The Smart Jigsaw Puzzle Assistant: Using RFID Technology for Building Augmented Real-World Games

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Abstract. Radio Frequency Identification (RFID) can be used as technology for coupling the physical and the virtual world in ubiquitous computing environments. In this paper, we show that RFID is also a very interesting option for building augmented real-world games. First, we describe several advantages of employing RFID technology for the development of gaming applications. Then we present the Smart Jigsaw Puzzle Assistant, a fully operational augmented jigsaw puzzle game which we have developed and prototypically implemented using miniature RFID tags and a palm-sized RFID scanner.

Motivation

Radio Frequency Identification (RFID) has been identified as a suitable technology for coupling the physical and the virtual world in smart environments [4]. In this paper, we motivate the use of RFID technology for the development of gaming applications in the domain of ubiquitous computing. In doing so, we first describe several advantages of RFID technology for building augmented real-world games. Afterwards, we present the Smart Jigsaw Puzzle Assistant, an augmented jigsaw puzzle game we have developed and prototypically implemented by using miniature RFID tags and a palm-sized RFID scanner.

Using RFID Technology for Building Augmented Real-World Games

RFID technology in general provides means for computer applications to keep track of changes of the physical world in order to reflect them in the virtual world. We have already successfully applied RFID technology to augment a classical card game with *information-technological* functionality by attaching RFID tags to the cards: the *Smart Playing Cards* application [6] allows a *passive* monitoring of the game play in order to keep track of the players' scores and to rate particular game situations (e.g., to provide playing hints for beginners or to enforce the game rules by providing a "cheat alarm"). In this context, our main focus was on gaining insights into the requirements of RFID-based software infrastructures in general. The work we present in this paper now demonstrates that RFID also provides a valuable means for *actively* reshaping and augmenting physical games, thus allowing to further close the gap between physical real-world games and augmented virtual games.

In the following, we first give a vivid example of how RFID makes it possible to realize novel gaming features and playing functionality. We then show how RFID can be employed to provide new intuitive and comfortable means of user interaction and game control. Finally, we explain how the application of RFID technology allows preserving the original qualities of augmented games with regard to robustness and social compatibility aspects.

Finding the Needle in the Haystack – Novel Solutions to Ancient Problems

Who hasn't lost or mislaid an object and wished for a flash of inspiration on where to look and find it again? This is a well-known trouble and probably as old as humanity itself. For certain situations in everyday life, technical solutions have been suggested, such as a whistle detector attached to one's personal key ring which answers to whistle calls with a loud beep, thus revealing the location of the object if it is in whistle range.

But what if we are looking for the famous needle in the haystack? For a person, seeking out a particular item out of a multitude of alike-looking objects, this still remains a tedious task. For instance, imagine playing a large

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jigsaw puzzle with several thousand pieces, and then you get stuck, sifting for hours through the pile of remaining pieces that look all too similar, desperately trying to find a next matching piece. As of today, the ambitious player has no alternative but to back down and accept the unavoidable discomfort of manually trying out each of the remaining pieces until he or she finds the one which fits into the eyed spot of the jigsaw game.

Now by tagging all the jigsaw pieces with miniature RFID tags, we are finally in a position to offer a remedy for this needle-in-the-haystack problem. We have developed a system, the *Smart Jigsaw Puzzle Assistant* (SJPA), which enables the user to efficiently seek out further matching pieces of a jigsaw puzzle by simply using a small RFID antenna as a detector. In the fashion of a Geiger counter, the user moves the detector over the remaining jigsaw pieces until it detects another piece that can be added to the already combined pieces of the puzzle. Alternatively, the player can choose to pick a random jigsaw piece whose position in the overall puzzle game is then visualized by the SJPA. Here a major advantage of the RFID tags is that – by tagging the single pieces of the jigsaw game – each piece obtains its own unique ID, so that, as a consequence, the SJPA can easily and unambiguously distinguish the various pieces of the puzzle. And once the relative position of each tagged jigsaw piece is determined with respect to the overall jigsaw puzzle, the SJPA is able to decide which pieces can be attached to a given jigsaw piece or to an already combined set thereof.

This example vividly demonstrates how RFID technology can be successfully applied to augment classic physical games with novel and innovative gaming features.

Clicking in the Real World – Intuitive and Consistent User Interfaces

In our smart augmented puzzle game, the application of RFID technology serves two purposes. Firstly, we use RFID tags to augment the physical jigsaw puzzle by tagging its various pieces. In the previous section, we described how this permits to realize novel game features. Secondly, we also use RFID tags to represent certain functions of the game, thus providing an alternative user interface to the player. We think that this interface is more comfortable and intuitive than the currently available computer-based graphical user interfaces. It is more comfortable, because this way, the player can fully consecrate himself to play with the tangible parts of the puzzle game during game play. Consequently, the player is saved from changing his posture in order to reach the mouse or keyboard whenever he or she wants to select a special game function of the augmented puzzle game. In this way we can significantly increase the ease of use of the augmented game and keep low the annoyance level associated with frequent change-overs between the physical real-world game and the computer.

The augmented game is also more intuitive and consistent, because the RFID-based interface enables the user to actively interact with all parts of the physical real-world game – both with the physical jigsaw pieces and with the printed game instructions (the latter containing RFID-tags embedded in the paper which provide direct "physical" links to the special functions of the augmented game, for instance). Such RFID-based user interfaces can play an important role in bridging the gap between physical real-world games and virtual games, providing new means of user interaction and game control. Ultimately, they contribute to realizing the vision of "clicking in the real world" as described in [2].

Preserving the Original Qualities of the Game – Robustness and Social Compatibility

The process of augmenting physical real-world games threatens to change the original qualities of the game. Due to novel dependencies on newly introduced technologies, the augmented game may no longer be playable in exactly the same way as originally. This is especially the case when the original game board is abandoned and the physical world used as a game board instead (see [1] for instance).

In our case, using RFID technology proved to be *minimal invasive*, allowing us to actively augment a real-world jigsaw game while preserving its original quality and characteristics. The augmented game is *robust* in the sense that even if the computer or RFID hardware should fail or be temporarily unavailable, the augmented puzzle can still be played in the traditional way.

The aspect of minimal invasiveness has also a beneficial impact with respect to *social compatibility* issues. On the one hand, it helps to preserve knowledge sustainability (it *looks like* a puzzle game and it still *functions like* a puzzle game). On the other hand, it prevents potential social accessibility problems, in particular with regard to elderly persons or cognitively disabled people who may have profound difficulties in using the augmented computer-aided version of the game [3].

The Smart Jigsaw Puzzle Assistant

We have designed and prototypically implemented a smart jigsaw puzzle game based on latest RFID technology. For that, we tagged the single pieces of a puzzle game with small miniature tags and developed a smart game

application we call the *Smart Jigsaw Puzzle Assistant* (SJPA). The SJPA application is executed on a computer (laptop or desktop PC) and closely monitors the current status of the physical jigsaw puzzle. Whenever the player chooses a new piece of the physical jigsaw game to be added to the previously combined pieces on the table, he or she scans it with a handy RFID reader connected to the computer. The SJPA then automatically recognizes the added piece and updates the status of the jigsaw game on the computer screen (see screenshot in Figure 1).

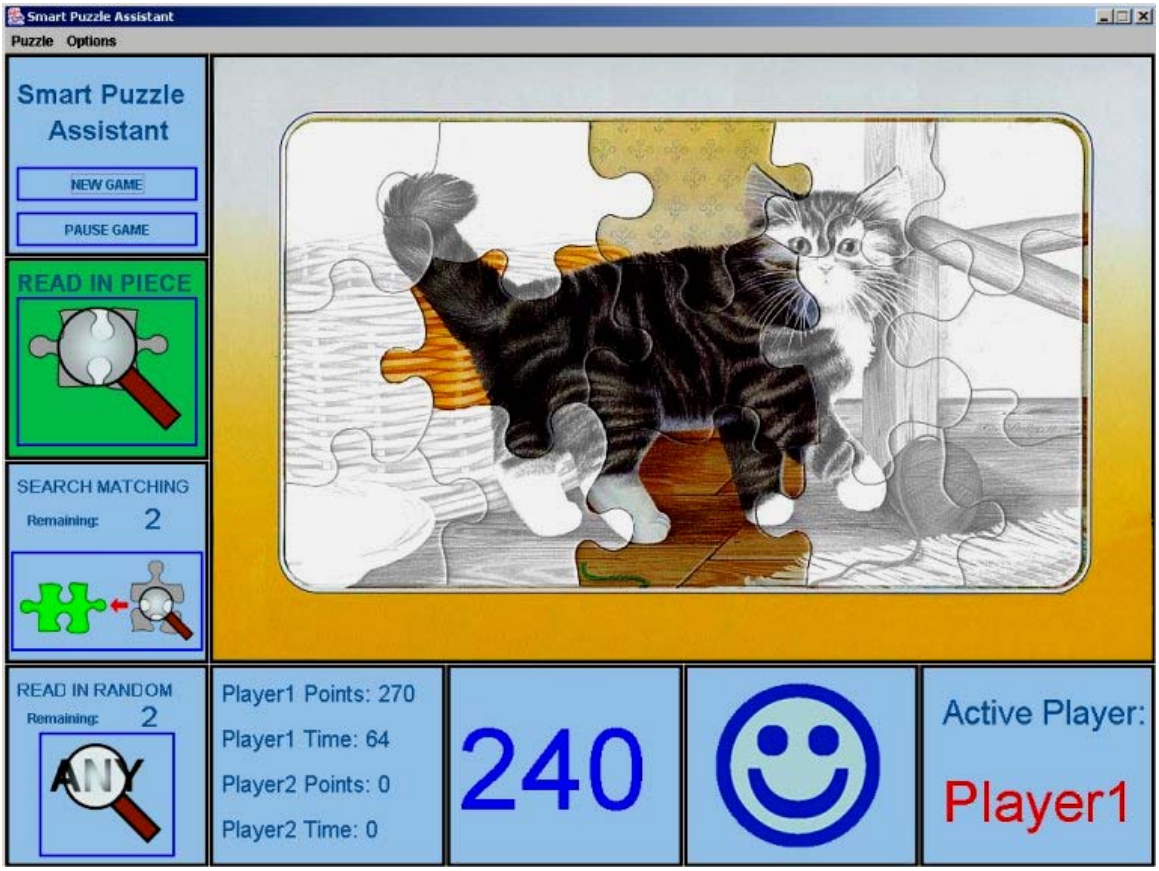

Figure 1: Screenshot of the Smart Jigsaw Puzzle Assistant during game play. On the left side of the graphical user interface (GUI), one can see the currently active default game operation ("read in piece"), and below it two Joker functions ("search matching [piece]" and "read in random [piece]"). Currently player 1 is playing a solitary game. He has just managed to add three matching pieces in a row and was therefore awarded extra bonus points (indicated by an appearing "smiling face"-icon and the "240"-points message). The current status of the jigsaw game is displayed in the centre of the GUI: whenever the player adds a new matching piece to the previously combined puzzle pieces, that piece is also shown in the GUI as a colored piece. In contrast, pieces that are still missing are displayed in light grey

Supported Game Modes

The SJPA supports a one-player solitary game mode (single player mode) and a competitive game mode for two players (multi-player mode).

In *single player mode*, the player chooses an arbitrary piece to begin with. Then he or she tries to find and scan matching pieces as fast as possible by placing the mobile RFID reader on top of each new piece. If a scanned new piece is matching, the player is awarded points. Otherwise, if a scanned piece cannot be added to the previously combined pieces, the player loses points. If the player successfully scans matching pieces within a certain time interval, he or she is awarded bonus points or may receive a joker. Currently we have implemented two kinds of jokers (see Figure 1). First, the "add random piece" joker allows the user to add any piece to the puzzle, even if it starts a new section in the puzzle and is not connected to the previously scanned and combined pieces. Second, the "find matching piece" joker allows browsing through the remaining jigsaw pieces to find another matching one. The goal of the game is to complete the puzzle as fast as possible by repeatedly finding matching jigsaw pieces among the remaining pieces. Once the puzzle is completed, the value of the timer is subtracted from the player's score. If the player achieved a new high score, he or she is asked to enter his name into the SJPA's *hall of fame*.

In *multi-player mode*, at the beginning of the game, the SJPA randomly selects an initial piece that has to be found and scanned by player one. Afterwards, the players take turns in scanning and adding new jigsaw pieces to the puzzle. The SJPA keeps track of the players' scores and jokers, and it displays the previously combined puzzle pieces on the screen. In our current implementation, two players can play against each other in multi-player mode.

The system can easily be extended to support an arbitrary number of players. However, for the game to become a real challenge, the jigsaw game should consist of a sufficiently large number of pieces. In our case, to provide a proof of concept, we contented ourselves with a small but picturesque jigsaw puzzle for children, which consisted of 15 pieces altogether.

While working on the rules for the smart augmented jigsaw game, we found a number of further challenging *game play variations* in comparison to the classic puzzle game, both in single and multi player game mode. In order to increase the complexity of the game, the SJPA could always determine the exact next piece to be searched for and added to the already combined jigsaw pieces by the player(s), for instance. Or in multi-player mode, instead of switching players whenever a new piece was added to the puzzle, the SJPA could allot each player a certain amount of time per move. Then each player tries to find as many matching pieces per time slot as possible, increasing the competitiveness of the game.

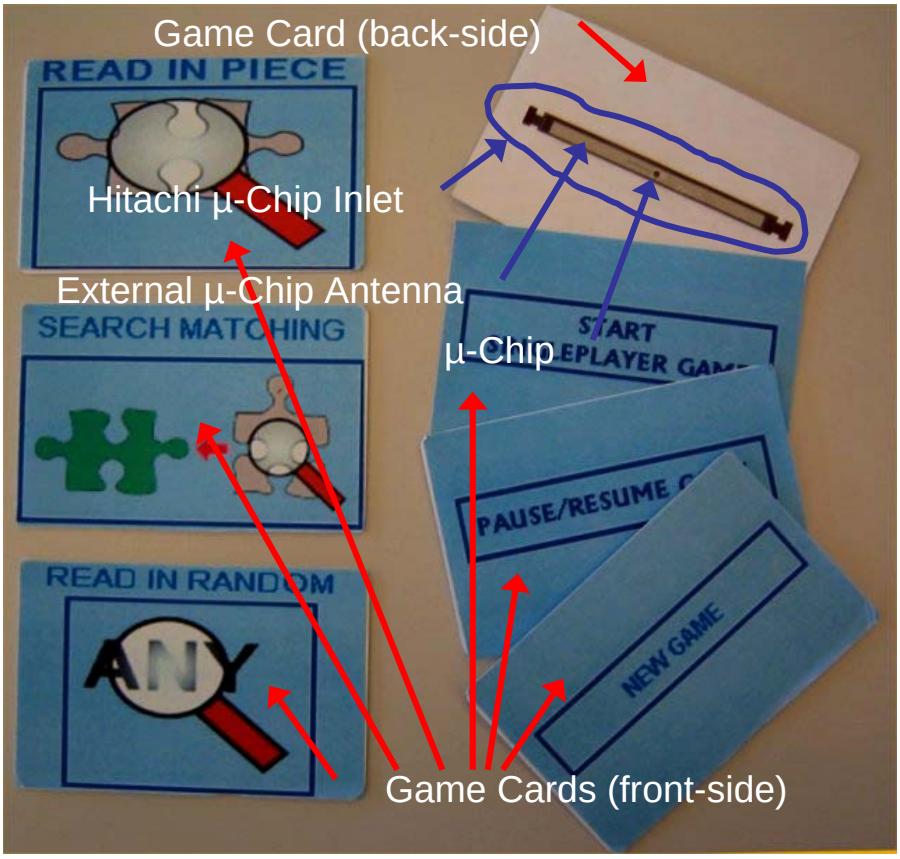

Figure 2: Game cards of the Smart Jigsaw Puzzle Assistant, tagged with RFID tags (Hitachi µ-chip inlets) on the back-sides. In the top right of the photo, one can discern the external antenna and the tiny µ-chip of a µ-chip inlet

RFID-tagged *Game Cards* for Intuitive Game Control

For each of the major game functions of the Smart Jigsaw Puzzle Assistant (such as "new game", "search matching", "read-in random", etc.), we created a separate *game card*. Each game card consists of a piece of cardboard onto which a graphical or textual representation of the corresponding game function is printed. On the back-side of each cardboard, a unique RFID tag is attached and associated with the represented game function. All RFID tags that are linked to game functions on a game card are registered with the Smart Jigsaw Puzzle Assistant. Thus, the smart puzzle assistant application can tell jigsaw RFID tags from game card RFID tags and vice versa. Figure 2 shows the RFID-tagged game cards that were created for the SJPA.

During game play, the user has the choice between activating the available game functions in the graphical user interface of the SJPA application and using the RFID hand-scanner to read the tag of the corresponding game card. The latter has the advantage that the players are spared to use a mouse/keyboard in order to control

the SJPA, so that they can concentrate on the game play and stick to the RFID scanner as a sole manipulation instrument instead.

Equipment Used for the SJPA Prototype

For the prototypical implementation of the SJPA, we used a small jigsaw puzzle game for children, consisting of 15 pieces. We attached a miniature RFID tag to the back-side of each jigsaw piece. Hereby, the RFID tags we used are Hitachi µ-chip inlets, which consist of a tiny 0.4 mm x 0.4 mm µ-chip together with an external antenna of approx. 5 cm length (see Figure 3). We obtained the µ-chip RFID hardware from Hitachi Ltd., Japan, as part of a joint research collaboration between Hitachi Systems Development Laboratory (SDL), Japan, and the Distributed Systems Group at ETH Zurich, Switzerland (see Figure 4). The Hitachi µ-chip operates at a frequency of 2.45 GHz and has a 128-bit ROM for storing a unique ID. Detailed information on the Hitachi µ-chip technology is available at [5].

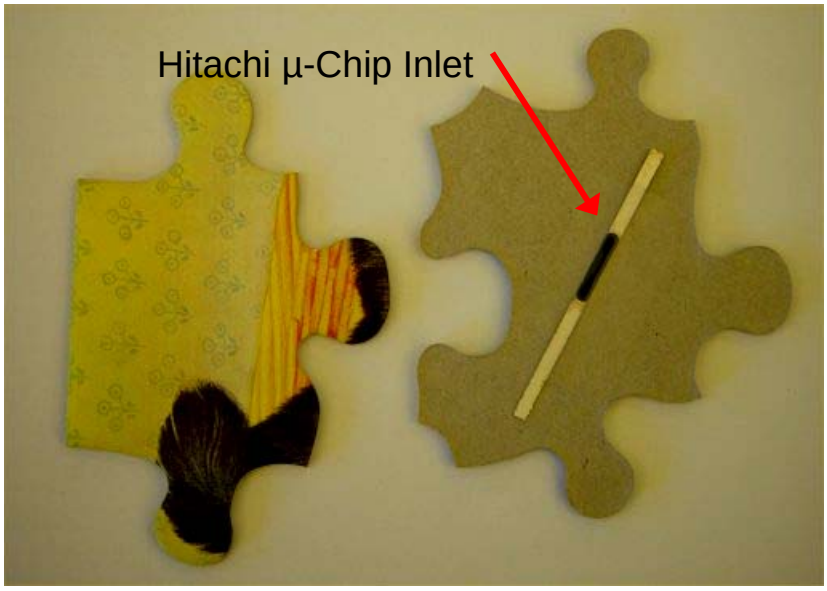

Figure 3: Two pieces of the tagged puzzle game. On the left the front-side view of a tagged piece is shown. On the right, one can see the back-side of a matching piece with an attached miniature RFID tag (Hitachi µ-chip inlet). The Hitachi µ-chip inlets we used for our SJPA prototype consist of a µ-chip with a size of 0.4 mm square and an external antenna

Figure 4: Hitachi µ-chip RFID equipment used for building the Smart Jigsaw Puzzle Assistant prototype. In the left photo, one can see the RFID antenna and below the corresponding µ-chip reader device by Hitachi. In the right photo, there is the physical puzzle game with four of its µ-chip-tagged pieces shown underneath

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Current Research Interests and Activities

The author's main research interests are in the field of reliable service infrastructures for ubiquitous computing, including dependable location systems, reliability in highly dynamic smart object environments, and the roles of redundancy and connectivity. Besides technical dependability aspects, he also investigates the social and ethical implications of living in a world which is strongly influenced by ubiquitous computing technologies.

Biography

Jürgen Bohn received a master's degree in computer science from the University of Karlsruhe (TH), Germany, in March 2000. In June 1999 he joined the IBM Zurich Research Laboratory in Rüschlikon, Switzerland, where he worked on his master's thesis in the field of mobile agent security. Since May 2000 he is a research assistant at the Distributed Systems Group in the Institute for Pervasive Computing at ETH Zürich, Switzerland.

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