A study of comparing RFID and 2D barcode tag technologies for pervasive mobile applications

Ernest Arendarenko

March 23, 2009

Department of Computer Science and Statistics

University of Joensuu

Master’s thesis

Abstract

Radio frequency identification technology has been developing for many years and now became a serious concurrent for barcode technology. Nevertheless, the latter obtained its more advanced type: a two dimensional barcode. Both RFID and 2D barcodes may be used in mobile technologies, for example in ubiquitous and pervasive computing, and this thesis is focused on usability study of these two technologies.

The study combines different research methods. It started with literature review, RFID and 2D barcode technologies were analyzed. Special attention was put on comparing strong and weak sides of each technology. The next stage was design based research on which an NFC plugin and a MemGame mobile application were implemented for experiment purposes. And on the last phase of research experiments were conducted. Feedback from users was collected by questionnaire upon usability study. The obtained data was analyzed according to the research questions.

The knowledge of results of this study might be useful not only for further pervasive application development, but for mobile application development in general where RFID and/or 2D barcodes are utilized. The research has two main technical contributions: (1) development of a NFC/RFID plugin for MUPE; and (2) development of a pervasive memory game for training memory and learning vocabulary. These developments were prerequisites for the comparison of the two smart tagging technologies, namely 2D barcode and RFID, in an educational setting.

Table of contents

List of abbreviations

API

Application programming interface.

LAN

Local Area Network

LED

Light Emitting Diode, a high reliability, illuminating device used as an indicator of status.

MIDP

Mobile Information Device Profile.

MUPE

Multi User Publishing Environment.

NDEF message

An NDEF message contains one or more NDEF records. Defined in the NFC Data Exchange Format specification.

NDEF record

Data that is formatted according to NFC Forum data format specification (NDEF). One record consists of the record type, record identifier and of the actual data of the record.

NDEF

NFC Data Exchange Format.

NFC

Near Field Communication, a short-range high frequency wireless communication technology, extension of RFID standard.

OCR

Optical character recognition.

RFID (or RFId)

Radio Frequency Identification. A technology of automatic identification with RFID tags.

URL

Uniform Resource Locator, specifies where an identified resource is available and the mechanism for retrieving it.

Wi-Fi

Wi-Fi is short for "Wireless Fidelity" and is a set of standards for wireless local area networks based on the specifications known as 802.11.

XML

Extensible Markup Language.

Chapter 1 Introduction

1.1 Background

Radio Frequency Identification (*RFID*), *barcodes* and *2D barcodes* are branches of the Auto Identification technology. Tags (radio frequency and visual) may be attached to an object for purposes of identification and this action is called *tagging*.

Tracking and tagging of products and materials is a necessary part of any business. The object of tagging can be anything: from a piece of chocolate you buy in a market to truck-size containers carried with cargo ships. The larger the system, the more extensive and expensive becomes tracking and tagging. It can be performed in manual, semi-automatic and automatic modes.

Manual tagging is carried out with the help of labels, or numbers written with paint. Optical character recognition is one of the research fields of machine vision. Its purpose is translating images of handwritten or printed text into computer editable text. Still this technology is not reliable enough to use it for industrial automatic identification systems. Such information remains to be hard for processing without human interaction.

Barcodes make tagging process significantly easier. The barcodes have been developed for nearly twenty years. Hundred different types of barcodes exist, while the most used is *Uniform Product Code* (UPC) [51]. Printing and reading the barcode is carried out with electronic devices, but certain conditions must be met. The scanning device must be correctly positioned near the barcode in order to read the data from it. Barcodes make tracking processes faster when compared to manual mode. Still, the human factor and possible counterfeiting must be considered. This technology was the best solution for a while, but it was impossible to build a fully automated tracking system for no alternatives existed.

A new generation of barcodes is known as *2D barcode* or *bidimensional barcode*. The main difference from general barcodes is that data is extended to the second dimension, which enables storing more data. There are hundreds of 2D barcode standards, including black and white and colored versions. 2D barcodes inherited strong sides as well as some weak sides of barcodes. It still needs proper reader positioning and light conditions.

A new technology called RFID, which uses radio waves, appeared to concurrent barcodes. The size of RFID chip is very small while data it store can be large. For example, a passive *High Frequency* RFID tag may store up to four Kilobytes of data and active tags are capable storing hundreds of Kilobytes of data while 2D barcodes may store three Kilobytes of binary data. RFID technology puts tracking to a new level where human controlling is minimal or not needed at all. With RFID, tracking of objects can be completely automated. Applying modern anti-collision algorithms makes possible to get information about each product in a pack by just passing the whole pack through an RFID scanner, rather than scanning each product label. Currently RFID equipment is more expensive compared to barcode equipment, but further development of electronics causes lowering the prices of RFID chips. Currently cheapest tags are passive ones, because they work without battery and have less complex internal circuitry. Reaching the cost of 5 cents per tag is possible, but requires purchasing millions of tags. Still, barcodes is the most widely used technology nowadays for tagging, except several nation-wide RFID projects [50].

With development of technology, RFID is becoming more wide spread, for example in mobile technologies. Mobile phone manufacturing companies such as Nokia and Motorola produce RFID enabled models of mobile phones and extension modules for RFID support. *Near Field Communication* technology which is supported by Nokia phones simplifies the way mobile devices interact with each other or information that is stored in RFID tags. The way that RFID phones work is quite simple. A tag and a reader are embedded inside the mobile device which together may store, transmit and read data wirelessly. It allows receiving and sharing information, making payments, carrying out ticketing control, security authorization, and used for many other purposes.

Barcodes are mostly used for tagging goods and require scanners for reading them. Also an integrated camera and decoding software are required to work with barcodes and 2D barcodes. In the case of RFID, a special hardware is needed, which is still not common for modern mobile phones. Detailed comparison of 2D barcodes and RFID in the scope of mobile technologies will be considered later in thesis.

Previously MUPE did not support RFID tag reading, and there was a need of such plugin. MUPE was used in development of pervasive environments such as SciMyst [43, 45], TekMyst [44] and LieksaMyst [58]. After a plugin is developed, RFID technology might be utilized in these environments.

There was no research found dedicated to comparing of 2D barcode and RFID technologies in the scope of pervasive mobile applications like MUPE. In the case of MUPE it was impossible to conduct such study before, because no plugin capable of reading RFID tags existed. This thesis is focused on research regarding comparing usability of RFID and 2D barcode technologies. The study contribution includes a plugin for MUPE, which extends its capabilities and allows reading NFC/RFID tags. The outcomes and conclusions of this research may be used for further pervasive application development and help choosing the best tagging technology applicable for a concrete case.

1.2 Definitions

This section defines the main terms which are used in this thesis.

2D Barcode

Visual two-dimensional way of representing information. It is similar to a linear (one-dimensional) barcode, but has more data representation capability.

Auto Identification

Auto-Id, a real-time process of automatic data collection and identification. Examples: barcodes, 2D barcodes, RFID, biometrics, optical character recognition (OCR). [19]

Game

It is a structured activity, usually undertaken for enjoyment and sometimes also used as an educational tool. Key components of games are goals, rules, challenge, and interaction [52].

Mobile device

A portable computing device supporting communication and running applications. Such devices are: a mobile phone, Smartphone or PDA (Personal Digital Assistant).

Pervasive computing

Also referred as Ubiquitous or Location based computing, a model of human-computer interaction that involves processing of information integrated into objects.

Plugin or plug-in

A hardware or software module that provides specific feature or service to a larger system. [20]

RFID tag / tag / label

An RFID tag is a microchip combined with an antenna in a compact package. The packaging is structured to allow the RFID tag to be attached to an object. The tag contains a unique serial number, and may have other information.

Smartphone

There is no standard definition of this term: a handheld device integrating mobile phone capabilities and more common features of a handheld computer or PDA.

1.3 Structure of thesis

This thesis is divided into six chapters. The topic and main terms are introduced in Introduction. Chapter two starts with research questions and describes different research methods used to answer these questions. Chapter three provides an overview to barcodes technology and continues with description of radio frequency identification systems and its components. Then there is an overview to existing research on RFID and 2D barcodes and examples of using them in pervasive applications. The purpose of this chapter is to analyze technologies, their advantages, disadvantages and usage. Chapter four is dedicated to description of the implementation part of research. The purpose is to describe development of the application that provided a base for conducting experiments. Chapter five describes the experimental research part of the study and contains study settings, process and the results of conducted study. The last chapter contains conclusion, critics and future work sections.

Chapter 2 Research questions and methods

This chapter contains a list of research questions and describes different research methods used to answer research questions.

2.1 Research questions

Selecting proper technology from existing options to be used in mobile pervasive applications is usually not an easy task. This research is quite original and nobody did it before for Multi-User Publishing Environment (MUPE). MUPE is an application platform for mobile multi-user context-aware applications (see subsection 4.1.1). The goal of this research is to conduct usability testing to compare RFID and 2D barcodes technologies attributes like speed of reading a tag, convenience and more in the scope of MUPE. The results of this research might further help assessing the attributes that affect the decision about technology to be used for a certain application. Reaching the goal of this research required implementation of NFC plugin for MUPE platform to enable accessing an RFID sensor of mobile phones and a test application for experiments. One of the purposes of this thesis is to conduct a literature review and aggregate the knowledge in the field of RFID and 2D barcodes. Another purpose is to introduce these technologies and show their practical use and applications.

Research questions represent goals and purpose of thesis:

1. "*What are the existing applications for RFID?*" Knowing the areas of successful usage of RFID technology might be useful when planning and implementing a pervasive system or application. Furthermore, it allows highlighting the benefits that RFID technology brings.
2. "*How RFID and 2D barcodes are compared to each other?*" Having pros and cons of each technology in mind is very important when selecting the technical approach to solve a problem. Each technology has its features and therefore should be applied to a concrete case when its advantages are fully utilized.
3. "*What are the users expectations regarding RFID and 2D barcodes?*" Many people do not know or not familiar with RFID and 2D barcodes technologies. Some of them are not even aware of using it (for example, university electronic key is in fact an RFID tag). Finding out an answer to this question helps revealing actual user perceptions and preconceptions regarding these technologies.

4. "*Which of two technologies users would prefer to use in their everyday life?*" Research is designed in a way of allowing participants to interact with RFID and 2D barcode technologies and after they may carry out a decision on which technology is more preferable. Knowledge of results of this research might be useful for example, in pervasive applications development for everyday life scenarios.
5. "*Which of two technologies users would prefer to use in pervasive mobile applications like MemGame?*" The answer to this question provides information about users' preferences of technology to be used in more specific area: pervasive mobile applications.
6. "*How do the RFID and 2D barcode technologies affect players' game success?*" Playing a game includes interaction with radio frequency and visual tags, thus there is a difference in usability attributes that shows up clearly. This research highlights them and provides evaluation of the game performance statistics of playing two game modes utilizing RFID and 2D barcodes technologies respectively.

Answering the last three research questions requires an application for usability testing and implementation of this application is a local development goal. Implemented application is a memory training mobile game where users may play either with 2D barcodes or RFID tags. A questionnaire was prepared and users were suggested to play a memory game in both modes and fill in the questionnaire. There were seventeen Computer Science students from the University of Joensuu who participated in this research. Each of them played game in two modes and left their feedback in suggested questionnaire. Collected data was used to evaluate and compare 2D barcode and RFID technologies.

2.2 Research methods

It is important to spend time choosing the appropriate method for research of any kind. Once this is done, following a selected method enables reaching the goal of the research. The best research method can never be determined for hundred percent sure. Every new study or research is started from the very beginning. And the starting point is selecting the methods to be used.

Qualitative and quantitative research

Quantitative research is a kind of research that relies primarily on the collection of quantitative data [21]. Quantitative research is based on numbers and statistics. It is used to investigate quantitative properties of a phenomenon and for further modeling, forecasting and other applications. Researchers acquire data with different techniques, for example with questionnaires. The quantitative research often uses large data sets to validate hypotheses. This method of analysis is easily related to scientific practices for it is based on statistics and concentrates on what can be measured. Sample quantitative research traditions: Questionnaire, Causal-comparative, Correlation and Experimental research. Details on these methods are below:

1. Questionnaire (survey) approach is used to determine proportions or frequencies within a population. The example is election poll. Used tool are surveys (representative set) and censuses (every individual).
2. Causal-comparative (case-control) research. Researcher typically compares a group to one or more different groups or compares the same group at different times and does not manipulate a variable. It is best applicable to situations in which an effect is known, but the cause is not known. Still, it is hard to find a cause without a lateral research.
3. Correlation research is designed to find how one or more variables change in relation to other variables change. It may be used for prediction or multi correlation analysis. The correlation coefficients r are in [-1...1] range, where the |r| shows the strength of the relation. It is often used in statistic applications.
4. Experimental research. The researcher manipulates an independent variable and determines how changing that variable affects one or more dependent variables.

Qualitative research is a research relying primarily on the collection of qualitative data [21]. Qualitative approach can be used to achieve domain understanding of a phenomenon and is designed to answer “why” question. This method may help to reveal some details which quantitative approach may miss. Qualitative approach has own techniques and methods to analyze and interpret the environment and data collected. Compared to quantitative approach, qualitative approach is more subjective as it is based on researchers’ interpretations. The question about unambiguity is open, for interpretations may be too subjective leading to improper conclusions. Within being subjective, qualitative approach may generate new ideas and concepts. Qualitative research gives a large variety of methods to be used like Narrative, Phenomenological, Ethnographic, Case study and Grounded theory research:

1. Narrative research method is suitable for cases where life stories are meaningful. Used techniques are interviews and documentation.
2. Phenomenological technique is used for uncovering the essence of a lived experience or phenomenon. The researchers take interviews from individuals, add own experience and make a summary of event.
3. Ethnographic research goal is a description of principles, values, behavior of a group from certain culture level. Observation and interviews are used.
4. Case study research is an empirical inquiry that investigates a contemporary phenomenon within its real life context, especially when the boundaries between phenomenon and context are not evident. Researchers conduct data collection using available sources and then analyze the acquired data.
5. Grounded theory research goal is to create a theory that is based on the data collected. The ideal result of a grounded theory study is a substantive theory that explains the phenomenon. It is suitable when no theory exists, or a theory is partly available.

The mixed approach suggests using strong sides of both two methods. It is used in cases when several techniques are needed for conducting a research. Mixing approach makes possible to include the benefits from both quantitative and qualitative approaches. Therefore mixed approach provides better flexibility to researchers.

Descriptive research

This method answers the "who, what, when, where and how" questions of a process being researched. It provides the number of times something happens, or frequency, leading to statistical methods. Typical methods used in descriptive research are:

- Questionnaires
- Sampling
- Interviews

The thesis does include evaluation of user’s experience of 2D barcode and RFID technologies and user’s opinion on potential uses in their everyday life. Therefore questionnaire is an appropriate method for this research.

Research methods summary

The choice between different research methods depends on the aims of the study. There is a problem to solve which comes up with research questions. As the part of my study is based on exact data and another part is implementation, mixed or pluralistic approach is used. Quantitative and qualitative research may complement each other and pluralistic research combines its advantages together.

One of research methods used in thesis is literature review. This method is about searching for relevant information sources and discovering existing research in the relevant field. Conducting a literature review allows answering the first and partly the second research questions. The sources of information are: Joensuu University Library, IEEE Xplore and ACM scientific databases, Internet sources and publications.

Other method is design-based research, which includes design and implementation of a mobile game application "MemGame" and an RFID plugin for MUPE. This game is based on MUPE client-server application and utilizes RFID and 2D barcode technologies. Further chapters would describe this application in more precise way. Implementation of such system involves comparing of mentioned technologies and reviewing their features. It allows answering the second research question.

Working application is a starting point for applying the next research method – experiment and evaluation. Experiment involved volunteers for testing and a questionnaire to record their feedback. A pre-test part of the questionnaire (see Appendix, "before test" section) helps to understand the background of participants and a post-test part (Appendix, "after test" section) is to record users' feedback of usability study. Evaluation of results gives answers to the last four research questions.

The whole research connects different research methods to one flow, which starts with literature review and analysis (fig. 2.1). Different sources of information are reviewed and processed for further use. The next phase is design-based research which outcome is implementation of a mobile application for testing. And the last phase is conducting experiments and evaluation of obtained results. Evaluation of results may affect the design of a system, thus later it is possible to return from last phase to the implementation phase.

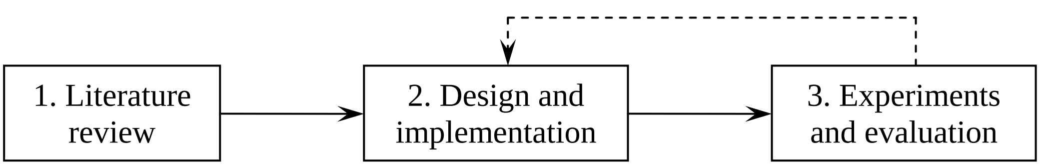

Figure 2.1. Research methods in work flow.

Chapter 3 Mobile technologies and tagging

This chapter begins with an overview to barcodes technology and continues with description of radio frequency identification system and its components. The last section gives an overview to existing research on comparing these tagging technologies and using them in pervasive mobile applications.

3.1 2D barcodes overview

Most of the people saw barcodes (fig. 3.1) printed on goods and food they buy in stores. *UPC* and *EAN* codes are mostly used for labeling such products, while the number of different barcode types is over three hundred. Since barcodes are cheap to produce and machine recognizable, they are very popular tagging technology. Usually barcode labels contain a unique serial number for storing in database and such a little capacity of data was enough. This unique identifier is used to access additional product information like name or price stored in database.

Figure 3.1. Barcode: UPC (left) and Code-93 (right)

The needs of market were growing and in 1987 [22] the first 2D barcode specification was introduced. The *Code 49* was brought by Intermec Corporation and was actually a series of barcode one on the top of another. The new specification allowed storing more data in smaller space by utilizing the second dimension of barcodes. 2D barcodes use a visual representation of binary code: a white module is zero and a black module is one, or vice versa. Also there are barcodes that use more colors in its coding scheme.

There are more than 20 different types of 2D barcodes nowadays. Typical 2D barcodes examples: *QR Code, PDF417, Data Matrix, Semacode* and *MaxiCode*. A PDF417 2D barcode may encode 1850 alphanumeric data while with one dimensional barcode it is difficult to encode 30 characters.

Figure 3.2. 2D barcode: PDF417

PDF417 (Portable Data File) is a type of 2D barcodes that supports fully textual, binary, and numeric data (fig. 3.2). It consists of 17 modules each containing 4 bars and spaces. PDF417 supports setting vertical and horizontal dimensions specified by user. Linking is a feature of this specification, which allows linking PDF417 barcodes to other ones, consequently increasing the amount data to be stored. PDF417 supports error correction, which enables making corrections for missing data due to a damaged or defaced label. Part of the label can be corrupted, and because of PDF code redundancy, it can still recover all the information encoded. This standard is used for encoding large amount of data characters. The US Department of Defense has declared PDF417 its "official 2D symbology" [23]. Another examples where PDF417 is used includes logistics, manufacturing, ticketing, healthcare and transportation.

Figure 3.3. QR Code (left), Data Matrix/Semacode (center) and MaxiCode (right).

QR Code (Quick Response) is a matrix type two-dimensional barcode (fig. 3.3 left). It may encode more than seven thousand numeric symbols and is similar to Data Matrix in a way that it has dark and light square data modules. The data types carried by QR Codes may be text, numbers, characters, URLs and even files. It has position detection markers on its four corners. A reading device like mobile phone camera needed for reading such code. QR Codes are used in many areas, for example in industrial tracking, mobile phone applications, manufacturing, rental services and sales applications. [24]

Data Matrix is a matrix type two-dimensional barcode that uses a visual representation of binary code. It has two solid lines and two alternating dark and light lines on the perimeter of the barcode (fig. 3.3 center). Data Matrix is capable of encoding large amount of data characters like text and numbers and supports error correction. It is used to store serial number of products and other information during production, in pharmaceutical industry and manufacturing. Initially Data Matrix was created for the Space Shuttle Program, where millions of items must be tracked.

Semacode is a machine readable 2D barcode which was created to link objects of the real world to the Internet. It uses the Data Matrix format. A Semacode is a small symbol that encodes a standard, web-oriented URL [25]. The URL is embedded into a 2D barcode together with error correction information. When the Semacode is decoded by software, it launches a web browser and opens the embedded URL.

MaxiCode is a fixed size type of 2D barcode containing a number of hexagonal modules instead of classic square modules (fig. 3.3 right). MaxiCode has a marker in the center for detection. It can be read with a camera and decoded by software. MaxiCode is designed to support error correction. This standard was introduced by United Parcel Service of America to quickly scan packages. It has been certified by AIM and ANSI as the recommended symbology for sorting and tracking purposes.

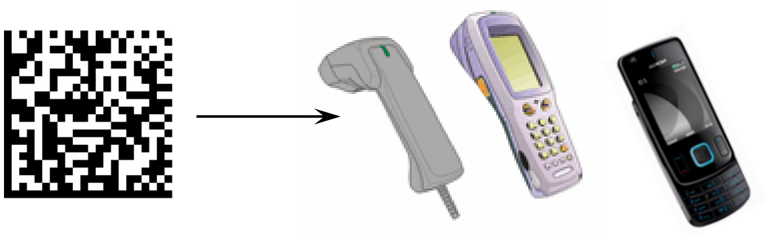

Figure 3.4. 2D barcodes may be read with special readers or with cameras of mobile devices.

Working with 2D barcodes requires special hardware (fig. 3.4) and software. In case of special reader devices the software is already put into device. Mobile phones may read 2D barcodes if they have onboard cameras and proper decoding software installed. Some models of mobile phones have this software preinstalled and phone is ready to work with 2D barcodes (e.g. Nokia N82, N93, N93i, N95, N95 8GB, E66, E71, E90 and 6220 Classic). [26]

Exact decoding process depends on the type of a tag which is being decoded. Consider decoding an Internet link (URL) embedded into a Semacode. A mobile phone with camera and Semacode software installed in it are needed for this purpose. When the user points mobile phone's camera to the 2D barcode and presses a button to read it, the mobile phone camera takes the image and the software recognizes a 2D barcode in it. Semacode has two black solid and two alternating black/white border lines to identify orientation in space. Then the software extracts the data coded with black and white blocks from the visual tag and the output is an URL. The browser is launched automatically and takes the user to a website by the Internet link decoded from the Semacode tag.

Some parameters of mentioned 2D barcode standards may be found in table 3.1. [24]

Table 3.1. 2D barcodes overview.

Name	**QR Code**	**PDF417**	**Data Matrix**	**MaxiCode**
Type	Matrix	Stacked Bar Code	Matrix	Matrix
Developer	Denso	Symbol Technologies	RVSI Acuity CiMatrix	UPS
Numeric capacity	7,089	2,710	3,116	138
Alphanumeric capacity	4,296	1,850	2,355	93
Binary capacity	2,953	1,018	1,556	-

2D barcodes are now used in many areas of applications, for example: logistics, office and factory automation, postal services and mobile phones. In this research Semacode type of 2D barcodes was used. This standard is open for public use and the MUPE plugin for decoding Semacode was developed already. Compared to concurrent QR Code standard (table 3.1) Semacode has a number of advantages:

- Data Matrix is 30 to 60 percent more spatially efficient for encoding the same data, meaning that the barcodes fit more easily onto the page or screen.
- Data Matrix has more third-party industry support for both creation and decoding.
- The minimum size of Data Matrix is 77 percent smaller than QR Code.

Based on advantages, Semacode (Data Matrix) is the best choice to be used in this research compared to QR and proprietary formats. [27]

3.2 Radio Frequency Identification system

“Radio Frequency Identification is a technology that allows a small radio device attached to an item to carry an identity for that item” [53]. Items may be goods, pets and people. The RFID system includes at least a tag (transponder), a reader (interrogator with antenna) and a data processing environment, which operates the obtained data. The RFID enabled mobile phone may function as a processing unit. In this case the reader and the processing unit are integrated to one handheld device (fig. 3.5) [28]. Due to many possible uses of RFID, there are a lot of differences in RFID systems components: different types of tags as well as variety of readers.

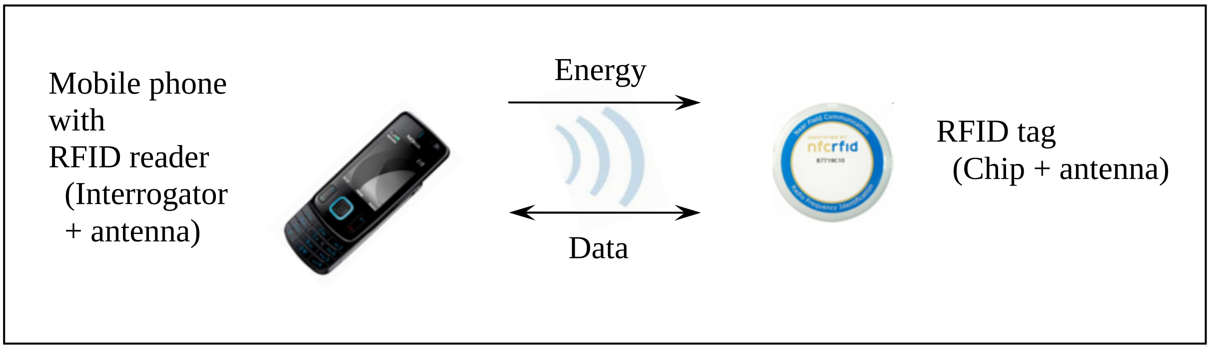

Figure 3.5. The mobile device as part of the RFID system.

The function of RFID systems may be described in the following way. Reader’s antenna emits radio waves and once a tag (passive) is within the working range, it receives the radio signal. Then the tag responds back with own data message. The reader decodes received data from the tag and this data is passed to further processing.

3.2.1 RFID tag

The RFID tag usually has an integrated circuit or chip and an antenna. This enables tag responding and emitting a radio frequency. Tags may be categorized by power type (*active* or *passive*), memory capacity / working mode (*read only* or *read and write*) and frequency range.

Read only tags are the simplest and cheapest tag type which contains a unique identifier which cannot be changed. Another type of RFID tags is called Write Once Read Many (*WORM*) which mean once data is written to this tag it cannot be changed, but read many times. Read and write tags allow changing the data stored in the tags. Those tags are usually more expensive and able storing more data. [29]

Tags can be passive or active. Active RFID tags contain its own power source, while passive tags are powered by induced energy received with antenna. Active tags are implemented in more complicated way and contain battery, thus cost more. One of advantages of active type of tags is that they provide high signal strength and continuously available, while passive tags may function only in the range of readers' interrogation area. However, even with higher data capacity of those tags, passive tags have a number of advantages such as lower production cost, light weight, small size and almost unlimited lifetime. Battery equipped tags have limitations to environmental factors. For example, active tags are not suitable for operating in low temperatures.

Sometimes tags combine passive and active approaches and such tags are called *semi-passive*. They have own power source for performing several functions like powering the integrated circuit or onboard sensors. Therefore this provides a longer reading range. Semi-passive tags use radio waves from reader to power communication antenna.

RFID tags as well as readers may operate in a range of frequencies from 125 kHz to 5.8 GHz depending on the application. Basically, higher frequencies allow faster data transfer and such tags consume more power. Local regulations and licensing allocate available radio frequencies for industrial, medical and scientific applications including RFID operating. The RFID frequency may be divided into four general bands.

1. *Low Frequency* (LF: 125 kHz to 134 kHz) tags are used in many applications. They are passive tags, thus providing the lowest reading distance (less that one third of a meter) and lowest data transfer rates among tags with other working frequencies. LF tags have limited anti-collision support; it is difficult to read a number of tags simultaneously. An advantage of such tags is ability to successfully operate near liquid environments.
2. *High Frequency* (HF: 13.56 MHz) tags are passive tags too, but data transfer rate is better than in the case of LF. HF tags are cheaper to produce because of simpler antennas (fig. 3.6). Due to no limitations for HF frequency, such tags are the most popular [51]. The maximum reading distance is around one meter (information may be found in [30]). *Near Field Communication* technology (NFC) utilizes this operating frequency (see section 3.3). HF and LF tags are available for global use without licensing.

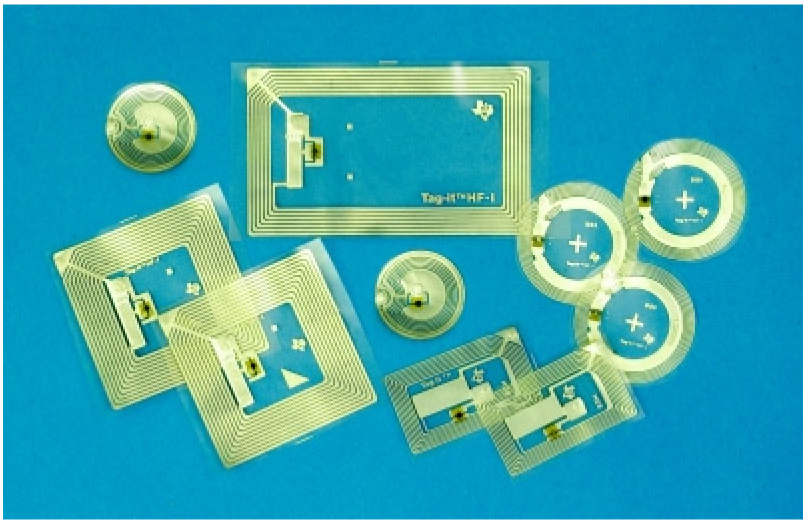

Figure 3.6. HF family of passive RFID tags.

3. *Ultra High Frequency* (UHF: 433MHz and 860 to 930 MHz) tags are implemented in several designs: 433MHz frequency is best suitable for active tags (fig. 3.7) and latter UHF frequency window is mostly used for passive and semi-passive tags. UHF tags support anti-collision protocols, which enables reading hundreds of tags at the same time. UHF tag must be isolated from substances with water or metal in order to be successfully read. The reading range varies depending on the power source of a tag and is up to 30 meters for active tags (more information may be found in [31]).

Figure 3.7. UHF active RFID tags. [32]

4. *Microwave frequency* tags are available using mostly 2.4 GHz and sometimes 5.8 GHz frequency. Higher frequency may carry more energy, therefore the reading range as well as the data transfer rate is much higher compared to tags with lower frequencies. The common issue is that radio waves of Microwave and UHF bands are easily absorbed, interferenced or reflected which causes certain troubles. The cost of equipment and usage restrictions make microwave solutions to be rarely used. Only few companies produce this type of equipment [54].

Table 3.2 contains summary description of different types of RFID tags and a short comparison of them [55]. More examples of applications for RFID technology may be found after following subsection.

Table 3.2. RFID frequency spectrum details.

	LF 125-134 kHz	**HF** 13.56 MHz	**UHF** 433, 860-930 MHz	**Microwave** 2.4, 5.8 GHz
Tag expense	High	High, Medium	Medium	High
Reader cost	Low	Medium	High, Medium	High
Work range (max.)	~30 cm	~1m	~30 meters (active)	More than 100 m (>300m active)
Data transfer rate	Low	Medium	High	High
Interference	Low	Low	Medium	High
Advantages	Low environment absorption	Available worldwide	Perfect for medium range applications	Wide access range
Common applications	Animal ID, security, engine immobilizers	Security, item tracking, ticketing.	Container, truck tracking	Access control, industry, production lines

Planning the successful RFID system involves selecting the tag type. There is a large variety of RFID tags available. Selecting the best solution suitable for concrete case is not a trivial task and is based on several factors: frequency, the nature of a material to be tagged, methods of attaching tags, reading range and rate, tag size, cost and environmental constraints. One more important factor is the device which will read and write tags – the RFID reader.

3.2.2 RFID reader

The reader (*interrogator*, *transceiver*) is a part of the RFID system for bidirectional communication with RFID tags and other RFID enabled devices. Reader's purpose is to retrieve the data stored in RFID tag and send it to further processing. Another function of the reader is writing the data into tags. Readers may have on-board or separate antenna depending on the application. Readers are powering passive and semi-passive RFID tags by transmitting radio waves with its antennas.

Usually reader is a part of a bigger system connected with LAN, wireless network and other connectivity technologies. Thus they are equipped with data interfaces for sending data to further processing. In some cases interrogators may have integrated processing device which is capable of filtering, aggregating, storing data and react on certain events. Different peripheral devices may be connected to provide visual or sound feedback. It may be LED indicators or alert speakers.

The format in which readers come may be either fixed or mobile. Fixed interrogators are mounted near doorways as door portals (fig. 3.8 right) or attached to walls (fig. 3.8 center) and are usually powered with electric cord. Mobile readers have variety of formats, usually small – it may be a handheld RFID reader (fig. 3.8 left), mobile phone or PDA integrated reader (fig. 3.5), RFID extension module for laptops or vehicle mounted device (e.g. forklifts and cargo trucks). In fact, mobile readers have less reading range than fixed readers. Reading range also depends on the frequency being used.

Figure 3.8. Different formats of RFID readers: handheld (left), wall mounted (center), portal (right)

RFID readers operate with different frequencies and protocols, therefore support a number of air and data communication protocols. Anti-collision methods and algorithms enable interrogator to reading several tags at once. This ability is critical when a number of tags are passing through interrogation zone of reader and every single tag has to be read properly (fig. 3.8 right) [33]. Anti-collision algorithms concern normal operation of several readers with overlapping interrogation areas. These methods prevent RFID readers from reading one tag for several times.

3.2.3 Applications for RFID

The first applied use of RFID-like technology dates back to World War II time (1939), when British Royal Air Force used it for friend or foe aviation identification [55]. Nowadays RFID technology is used in a variety of applications where tracking of objects, people or animals is required. Examples are provided in table 3.3:

Table 3.3. Applications for radio frequency identification.

Application	Purpose	References and examples
Supply chain	Retail inventory, shipping and receiving, warehousing, material management	Wal-Mart, Metro Group, Siemens, Mars, Wrigley. [5, 6, 50]
Consumer goods tracking	Tracking items inside stores	Prada. [8, 37]
Pharmaceutical	Drugs counterfeiting detection.	[3, 4]
Healthcare	Tracking patients, equipment, and services.	[1, 13]
Sports	Track timing	NASCAR. [34]
Library and media carriers	Track rental items, books, digital disks.	[2]
Access control	Control access to buildings, rooms and secured areas; passport and border control	USA, Japan, Holland, Norway, Malaysia. [13, 14, 15, 54]
Ubiquitous programming	Tagging objects and people for variety of applications.	[7, 9, 38, 50]
Contactless payment systems	Credit cards (MasterCard, American Express), smart cards, toll payment systems	USA. [16]
Entertainment	Amusement parks, clubs, event management, smart posters	Olympic Games. [9, 10, 11, 38]
Document management	Track documents in offices and hospitals	3M file tracking system.
Transportation management	Truck and containers tracking, rail ways, speed tracking, keyless start systems and engine immobilization systems.	Audi, Lexus, Toyota, Ford, Honda. [12, 54]
Ticketing	Public transport, bus, underground, railway, airline tickets	Washington, London Metro payment systems, ski pass
Wildlife and pets	Tracking animals.	[35]
Luggage tracking	Track baggage at airports and other transportation stations.	Hong Kong Airport, Globalbagtag. [18, 54]

More detailed description for specific and interesting applications (from author's point of view) follows.

Supply chain.

RFID is used to track items, components and materials at manufacturer's place. Parts arrive from a warehouse and upon assembling the finished products move out to customers and retailers. Pallets and bigger items are tracked using RFID tags. As RFID tags have been attached to outbound pallets and items, they are tracked while passing a facility entrance with an RFID reader. When the package arrives at the customer's warehouse, readers placed at the warehouse entrance read tags on cases and pallets and provide important information regarding the package and items being accepted.

Electronic engine immobilization systems.

The main purpose of such systems is the anti-theft protection. Radio frequency remote controls have been used for many years in automotive industry to control central locking system and built-in alarm. Systems with remote controls still could be opened with suitable tools by hijackers because ordinary mechanical keys were installed to vehicles. Since the early nineteen's RFID technology is used to solve the problem of checking the genuineness of a key. A small RFID tag is integrated to a mechanical key or remote control and reader is integrated into an ignition lock of a vehicle. When a person inserts a key to an ignition lock to start the vehicle, the reader activates an RFID tag inside the key. If it contains the proper security code, authentication system connects the electronic circuit of engine and it starts. An electronic immobilization system has proven to be efficient and no cases of hacking or cracking it were reported since 1995 [55]. But still, hijackers use another ways of stealing cars such as stealing the original key or transporting it away on trucks.

3.3 JSR257 and Near Field Communication

JSR257 (Contactless Communication API) provides the communication bridge between the application and some information medium. Contactless communication may be carried out with RFID, NFC or barcodes.

Near Field Communication is a short-range wireless connectivity technology that comes from a combination of existing radio identification and interconnection technologies. It is an extension of ISO14443 contactless card standard which includes a smartcard and a reader into one device. That allows an NFC enabled phone acting like a reader or a tag, depending on a selected operating mode. NFC supports HF operating frequency (13.56 MHz) and data transfer rates are up to 424 Kilobits per second [49].

A Contactless Communication API allows exchanging data between RFID/NFC enabled mobile devices, for example, “Nokia 6212 Classic NFC” as well as exchanging data between an NFC mobile device and a tag. The JSR257 specification (fig. 3.9) is a core of the NFC plugin which is implemented in the scope of this thesis. It is used to communicate with internal RFID sensor in order to read the data from tags.

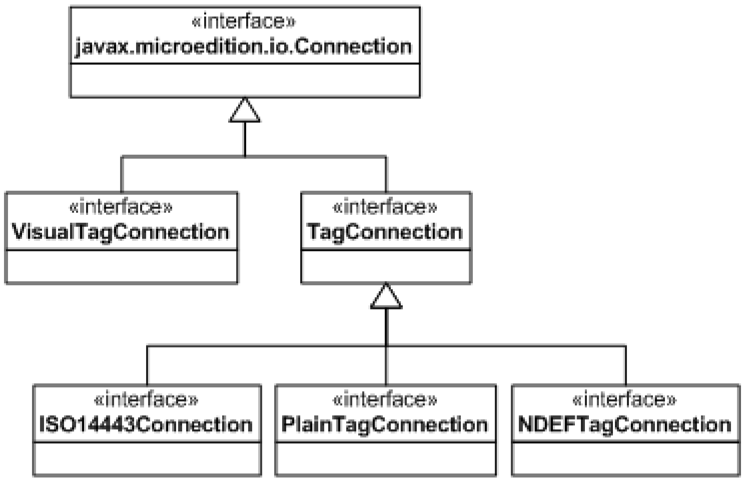

Figure 3.9. JSR 257 API UML diagram

Each connection that is used to communicate with RFID tags extends common “Connection” interface. The class diagram displays the relationship of different connections in Contactless communication API [46].

NFC is a short range communication technology and it provides a certain level of security. It may be used as a transaction framework in electronic payment systems, ticketing, toll collection and access control. Another scenario of NFC usage is service discovery, which includes content distribution, information access, and smart media communication. NFC provides the connectivity feature. Two NFC enabled devices may use this function for peer to peer data communication. With spreading of this technology a number and areas of applied usage of NFC will grow.

3.4 Research in the field of RFID and 2D barcodes

This section gives an overview to existing research in the field of RFID and 2D Barcode technologies and compares them.

3.4.1 RFID and 2D barcodes for generic applications

A number of authors dedicated articles and books to RFID. Some of them (Sandip Lahiri, Frank Thornton and Mark Brown) have brief sections with barcode and 2D barcode technologies compared to RFID.

Following are the advantages of Radio Frequency Identification systems compared to (2D) barcodes based on mentioned literature.

- ✓ *Rewrite capability.* RFID tag content may be changed several times (rewritable tags). The data encoded to the bar code can not be changed, once it is written while printing a 2D barcode.
- ✓ *No need for line of sight.* RFID readers do not require the direct line of sight to read the data from a tag. Therefore tags can be read through packaging materials, which makes possible to hide them inside. Reading the data from a tag is possible by letting it pass an interrogator reading area, possibly on a high speed. Since the principle of work of barcode scanners is the visual registration, they always require a direct line of sight for reading and proper mutual orientation of visual tag and reader is important for successful operation.
- ✓ *Increased the distance reading.* RFID tags may be read at much greater distances than 2D barcodes. Depending on the type and frequency of equipment, it allows reading tags in a radius of up to several hundred meters. At the same time, such distance is not always required.
- ✓ *Increased amount of data storage.* RFID tags can store much more information than (2D) barcodes. The chip with area of one square centimeter can store up to 128 Kilobytes of information. 2D barcodes can hold about three Kilobytes of information (in binary mode), which takes tens of square centimeters.
- ✓ *Reading multiple tags.* Industrial readers can simultaneously read thousands of RFID tags per second utilizing anti-collision protocols. A barcode reader can usually read only one bar code at a time.
- ✓ *Reading RFID labels from any of its location.* In order to ensure the proper automatic reading of barcodes, standards committees (e.g. EAN) have developed a standard of

barcodes placement on the product and transport packaging. These requirements do not apply to radio frequency tags. The only requirement is that the location of tag is within the range of a reader.

- ✓ *Working environment.* There are RFID tags with high durability and resistance to harsh conditions of working environment, while barcodes may be easily damaged. In applications where the same object can be reused an unlimited number of times (for example, the identification of containers and returnable packaging), RFID is more appropriate technology of identification, and it is not required to be placed on the outside of the package. Passive RFID tags ideally have an unlimited service life.
- ✓ *Smart behavior.* The data stored in RFID tag may contain small applications and be protected to prevent unauthorized access or manipulations. For example ISO 14443 defines a standard for such contactless smart cards. RFID tags may support different levels of security and encryption and may be used for many tasks, not only as data storage function. For example, electronic payments, access control and others. Barcode is not programmable, and is used only by means of storing data.
- ✓ *High security.* Unique identifier number that becomes an attribute of the tag on production stage ensures high security and protection from counterfeiting. In addition, the tag's data may be encrypted. Radio frequency tag is capable of using passwords to write and read data, and encrypt it during transmission. Also an RFID tag may keep open and secured data at the same time providing several levels of security. [51, 54, 56]

Advantages of 2D barcode compared to Radio Frequency Identification technology.

1. The complexity of production. (2D) barcode can be printed on any printer, while RFID tags production requires either industrial equipment or special printers.
2. The cost of RFID system is higher than the one which is based on (2D) barcodes. Companies calculate business functions like Return On Investment to find out how technology improvement may benefit the company.
3. Interference to electromagnetic fields. This is an issue that radio frequency equipment users have to deal with. However, LF and HF are less exposed to interference than higher frequency spectrum tags and readers.
4. Lack of trust, ability to gather private information about people.
5. The number of barcode based solutions is substantially greater than solutions based on RFID.
6. Lack of open standards developed for RFID. Equipment produced by some manufacturers may have different standards. Thus there are compatibility issues.

Table 3.4 aggregates most of the features of RFID and (2D) barcode technologies. The features' importance depends on the area of application and concrete case.

Table 3.4. Features of RFID and (2D) Barcode technologies.

Parameters	**RFID**	**2D Barcode**
Line of sight	No line of sight required	Line of sight required
Reading range	Up to 300 m	Up to 4 m
ID capabilities	Uniquely identifies items, cases, pallets	Identifies only item category
Item orientation to reader	Not important	Requires proper orientation
Simultaneous identification	Thousands tags per second (anti-collision dependent)	Read only single item at a time
Security, counterfeiting	High security, hard/almost impossible to clone	Easy for copying/counterfeiting
Privacy	If not destroyed or deactivated, tag may be read remotely (e.g. after leaving a supermarket)	No private data available for remote reading
Rewrite, reusability	Support read and write capability	No write capability, static information
Tag lifetime	More than 10 years	Depends on carrier material
Harsh environment resistance	Can be used in harsher environment	Weak, depends on carrier material
Functionality if damaged	Impossible	Possible
Interference with magnetic fields	Functionality is affected by magnetic fields	Not affected
Data storage	More data storage capacity (128 Kilobytes for active tags)	Limited data storage capacity (7 Kb of numeric data for QR code)
Standardization	Worldwide standards still in process	Worldwide standards in place
Size	Medium, small (25 mm2), tiny (2 mm2)	Medium, small
Cost	More expensive tags: $0.10 *additional costs to attach	Cheaper to produce: $0.001
Attachment	Currently requires two steps: tag creation and tag attachment	Single step: can be easily printed on boxes during manufacturing

RFID is the advanced tagging technology and provides many benefits. But to successfully using this technology some security issues should be considered. RFID is a wireless/contactless technology, avoiding remote manipulations requires special protection service and risk management. Typical RFID system consists of tags, a reader and a processing device. There are techniques for attacking each of components of such system. For example, some materials like aluminum foil may block radio signals thus preventing tag reading and limiting system functionality. Other examples may be broadcasting the wrong data to the reader, manipulating the tag data, Denial Of Service attack and so on [54]. Some of RFID security issues are a common to barcode technology too.

3.4.2 Existing research in comparison of mobile tagging technologies

The search for relevant information sources and existing research was conducted during December 2008 – February 2009. The sources of information were Joensuu University Library, IEEE Xplore and ACM scientific databases, Internet sources and publications in English. The search criteria contained the following keywords: mobile technologies, RFID, 2D barcodes, usability, MUPE.

A search of studies that cover mobile RFID and 2D barcodes interaction technologies gives very few results. For example, article [36] introduces Bluetooth and RFID technologies for location based games using mobile phones, like the “Pac-Lan”, a game inspired by original “Pacman” game. Another example of mobile pervasive game is the “Mobio Threat” game that combines different wireless technologies [9]. RFID, IrDA and QR codes are used for object interactions. Communication between players and the server is established by Bluetooth and Wi-Fi. Several articles described physical gestures like touching an RFID tag or scanning a visual tag in different contexts [39, 40 and 41].

One paper [42] is dedicated to a field study of user mobile interaction with visual (QR code) and RFID tags. 50 random people from Oulu and Tampere were participating in that research, which goal was to assess the knowledge and expectations of people regarding tagging technologies. Study was conducted by suggesting a person to interact with given poster with tag and a device set up to interact with that tag. Person was not informed on how to interact with it. Each test set included RFID and QR code with embedded to posters with according devices and an interview after activity. The study uncovered usability problems, misconceptions and lack of experience and knowledge about RFID and visual tags for a majority of participants. Tags’ function was treated by participants as some data storage in an encrypted form rather than acting as an Internet link. As a result of study, RFID was considered to be more interactive and to have wider functionality. Scanning QR code by taking a picture was considered to be more familiar, but less intuitive in understanding of interaction principle.

O'neill et al. [59] investigated the use of NFC and 2D barcode technologies. The study was organized as a field trial with users and included interaction with tagging technologies and an interview. Users were not instructed on how to use the suggested technologies. The study showed that users were more familiar with visual tags (2D barcode) interaction because the location of camera was obvious and the visual feedback on the display of camera image. For case of NFC, some users were slightly confused with exact location of RFID sensor in the mobile phone and manipulated or held the device in ways that were not necessary.

Further search revealed absence of studies where 2D barcode and RFID technologies are compared in usability perspective in the scope of mobile pervasive applications and MUPE platform.

Chapter 4 MemGame mobile application development

This chapter is situated between technical background and evaluation of results. It describes the implementation part of research.

4.1 MUPE

4.1.1 Overview

There are several research questions and answering them involves creating a mobile application. Multi-User Publishing Environment (MUPE) is an application platform for mobile multi-user context-aware applications. It suggests fully working client for mobile devices. Only server programming is required to build own application thus saving a lot of time. MUPE has been used before for developing pervasive mobile games such as SciMyst [43 and 45] and TekMyst [44]. I found this application platform very useful for implementation phase and it became a base for the "*MemGame*" test application.

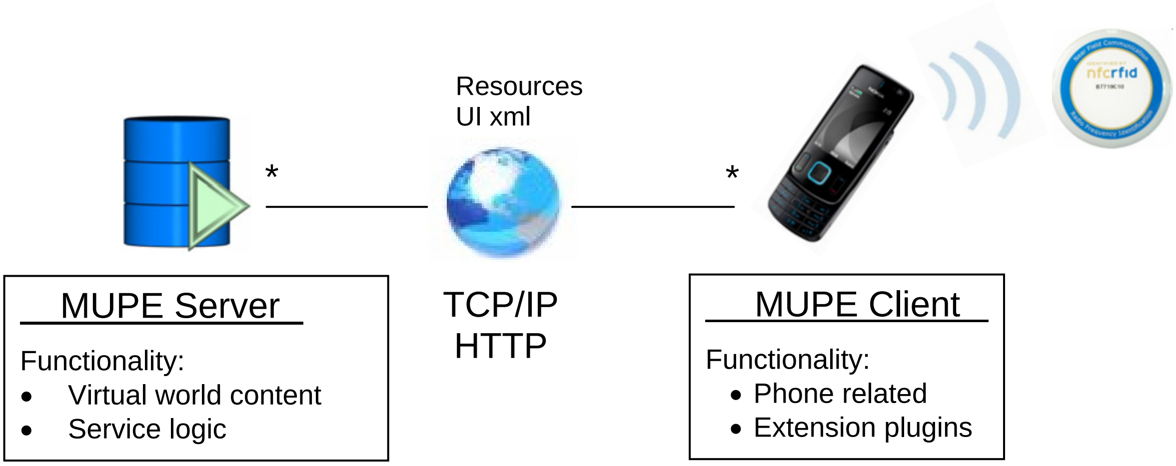

Figure 4.1. MUPE architecture.

Figure 4.1 shows the general idea of MUPE architecture. The MUPE client uses a special script language, which encapsulates J2ME functionality. Most of the things that available with Java Mobile Edition can be accessed in MUPE via MUPE XML script language. User with the MUPE client subscribes to a MUPE server from the Internet and it downloads all the functionality from it. MUPE is a client server application and users may subscribe to different servers and every server can handle a number of users connected simultaneously. This multi-user feature was used on testing phase of research.

Programmer using MUPE may concentrate fully on server-side programming as communications framework, client and client's basic functionality are in the MUPE client and do not need to be changed.

An example of XML language used for building a user interface is shown below:

```
<on_activation>
        <commondialog type='information' caption='Instructions:'
                question="Welcome to the game! Enjoy!"/>
        <show id='strLeft' />
        <attribute game_state='100'/>
        <hide id='image'/>
        <event hook='on_new_game' />
</on_activation>
```

The first tag “<on_activation>” is an event which is triggered upon loading of a user screen. Next tag is “commondialog” which makes a dialog box with specified text appear on a display. Following tags change appearance of the user screen (“show” and “hide” with attributes) and change a value of variable (“attribute” tag). “Event” tag activates the following event (“on_new_game”). Detailed description of MUPE XML language may be found in [48] and MUPE plugin development manual may be found in [47].

4.1.2 RFID plugin development for MUPE

At the initial development stage MUPE was chosen to be the base platform for further application development. Research questions of this study include 2D barcode and RFID technology to be evaluated and compared. Answering those questions require both technologies to be available for test application.

The MUPE client supports third party plugins (e.g. GPS or Bluetooth) for extending functionality of the initial client application. At the beginning of development an extension plugin supporting 2D barcode technology was already available. Support of RFID technology for MUPE required development of a special plugin. Development became one of the methods to answer the research questions. Generally plugin is a piece of software that can communicate with hardware sensor connected to the mobile device. Plugin is capable to parse the data in a suitable form into the client through the MUPE plugin interface. This may be described as shown on diagram 4.1.

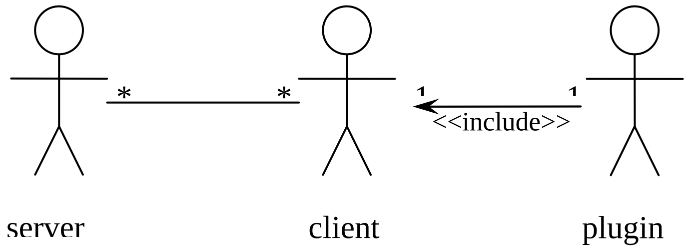

Diagram 4.1. Use case diagram of components' relation

The developed NFC/RFID plugin is also an extension module which is integrated to a client and is a part of it. This plugin allows MUPE applications to read contactless tags with RFID enabled mobile phones. Server and client applications communicate with each other through the Internet (TCP/IP, HTTP). The relation between the server and client is one to many, because the server may handle a number of users at the same time.

Use case of the NFC/RFID plugin is shown in the diagram 4.2. It describes the interaction between the client and the plugin and represented as a sequence of simple steps. Actors are the client and the server, they may be considered to exist outside the system, and taking part in a sequence of activities with the system.

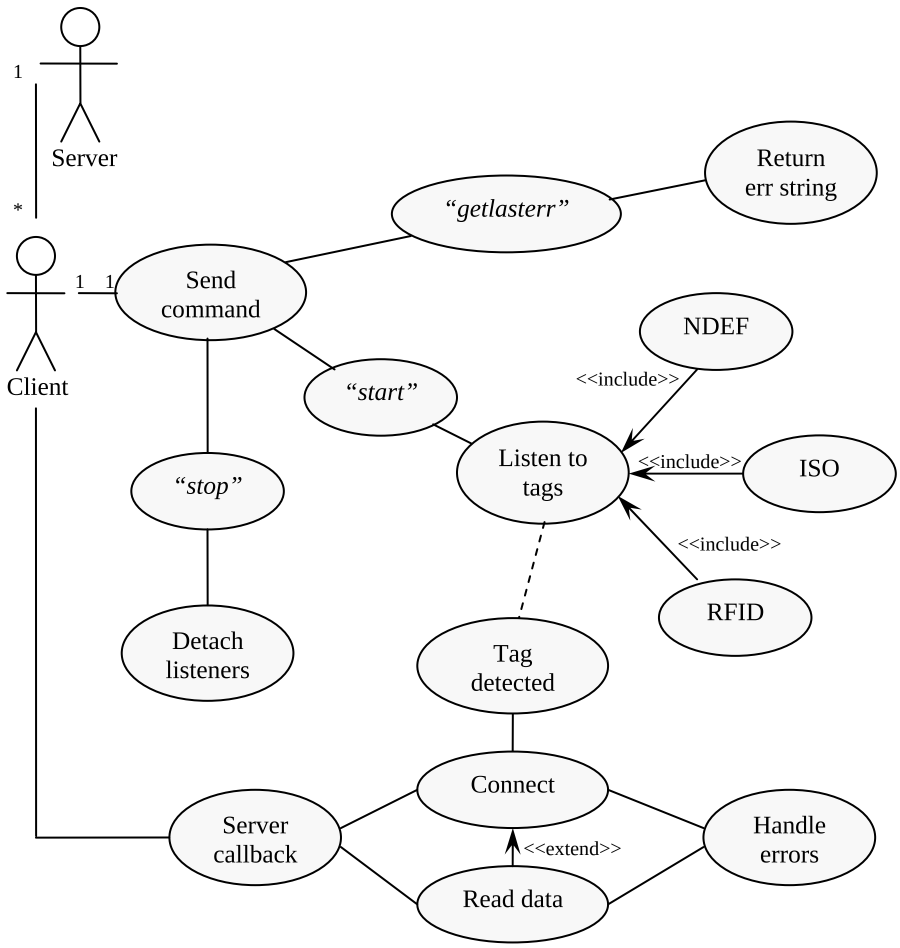

Diagram 4.2. Use case diagram of plugin

As soon as the supported tag is at the reader's proximity of reading tags, plugin tries to connect and read the message written into it. Normally the plugin handles errors that may occur. The relation between 'connect' and 'read data' is extension, because in some cases it is impossible to read the data from the tag. As the plugin successfully connects to a tag and reads the NDEF message, it sends the data to callback for processing.

Plugin allows making RFID enabled applications with MUPE. At this implementation stage MUPE supported 2D barcode and NDEF tags reading. The next stage of implementation was creating the server application.

4.2 MemGame

4.2.1 Introduction

In order to run the usability testing with users a game application was developed. It is a memory game that utilizes RFID and 2D barcode technology. This is a memory and language training game where one need to "open" cards and find two matching words. It has two modes, 'NFC' and 'Semacode'. NFC mode utilizes RFID technology and uses developed NFC plugin. Semacode game mode uses Semacode plugin and bases on the reading of Semacode type of 2D barcodes.

NFC and Semacode modes have the same idea. Let us consider the user has selected the NFC mode. An even number RFID tags are placed to form a rectangle of playing field. Each tag has its own unique ID. Then user inputs the size of playing field and reads each tag line by line to initialize the game and assign tags to inner data logic. Word pairs are assigned to tags in such manner that two tags share identical pair. When the game starts, the user "touches" the tag, the phone vibrates as the NFC plugin successfully reads the tag and the word is shown in a dialog box according to the data in the tag. As the user touches consistently two tags with the same text associated, the phone notifies the user with a dialog box and sound, and those two tags are removed from the virtual tag map displayed on the screen of a mobile phone. The game continues until the user uncovers all the tags and there are no tags left. The game may be restarted any time and tags are shuffled to form new pairs randomly.

A sequence chart (diagram 4.3) represents the order, in which the user switches between the game screens. Typical game in both modes runs through all these sequences. Precise description of screens, interface and dialogs follows in the next chapter.

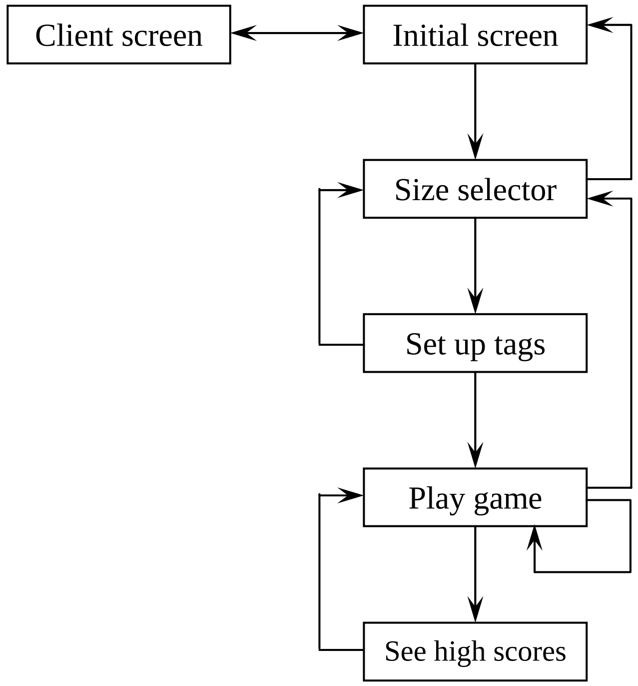

Diagram 4.3. Memory game sequence chart

Playing this game in both modes is an experience for the user. This enables participants to answering the post-test part of the questionnaire prepared for usability testing purpose. Results of the usability testing allow researcher to answer several research questions concerning comparison of 2D barcode and RFID technologies: "*Which of two technologies users would prefer to use in their everyday life?*", "*Which of two technologies users would prefer to use in pervasive mobile applications like MemeGame?*" and "*How do the RFID and 2D barcode technologies affect players' game success?*"

4.2.2 User interface

The user interface of application is intuitive. A user is guided with the information from dialog boxes with every step he takes.

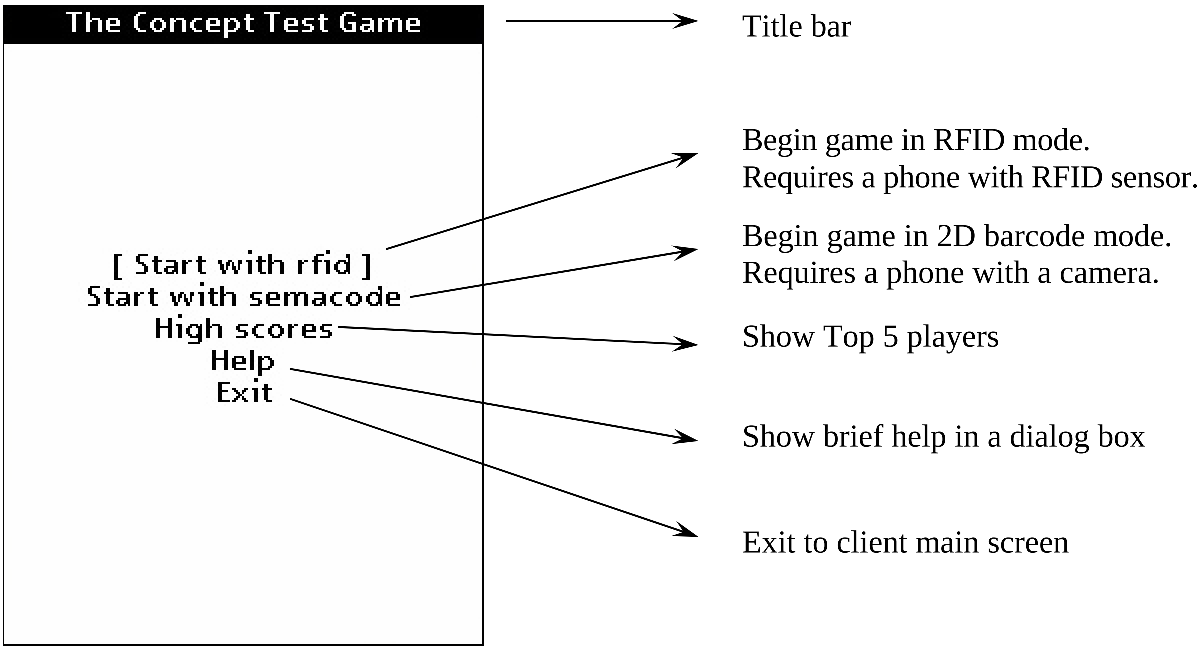

Figure 4.2. Initial game screen

This is the screen (fig. 4.2) which user sees as he subscribes the "MemGame" service from the client menu. The user may select menu items, activate selected menu item, or exit from the game.

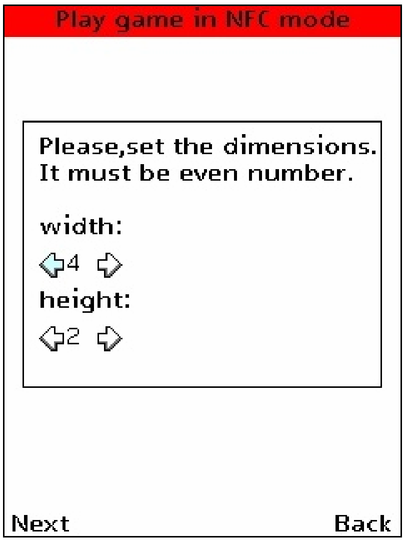

Figure 4.3. Dimension selection

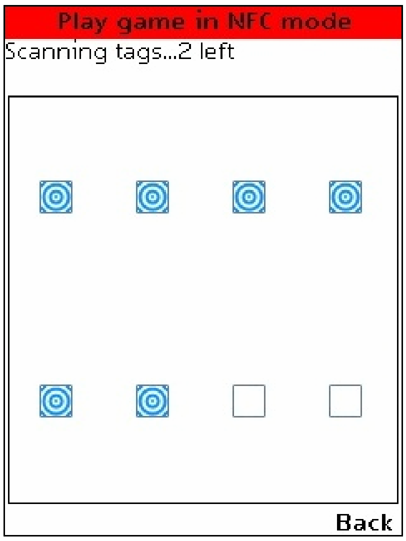

Figure 4.4. Setting up the game (4x2)

As the user selects one of the game modes, he sees the screen with two selectors which allow setting width and height of tags field (fig. 4.3). The number of tags should be even number in order to continue. The user may select certain dimension by using navigation keys to decrease or increase the number. The maximum number of tags allowed in game is ten by ten. Available actions are return to previous screen or switch to the next screen if the number of tags is even.

The next screen contains a virtual map of tags and displays the progress of scanning process (fig. 4.4). The virtual map is an onscreen representation of the order of physical tags. It is implemented for users' convenience in playing and scanning phases.

Empty tag pictures are shown from the start. The user reads tags by consequently pushing the NFC/RFID reader close to tags (in NFC mode) or by directing the mobile phone camera to a 2D barcode and pressing the Left Soft button (in Semacode mode) to scan it. As the user reads a tag, the onscreen map indicates it by changing the tag representation with blue and white circles image. The user is also notified of how many tags are left to scan. That information is located under the red title bar. Users may return to previous screen any time.

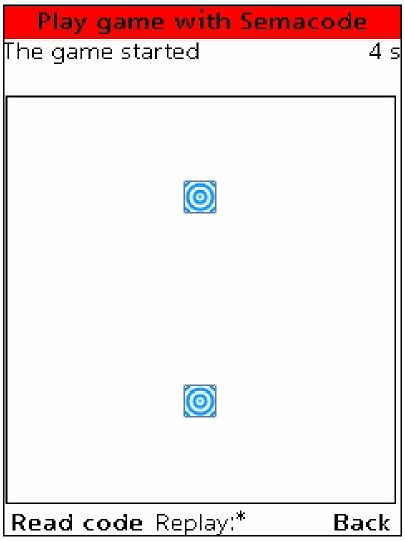

Figure 4.5. Semacode game mode (1x2)

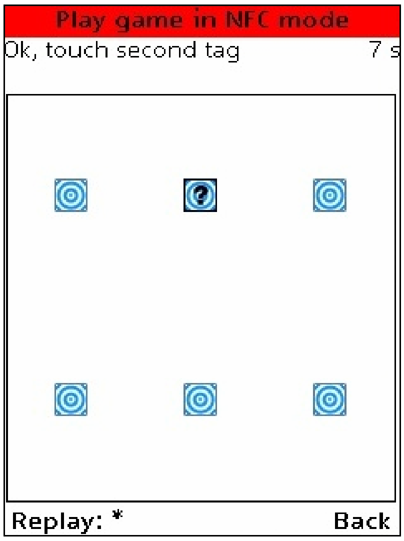

Figure 4.6. Touched a tag in NFC game mode (3x2)

As the user scans the last tag at the set up screen, he sees an information dialog box notifying about that and then user may start to play. The game starts when the Left Soft button is pressed. The play time is an important parameter for this game and it affects the resulting game score in a straight way. The playing time is displayed under the title bar on the right.

The user interface of playing screen is almost the same for NFC and Semacode mode. The difference is because the user has to press Left Soft button in order to read a visual tag (fig. 4.5) in Semacode mode, while NFC mode does not require the user to press any buttons in order to read the RFID tag.

The table 4.1 contains a list of actions available for the player at play screen in game mode.

Table 4.1. Available actions within play screen

NFC mode	Semacode	Action
✓	✓	Go back to dimension selector screen. Equals to restarting the game by means of loosing game progress.
	✓	Read a visual tag (redirect to snapshot screen).
✓	✓	Decoding a tag (Automatically after tag is read). User sees the result on a mini map of a mobile phone. The picture of currently decoded tag becomes with a black question mark (fig. 4.6).
✓	✓	Restart the game. When restarted, there is no need to perform scanning the tags again. Tags location data remains stored in the game. The tags pairs are randomly shuffled again.

Player receives game feedback every for every action. It appears in dialog boxes and information text located under the title bar. When the user reads a tag, a dialog box appears with a word in English and the same word in Finnish. The user is supposed to remember which word belongs to the tag and find pairs of tags with the same words.

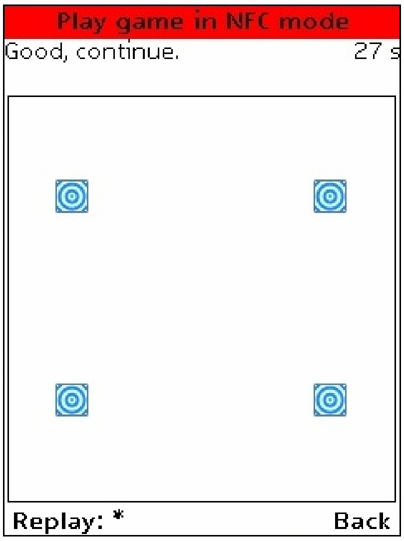

Figure 4.7. Two tags made a match (3x2)

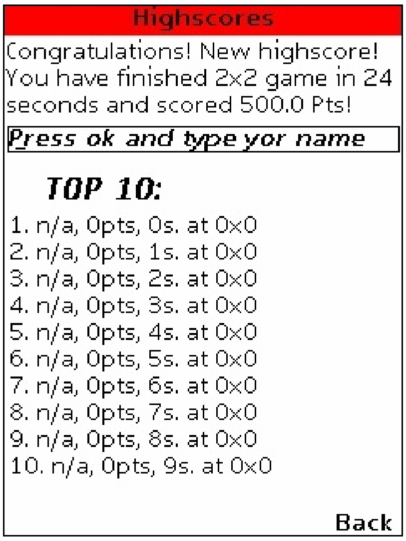

Figure 4.8. Player hits the high score

If a user touches consistently two tags with the same words, those two tags are removed from the game. Fig. 4.7 displays the example of how the screen looks like when tags number two and five are matched and removed from the map in three-by-two game.

The client application sends the data stored in a tag to the server. The server application stores the first data string and compares it to the pairing scheme. The same goes with the second data string received from the client.

There are several situations that may be:

1. the first and the second tag are not a pair; in this case user gets a notification and the tags' map changes representation of those two tags to default pictures and continue;
2. the first and the second tag are a pair; in this case the user also sees a dialog box and those two matching tags are removed from the tags map, and the game continues;
3. the third case is like a previous event, when the first and the second tag are a pair and they are the last two tags; in this case the user sees a dialog box notifying that he has finished the game; the last two tags are removed from the tags' map, and the screen switches to the high score view;
4. an exceptional case: when the user touches the tag which has already been read or removed from the game; the user gets a notification of that and game resumes.

When the user manages to pair all the tags, he sees the dialog box which notifies about it (fig. 4.8). As he presses 'ok' on that dialog, he may see the message with scores and time spent to finish the game. If the score is high enough to get into the top-10 players list, the user is asked to enter his or her (nick) name. One has to press the middle button in order to do it. After the player entered a nick name and pressed 'ok', s/he may see a nick name, scores, time and size of the game s/he completed in top-10 list (fig. 4.9).

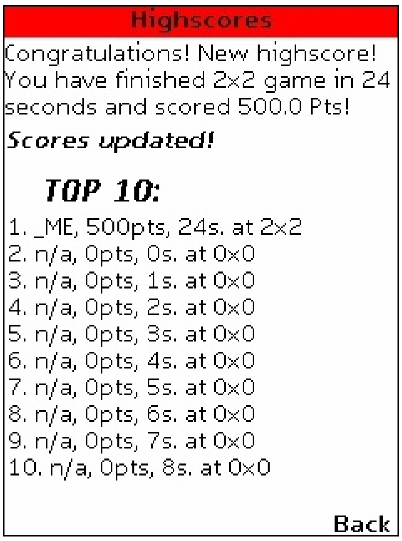

Figure 4.9. Updated top-10 list

If the score is not enough, then no input is needed. Users may press Right Soft button to return to the previous screen, and may either replay the game or return to the size selector screen.

Chapter 5 RFID and 2D barcode technology usability testing and evaluation

This chapter describes the study settings and contains results of the conducted study.

5.1 Study setting

The usability study took place in December 2008 at the University of Joensuu. The testing included playing the MemGame game with RFID and 2D barcodes and filling a prepared questionnaire.

A testing environment included the following components:

1. Testing devices were Nokia 6212 classic NFC, Nokia 6212 NFC and Nokia N95. The first two devices are NFC enabled and were used for playing the game in NFC mode with RFID tags, while the latter was used in Semacode mode to play with 2D barcodes.
2. Each device had the MUPE client preinstalled and launched. The exact client is a TekMyst client by UbiqueLab team (with Semacode and NFC plugin integrated).
3. Environment setting: a well-illuminated room for proper reading of 2D barcodes.
4. A MUPE server was available through the mobile Internet connection with MemGame service running. Each device was connected to the MUPE server during testing.
5. RFID/NFC tags – a set of six Trikker-1k CL42 RFID sticker labels based on Mifare standard 1k chips. NFC tags have HF operating frequency (13.56 MHz). Each tag had an NDEF message with record ID ‘mupe_game’ and a one digit number as a payload.
6. Visual tags – a set of six Semacode 2D barcodes. Each 2D barcode has an integer number of three digits encoded in it.

The study consisted of three consequential steps. The first step was filling in the “before test” section of the questionnaire (see Appendix). Users were asked to put their personal information and answer several questions regarding their preliminary experience and expectations regarding suggested technologies.

The second step was playing the game in two modes. Users were instructed on how to interact with RFID tags and 2D barcodes as well as how to play the mobile memory game.

After a person played the game in both modes, the third and the last step started. Participants left their feedback in “after test” section of the questionnaire (see Appendix).

5.2 Usability testing results

Results of this study help answering the last four research questions: "*What are the users expectations regarding RFID and 2D barcodes?*", "*Which of two technologies users would prefer to use in their everyday life?*", "*Which of two technologies users would prefer to use in pervasive mobile applications like MemGame?*" and "*How do the RFID and 2D barcode technologies affect players' game success?*"

5.2.1 Pre-test part

There were seventeen volunteers (five female, twelve male) from 22 to 30 years old who were invited to participate in this usability study. The first part of the questionnaire (Appendix, "before test" section) helps to understand background of participants. All of them have a mobile phone and use it for different tasks (diagram 5.1).

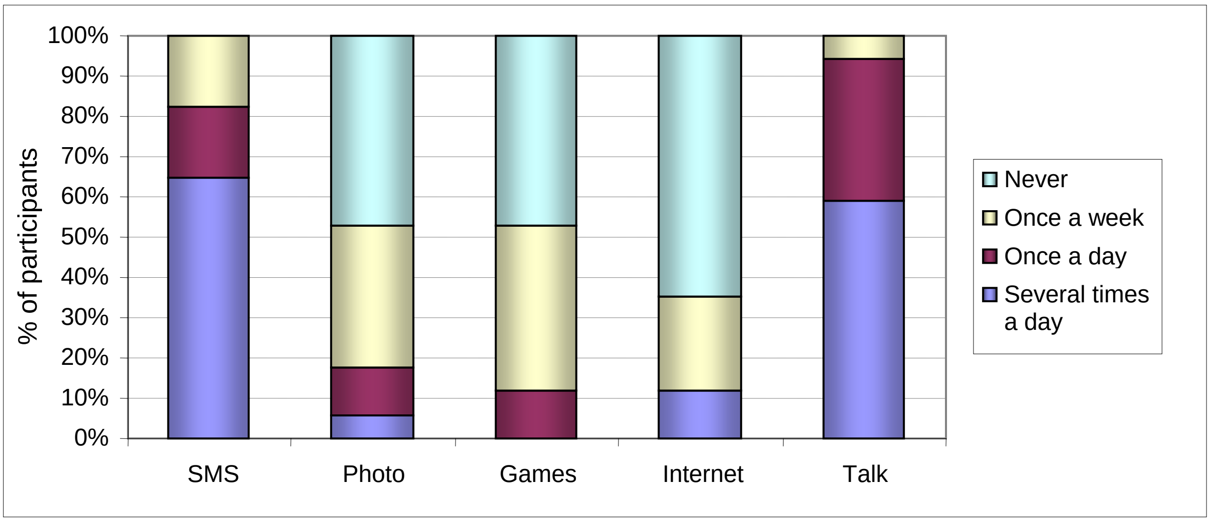

Diagram 5.1. Participants' phone related activity.

Talking on a phone and sending SMS are the most frequent things users do. Approximately half of them play games and take photos with mobile phones at least once a week. A one third of participants use their mobile phones to access Internet weekly. This information shows that every participant has a mobile phone and knows how to use it.

Diagram 5.2 contains data on users' experience in the field of radio frequency identification and 2D barcodes technologies.

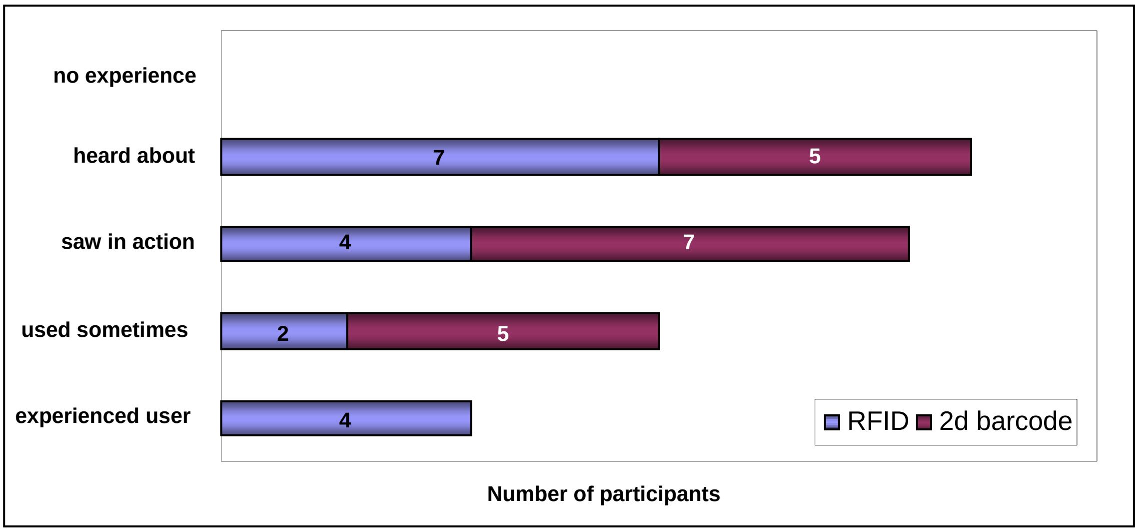

Diagram 5.2. User's experience of 2D barcode and RFID technologies before test.

Only few participants were familiar with RFID technology while the most of them (twelve participants) have used or saw 2D barcodes. Nobody of participants had good experience with 2D barcodes technology in their everyday life. At the same time among people who did not see those technologies the most of them (seven participants) heard about RFID technology.

Diagram 5.3 shows user expectations regarding the usage of RFID and 2D barcodes. This information helps answering the corresponding research question.

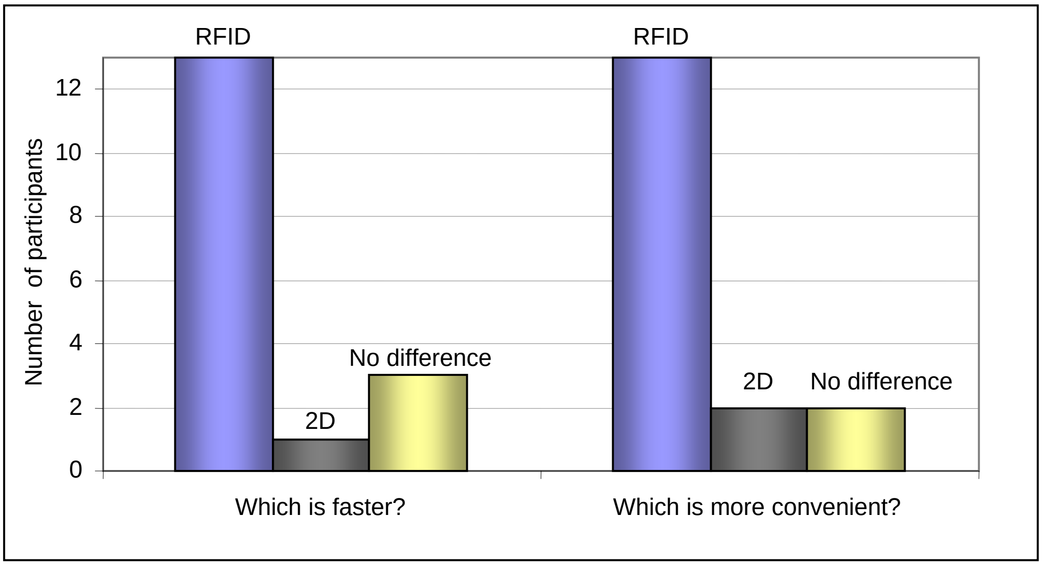

Diagram 5.3. User's expectations before test.

Convenience and speed of interaction are very important attributes of tagging technologies. These features have direct influence on the process of interaction and on what user would prefer to use. RFID and 2D barcode technologies both allow successfully performing related tasks, thus it is possible to rank them by applying such criteria. Convenience affects user's satisfaction while the speed of decoding data from a tag is a measure of effectiveness and efficiency of respective technology. It is clear form diagram 5.3 that the most of participants (75 percent) consider radio frequency identification technology to have the best performance and convenience attributes compared to two-dimensional barcodes already before the test.

5.2.2 Experiment part

The experiment part involved users into playing the game in two modes (fig. 5.1). Users were given instructions on how to interact with RFID tags and 2D barcodes and how to play the mobile memory game.

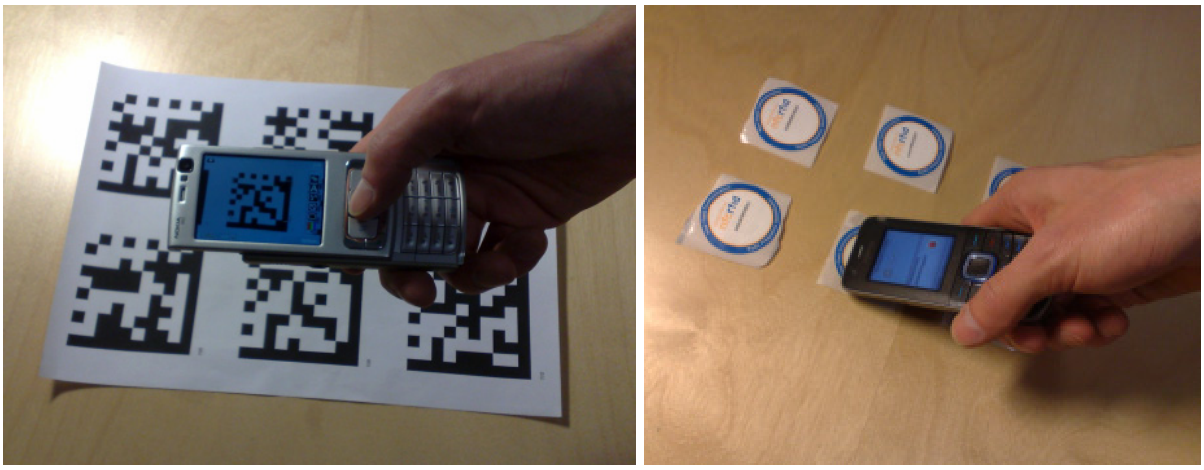

Figure 5.1. Interaction with tags in Semacode (left) and NFC (right) modes.

The MemGame is a multi-user application and several users may play it simultaneously. In this test there was a maximum of two users playing at one time because of limited availability of SIM cards and NFC enabled devices. Each participant started the game from initial game screen (fig. 4.2) and played it till the end of the game (fig. 4.9). About half of participants were suggested to start playing in NFC mode first and another half in Semacode mode first. Fig. 5.1 (left) shows an example of interaction with 2D barcode. A user points a camera of a mobile phone (Nokia N95) to a visual tag and presses a button assigned to take a photo for processing a tag. In NFC mode the process of interaction is simplified because decoding the tag requires only approaching an NFC enabled phone close enough to a tag (fig. 5.1 right).

5.2.3 Post-test part

As users filled in the information about their experience and expectations, they were suggested to play MemGame in two modes. After this step users completed the second part of the questionnaire. Users' feedback for this part of usability study questionnaire (Appendix, "after test" section) helps answering the last three research questions of the thesis.

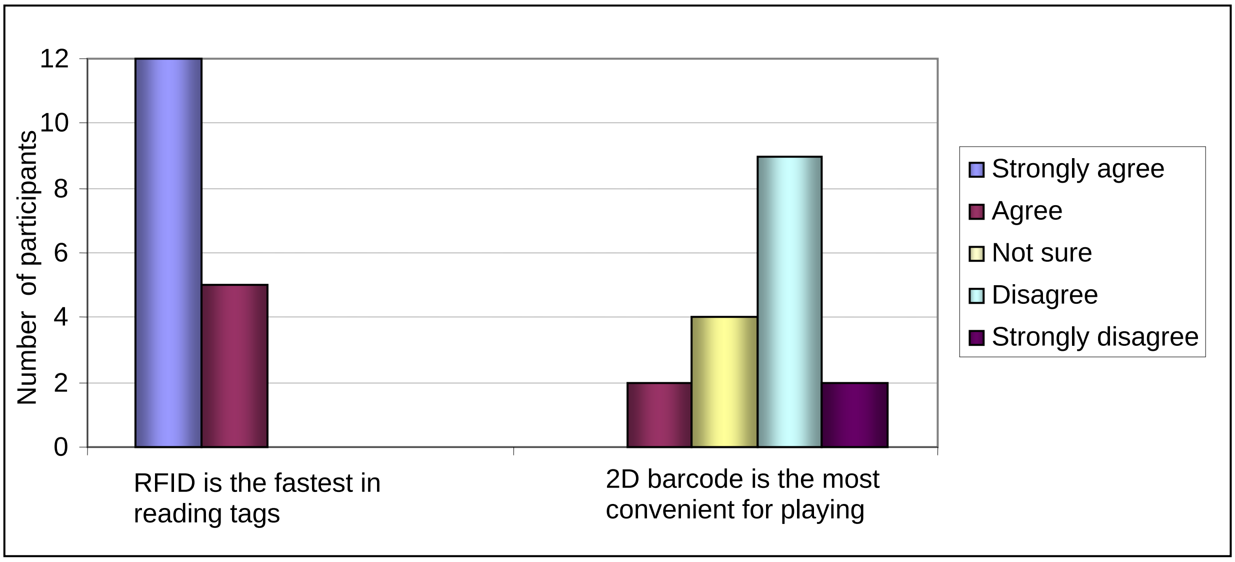

Diagram 5.4. Users' evaluation of game experience.

As volunteers gone through the usability study, all of them agree (twelve strongly agree and five agree) that RFID had shown the best performance on reading tags (diagram 5.4). That means that four persons which were thinking either that there was no difference or 2D barcode was faster (diagram 5.3, "Which is faster?" question) changed their mind towards RFID superiority. Two participants preferred two dimensional barcodes as more convenient than RFID, while eleven participants (nine disagree and two strongly disagree) think otherwise. Four persons doubted in their preferences. These questions show that radio frequency identification technology was the fastest in reading tags and only two of seventeen participants consider 2D barcodes to be more convenient.

Volunteers provided their feedback regarding what technology would they prefer to use in suggested scenarios. Most of participants preferred using radio frequency identification technology in suggested scenarios. Preferences of users are shown on diagram 5.5, where the most of area of the diagram belongs to RFID.

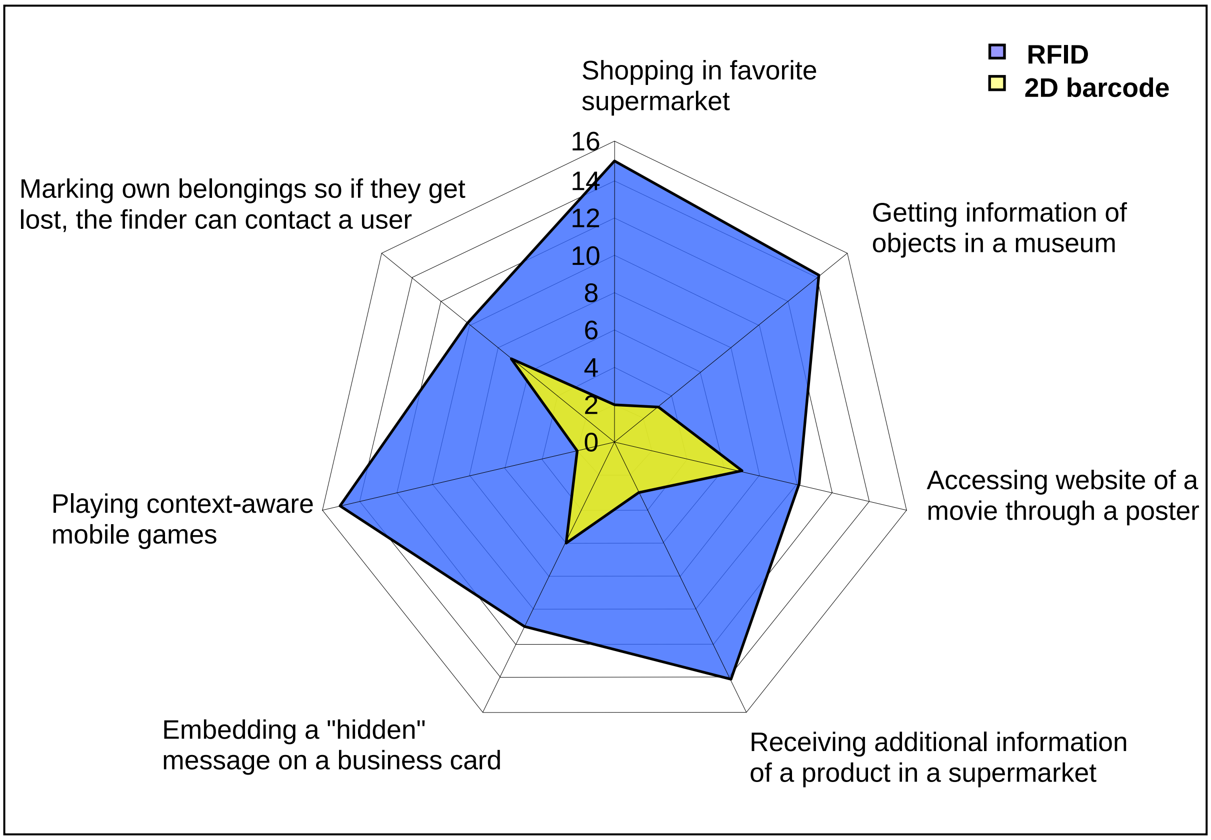

Diagram 5.5. Users' preferences in technologies for using in everyday life.

The number of people preferring 2D barcodes technology comes close to people who prefer RFID for some scenarios. For example, seven people against ten prefer using 2D barcodes to access website of a movie through a poster and marking own belongings for the case if they get lost and the finder could contact them. At the same time fifteen participants against two prefer shopping in favorite supermarket and playing context-aware mobile games with RFID technology.

Diagram 5.6 shows which technology volunteers liked most while playing MemGame. Results demonstrate that the most of users liked the NFC mode, while five of them considered no difference in NFC and Semacode modes. Fifteen participants (diagram 5.6) found that NFC mode is easier to play. The reason for that may be that in Semacode mode a user interacts with camera and takes pictures of 2D barcodes, which requires certain accuracy and conditions. Sometimes volunteers had to read a visual tag again for proper decoding. NFC mode seems to be more automated and reading an RFID tag with NFC enabled mobile phone requires only "touching" a tag. This is a one of the benefits RFID provides and people may use it without knowing the technologies or how it works.

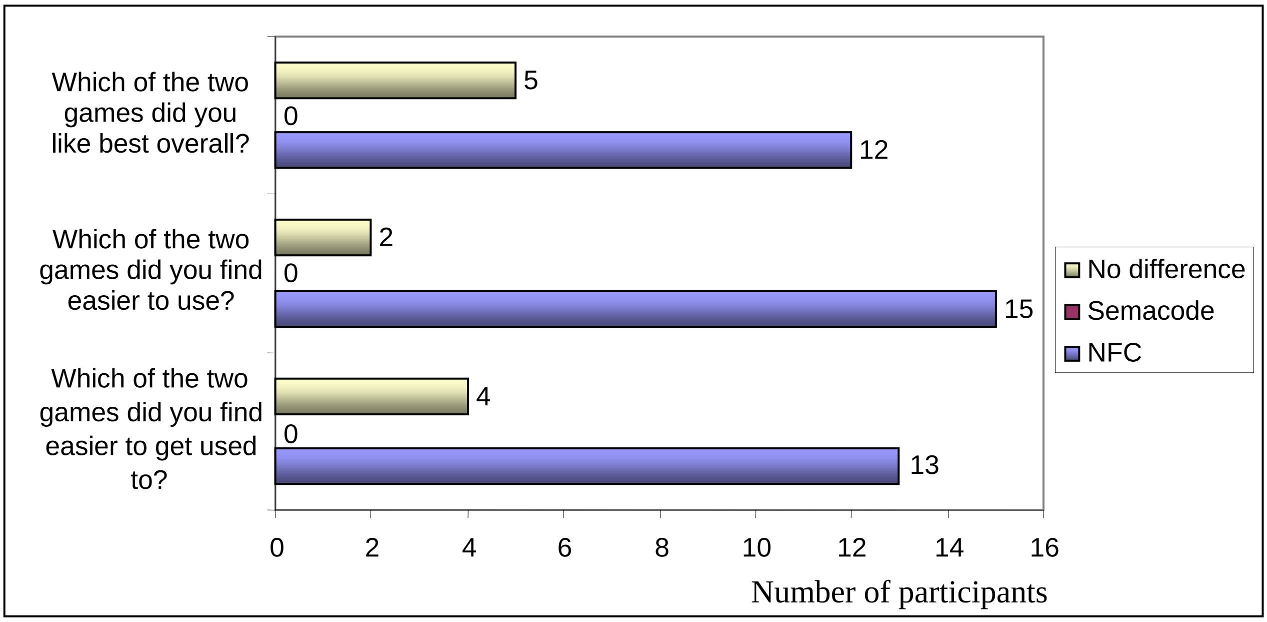

Diagram 5.6. Participants' feedback on MemGame modes.

The data from diagram 5.6 is interpreted to answer the fifth research question: "*Which of two technologies users would prefer to use in pervasive mobile applications like MemGame?*" Users' answers represent their preference in one concrete pervasive application and it may be distributed to other pervasive applications like MemGame.

Answering the next research question regarding users' success in two different modes of MemGame requires analysis of users' performance attributes: a time needed to finish the game, a total score and an amount of mistakes done. Table 5.1 contains users' in-game achievements data such as the time of completing the game, scores earned and the amount of mistakes done. For better differing of two game modes, the lowest of playing times and the lowest number of mistakes are highlighted with bold font in this table.

Table 5.1. Users' performance in MemGame.

Mode:	NFC			Semacode		
	Time (s.)	**Score (pts.)**	**Mistakes**	**Time (s.)**	**Score (pts.)**	**Mistakes**
Min	**40**	1323	**0**	68	1387	2
Max	**178**	6059	12	316	5653	**6**
Average	**69**	3446	4	143	3386	**3**

The first time MemGame was tested with a volunteer there was a technical problem in NFC mode which was fixed after. That was a reason for a poor game competition time (600 seconds). The average time for NFC mode is lower than users spent to complete the game in Semacode mode, but still, in order to provide reliable data on users' performance, this time was removed from statistics.

The score user gets is calculated with following formula:

Total score (points) = multiplier · time bonus + accuracy bonus

The accuracy bonus is an award for fewer mistakes done in MemGame and is a function of its quantity and number of tags. Of course, the number of mistakes depends on player's luck. But after a half of tags have been scanned, correct matching of tags is a matter of memory skills of a player. Diagram 5.7 shows a distribution of accuracy bonus.

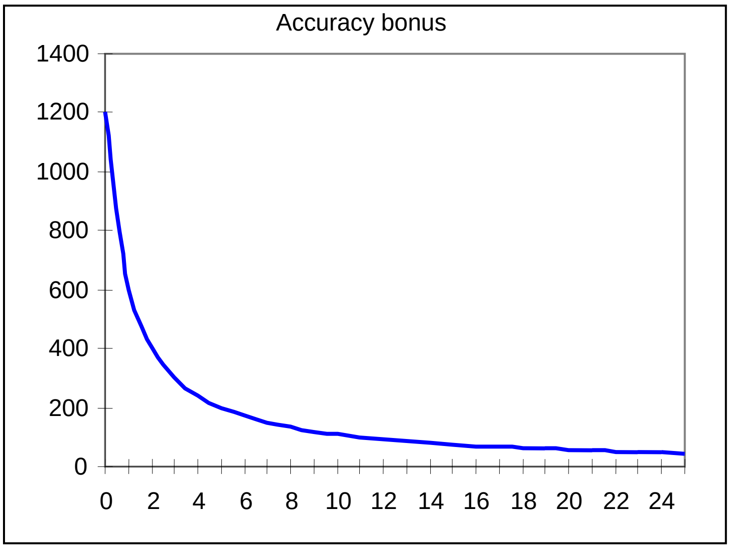

Diagram 5.7. Accuracy bonus distribution.

A time is an important factor in score calculation. The faster the player completes the game, the higher time bonus s/he gets. The multiplier of the time bonus was introduced in order to let Semacode mode players earning as much points as in NFC mode. In latter mode this parameter is set to five thousand, while Semacode has twice as much. This approach compensates the difference in time needed to read and decode a tag. The total scores formula includes such parameter as the size of playing field, which equals six for this study.

From table 5.1 it is obvious that NFC mode is leading with time performance of users. Its average time of the game completing is twice less than in Semacode mode. The main reason for that is additional time needed to make a photo for a player. Decoding a visual tag also takes some time for device. In RFID case the data is encoded into an electronic chip and can be retrieved straightly and very fast compared to visual tag.

Performance results show that the minimum number of mistakes players did is lower for NFC mode. At the same time, the minimum average amount of mistakes belongs to Semacode mode (average three mistakes against four in NFC mode). Players have more time to think and remember the data encoded to visual tags in Semacode mode as time performance shows. Possibly this allows making less mistakes.

Chapter 6 Conclusion and future work

6.1 Conclusion

Pervasive computing is relatively new area of computer technology which has expanded in recent years. It may utilize different tools and techniques like GPS, Bluetooth, visual tags, RFID and other. Existing mobile technologies extend abilities of pervasive applications and make it easy to use it in everyday life. There are different options for tagging approaches to be used in pervasive applications. 2D barcodes and RFID technology were considered in the scope of this thesis. Implementation of the mobile game application and usability testing enabled the comparison of these two technologies for pervasive applications.

The first research question was "*What are the existing applications for RFID?*" A literature review was conducted and RFID technology with 2D barcodes was introduced. Literature review revealed several examples of successful applications of RFID technology: supply chain, transportation, ubiquitous programming and other. Further development of standards and lowering the prices should cause RFID to be more spread for variety of applications.

The second research question was "*How RFID and 2D barcodes are compared to each other?*" A section of chapter 3 describes features of each technology. Among the most valuable advantages of radio frequency identification compared to 2D barcodes there are its reading range, memory capacity, speed of reading, no need of line of sight feature and reuse capability. Meanwhile, 2D barcodes are cheaper to produce, not affected by electromagnetic interference and have well established standards. That means that probably RFID will coexist with (2D) barcodes technology and they might complement each other.

The future of RFID technology for mobile pervasive computing also depends on an important factor: the device hardware must meet certain requirements. A device must have a reader in order to use RFID and for visual tags a device must have an integrated camera. The most of modern mobile phones have cameras, while only few models are manufactured with RFID/NFC sensor or RFID extension module support. The situation changes and analytics forecast that "while the yearly number of mobile phones sold rises from one to two billion in the next few years, the number of RFID enabled phones sold will rise from 134 million in 2008 to 860 million in 2018". [57]

Research question “*What are the users expectations regarding RFID and 2D barcodes?*” The fifth chapter is dedicated to experimental research. The pre-test part of the questionnaire helped to find out an answer to this question and reveal users’ preconceptions and expectations regarding these technologies. It showed that only few participants were familiar with RFID technology and most participants had experience using 2D barcodes or saw it in action. 75 percent of participants expected RFID to have the best performance and convenience attributes compared to two-dimensional barcodes. Participants were quite positive towards radio frequency identification technology.

The fourth research question “*Which of two technologies users would prefer to use in their everyday life?*” was answered by conducting an experiment. Participants interacted with RFID and 2D barcode technologies while playing the MemGame and then decided which technology is more preferable. This test had shown that radio frequency identification technology was the fastest in reading tags for users and only two of seventeen participants consider 2D barcodes to be more convenient. The results might be used for implementing pervasive applications in the context of different situations that were suggested (diagram 5.5).

Research question *“Which of two technologies users would prefer to use in pervasive mobile applications like MemGame?”* The most of players liked NFC mode because it was easier to use than Semacode mode and overall users’ perception comparison (diagram 5.6, “Which of the two games did you like best overall?”) support this fact. Results of this research show that users prefer RFID technology not only in suggested everyday life scenarios, but in pervasive mobile applications in general.

The last research question was “*How do the tagging technologies affect players’ game success?*” The game play statistics showed a difference in players’ performance attributes. Players were finishing the MemGame game twice faster in NFC mode than in Semacode mode. Taking a photo and decoding a visual tag takes more time than decoding data from an electronic tag. Nevertheless, the minimum average amount of mistakes players did belongs to Semacode mode. Players had more time to remember the data encoded to visual tags in the case of Semacode mode.

The study revealed that players showed better time performance in NFC mode. Thus, using RFID might be a better solution in pervasive applications where the interaction speed is an important or critical factor. Also visual tags required proper light conditions to be set for correct decoding. In cases when these conditions are not possible, RFID may be an alternative approach. Participants expected RFID to be faster and more convenient to use than 2D barcodes and these views only strengthened after the test. For everyday life scenarios RFID was more preferred. While RFID is clearly preferred technology, cheap price and wide availability of reader devices still makes 2D barcode a good alternative.

6.2 Critics and future work

The application was implemented for testing purposes, which gives results for one game context. If a newer version of Nokia NFC mobile phone arrived earlier, testing would be also possible with "LieksaMyst" application [58]. Probably it would give more statistics for analysis.

The research was conducted with seventeen Computer Science students. A larger number of participants should be invited for testing for future research. Also testing should give better results if participants have different background and knowledge of technologies that are introduced. As the number of participants grows, the more reliable statistics might be obtained.

The testing application seemed to be stable during experiments, but still some improvements might be implemented. This may concern changes in UI, testing with other mobile devices and server connection failure safety. If MemGame is used for language learning, vocabulary may be modified to contain more words or short sentences. The current virtual representation of tags is textual, instead or in addition some graphics and pictures may be used. Of course it causes more network traffic between client and server. There are several solutions for this issue: using unlimited mobile Internet tariffs or using local wireless networks. The latter may become possible when NFC/RFID enabled phones will support Wi-Fi as well.

Further usability testing might be more extensive and include several contexts and testing applications. As there will be more data, the obtained results could be processed with more complex statistic methods like correlation and principal components analysis.

References

1. Ho, L., Moh, M., Walker, Z., Hamada, T., and Su, C. 2005. A prototype on RFID and sensor networks for elder healthcare: progress report. In *Proceedings of the 2005 ACM SIGCOMM Workshop on Experimental Approaches To Wireless Network Design and Analysis* (Philadelphia, Pennsylvania, USA, August 22 - 22, 2005). E-WIND '05. ACM, New York, NY, 70-75.

2. Walczyk, D. 2009. RFID and Its Message. *Library Journal,* Vol. 134 Issue 1, S4-S7 2009.

3. Staake, T., Thiesse, F., and Fleisch, E. 2005. Extending the EPC network: the potential of RFID in anti-counterfeiting. In *Proceedings of the 2005 ACM Symposium on Applied Computing* (Santa Fe, New Mexico, March 13 - 17, 2005). L. M. Liebrock, Ed. SAC '05. ACM, New York, NY, 1607-1612.

4. Tuyls, P., and Batina, L. 2006. RFID-Tags for Anti-counterfeiting. D. Pointcheval (Ed.): CT-RSA 2006, LNCS 3860, pp. 115–131.

5. Wamba, S. F., Lefebvre, L. A., and Lefebvre, E. 2006. Enabling intelligent B-to-B eCommerce supply chain management using RFID and the EPC network: a case study in the retail industry. *ACM International Conference Proceeding Series*; Vol. 156, 2006. New York, NY, 281-288.

6. Niederman, F., Mathieu, R. G., Morley, R., and Kwon, I. 2007. Examining RFID applications in supply chain management. *Communications of the ACM* 50, 7 (Jul. 2007), 92-101.

7. Konomi, S. and Roussos, G. 2007. Ubiquitous computing in the real world: lessons learnt from large scale RFID deployments. *Personal Ubiquitous Computing,* 11, 7, 507-521.

8. Want, R. 2004. The magic of RFID. *Queue* 2, 7 (Oct. 2004), 40-48.

9. Segatto, W., Herzer, E., Mazzotti, C. L., Bittencourt, J. R., and Barbosa, J. 2008. Mobio threat: A mobile game based on the integration of wireless technologies. *Computer Entertainment,* 6, 3 (Oct. 2008), 1-14.

10. Rashid, O., Mullins, I., Coulton, P., and Edwards, R. 2006. Extending cyberspace: location based games using cellular phones. *Computer Entertainment,* 4, 1, 4.

11. Taylor, A. S., Harper, R., Swan, L., Izadi, S., Sellen, A., and Perry, M. 2007. Homes that make us smart. *Personal Ubiquitous Computing,* 11, 5, 383-393.

12. Brooks, R. R., Sander, S., Deng, J., and Taiber, J. 2008. Automotive system security: challenges and state-of-the-art. In *Proceedings of the 4th Annual Workshop on Cyber Security and information intelligence Research: Developing Strategies To Meet the Cyber Security and information intelligence Challenges Ahead* (Oak Ridge, Tennessee, May 12 - 14, 2008). CSIIRW '08, vol. 288. ACM, New York, NY, 1-3.

13. Garson, K. and Adams, C. 2008. Security and privacy system architecture for an e-hospital environment. In *Proceedings of the 7th Symposium on Identity and Trust on the internet* (Gaithersburg, Maryland, March 04 - 06, 2008). IDtrust '08, vol. 283. ACM, New York, NY, 122-130.

14. Burmester, M., de Medeiros, B., and Motta, R. 2008. Robust, anonymous RFID authentication with constant key-lookup. In *Proceedings of the 2008 ACM Symposium on information, Computer and Communications Security* (Tokyo, Japan, March 18 - 20, 2008). ASIACCS '08. ACM, New York, NY, 283-291.

15. Tsudik, G., Burmester, M., Juels, A., Kobsa, A., Molnar, D., Di Pietro, R., and Rieback, M. 2008. RFID security and privacy: long-term research or short-term tinkering? In *Proceedings of the First ACM Conference on Wireless Network Security* (Alexandria, VA, USA, March 31 - April 02, 2008). WiSec '08. ACM, New York, NY, 160-160.

16. Angell, I. and Kietzmann, J. 2006. RFID and the end of cash? *Communications of the ACM* 49, 12 (Dec. 2006), 90-96.

17. Neumann, P. G. and Weinstein, L. 2006. Risks of RFID. *Communications of the ACM* 49, 5 (May. 2006), 136.

18. DeVries, P. 2008. The state of RFID for effective baggage tracking in the airline industry. *International Journal of Mobile Communications*, 6, 2, 151-164.

19. Auto ID definition. Retrieved February 7, 2009 from http://www.webopedia.com/TERM/A/auto_ID.html.

20. Plugin definition. Retrieved January 1, 2009 from http://www.webopedia.com/TERM/P/plug_in.html.

21. Johnson, B., and Christensen, L. 2007. *Educational Research: Quantitative, Qualitative, and Mixed Approaches*. Thousand oaks, CA: SAGE Publications Inc. Available online. Retrieved June 12, 2008 from http://www.southalabama.edu/coe/bset/johnson/

22. Overview to popular 2D barcodes, Adams Communications. Retrieved January 24, 2009 form http://www.adams1.com/stack.html

23. 2D Barcode Symbologies Overview. Retrieved January 23, 2009 from http://www.tec-it.com/en/support/knowbase/symbologies/barcode-overview/2D-barcodes/Default.aspx#PDF%20417

24. QR code developers site. Retrieved January 24, 2009 from http://www.denso-wave.com/qrcode/index-e.html

25. Semacode developers site. Retrieved October 4, 2008 from http://semacode.com/

26. Scan and decode mobile codes with Nokia. Retrieved February 2, 2009 from http://mobilecodes.nokia.com/scan.htm

27. Choosing the best 2D barcode format for mobile applications. Retrieved January 21, 2009 from http://semacode.com/documents/best_2D_code.pdf

28. Nokia international site. Images retrieved February 2, 2009 from www.nokia.com

29. RFID solutions. Retrieved February 3, 2009 from http://www.rfidusa.com/

30. RFID information and news journal. Retrieved February 2, 2009 from www.rfidjournal.com

31. RFID research and analysis company. Retrieved January 28, 2009 from http://www.idtechex.com/

32. Wavetrend, industrial solutions company. Retrieved February 4, 2009 from http://www.wavetrend.net

33. Epicdata, industrial solutions company. Retrieved February 5, 2009 from http://www.epicdata.com/data/rfid-tag-readers.php

34. Electrocom, RFID solutions of sports timing. Retrieved February 10, 2009 from http://www.electrocom.com.au/rfid_sportstiming1.htm

35. Animal Tagging: Setting Standards for Tagging Pets. Retrieved February 10, 2009 from http://www.rfid-eblog.com/50226711/animal_tagging_setting_standards_for_tagging_pets.php

36. Rashid, O., Mullins, I., Coulton, P., and Edwards, R. 2006. *Extending Cyberspace: Location Based Games Using Cellular Phones*. ACM Computers in Entertainment, 4, 1, Article 3C.

37. Resatsch, F., Karpischek, S., Sandner, U., and Hamacher, S. 2007. Mobile sales assistant: NFC for retailers. In *Proceedings of the 9th international Conference on Human*

Computer interaction with Mobile Devices and Services (Singapore, September 09 - 12, 2007). MobileHCI '07, vol. 309. ACM, New York, NY, 313-316.

38. Media & Entertainment applications. Retrieved February 9, 2009 from http://www.barcoding.com/industry/Media_Entertainment/media_entertainment.shtml.

39. Salminen, T., Hosio, S., and Riekki, J. 2006. Enhancing Bluetooth Connectivity with RFID. *Proceedings of the Fourth Annual IEEE International Conference on Pervasive Computing and Communications*, 36-41.

40. Välkkynen, P., and Tuomisto, T. 2005. Physical Browsing Research. *In Pervasive 2005 Workshop on Pervasive Mobile Interaction Devices*.

41. Rukzio, E., Leichtenstern, K., Callaghan, V., Holleis, P., Schmidt, A., and Chin, J. 2006. An Experimental Comparison of Physical Mobile Interaction Techniques: Touching, Pointing and Scanning. *In Proceedings Ubicomp*, 87-104.

42. Mäkelä, K., Belt, S., Greenblatt, D., and Häkkilä, J. 2007. Mobile interaction with visual and RFID tags: a field study on user perceptions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (San Jose, California, USA, April 28 - May 03, 2007). CHI '07. ACM, New York, NY, 991-994.

43. SciMyst site. Retrieved February 11, 2009 from http://www.cs.joensuu.fi/SciMyst/2007/Whatisit.htm

44. TekMyst site. Retrieved February 9, 2009 from http://www.cs.joensuu.fi/SciMyst/TekMyst/game.php

45. Sedano, C. I., Laine, T. H., Vinni, M., and Sutinen, E. 2007. Where is the answer?: the importance of curiosity in pervasive mobile games. In *Proceedings of the 2007 Conference on Future Play* (Toronto, Canada, November 14 - 17, 2007). Future Play '07. ACM, New York, NY, 46-53.

46. Nokia 6131 NFC SDK 1.1 documentation. Retrieved August 16, 2008 from http://www.forum.nokia.com/info/sw.nokia.com/id/ef4e1bc9-d220-400c-a41d-b3d56349e984/Nokia_6131_NFC_SDK.html

47. Client-side plugin development for MUPE document. Retrieved August 3, 2008 from http://mupe.nrln.net/wiki/index.php/Plugindevelopment

48. MUPE script language manual. Retrieved August 3, 2008 from http://mupe.nrln.net/wiki/index.php

49. NFC forum official site. Retrieved February 10, 2008 from http://www.nfc-forum.org/aboutnfc

50. Sakamura, K., and Koshizuka, N. 2005. *Ubiquitous Computing Technologies for Ubiquitous Learning*. Wmte, pp. 11-20, IEEE International Workshop on Wireless and Mobile Technologies in Education (WMTE'05).

51. Brown, M. 2007. *Mike Meyers' Comptia RFID+ Certification Passport.* Emeryville, CA, USA: McGraw-Hill Osborne.

52. Crawford, C. 2003. *Game Design*. New Riders. ISBN 0-88134-117-7.

53. Glover, B., and Bhatt, H. 2006. *RFID essentials*. Sebastopol (CA): O'Reilly.

54. Thornton, F., 2006. *RFID security*. Rockland, MA : Syngress Publishing.

55. Finkenzeller, K. 2003. *RFID Handbook: Fundamentals and Applications in Contactless Smart Cards and Identification, Second Edition*. John Wiley & Sons Ltd.

56. Lahiri, S. 2005. *RFID Sourcebook*. IBM Press.

57. NFC-Enabled Phones and Contactless Smart Cards 2008-2018. Retrieved February 27, 2009 from http://www.idtechex.com/research/reports/nfc_enabled_phones_and_contactless_smart_cards_2008_2018_000201.asp

58. Laine, T.H., Islas-Sedano, C., Vinni, M. and Sutinen, E. 2009. Uncovering the richness of an authentic living museum through pervasive learning environment. Accepted to the *International Conference on Advanced Learning Technologies*.

59. O'Neill, E., Thompson, P., Garzonis, S. and Warr, A. 2007. Reach out and touch: using NFC and 2D barcodes for service discovery and interaction with mobile devices. *Proceedings of the 5th International Pervasive 2007 conference*, p.19-36.

Appendix: Questionnaire

RFID / 2D Barcode usability evaluation questionnaire.

"BEFORE TEST" SECTION

1. In case you are in highscores list, which nickname do you use?

____

2. Gender: O Male O Female

3. Age: _____ years old.

4. What is the model of your mobile phone (if any) ____________________

How frequently do you use the following functions of your mobile phone:

	Several times a day	Once a day	Once a week	Never
SMS	O	O	O	O
Taking photos	O	O	O	O
Playing games	O	O	O	O
Internet	O	O	O	O
Talking	O	O	O	O

5. What is your experience in following technologies?

RFID:

- O experienced / use by myself in everyday life (rfid phone, key pass, credit card, etc.)
- O used sometime
- O saw RFID in action
- O I have heard about it
- O no experience / never heard of RFID

2D barcode:

- O experienced / use by myself in everyday life (mobile applications, work, etc.)
- O used sometime
- O saw how 2D barcodes work
- O I have heard about it
- O no experience

6. Your expectations regarding those technologies:

	RFID	2D barcode	No difference
Which one is faster to read the tag?	O	O	O
What do you think is more convenient to use?	O	O	O

Turn the page after test

7. How do you evaluate the following:

	strongly agree	agree	not sure	disagree	strongly disagree
I have experience in playing such memory games.	O	O	O	O	O
I think this game is good for learning and practicing of foreign language.	O	O	O	O	O
RFID is the fastest in reading tags.	O	O	O	O	O
2D Barcode is the most convenient for playing.	O	O	O	O	O

8. Which one these technologies would you prefer to use for...

	RFID	2D barcode
shopping in your favorite supermarket?	O	O
getting information of objects in a museum?	O	O
accessing website of a movie through a poster?	O	O
receiving additional information of a product in a supermarket?	O	O
embedding a "hidden" message on your business card?	O	O
playing context-aware mobile games (such as this game)?	O	O
marking own belongings so if they get lost, the finder can contact me?	O	O

9. There are some more questions regarding the game:

	RFID	2D barcode	No difference
Which of the two games did you find easier to get used to?	O	O	O
Which of the two games did you find easier to use?	O	O	O
Which of the two games did you like the best overall?	O	O	O

10. Please list any other comments, recommendations or questions that you might have:

Thank you for completing the questionnaire and taking part in this research!

Contact: Ernest Arendarenko email: *earendar@cs.joensuu.fi*