$$T_{scan-mod} = N \times T_{scan-one-tile-mod}(msec) \tag{10}$$

Figure 5 shows the empirical measurements for T_{scan}, *i.e.,* the total time taken by the PC to scan $1 \leq N \leq 12$ tiles along with T_{scan} (Eq. 8), and $T_{scan-mod}$ (Eq. 10). $T_{scan-mod}$ provides a good estimate for the empirical results. Further, scanning a 12-tile floor was done in less than $100msec$ (i.e., $T_{scan-mod} = T_{reader}$). The error in the empirical calculations is linearly correlated to the number of tiles N, reaching $\approx 5msec$ at $N = 12$, as demonstrated in Figure 6. As for communication errors, the mean ratio between the number of error messages (*i.e.,* messages that were not received because of a wireless error, and the total number of received messages is 11.08%, with 95% confidence interval [11.03, 11.13].

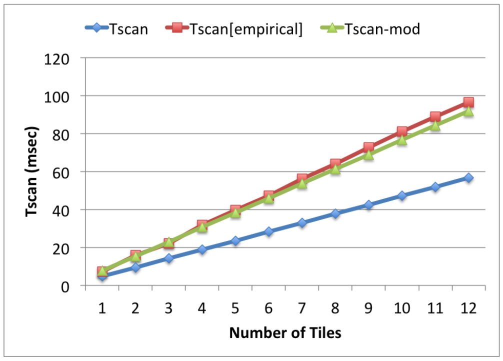

Figure 5: Empirical vs. analytical results of T_{scan} for different number of tiles N, $[R_1 = 38400bps, R_2 = 2Mbps, R_{air} = 2Mbps, W = 13bytes, T_{stby} = 130\mu sec]$.

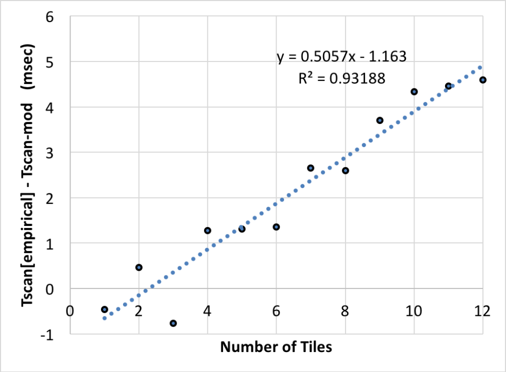

Figure 6: Error = $T_{scan[empirical]}$ - $T_{scan-mod}$ (Eq. 10), and its correlation to the number of tiles N.

6. CONCLUSIONS

The presented research is a part of ongoing efforts to investigate the means by which educational games and innovative low-cost technologies could improve learning in the Egyptian schools. We designed and implemented an interactive floor that tracks the position and identity of the students wearing passive RFID tags in their feet. We proposed a software architecture to support the development of educational games for the floor. The system is robust against environmental factors, and provides precision and response time suitable for interactive games. Empirical results showed that a 12-tile floor can be scanned in less than 100 *msec*, which is sufficient to provide a real-time interaction experience. We plan on exploring the design space for the educational games supported by the introduced design.

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