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MASTER

Personalized museum tour on a mobile device (PMTMD)

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Award date:
2007

Link to publication

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Eindhoven University of Technology
Department of Mathematics and Computing Science

MASTER THESIS
Personalized Museum Tour on a Mobile Device (PMTMD)

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Eindhoven, July 2007

ABSTRACT

Museum tours offer museum visitors a unique experience; adding personalization and new computer techniques makes the museum experience even more interesting. Here we propose a solution for moving a web-based personalized museum tour from the virtual space to the physical space using a mobile device. We discuss a method for importing tour data to a mobile device and returning behavioral user data to the User Model.

Furthermore, we propose a method to map the tour data from the virtual space to the physical space. We created a prototype of a mobile museum tour called the PMTMD which implements innovative features for guiding and positioning users inside the museum using RFID technology.

LIST OF FIGURES

LIST OF DEFINITIONS

Audio tour	:	Museum tour on a mobile device which provides audio content about museum artworks.
Bluetooth	:	Wireless communication technique that uses radio frequency.
CHIP demonstrator	:	The system containing the CHIP recommender, the CHIP tour wizard and the faceted browser.
CHIP recommender	:	Application from the CHIP project that captures the user's interest by rating artworks.
CHIP tour wizard	:	Application from the CHIP project that generates a virtual tour.
Class diagram	:	A UML diagram that describes the structure of a system by showing its classes and the relationships between the classes.
DOM	:	The Document Object Model, a platform- and language- independent standard object model for representing XML and related formats.
EDGE	:	Enhanced Data rates for GSM Evolution, a 2.75G mobile phone communication technology.
GPRS	:	General Packet Radio Service, a 2.5G mobile communication technology available to users of GSM.
GPS	:	Global Positioning System, used to determine the current geographical location using satellites.
Infrared	:	Wireless communication technique that uses electromagnetic radiation.
Location-based wireless	:	Wireless communication technique that uses wireless networks to locate objects.
Mobile phone	:	A long-range portable electronic device used for mobile communication.
Mobile tour	:	Client application which runs on a mobile device, providing a guided tour to the user.
Multimedia tour	:	Museum tour on a mobile device which provides multimedia content about museum artworks.
Online tour	:	Museum tour on a website providing information about museum artworks.
OWL	:	Web Ontology Language, a language for defining and instantiating Web ontology's. OWL is an extension of RDF.
PDA	:	Personal Digital Assistant, a handheld computer.
PMP	:	Portable Multimedia Player, a self-reliant electronic device that is capable of storing and playing files in one or more media formats.

RDF	:	Resource Description Framework, a specification from the W3C[1] for creating meta-data structures that define data on the Web.
RFID	:	Radio-Frequency IDentification, an automatic object identification method using radio frequency.
RFID tag	:	Sensor that is used within RFID implementations.
RFID reader	:	Hardware that can read RFID tags.
Sequence diagram	:	A UML diagram displaying messages between objects for a specific use case.
Smart phone	:	Full-featured mobile phone with functionality like a personal computer.
UML	:	Unified Modeling Language, a standardized specification language for object modeling.
UMTS	:	Universal Mobile Telecommunications System, a 3G mobile phone communication technology.
Use case diagram	:	A UML diagram that displays a graphical notation for representing the functional requirements of a system.
User Model (UM)	:	A model which stores user specific data.
Wi-Fi	:	Wireless communication technique for setting up local area networks.
XML	:	eXtensible Markup Language, a general-purpose markup language primarily used for sharing data across different systems.

[1] http://www.w3.org/

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1 INTRODUCTION

Museum tours offer museum visitors a unique experience; adding personalization and new computer techniques makes the museum experience even more interesting. In this thesis, we propose a prototype of a mobile museum tour, the PMTMD, which stands for Personalized Museum Tour on a Mobile Device. The project is performed in cooperation with the Eindhoven University of Technology (TU/e)[1], the CHIP project[2] and the Rijksmuseum Amsterdam[3].

Most museums provide human guided tours or audio tours. Some museums offer multimedia tours providing access to information about the museum collection on a multimedia device. Other museums provide virtual museum tours accessed through the Internet.

1.1 CHIP project

The CHIP project (Cultural Heritage Information Personalization) focuses on offering a personalized experience for museum visitors based on semantic web technology [1]. The project is a cooperation of the Eindhoven University of Technology (TU/e), Telematica Institute[4] (Telin) and the Rijksmuseum Amsterdam. It is part of the CATCH program[5] (Continuous Access To Cultural Heritage) which focuses on creating tools and technologies to provide collection owners a means to improve the access to their digital collections. Since early 2005, the CHIP research team worked on the CHIP demonstrator[6] [2] which is based on a subset from the artworks of the Rijksmuseum Amsterdam. The CHIP demonstrator consists of a museum artifacts recommender system [3] [4], a faceted browser to browse artifacts and an environment for building personalized museum tours (the CHIP tour wizard). Essential in the CHIP project is the User Model [5] which is used in the CHIP demonstrator to store user information. This project uses the museum tour that is created using the CHIP tour wizard and extends the tour with functionalities to put the tour onto a mobile device and perform the tour in the physical space of the museum.

1.2 Rijksmuseum Amsterdam

The Rijksmuseum Amsterdam is the biggest art and history museum in the Netherlands which provides a rich collection of artifacts to use within the CHIP Project. During the research and development of the PMTMD, the Rijksmuseum is used as the target museum. However the PMTMD can also be implemented for other museums or exhibitions.

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[1] http://www.tue.nl/

[2] http://www.chip-project.org/

[3] http://www.rijksmuseum.nl/

[4] http://www.telin.nl/

[5] http://www.nwo.nl/catch/

[6] http://www.chip-project.org/demo/

1.3 Motivation

Current museum experiences do not attract visitors to visit the museum more than once. The CHIP project focuses on improving the museum experience such that visitors will return to the museum. Personalization can help to achieve this. The PMTMD must contribute to the improvement of the museum experience. A mobile device is typically controlled by a single user which makes it a perfect platform to apply personalization. We believe that if the visitor can perform multiple museum tours using a mobile device, this will improve the experience and he or she will come back to the museum to perform other tours.

1.4 Problem statement

One way to extend the museum experience is to offer a personalized museum tour on a mobile device to the visitors. The tour wizard from the CHIP project provides a virtual personalized museum tour. A virtual personalized museum tour consists of a list of artworks which are relevant to the user's interests. The virtual tour, created by using the tour wizard must be converted to a physical tour on a mobile device.

The physical tour must offer the visitor an exciting museum experience. When converting a virtual tour to a mobile tour, the artworks of the virtual tour must be mapped against the physical space such that the tour only contains exposed artworks and the consecutive artworks are ordered logically regarding their location in the museum. Furthermore, data must be transferred from the web to the mobile device. To add personalization, the User Model must be used on the mobile device and synchronized with the CHIP demonstrator. We also focus on innovative features which are not found in other Dutch multimedia museum tours like user positioning and user guidance. User positioning is the notion of tracking the user's position in the museum. User guidance is the process of guiding the user through the museum building.

1.5 Research questions

For the problem described in the problem statement, we present a research question which is answered during the exploration phase, design and implementation of the PMTMD:

1. *Can we implement a personalized museum tour on a mobile device?*

To answer this question, we construct a set of sub questions based on the problem statement:

- The physical tour must offer the visitor an exciting museum experience in the form of a tour:

  2. *What makes a good museum tour on a mobile device?*

- The conversion of a virtual tour to a mobile tour implies the need for mobile technologies, data communication and environment mapping:

  3. *Which technologies can be used for a mobile museum tour?*
  4. *How can we import and synchronize tour and user data on a mobile device?*
  5. *How can a virtual museum tour be mapped to the physical space?*

- With respect to user positioning and user guidance we must answer the following research questions:

  6. *How can we retrieve the user's position in a museum?*
  7. *How can we implement user guidance in a mobile museum tour?*

1.6 Collaboration

The project is performed by Yuri Schuurmans and Rody van Sambeek at the University of Technology in Eindhoven. Rody's main focus of the project is on answering research question 4, while Yuri focuses on answering research question 5. The remaining questions are answered in collaboration with each other.

1.7 Approach

This master project is performed in three phases:

- Exploration phase
- Design phase
- Implementation phase

We start with an explorative approach where we visit different museum tours, create a set of scenarios for possible implementations, derive requirements and explore mobile technologies. The exploration phase answers research questions 2 and 3.

During the design phase we derive use cases, create a system architecture and propose models for data storage and communication. The design phase provides answers to research questions 4, 5, 6 and 7 by proposing technical solutions to the problems.

The design created during the design phase is used to create an implementation of a personalized museum tour on a mobile device. The implementation phase answers research question 1 by describing how the personalized museum tour on a mobile device is implemented.

1.8 Related work

In [6], Oppermann and Specht propose a mobile museum guide which focuses on the notion of adaptation. They use Infrared and GPS to retrieve the current user location in the physical space of the museum. The system uses this position as indicator for the user's interests. During the museum visit, the system continually adapts to the users preferences while presenting artwork information. Their tour uses a wireless LAN connection and offers several museum tours based on the user's interests and knowledge (this is stored in a User Model). Artwork information is offered in audio format and the system includes functions to make notes and share these notes with others.

Rocchi, Stock and Zancanaro created the Peach experience [7]. The Peach experience is a museum tour on a PDA which focuses on user interests. The user can provide the system with information about the degree of interest at any time. The content of their tour is adapted to the user and is location aware which means that it is only available on certain locations in the museum.

In [8] Rakotonirainy and Lehman present a museum tour which focuses on the visitor's learning process during the museum tour. The tour adapts to the knowledge and interests of the user. They use a PDA together with an Infrared transmitter to track environmental data and to track the interests and knowledge of the user.

Graziola, Pianesi, Zancanaro and Goren-Bar present a mobile museum guide which focuses on adaptation [9]. They investigate the relationships between personality traits and attitudes towards adaptivity.

1.9 Document structure

This document starts with describing the exploration phase in section 2, where we describe the exploration of museum tours in the Netherlands. Furthermore we give a set of scenarios which use the inspiration from the museum tour exploration. From the museum tour exploration and scenarios, we derive requirements. The exploration phase is finalized by exploring mobile technologies which could be used for the PMTMD. We give an overview of the available device classes, operating systems, application types, user positioning technologies, connection types and communication standards.

Section 3 describes the design of the PMTMD, we capture use cases, present a system architecture and we describe the internal system components.

Section 4 describes the implementation of the PMTMD, we present the development environment, hardware used for the implementation and show the graphical user interface.

Section 5 describes the process of importing and exporting virtual tours and the User Model on the mobile device.

Section 6 describes the mapping from the virtual space to the physical space in detail.

Section 7 describes the design and implementation of retrieving the user's position inside the museum.

Section 8 describes a method for user guidance inside the museum building.

We finalize this thesis by answering the research questions and discussing future work in the field of personalized mobile museum tours in section 9.

2 EXPLORATION PHASE

This section describes the exploration of museum tours in the Netherlands leading to a set of properties which define a good museum tour. Using these properties, we construct a set of scenarios for mobile tours and provide a set of requirements for the PMTMD. Finally we explore mobile technologies which can be used for the implementation of the PMTMD.

2.1 Museum tour exploration

Here we examine existing museum tours, mostly in the Netherlands. The information we retrieved is used as inspiration for the PMTMD. Furthermore new aspects of mobile museum tours are extracted from the information that is gathered, leading to innovative tour elements.

We finalize the museum tour exploration by presenting a set of properties which define a good museum tour.

2.1.1 Types of multimedia museum tours

In the Netherlands different museum tours are available; these tours are audio tours, online tours, multimedia tours or human guided tours. Especially multimedia tours are interesting for our project. However we do not only consider multimedia tours as other tours can give us valuable information for creating the PMTMD. We therefore decided to participate in an audio tour, an online tour, a human guided tour and several multimedia tours.

Table 1 gives an overview of multimedia tours in the Netherlands, showing their creators and location. Different multimedia tours from the same creator are equal in concept but not in content. We are interested in the tour concept and therefore participated in one multimedia tour from each creator.

Table 1 Multimedia tours in the Netherlands

Name	Location	Creator
Van Gogh museum[1]	Amsterdam	Antenna Audio[2]
Boijmans van Beuningen museum[3]	Rotterdam	GuideID[4]
Groninger museum[5]	Groningen	GuideID
Frans Hals museum[6]	Haarlem	Frans Hals museum
Kröller-Müller Museum[7]	Otterlo	GuideID
Netherlands Architecture Institute[8]	Rotterdam	GuideID

2.1.2 Domain exploration and data collection

Table 2 shows the selection of tours we participated in during the exploration phase. We do not only focus on multimedia tours, but also an audio tour, an online tour and a human guided tour are considered.

Table 2 Participated museum tours

Museum	Type	Description of tour
Van Gogh Museum Amsterdam	Multimedia tour Figure 2-4	The visitor walks through the museum following a timeline which leads the user through Van Gogh's life. Artwork information can be seen on a PDA by selecting an artwork from a list.
Netherlands Architecture Institute Rotterdam	Multimedia tour Figure 2-1 and Figure 2-2	The visitor walks through the exhibition. Some artworks have sensors which can be scanned using a PDA. If a sensor is scanned, the corresponding artwork information is presented to the visitor.

[1] http://www.vangoghmuseum.nl/
[2] http://www.antennaaudio.com/
[3] http://www.boijmans.rotterdam.nl/
[4] http://www.guideid.com/
[5] http://www.groningermuseum.nl/
[6] http://www.franshalsmuseum.nl/
[7] http://www.kmm.nl/
[8] http://www.nai.nl/

Frans Hals museum	Multimedia tour	The visitor walks through the museum, visiting the rooms with the artworks in a non deterministic order. On a PDA, the user must manually select the room from a list of rooms and then select an artwork to receive information about the artwork.
Rijksmuseum Amsterdam	Audio tour	The visitor can determine his or her own path through the museum. Most artworks are labeled with a number, which are coupled to an audio track on the visitor's audio device. On the audio device, the visitor enters the number on the labels next to the artworks to receive audio information about the artworks.
Rijksmuseum Amsterdam	Human guided tour Figure 2-3	The visitor follows a human guide, which selects the artworks that are shown to the visitor. When arriving at any of these artworks, the guide gives information about artworks to the visitor using speech, gestures or extra material.
Tate Britain[1]	Online tour Figure 2-5	The visitor sees a virtual representation of the museum on a map. Rooms can be selected and each room contains a set of artworks from which the user can receive information.

[1] http://www.tate.org.uk/britain/explore/

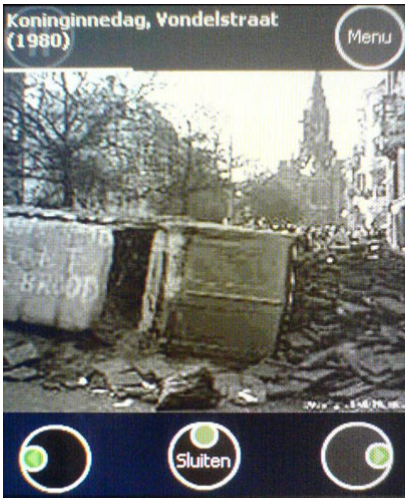

Figure 2-1 Multimedia tour NAI

Figure 2-2 Multimedia tour NAI hardware

Figure 2-3 Human guided tour Rijksmuseum Amsterdam

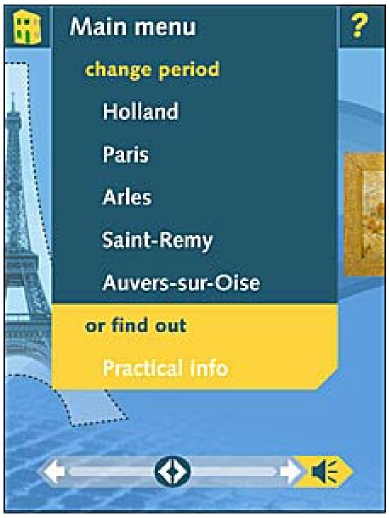

Figure 2-4 Multimedia tour Van Gogh museum

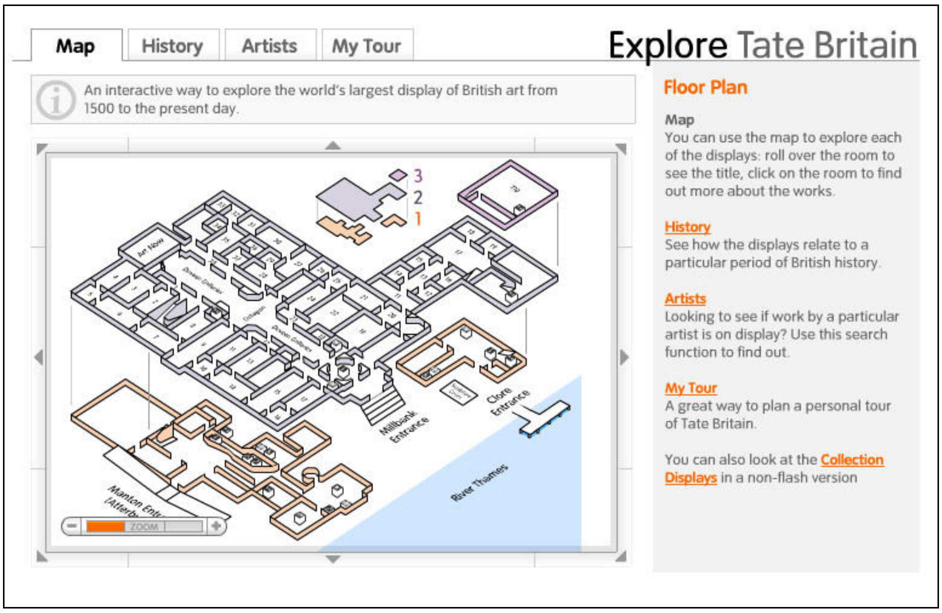

Figure 2-5 Online tour Tate (Tate Britain)

2.1.3 Domain and data analysis

We captured data for each tour using the following five criteria:

Tour properties:	General tour information.
Physical space:	Properties of the museum building.
Locator:	Properties of the artwork and user locator techniques.
Content:	Properties of the tour contents.
Interaction:	Properties of user interaction with the guide.

For each of the above criteria we constructed a set of properties. We captured these properties for each tour from which the data can be found in appendix B.

Tour Properties

Tour properties are general properties of a tour like the theme or the tour duration. Table B-3 contains the data for each tour. We discuss why this property is important for museum tours and what is preferred to have in the PMTMD.

Theme:

Every museum tour can have its own theme. A theme provides a link between different artworks, for example all artworks showing women or all artworks from a certain period in time. Assigning a theme to a museum tour limits the number of artworks that can be shown to the user. Furthermore it becomes easier to create relations between different artworks. For the PMTMD it is preferred to have the possibility of doing different tours, where each can have its own theme. Existing museum tours are limited to a certain theme or person, for instance the Van Gogh museum only offers one general tour containing only the most famous artworks of Van Gogh.

Number of participants:
The number of participants is the number of users that are following one specific museum tour concurrently. In a multimedia or audio tour, each user has his or her own device. In order to apply personalization to the fullest extend, the number of users is important. It is easier to apply efficient personalization for a single user than for a group of users. For the PMTMD application personalization is important; therefore only one participant is preferred.

Number of artworks
To maximize the experience of the museum tour, it is important that the number of artworks visited is chosen carefully. This number might differ per user according to the user's interests. Another factor that influences this number is the desired tour duration. For the PMTMD it is preferred to have a good balance between the number of artworks and the preferred duration of the tour.

Duration:
The duration is the time the user needs to complete the museum tour. The duration must be chosen carefully, wrong tour duration has a bad influence to the overall experience of the museum tour. When there is too little time for the number of artworks, the information about each artwork will be limited which will degrade the tour experience. For the PMTMD it is preferred to let the user be able to set the tour duration.

Languages:
The languages property, describes which languages are supported by the museum tour. A good museum tour is accessible too many users, speaking different languages. For the PMTMD it is preferred to feature different languages.

Personalization:
The property of personalization describes how a tour incorporates personalization. Personalization means adapting to the user's behavior and interests. Personalization, when applied correctly, increases the museum experience. Personalization is an important aspect for the PMTMD.

Platform:
The platform is the source from which information is given to the user. In an audio tour, the platform is the audio device and in the human guided tour, the platform is the human guide. The platform is important to distinguish different kind of tours from each other. It is preferred to let the PMTMD run on different types of mobile devices.

Tour explanation:
The tour explanation is the method of informing the user about available functions and actions of the tour. At some museums, the user is informed by desk personnel, other museum tours are self explanatory. For example a human tour guide might tell users, what they will do and see during the tour, and that it is always allowed to interrupt and ask questions. For the PMTMD it is preferred to have context sensitive information about contents.

All artworks featured:
When participating on a museum tour, a user might want to receive information about an artwork that he or she is attracted to. Even if this artwork is not selected in the current museum tour, a user might want to receive a description. Within the PMTMD it is preferred to feature all artworks that are available in the museum together with all artworks that were selected by the user.

Physical space

Properties of the physical space can influence the design of the PMTMD; large rooms for example require other navigation methods than small rooms. Table B-4 contains the properties about the physical space for each visited museum.

Museum units:

Units are parts of the museum containing a set of artworks. Units are for example: rooms, compartments or virtual rooms. User guidance depends on the size and type of the museum units. The Rijksmuseum consists of different rooms and therefore we will use rooms for guiding the user.

Unit size:

The unit size is important when choosing the method of user guidance. If a museum only contains small rooms with at most five artworks like the Frans Hals museum, it suffices to guide the user from room to room. But if a museum contains large rooms like the Rijksmuseum, this is not enough. The Rijksmuseum has different sized rooms, which must be considered when implementing user guidance.

User guidance:

User guidance is the method for guiding the visitor from one artwork to the other. User guidance makes it easier for the user to find the tour artworks in the museum. For the PMTMD it is preferred to offer a more advanced user guidance method than the existing multimedia tours because consecutive artworks might be exposed in different rooms.

Locator

The different museums implement several methods of locating artworks or users in the museum. Table B-5 contains data about the locators used in the museums.

Artwork locator:

The artwork locator allows the user to locate artworks within the physical space of the museum. For an optimal experience it is necessary to know exactly where the artworks are exposed in the museum. For the PMTMD it is preferred to have an artwork locator which can automatically identify the artwork like the Infrared tags in the multimedia tour at NAI in Rotterdam.

User locator:

The user locator is used to get the current location of the visitor in the museum building. The user location is used for the user guidance inside a museum. If there is no user locator available, the possibilities for user guidance are limited.

Content

The artwork information that is given to the user is different for each museum tour we visited. To determine the contents of the PMTMD, we gathered data about the content from different tours. This data is found in Table B-6.

Content type:

This property incorporates the way of presenting information about artworks to the user. The content type is important for the experience and focus of the user. A user can listen to audio information and look at the artwork at the same time; however he or she cannot read a textual description and look at the artwork simultaneously. For a physical tour through the museum, audio is considered to be the best way of presenting content. For the PMTMD it is preferred to have content of different media types.

Content focus:

The content focus can be on the artwork or on the mobile device. The mobile device can show an image of the artwork and a description such that the user barely has to look at the artwork itself. We believe that the user comes to the museum for the artworks and therefore prefer the content focus to be on the artwork within the PMTMD.

Referring to (parts of) artwork:

Referring to (parts of) the artwork increases the user experience because the user is more actively involved in the tour. Therefore often referring to (parts of) the artwork is preferred for the PMTMD.

Interaction

The interaction between the user and the guide differs per museum tour. The user can perform actions on the system to receive feedback from the guide. In Table B-7, we capture data from the different interaction methods.

Controls:

Interaction controls are used for interaction between the user and the guide. For the PMTMD it is preferred to use hardware buttons if available, or hide the hardware buttons when they are not used like in the Frans Hals museum tour.

Response time:

The response time is the time between the user action and the reaction of the system. A long response time can decrease the experience of a user as we noticed in the Van Gogh museum where the multimedia tour reacted very slowly. Therefore a fast response time is preferred for the PMTMD.

2.1.4 Conclusions of museum tour exploration

We started the exploration phase by focusing on existing museum tours in the Netherlands. From these tours we collected data which we analyzed. The analysis shows that a good mobile museum tour contains:

- A good balance between the number of artworks and the tour duration.
- Multiple languages
- Context sensitive help of tour functions
- Support for multiple platforms
- Information about all museum artworks
- User guidance trough the museum
- A wireless artwork locator mechanism
- A method to determine the current user position
- Content of different media types
- A method to focus the user on the artwork
- No unused hardware controls
- Fast response times

2.2 Scenarios

From the museum tour exploration (section 2.1), we derived several properties of a good museum tour. We now construct a set of scenarios which use these properties. These scenarios provide different solutions for implementing a mobile museum tour.

From the following scenarios, we choose one scenario which forms the basis of the PMTMD, however during the design phase we also consider other scenarios such that the architecture does not need to change for implementing these scenarios. For each scenario, we give a list of keywords to describe the scenario; furthermore we give a general description of the system and the user's actions.

2.2.1 Scenario: Basic tour

Offline mobile tour, synchronization of User Model

The user creates a tour on the website of the museum using the tour wizard at his or her own desktop computer. The user can download the tour on his or her mobile device, which is only possible when an Internet connection is available. When the download is completed, the user can start the tour. No Internet connection is necessary during the tour. The system provides the user with an image of the current artwork in the tour and indicates where the artwork can be found. It is possible to request a textual and audio description of the current artwork. After visiting the artwork, the user can proceed to the next artwork which will become the current tour artwork. This process is repeated until the user has visited the last tour artwork which ends the tour. At any moment the user can decide to stop the tour. When stopping or finishing the tour, the user can synchronize the tour data and progress with the CHIP demonstrator after connecting to the Internet again.

2.2.2 Scenario: RFID reader tour

Offline mobile tour, synchronization of User Model, user guidance, RFID reader on device

The process of creating and downloading a tour is the same as in the basic tour scenario. During the tour, the user is given a current artwork and directions how to walk to this artwork. The directions are given by telling the user in which room the artwork can be found and by showing a route line on a map of the museum. The user should follow these directions such that he or she reaches the artwork. Here the user can use an RFID reader (which is attached to the mobile device), to scan an RFID tag which is found next to the current artwork. After scanning the tag, the user is given textual and audio descriptions of the current artwork. Now the next artwork becomes the current artwork and this cycle is repeated until the last artwork is visited. Like in the baseline scenario, the user can again synchronize the tour data with the CHIP demonstrator.

2.2.3 Scenario: RFID bracelets tour

Online mobile tour, real-time synchronization of User Model, User guidance, RFID bracelets and stationary RFID readers, users shown on map

The user creates a tour using the tour wizard at his or her own desktop computer. After creating the tour, the system provides the user with a tour identification code which is unique amongst all tours. Inside the Rijksmuseum the user receives a bracelet with an embedded RFID tag. The mobile device must be connected to the wireless network. After starting the tour the user enters the unique tour identification number and the number on the bracelet. At each door, RFID readers are placed to retrieve the user's position using the bracelet. When the user passes the first RFID reader (the museum entrance) the system generates a map with a route to the first artwork. It shows how many users are in the rooms on the map. When the user enters the room of the current artwork it shows a small image of the artwork on the screen to help the user with finding the exact location. Once the artwork is found the user can view or hear the information about that artwork. If the user wants to continue to the next artwork he or she can click a button on the screen to proceed, then the map with the route is shown. During the entire tour the actions of the user are constantly synchronized with the CHIP demonstrator to update the online User Model.

2.2.4 Scenario: Friends tour

Online mobile tour, real-time synchronization of User Model, bracelets and stationary RFID readers, User guidance, users shown on map, communication with friends

This scenario uses the same method to create a tour as the basic tour scenario, also the RFID bracelets and readers are used here and the route to the current artwork is recalculated like in the RFID bracelets scenario. The difference with the RFID bracelets scenario is that the user can add 'friends'. The user can make friends on the website but also in the museum on the mobile device. Users who are friends can share tours by sending a tour from one device to the other. It is possible to see the friends' locations within the museum on the map and to send messages to each other. The actions of the users are constantly synchronized with the CHIP demonstrator.

2.2.5 Scenario: Hotspots tour

Offline mobile tour, synchronization of User Model, hotspots providing extra artwork information

This scenario resembles the basic tour scenario for creating the tour and using it in the museum. Hotspots are placed at central locations in the museum. They are easy to recognize by the user. In the surrounding area of the hotspot, the users can connect their device wirelessly to a network which provides them with extra information about the artworks.

2.2.6 Scenario: Video room tour

Online mobile tour with video screens, real-time synchronization with the User Model, high tech video room

The user creates a tour on the website of the museum using the tour wizard at his or her own desktop computer. The user goes to the museum where he or she enters a room which contains large video walls. The user can connect the mobile device to the system using a wireless connection. The user can select a tour from his online profile created using the tour wizard. The tour artworks will be displayed on the video walls, and the user can view or hear the information about the artworks. By selecting the next artwork on the mobile device, the artwork and its information will be shown on the video walls. It is also possible to see artworks which are currently not exposed in the museum.

2.2.7 Scenario: Mp3 tour

Offline audio tour on mobile device

The user creates a tour with the tour wizard application using his or her own desktop computer. A set of mp3 files is created with a specific order which can be uploaded to the mobile device. An mp3 player or IPod can be used to perform the tour. This scenario is a combination of a personalized tour and an audio tour.

2.2.8 Scenario choice

The basic tour scenario contains basic tour functionalities; however it does not contain innovative elements. Scenarios from sections 2.2.3, 2.2.4, 2.2.5 and 2.2.6 require large hardware investments for the museum and are therefore not feasible. The MP3 tour scenario does not differentiate enough from the typical audio tours which are already offered by many museums. The RFID reader scenario (section 2.2.2) is a good combination of technological challenges and innovative features and is feasible with respect to implementation costs. We therefore choose the RFID reader scenario for designing and implementing the PMTMD. Nevertheless the technical design is done such that implementing the other scenarios does not require structural changes.

2.3 Requirements Elicitation

From the museum visits and the scenarios we now derive requirements. This section describes how the requirements follow from the scenarios and from the museum tours. We finalize by presenting the total set of requirements for the PMTMD.

Directly from the project description certain requirements follow. First of all the tour must run on a mobile device. It must furthermore be possible to update the User Model such that user data is synchronized between the mobile application and the CHIP demonstrator. Other requirements follow from the museum visits and the scenarios.

2.3.1 Deriving requirements

In existing museum tours, each user receives a device when arriving at the museum. The user does not share his or her device with other users. To implement personalization, the PMTMD requires one user per device. The PMTMD must be platform independent because it must be possible for users to perform the tour on their own device.

From the Van Gogh multimedia tour we noticed that having high response times for user actions are annoying, therefore the PMTMD must have short response times. We also noticed that there are hardware control buttons on the mobile device which were unused. We would expect that these buttons can be used to control the device and the tour. Therefore we want to use the hardware control buttons within the PMTMD or cover the unused buttons when the device is supplied by the museum.

In the human guided tour we have seen that the guide determines the tour duration before starting the tour. The guide asks the visitor to give a preferred tour duration, which is used to determine a set of artworks that is shown to the visitor. While mapping a virtual tour to the physical space, the tour may not be too long and therefore a method to limit the set of artworks is needed. The user must be able to set the number of artworks or the tour duration directly. The number of artworks must be synchronized with the tour duration.

The guide in the human guided tour asks the visitors to follow to the next artwork. Similar user guidance however is not implemented in any of the multimedia tours we visited. Especially in a tour with a fixed set of random artworks, it is very useful to guide the user to the next artwork in the tour. Some of the multimedia tours have implemented a museum map, this is very useful to see your current position or to get an overview of the museum. The PMTMD should also implement such an overview of the museum. In the Netherlands Architecture Institute, the last Infrared tag that was scanned is highlighted on the map, indicating the current position of the user. The use of a museum map together with indicating the user’s position and guidance cannot be found in any existing tour and is therefore a challenge to implement in the PMTMD.

The Van Gogh and Frans Hals multimedia tours offer visual content to the user on the mobile device. This focuses the attention on the device in stead of the artwork. We want to keep the focus of the user on the artwork because people visit museums for the artwork collection. The PMTMD must provide audio descriptions of artworks such that the focus stays on the artwork.

The Van Gogh and Frans Hals tours only present a very small fixed set of artworks. There is no possibility to get information about other exposed artwork. The Online Tate museum however does feature all artworks in their virtual tour. The PMTMD should provide information of all exposed artworks.

Most museums offer tours in different languages. This makes the tour accessible for a wider audience. It must be possible for the user to switch between these languages in the PMTMD.

In the Frans Hals multimedia tour there is no help available to the user. An explanation is provided by the desk personnel when the user receives the device. The Van Gogh and the tour at the Netherlands Architecture Institute show a short introduction video which explains basic functionality. However in the Van Gogh tour this can only be shown at the beginning. In the PMTMD help of all basic functions should be available at any time.

2.3.2 Requirements for PMTMD

This section shows requirements for the PMTMD. Priorities are assigned to the requirements: (M) means that the requirement has a high priority and that it is a must have for the PMTMD; (W) means a low priority and is a want to have for the PMTMD.

System requirements:

1.1 (M) The tour must run on a mobile device.
1.2 (M) Every user must have one device.
1.3 (M) The application must be device independent.
1.4 (W) The response time of the system to each user action must be less then 0.5 seconds.
1.5 (W) Control buttons must be usable or not be visible for the user.
1.6 (M) The identification of users must be done using the same login credentials as on the website.

Synchronizing data:

2.1 (M) It must be possible to update the User Model.

Filtering and ordering:

3.1 (M) The user must be able to set the tour duration.
3.2 (M) The user must be able to set the number of artworks.
3.3 (M) There must be synchronization between the tour duration and the number of artworks.

User guidance and positioning:

4.1 (M) The user must be guided to the next artwork in the tour.
4.2 (M) The user must be able to request an overview of the tour.
4.3 (M) The system must give the user a route passing all artworks.
4.4 (M) The user must be able to request his or her current position.
4.5 (M) The identification of artworks must be done using a wireless technique.

Content:

5.1 (M) The focus of the user must be on the artwork.
5.2 (M) All exposed artworks must be available to the system.
5.3 (W) Content must be available in different media types.
5.4 (W) The tour must be available in different languages.
5.5 (W) The user must be able to switch easily between languages.

Help:

6.1 (W) The user must be able to get an overall explanation of tour functions.
6.2 (W) Context sensitive help must be available.

2.4 Technology exploration

In section 2.3, we created a set of requirements for the PMTMD. The PMTMD must run on a mobile device, therefore we now present a set of device classes which could be used. Each device runs an operating system; hence we present a set of operating systems which run on different mobile devices. Operating systems can run client applications, this can be a web application or a stand alone application and can be online or offline. An online application requires communication with a server; this communication can be done using different communication standards. The scenario we chose in section 2.2, works with a wireless identification technology. In this section we classify different wireless identification technologies.

This section is finalized with a conclusion in which we select different technologies which are used for the design and implementation of the PMTMD.

2.4.1 Device classes

In [10][11][12], classifications of mobile devices are given. Combining these leads to the following classification:

- PDA
- Smart phone
- Mobile phone
- PMP

In [12], tablet PC's and laptops are not considered to be classes of mobile devices because they do not fit in the definition of Livingston [13]. Livingston says that a mobile device must fit in a purse pocket or holster. We use the same definition of mobile devices.
A PDA is a handheld computer implementing the functionality of a desktop computer on a portable device. Mobile phones are primarily used as telecommunication devices to make audio calls. Combining the functionality of a PDA and a mobile phone leads to a device that is referred to as a smart phone. Smart phones and PDA's often implement standard operating systems enabling users to install native applications. A PMP as described in [12] is a personal media player which can be a MP3 player or a mobile video player.

2.4.2 Operating systems

The most commonly used operating systems for mobile devices are:

- Symbian OS[1]
- Windows Mobile[2]
- Embedded Linux[3]
- PalmOS[4]
- BlackBerry[5]

Each operating system uses its own application architecture and technologies. These technologies are not always interchangeable between the different operating systems. Therefore a good choice must be made about which operating system will be used when creating the PMTMD. It is also possible to create multiple clients for different operating systems which work with the same data.

2.4.3 Application types

Two main approaches exist regarding the type of the application. An application can be implemented as:

- Web application
- Standalone application

Web applications use a browser application to show the contents where standalone applications do not need such a browser. The advantage of using a browser based environment is that it is supported by many different devices and platforms. A standalone application is more dependant of the operating system but has much more control. A disadvantage of a browser based environment is the limited user interface, the limited media support and the lack of support for external devices.

---

[1] Symbian OS is a proprietary operating system which is designed for mobile devices, currently owned by Nokia (47.9%), Ericsson (15.6%), Sony Ericsson (13.1%), Panasonic (10.5%), Siemens AG (8.4%) and Samsung (4.5%). http://www.symbian.com/

[2] Windows Mobile is Microsoft's compact operating system combined with a suite of basic applications for mobile devices.
http://www.microsoft.com/windowsmobile/

[3] Embedded Linux is a Linux-based embedded operating system used in cell phones, personal digital assistants, media players and other electronic devices.
http://www.embedded-linux.org/

[4] Palm OS is a compact operating system developed and licensed by Palm for personal digital assistants.
http://www.palm.com/

[5] The BlackBerry is a wireless handheld device introduced by the Canadian company Research In Motion.
http://www.blackberry.com/

2.4.4 User positioning technologies

To implement user positioning, various techniques can be used:

- GPS
- RFID
- Infrared
- Location-based wireless
- Bluetooth
- Manual location entering

User positioning is an important aspect in a guided museum tour. The ideal situation is a system which always knows the exact user location. This however is non trivial, especially inside a building.

GPS

GPS stands for Global Positioning System and is the locator system commonly used in car navigational systems. It uses space satellites to obtain its position. A GPS receiver can receive the signal from a couple of satellites to calculate its own position by trilateration.

RFID

RFID implementations are always composed of two separate parts: the RFID reader and the RFID tags. The RFID tags are available in two different types: Passive tags and Active tags.

Active tags are tags which are powered by a battery and send out radio signals. These signals can be received by an RFID reader. Passive tags are tags without a power source, they absorb the power of the signal from the RFID reader to bounce signals back. Because they have no power source their lifespan is much longer than the active tags. However their range is dependant on the strength of the RFID reader.

Hähnel, Burgard, Fox, Fishkin and Philipose describe an implementation of RFID based user positioning in [14]. They use stationary RFID readers and mobile RFID tags.

Infrared

Infrared implementations are similar to RFID implementations. An Infrared receiver receives signals from Infrared beacons. The Infrared beacons must be in direct line of sight with the Infrared receivers. This technique is used by the Antenna Audio tours in the Netherlands Architecture Institute and in the Boijmans van Beuningen museum.

Location based wireless
Location based wireless uses the signal strength of different wireless access points to discover the location of the user, this technique is described in [15]. The radio frequencies used by location based wireless can travel through walls and doors.

Bluetooth
Bluetooth senders send signals to nearby Bluetooth devices. Bluetooth has a working distance of 10 meters; however signals may interfere with each other when there are multiple devices in the area. Bluetooth does not require line of sight for a connection.

Manual location entering
An alternative user positioning technique in contrast with the technical solutions provided so far is using the manual input from users. For instance the user can enter a code displayed at a label next to an artwork to inform the system about his position.

2.4.5 Connection types
While performing the tour, the device can be connected to a wireless network. The connection type can be either online or offline:

- Online
- Offline

Reading data from an online source has the advantages above offline sources that it needs less memory to store the tour data, there can be automatic synchronization between the PMTMD and the CHIP demonstrator and the information about artifacts is always up to date. On the other hand, there are also some disadvantages such as the high dependency of the network: the network should always be available and have enough capacity. It is also possible to combine an online and offline implementation such that the most frequently used data is stored on the device and additional information can be requested from an online source.

2.4.6 Communication standards

When an application uses an online data source, a communication protocol is used for the connectivity. In [16], an overview of mainstream communication standards is given:

- WI-FI
- UMTS
- GPRS
- EDGE
- Bluetooth
- Infrared

Table D-5 shows the range and speed of each communication standard. UMTS, GPRS and EDGE are based on the GSM[1] network and their range depends on the signal strength of the network. However for GPRS and EDGE the network covers the entire country of the Netherlands and for UMTS the coverage is still growing. The coverage of the GPRS and UMTS networks can be found on the website of KPN[2].

2.4.7 Conclusions of technology exploration

We conclude the technology exploration by selecting technologies for the design and implementation of the PMTMD. The selected technology is underlined and we provide a motivation for each choice.

Device classes

- <u>PDA</u>
- <u>Smart phone</u>
- Mobile phone
- PMP

Table D-3 shows that PDA's and Smart phones have the ability to run native applications and are able to use external hardware. We therefore choose PDA's and smart phones for the implementation of the PMTMD.

Operating systems

- Symbian OS
- <u>Windows Mobile</u>
- Embedded Linux
- PalmOS
- BlackBerry

In Table D-4 we see that Windows Mobile is the most popular operating system for a PDA. However we want the PMTMD to be able to run on a PDA and on a smart phone. On smart phones Symbian is currently more popular than Windows Mobile, but Windows Mobile is rapidly gaining market share in this field [17]. More and more manufacturers are currently choosing for Windows Mobile on their Smart Phones. We therefore use Windows Mobile for the PMTMD.

---

[1] The Global System for Mobile communications is the most popular standard for mobile phones in the world.

[2] http://www.kpn.com/kpn/show/id=839513

Application types

- Web application
- Standalone application

The application type used for the PMTMD is a standalone application because from Table D-1 we can see that web applications cannot show video and audio content without installing extra software. Furthermore, external hardware cannot be used with web applications.

Connection Types

- Online
- Offline

For the PMTMD we will not use a network connection during the tour such that no hardware implementations are necessary in the museum. Connections which require no additional hardware in the museum like GPRS, EDGE or UMTS are not supported by PDA's and therefore not used.

Communication standards

Because the PMTMD will use no network connection when in the museum, no communication standard is necessary.

User positioning technologies

- GPS
- RFID
- Infrared
- Location-based wireless
- Bluetooth
- Manual location entering

For determining the user's position, RFID technology will be used. Table D-2 shows that RFID is relatively cheap to implement and is currently rising in popularity. Furthermore it is a challenge to implement RFID technology in a museum tour because no museum tours in the Netherlands use RFID for user positioning purposes.

3 DESIGN

After elicitation of the requirements we propose a design for the PMTMD. In this section we describe the design and the design choices we made with respect to the requirements. The design forms the basis for the implementation of the PMTMD.

We start this section by encapsulating a set of user actions on the system. For modeling the user actions we use UML use case diagrams. After the use cases we present a system architecture which captures the hardware components that are used in the system. We also present a technology stack which combines these hardware components with the technology selection from section 2.4.7. Then we model the communication between the hardware components and present data models which are used for the communication. Finally we capture data classes and application logic using a UML class diagram.

3.1 Use cases

The user interacts with the system by using the CHIP demonstrator from a computer with Internet connection. With the CHIP tour wizard [2], a personalized tour can be created. Furthermore, the user can interact with the system using a mobile device (requirements 1.1 and 1.2).

When the user has an Internet connection the mobile device can be used to synchronize the User Model (requirement 2.1) and to import tours to the mobile device. When the user is inside the physical space of the museum, the user is able to switch between languages (requirements 5.4 and 5.5), retrieve explanation of tour functions and context sensitive help (requirement 6.1 and 6.2), set tour properties like the tour duration and the number of artworks (requirements 3.1 and 3.2) and the user can perform a museum tour. While performing the tour, the user can request his or her current position in the museum (requirement 4.4) and retrieve an overview of the tour (requirement 4.2).

These interactions lead to a set of use cases which are visualized in the use case diagram of Figure 3-1. All direct actions from the user on the system are described in the use case diagram.

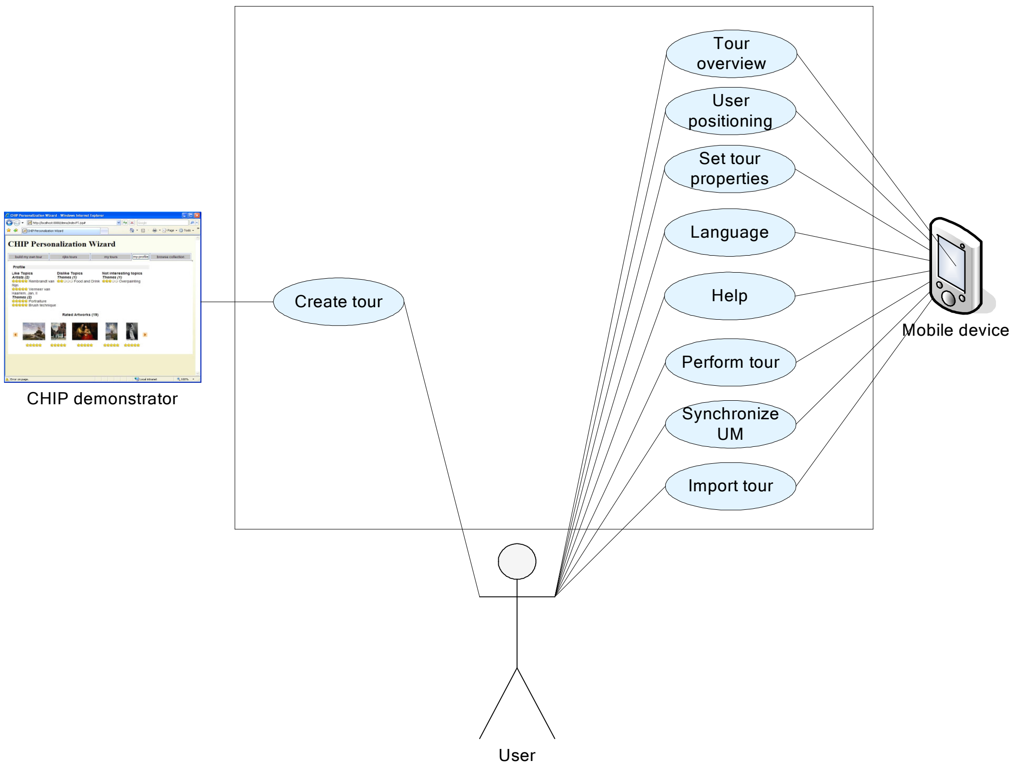

Figure 3-1 Use case diagram

3.2 System architecture

When the user is at a location with an Internet connection, the PMTMD can be used to update the User Model or to import tours to the mobile device. Using the Internet connection, the PMTMD connects to the CHIP demonstrator on a web server. This situation is visualized in Figure 3-2. Two components communicate with each other: the client application located on the mobile device communicates with a server application located on a web server. This is a client/server architecture where multiple mobile devices (clients) can connect to the web server. The communication between the client and server is done using the TCP/IP protocol and is explained in more detail in section 3.3.

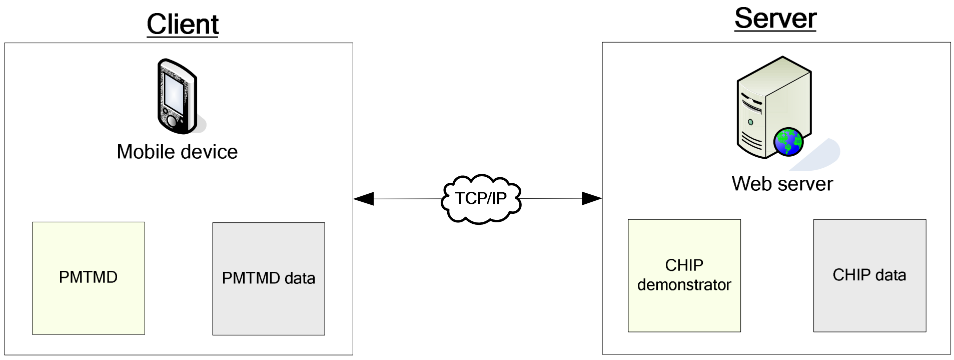

Figure 3-2 System Architecture (Internet connection)

While in the museum, we have chosen not to use an Internet connection because of the hardware costs and device limitations (Section 2.4.7). There is no need for an Internet connection because tour data can be imported before starting the tour and the User Model can be synchronized after visiting the museum. While in the museum, it must be possible to identify artworks using a wireless technique (requirement 4.5). In Section 2.4.7, we chose to use RFID technology for identifying artworks. To use RFID technology, we attach an RFID reader to the mobile device. This RFID reader can communicate with RFID tags using radio frequency signals. This leads to the system architecture for inside the museum shown in Figure 3-3.

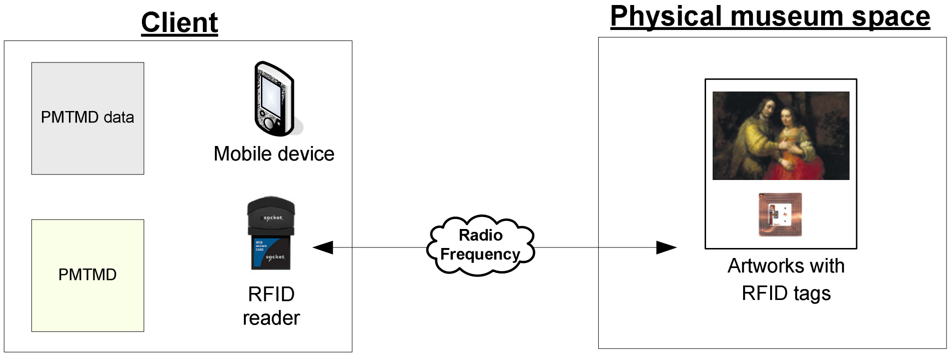

Figure 3-3 System Architecture (Inside the museum)

In section 2.4.7 we chose to implement the PMTMD on a PDA or smart phone with Windows Mobile as operating system. Every PDA or smart phone which runs on Windows Mobile can be used (requirement 1.3). We chose to write a Windows Mobile application using the .NET framework with the C# language. Furthermore, we use the OpenNetCF and fmodCE libraries to support audio (requirement 5.3). Implementing audio makes the user focus on the artwork and not on the mobile device (requirement 5.1). These technologies are shown in the technology stack from Figure 3-4. This figure also shows a technology stack for the web server which is running the CHIP demonstrator. The CHIP demonstrator runs on the Linux operating system and is implemented in JAVA using Sesame to access data stored in an RDF repository.

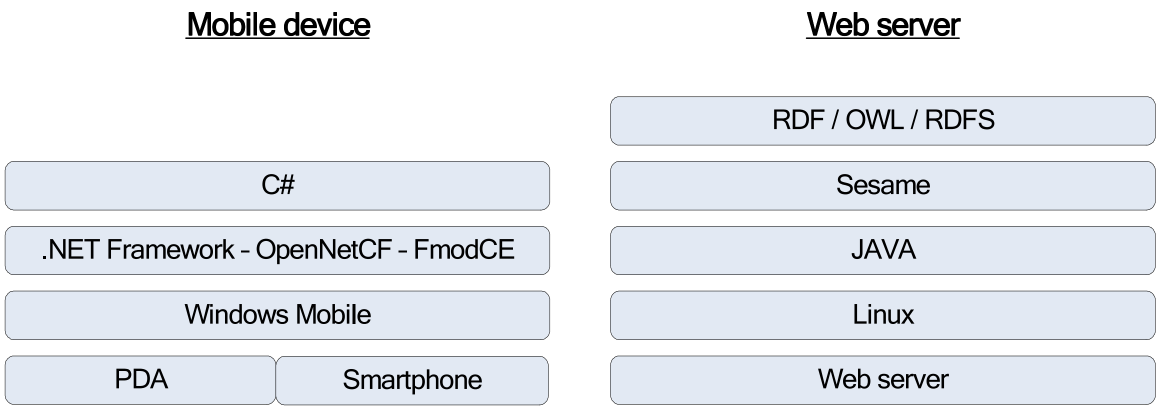

Figure 3-4 Technology Stack

3.3 Communication and data models

In section 3.2 we proposed a system design which uses a client / server architecture. Here the mobile device communicates with the web server using the TCP/IP protocol. This communication protocol allows the user to import tours and to synchronize the User Model. Figure 3-5 shows the communication in more detail.

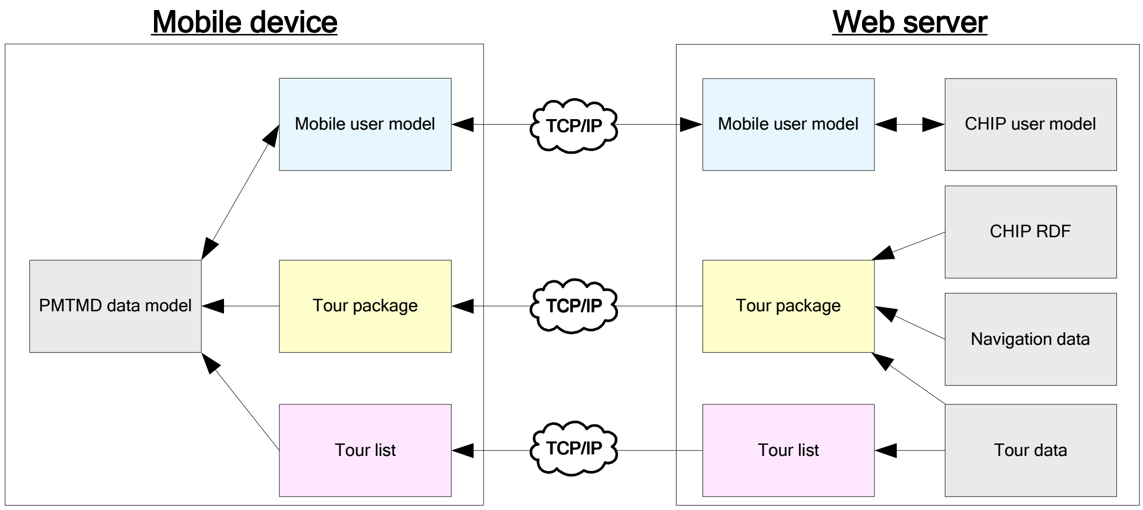

Figure 3-5 Communication between PMTMD and web server application

To import tours from the web server to the mobile device, we create a tour package which contains all information needed for an offline tour. This package includes navigation data which allows us to implement user guidance through the museum (requirement 4.3), personal data to identify the user (requirement 1.6), artwork data from tour artworks and all other artworks from the museum (requirement 5.2) and basic tour properties such as the name of the tour. The tour package is created on the web server by combining artwork data from the CHIP RDF repository with tour data from the tour wizard and user guidance data. For now we manually enter static user guidance data which can be used for calculating routes trough the museum. A more detailed description of the user guidance approach is given in section 8. The tour package data model is shown in Figure 3-6.

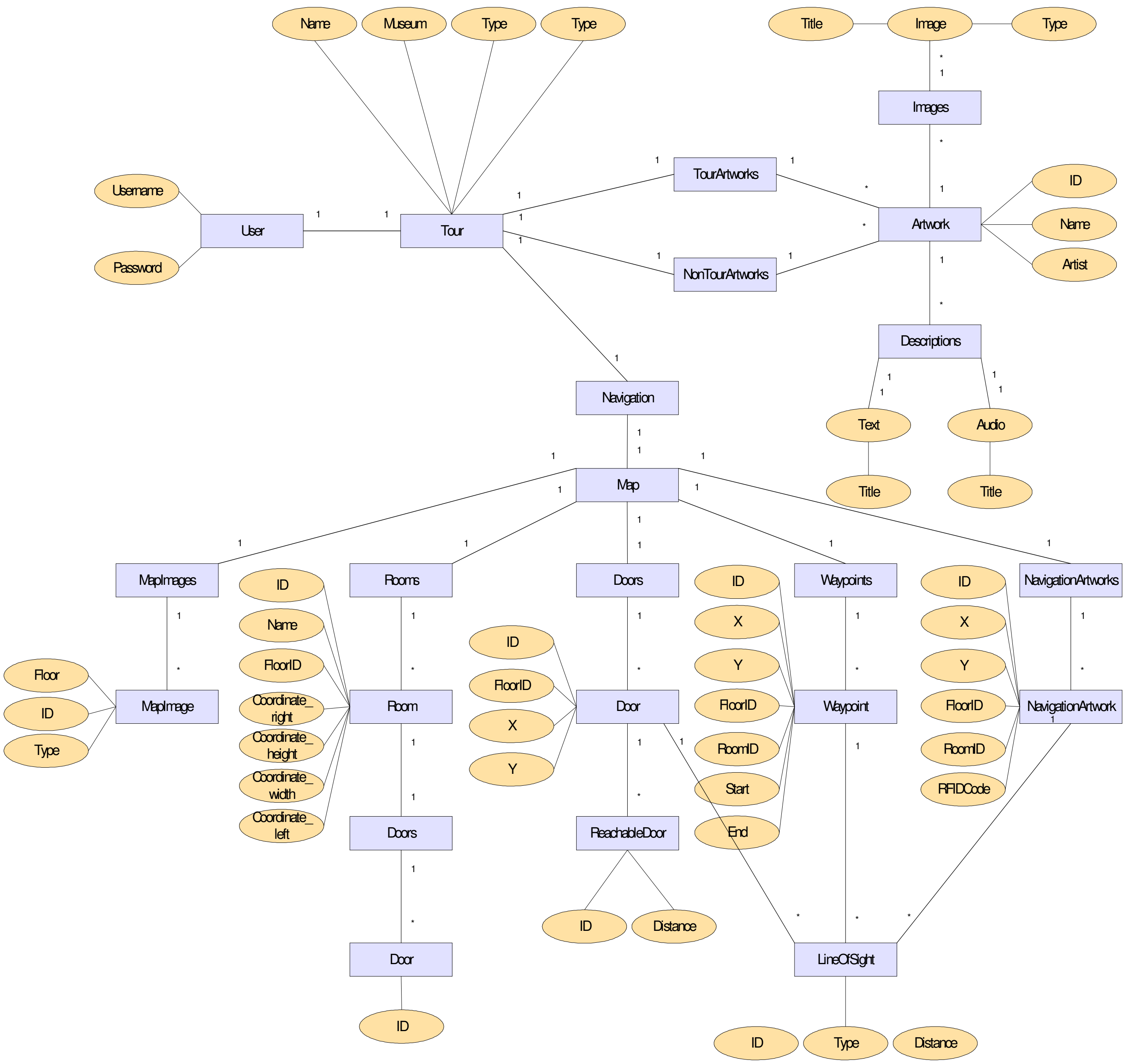

Figure 3-6 Data model: Tour package

The User Model on the CHIP web server is stored as RDF, but this cannot be accessed directly from the mobile device. Therefore we convert the User Model to another format. The User Model contains: Personal information (User id, Password), artwork ratings, and interaction data from each tour. Other aspects can be added easily in the future. The interaction data consists of the sequence in which the artworks are visited in previous tours and the attraction power of each visited artwork. The attraction power is the time a user spends at an artwork, the longer this time is, the higher the attraction power will become. The exact data which is contained in the mobile User Model is shown in Figure 3-7. When synchronizing the User Model, it is converted back to the old format by The CHIP demonstrator.

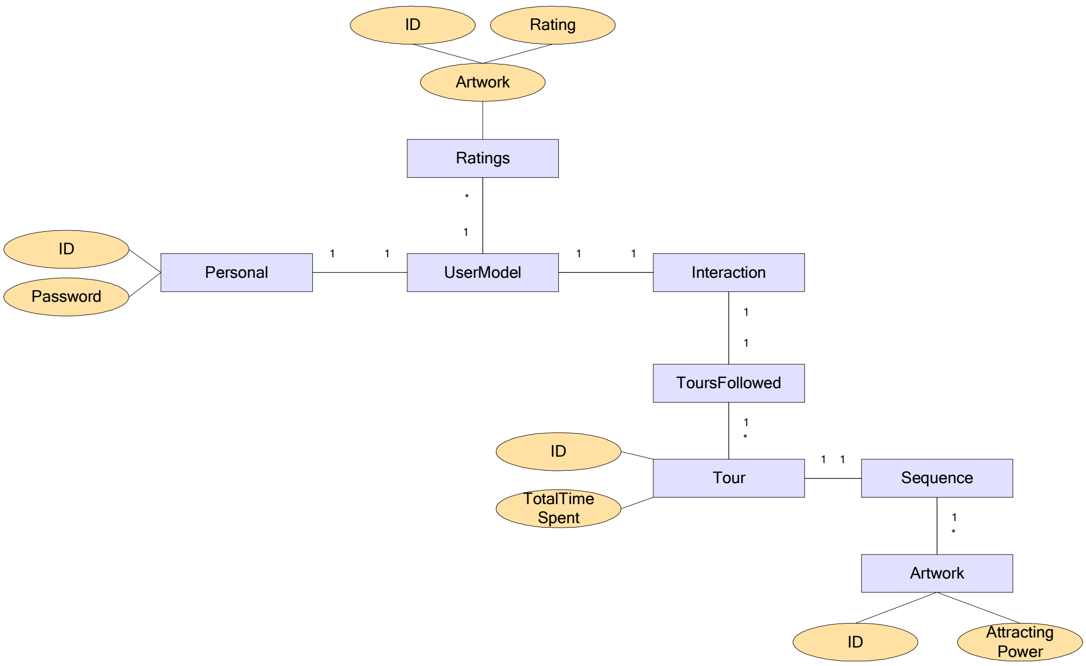

Figure 3-7 Data model: Mobile User Model

In Figure 3-5 we see communication of a tour list from the web server to the mobile device. A user might not want to import all available tours to the mobile device; therefore the user is able to select tours from a list before importing. Now only a subset of the tours is imported. The tour list contains basic information about all available tours. This basic information consists of the name, the type, the museum and the number of artworks that are contained in the tour. Each tour has a type, this type can for example be: My tour (created by the user), Rijks tour (created by experts of the Rijksmuseum), Shared tour (created by other users). The data model for the tour list is shown in Figure 3-8.

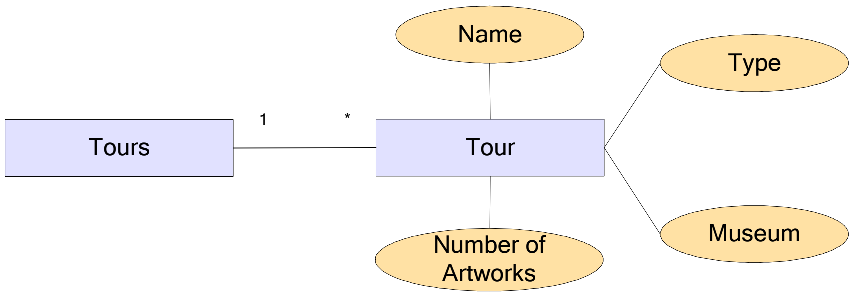

Figure 3-8 Data model: Tour list

The mobile User Model, the tour package and the tour list together provide the PMTMD application with all the data that is necessary to perform a tour. In section 3.4 we show a class diagram of the data model for the PMTMD.

3.4 Class diagram

For the PMTMD application we propose a class diagram which includes data classes to store the User Model, tour data and navigation data. Furthermore it includes a number of classes with application logic to perform calculations and process data. The class diagram is shown in Figure 3-9.

The class diagram consists of two layers:

- The communication layer, Handles communications with the outside world (RFID tags, web server).
- The application layer, Forms the core of the PMTMD and handles internal actions.

The classes are spread over different components:

- RFID Scanner component, Handles signals from the RFID scanner, used for user positioning and user guidance.
- Communication component, Handles communication with the web server to synchronize the User Model and to retrieve tour data.
- Package manager component, Processes the tour package such that the data can be used within the PMTMD.
- Tour component, Forms the core of the PMTMD and is used to store artwork and user data.
- User guidance component, Handles the user guidance through the museum by displaying the museum map and calculating routes. Furthermore it contains the data describing the physical space.
- Mapping component, Handles the mapping from virtual space to physical space.

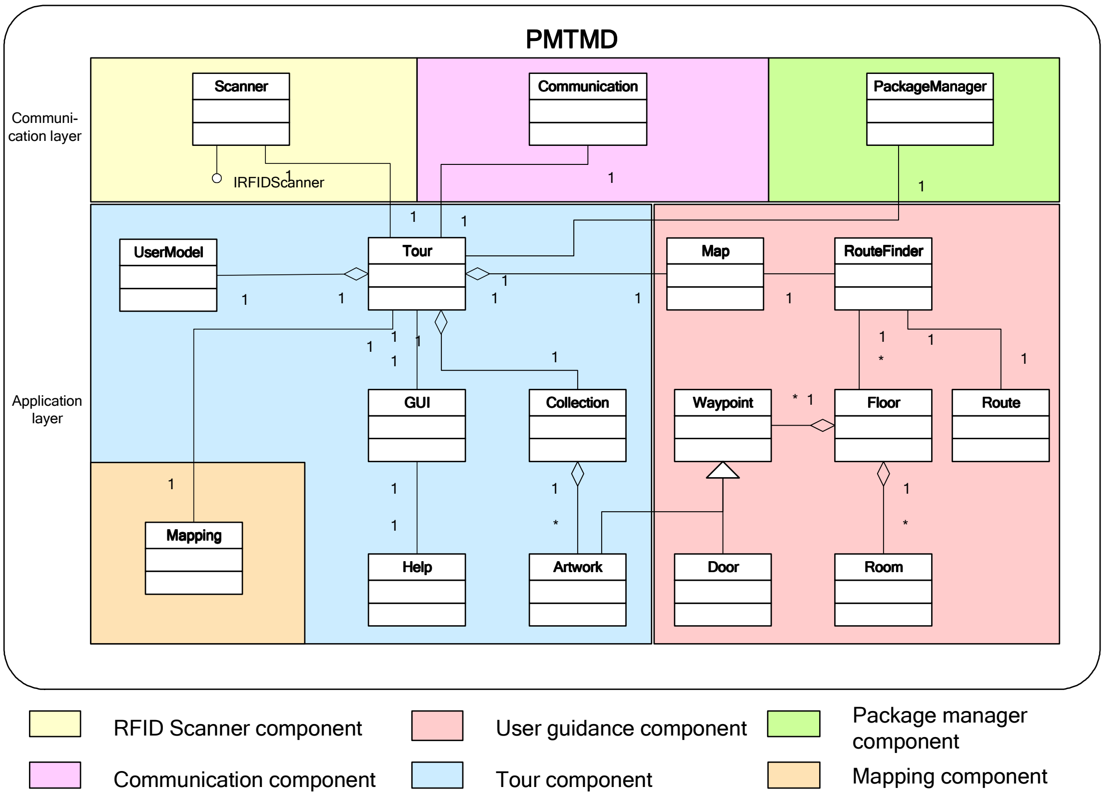

Figure 3-9 Class diagram

4 IMPLEMENTATION

From the design we proposed in section 3, we created an implementation of the PMTMD. In this section we present the development environments which we used for the development of the PMTMD. Then we present the hardware on which we implemented the application. After presenting the hardware, we show the graphical user interface of the PMTMD and describe the different screens and how they are connected.

4.1 Development environment

In Section 2.4.7 we decided to use Windows Mobile for the implementation. We use the .Net Compact Framework[1] in combination with the C# programming language to create a device independent implementation. To add more functionality we include the open-source OpenNetCF[2] Smart Device Framework. For implementing audio and MP3 support we use the free FModCE[3] audio library for Windows CE / Windows Mobile. The communication between the CHIP demonstrator and the PMTMD is done using XML.

.Net Compact Framework

The .Net Compact Framework is a set of classes on top of the Windows Mobile operating system which provides a higher level programming interface and manages the execution of the programs written for the Compact Framework. A JIT compiler[4] is used to run applications.

We use the latest version of the Compact Framework which is version 2.0. The Compact Framework 2.0 is supported by Windows Pocket PC 2003, Windows Mobile 5.0, Windows CE .NET 5.0 and higher, regardless of the underlying hardware.

Visual Basic .NET and C# can be used as programming languages for the Compact Framework. We use C# 2.0 for the implementation.

OpenNETCF

In addition to the Compact Framework we use the open-source library OpenNETCF Smart Device Framework 2.0 library which adds a set of classes on top of the Compact Framework. This library is primarily used for advanced I/O support.

[1] http://msdn2.microsoft.com/en-us/netframework/aa497273.aspx
[2] http://www.opennetcf.org/
[3] http://www.fmod.org/
[4] Just-In-Time Compiler: Compiles the Common Intermediate Language (Bytecode in Java) to native machine code before executing the application.

FMod CE
For audio support we use the free FMod CE 3.75 library created for Windows CE and for Windows Mobile 5.0 and higher. This library is not written in managed code to be compatible with the Compact Framework but is delivered as an external Windows CE / Mobile library which we reference indirectly through the Compact Frameworks COM interoperability interface.

Xml
The PMTMD communicates with a web server. The CHIP project uses an Apache Tomcat server 5.5 with a Sesame 1.2 store containing the RDF repository. Sesame is not supported on mobile devices; therefore we use a translation from the RDF data to XML.

4.2 Hardware

For implementing the PMTMD we use two Windows Mobile 5 based devices, the Hewlett Packard Ipaq hx2790 (Figure 4-1) and the Hewlett Packard Ipaq rx4240 (Figure 4-2). These devices are supplied with two RFID readers connected to the mobile device through a Compact Flash interface (Figure 4-3) or an SDIO interface (Figure 4-4).

Figure 4-1 Hewlett Packard Ipaq hx2790

Figure 4-2 Hewlett Packard Ipaq rx4240

Figure 4-3 Socketscan CompactFlash RFID reader

Figure 4-4 SDID SDIO RFID Reader

The RFID tags are standard ISO 15693 tag labels (Figure 4-5). This is a widely supported standard which can be read by most current mobile RFID readers. We use the adhesive label tags which are attached to artwork labels.

For storing tour data we use 2 Gigabyte SD memory cards (Figure 4-6).

Figure 4-5 *ISO 15693 RFID tag labels*

Figure 4-6 Dane Elec 2 GB SD memory card

Using the PMTMD inside a museum requires headphones for audio descriptions. Therefore we attach wireless Bluetooth headsets to the mobile devices (Figure 4-7 and Figure 4-8).

Figure 4-7 Hewlett Packard Bluetooth headset

Figure 4-8 Logitech Bluetooth headset

4.3 Graphical user interface

The graphical user interface of the PMTMD consists of a set of screens depicted in Figure 4-9. The arrows show the navigational actions between the screens.

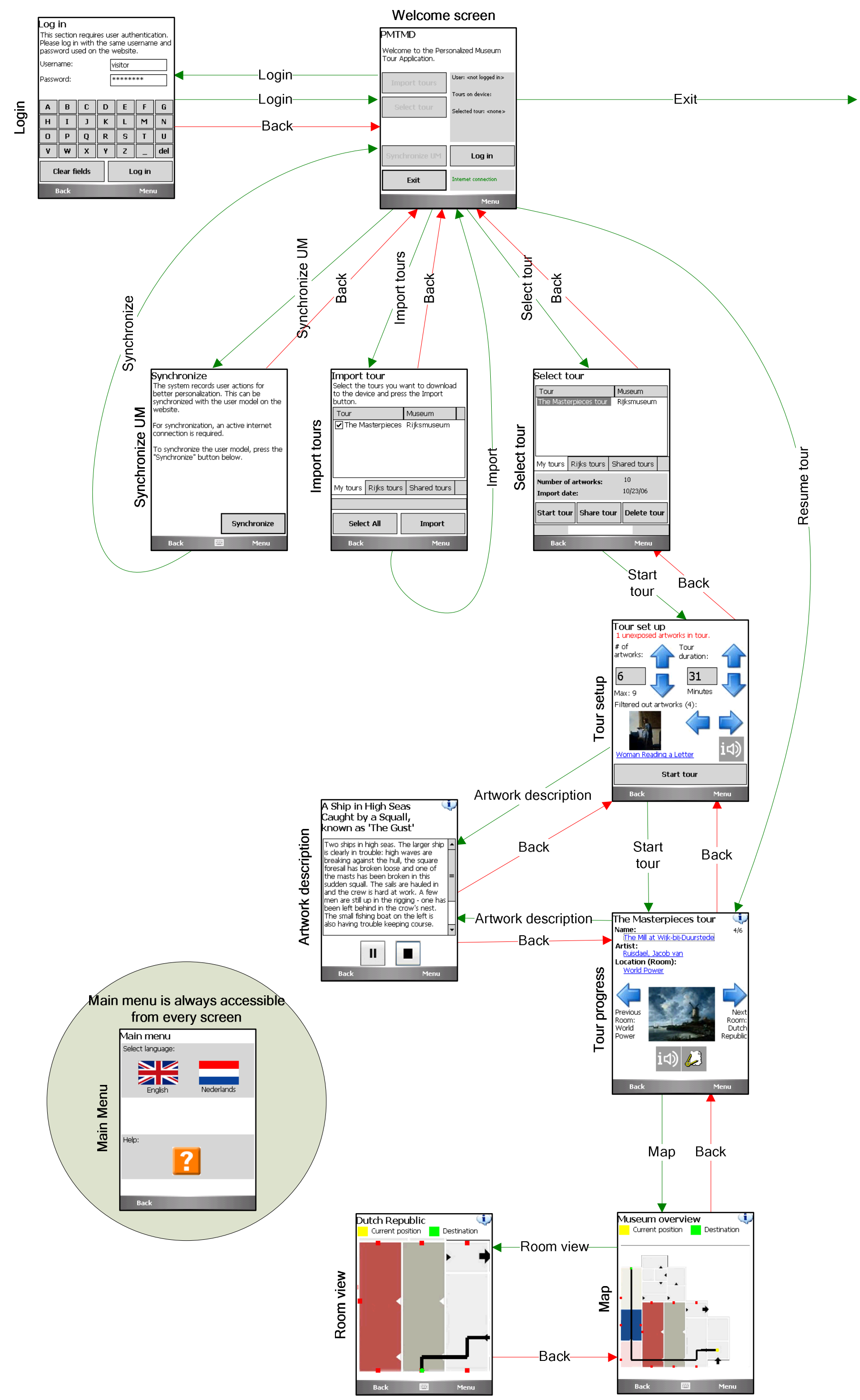

Figure 4-9 Navigational structure

During the museum tours we noticed that styli were often lost or not supplied by the museum. As a consequence it was hard to control the touch screen of the mobile device. The software buttons where too small for our fingers. In the PMTMD we use a touch screen with software buttons, but we have chosen to use large buttons which can be controlled without a stylus.

All screens contain a similar look-and-feel and a menu on the bottom. The menu bar provides the user with the possibility to go back to the previous screen or to display the menu screen. Several screens contain an information button in the top right corner of the screen. This information button shows a popup with context sensitive information about the objects shown in the current screen. We now look at each screen in more detail.

Welcome screen
The PMTMD starts with the "welcome screen", providing the user with the possibility to login or to exit the application. After a successful login the user returns to the welcome screen which now shows three new buttons. The user can:

- Synchronize the User Model
- Import tours
- Select tour

When the buttons are clicked the corresponding screen is shown. The welcome screen furthermore shows the following information:

- Internet connection status (online or offline)
- Currently logged in user (only when a user is logged in)
- Number of tours on the device from the user (only when a user is logged in)
- Name of the selected tour (only when a tour is started)

Import tours
The screen to import tours displays a list of tours from the current user. This list is divided in three categories: "My Tours", "Rijks Tours" and "Shared Tours". The first category contains all tours created by the user with the Tour Wizard. The "Rijks Tours" category consists of the predefined tours from the Rijksmuseum and the "Shared Tours" category contains the tours that are received from other users.

A user can select one or more tours and click the "Import Tour" button to start the process of downloading and importing as described in section 5.

Select tour
The select tour screen allows the user to select tours which are available on the device. It shows the available tours in the same three categories as importing the tour: "My Tours", "Rijks Tours" and "Shared Tours". A tour can be selected and started which loads the tour into memory. Tours can also be deleted which will remove all tour data from the device. However the tour will still be available in the CHIP demonstrator.

Synchronize User Model
If a network connection is available, the synchronize User Model screen allows the user to manually synchronize the User Model. The synchronization process is described in section 5.

Login
The login screen provides login functionality. The user identifies him or her self with the same login credentials as on the website using the built-in keyboard (requirement 1.6).

Tour setup
The tour setup screen allows the user to shorten his tour by decreasing the tour duration or by decreasing the number of artworks (requirements 3.1 and 3.2). If the user changes one of the values, a filtering mechanism is used to calculate a new set of tour artworks. The filtered out artworks can be browsed and a description of these artworks can be requested.

Artwork description
The artwork description screen shows textual information about the artwork. Furthermore the same information is also provided in audio format. The user can stop, pause or restart the audio description. By pressing the information button the user can rate the artwork (Figure 4-10) from which the rating is stored in the User Model.

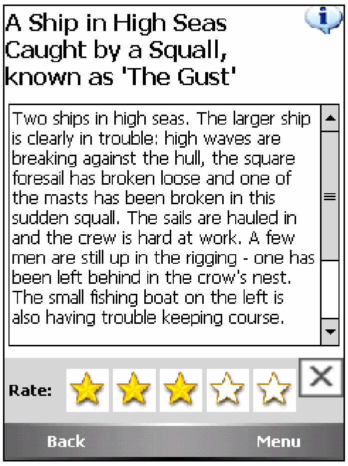

Figure 4-10 Rate artwork

Tour progress
The tour progress screen allows the user to perform the tour. He or she sees the location of the current, next and previous artworks. Furthermore the tour progress is given.

In the center of the screen an image of the current tour artwork is shown to the user. Using the information button the user can pop up basic information from the tour (tour name, number of artworks, duration and museum) (Figure 4-11). Furthermore, the user can request artwork details or see the museum map.

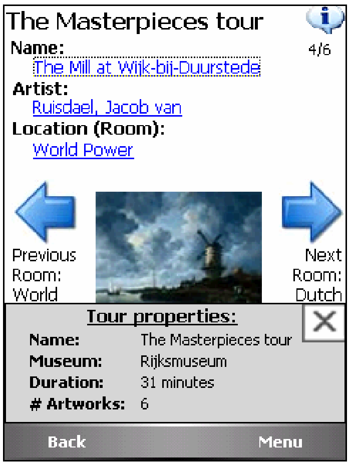

Figure 4-11 Tour properties

Map

After selecting the map view in the tour progress screen, the map of the museum is shown. By pressing the information buttons, the user can enable or disable the following options (Figure 4-12):

- Tour artworks: Show tour artworks on map.
- Route: Show route from the current position to the next tour artwork on map.

When a user clicks on a room, the map zooms in to the selected room and the room view is shown.

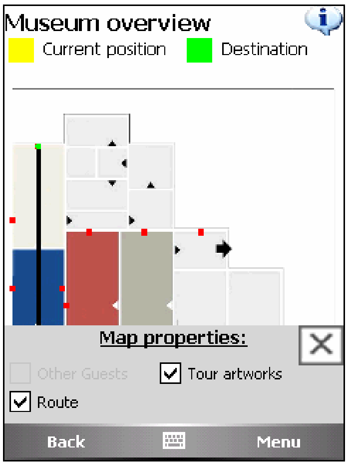

Figure 4-12 Map properties

Room view

In the room view, the user sees a map which is zoomed in such that the room fits in the screen. The user can retrieve information about the room such as the number of tour artworks that are available in the room (Figure 4-13). Clicking on an artwork shows a popup with the artwork properties (Figure 4-14). The map can be dragged by moving the finger over the screen.

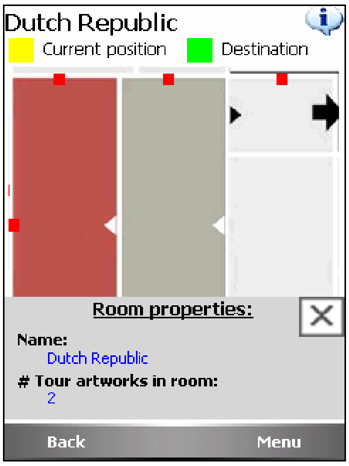

Figure 4-13 Room properties

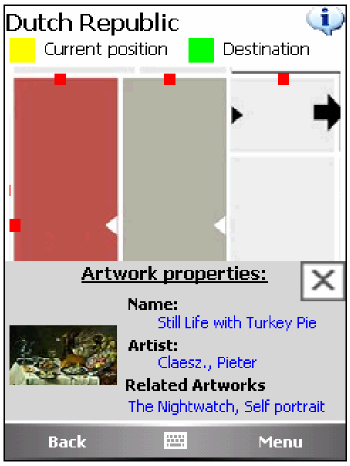

Figure 4-14 Artwork properties

Main menu

The main menu provides general settings and tasks to the user. Currently there are buttons to change the language and show context sensitive help (Requirement 6.2.)

5 IMPORTING AND EXPORTING VIRTUAL TOURS AND USER MODEL

For synchronization between the website and the PMTMD two main tasks need to be accomplished, the tours should be imported from the website, and the User Model must be imported and exported between the CHIP demonstrator and the mobile device. In the following sections we will describe both.

5.1 Import tour(s) from CHIP demonstrator

The user must be able to view an overview on the mobile device containing all virtual tours he or she created using the CHIP tour wizard. It is not practical to transfer all tour data to the mobile device for this overview. Therefore, to save bandwidth, only the basic information is downloaded for displaying the overview. The complete virtual tour will be downloaded when the users selects it for importing.

This means there must be two different levels of communication between the mobile device and The CHIP demonstrator:

- Download a tour overview (Get all basic information of the virtual tours of a user)
- Download a tour (Import a selected tour)

The CHIP demonstrator uses an RDF repository as the data store for the tour information. Unfortunately there is no stable RDF framework like Sesame available for mobile devices. Therefore we will translate the tour information from RDF to a general XML structure which will be uses to communicate data between the CHIP demonstrator and the mobile device. The RDF data from the CHIP demonstrator can be serialized and expressed as a standard XML serialization. However we will be using our own XML structure (Figure C-1) to minimize data overhead and to support other data sources than RDF as well.

Download a tour overview (Get all basic information of the virtual tours of a user)

For displaying the list of tours from a user, the PMTMD must know which tours the user created using the CHIP tour wizard on the Internet. A graphical representation of this process is shown in Figure 5-1.

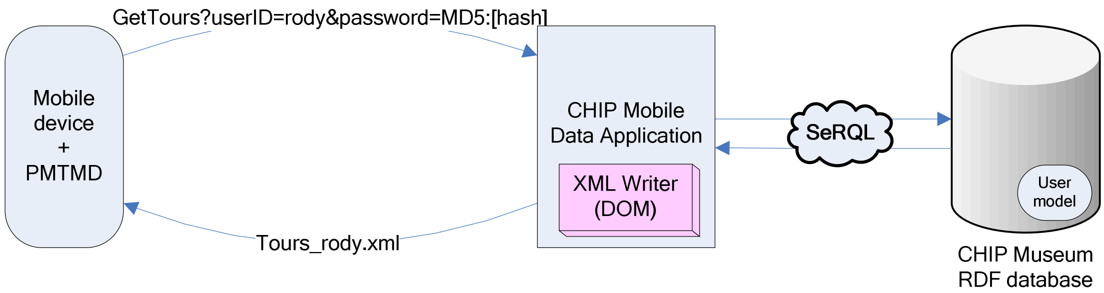

Figure 5-1 Get all tours from a user

To accomplish the process of downloading the tour list to the mobile device, the PMTMD will invoke a web application on the CHIP website we call the CHIP Mobile Data Application, especially created for exporting (and importing) information in XML. This CHIP Mobile Data Application consists of 4 Java Servlets which are used in a similar way but export (or import) different data.

For downloading the tour list a Servlet called GetTours will be invoked (see Figure 5-1) passing the log-in credentials of the selected user. This Servlet fetches the tour data from the data store using SeRQL and returns this to the mobile device as an XML file using a DOM approach using a separate component called the XML Writer. The generated XML file (called Tours_rody.xml in Figure 5-1) is returned to the mobile device. This XML file contains the basic tour information the PMTMD must have to show the overview of the tours of a user. The data model for this XML file is shown in Figure 3-8, an example and description of such an XML file is shown in Figure C-3.

Download a tour (Import a selected tour)
When a user selects one or more tours from the Import Tours screen (Figure 5-4) and imports these to the mobile device the following procedure is performed:

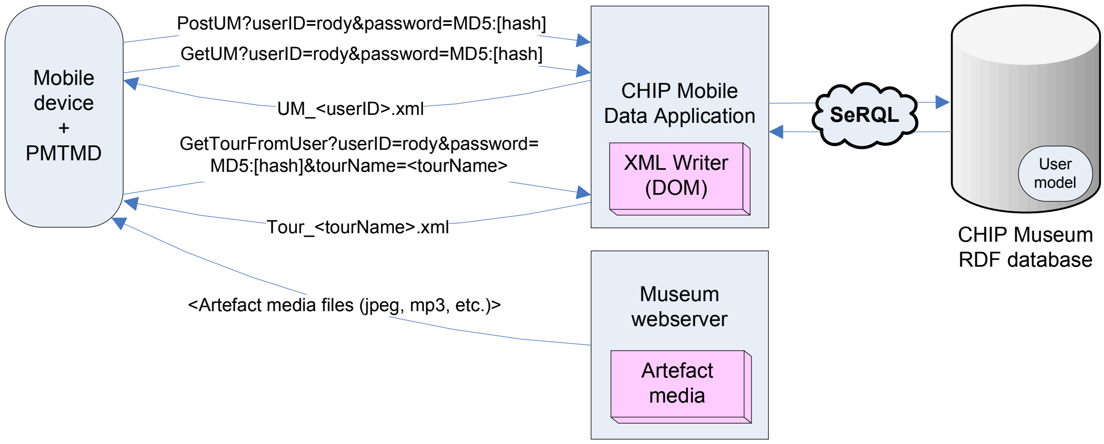

Figure 5-2 Import a selected tour

The PMTMD starts with a synchronization of the User Model invoking two calls to the CHIP Mobile Data Application which deliver the latest User Model to the PMTMD. The process to synchronize the User Model is described in detail in Section 5.2. After synchronization of the User Model, the PMTMD initiates a call to the GetTourFromUser Servlet which retrieves all data from the selected tour and puts it into one XML file per tour. The XML file data model is depicted in Figure 3-6. It consists of three parts:

- User data
- Tour data, which is divided in:
    - Tour Artwork data
    - Non-tour artwork data
- Navigation data

The user data are the login credentials of the user. The tour data consists of the basic information about the tour and the museum collection, split up into Tour-artworks, and Non-tour artworks. This is split up to support online tour scenarios in the future. The artworks in these two sections contain links to images and descriptions. The descriptions are currently in text and audio. But using this extendable structure, video or other multimedia descriptions can be easily added.

The Navigation data contains a museum specific part of the physical space of the museum. It contains floor map images and its rooms, doors, artworks and waypoints. Waypoints are specific coordinates in a museum to help the navigation construct smooth paths through the rooms. The doors, artworks and waypoints are connected to each other using a “Line Of Sight” object which contains information about which door (or artwork or waypoint) is reachable from which other door, artwork or waypoint. The navigation data is necessary to provide user guidance and user positioning.

The tour XML contains all data the PMTMD should have to perform this tour except for the media files. These are stored on the museum (or CHIP) web server. The tour XML contains URLs linking to these media files. After the tour XML is received, the PMTMD will download the media files and store them on the mobile device.

All data transfers use a similar method to preserve the possibility of resuming a failed download. All files are transferred separately and stored as a temporary file until the download is completed. If a download fails, the temporary files are recognized and downloading can be resumed.

The tour list, and tour XML provide a one-way communication from the CHIP demonstrator to the device. Changes to the tour, progress indication and user behavioral data will be transmitted back to the CHIP demonstrator using the User Model. The next section will describe the synchronization of the User Model between the CHIP demonstrator and the PMTMD.

5.2 Synchronize User Model data

While using the PMTMD the user generates a lot of interesting behavior information which can be used by the CHIP project to improve personalization. On the CHIP demonstrator this information is stored in the User Model. The PMTMD uses a local version of this User Model to save the behavior information.

When altering the User Model on the mobile device, the User Model on the website should be updated with the same information. When the User Model on the website is changed this should not collide with the mobile User Model. Therefore synchronization of the User Model is necessary.

To use this User Model on the mobile device the User Model should be transferred to the device. The synchronization process is shown in Figure 5-3.

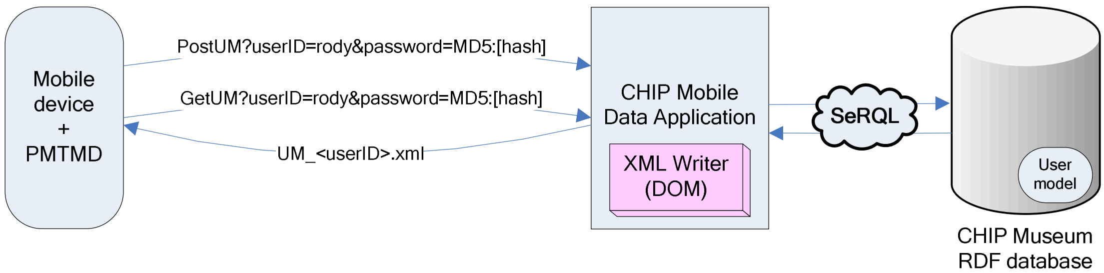

Figure 5-3 Synchronize User Model

To ensure no User Model data is lost when synchronizing, two steps are performed to synchronize the User Model. The first step is to add the current pending updates from the mobile device to the User Model on the CHIP Database. This is performed by the PostUM Servlet which receives the User Model from the PMTMD as a POST variable. This will update the User Model at the CHIP museum database to the current version. The second step is to receive the new updated User Model from the database. The PMTMD calls a second Java Servlet (GetUM) to retrieve the updated User Model to the mobile device and overwrites the current mobile User Model with the new one.

The User Model is synchronized when a user imports a tour and can be manually initiated from the Welcome Screen (Figure 4-9). We chose to use two separate User Models in stead of updating the User Model of the CHIP Demonstrator in real-time to support an offline scenario where there is no Internet connection available when performing the tour.

The User Model is stored in the CHIP RDF database. We use an XML structure to communicate the RDF User Model to the PMTMD. This representation of the User Model is shown in the data model of Figure 3-7.

Currently the User Model is divided in three parts:

- Personal information
- Artwork ratings
- Interaction data per tour

The personal information contains the login credentials for the user and will not be changed by the PMTMD. This is used to identify the user to the PMTMD application when no Internet connection is available. The second part contains the artwork ratings by the user. An artwork can be rated both on the website using the CHIP recommender and using the PMTMD. Using these ratings, personal preferences are calculated by the CHIP demonstrator. The third part of the User Model contains the interaction data. For each performed tour this stores the sequence of visited artworks, which artworks are skipped, the duration the user stayed at a certain artwork and the total duration of the tour.

To ensure the integrity of the User Model, only the added values are updated in the User Model on the CHIP RDF Database. To achieve this, the XML file is split up into two parts: the mobileModel and the websiteModel. This can be seen in the example of the XML file in Figure C-2 where there are two tags websiteModel and mobileModel which contain similar data. Although the websiteModel is the static part retrieved from the CHIP Mobile Data Applications and the mobileModel contains the user data generated and gathered on the PMTMD.

5.3 Problems and risks

All communication between the mobile device and the CHIP demonstrator will be done through the Internet. This can be: wired, GPRS, UMTS, Wi-Fi or any other Internet connection available. Using Internet based communication create risks, especially using wireless Internet communication.

The problems that can be expected are:

Connection drops during synchronization or importing

While the user is synchronizing the User Model or importing tour data the connection can drop.

Solution: To prevent the user has to download (or upload) everything again, the separate files are downloaded and saved at a regular interval (fixed buffer size of 2048 bytes) during the transfer to resume a broken download. A buffer is used which is constantly updated to the disk in a temporary file. When the transfer is completed this temporary file will be moved to the final destination. In the case the transfer fails before successful completion the temporary file will stay on the disk. When the transfer is restarted the temporary file is detected by the PMTMD and the system will ask the user if he or she wants to resume the previous transfer. If the user does not want to resume, the temporary file will be deleted. If the user wants to resume the transfer, the download will be resumed at that file.

Data corruption after synchronization or importing

It is possible that during the communication with the website the transferred files get corrupted.

Solution: To prevent this, a hash of the XML file can be implemented in the XML files which will be checked on completion of the download.

The mobile User Model can be outdated

When the user imports a tour, the current User Model is synchronized. Then there exists two separate User Models, one on the CHIP demonstrator and one on the mobile device which are updated separately. So when the user finished a tour on the mobile device and wants to update his User Model there can be properties in the User Model on the CHIP demonstrator which are not on the mobile device.

Solution: When synchronizing, only new items from the mobile device are added to the User Model on the CHIP demonstrator and should not be completely overwritten with the mobile device model.

5.4 Importing and exporting virtual tours and User Model implementation

To import a tour or to synchronize the User Model, the mobile device must be connected to the Internet and the user must be successfully authentication by the PMTMD. If the device is not connected, the user cannot select the menu option to import tours or to synchronize the User Model.

In the import tours screen from Figure 5-4 the user can select one or more tours and press the Import button to start the import process. To manually synchronize the User Model the user can push the button shown in Figure 5-5.

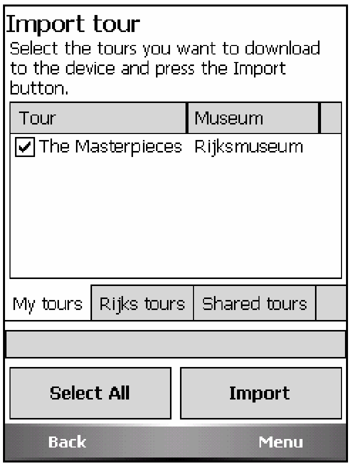

Figure 5-4 Import tour

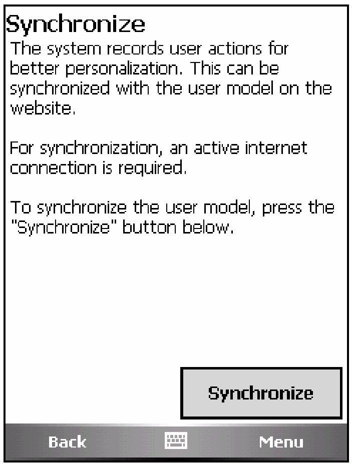

Figure 5-5 Synchronize User Model

During the import or synchronization process, the communication is performed by sending and retrieving XML data. The structure of the mobile XML User Model and the tour XML provide a general way to transfer user and tour information from and to the mobile device.

In Figure C-2 a sample mobile User Model is shown. It contains three parts, the personal information, the website model and the mobile model. The personal information contains the username and password of the user. The website model contains the imported User Model from the CHIP database and the mobile model contains all recorded actions from the user. These will be added to the CHIP database on synchronization.

Figure C-1 shows a sample of a tour XML package. It contains basic tour information like name, museum, type and language, followed by the user information and a museum specific navigation part. And finally the tour and non-tour artworks are described. This XML package is a straight XML representation of the data model from Figure 3-6.

6 MAPPING A VIRTUAL TOUR TO THE PHYSICAL SPACE

When converting a virtual tour to a mobile museum tour, properties of the physical space such as artwork locations play a role. While performing the human guided tour, we saw that a good museum is not too long. A virtual tour can contain a large number of artworks which would lead to a very long museum tour. To limit the duration of the museum tour, the user can set tour constraints such as the number of artworks that are in the tour.

Here we propose a mapping mechanism to map a virtual tour to a physical mobile museum tour. First we filter out unexposed / unavailable artworks from the total set of artworks and then we order them such that an optimal route passing all artworks can be given. Finally we apply constraints to limit the number of tour artworks. This mapping process is visualized in Figure 6-1.

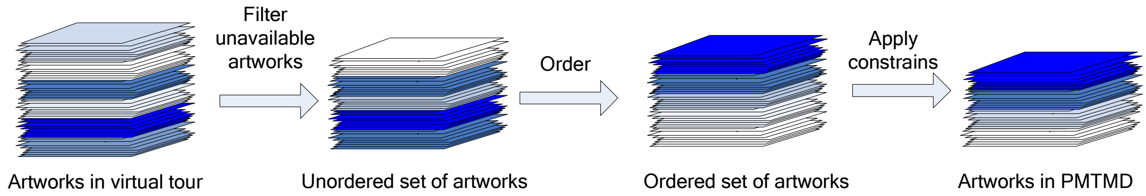

Figure 6-1 Mapping process

The filtering of unavailable artworks and applying the constraints might remove artworks from the input set; however it is also possible that no artworks are removed from this set. Equation 6-1 shows the number of artworks in the virtual tour with respect to the number of artworks in the PMTMD.

$$\#V \geq \#U \equiv \#O \geq \#M$$

Where:

$\#V$	:	*Number of artworks in virtual tour.*
$\#U$	:	*Number of artworks in tour after filtering out unavailable artworks, but before applying constraints.*
$\#O$	:	*Number of artworks after ordering.*
$\#M$	:	*Number of artworks in the PMTMD.*

Equation 6-1 Artwork count during mapping process

In this section, we describe the mapping process as proposed in Figure 6-1 in more detail. Here we discuss the filtering of unavailable artworks from the set of artworks, the ordering process and how constraints can be applied on the set of ordered artworks. Finally we discuss the implementation of the mapping process in the PMTMD and how the tour can be adapted to the user's behavior.

6.1 Filter unavailable artworks

While creating a virtual tour using the tour wizard, the user is not restricted to the properties of the museum building and the current museum exhibition. All museum artworks in which the user is interested can be added to the virtual tour. When moving from the virtual space to the physical space of the museum, several restrictions must be taken into account. A crucial aspect for a physical tour is the availability of artworks. If an artwork is not part of the current exhibition it forms a restriction for the PMTMD, now the user cannot visit the artwork.

Another restriction can be formed by the physical locations of the tour artworks in the museum. On the website, an artwork is just an image which can be downloaded to every computer with an Internet connection; the artwork comes to the user. In the museum the artwork is a physical object located in a certain part of the museum; here the user should come to the physical location of the artwork. This might restrict users which are less mobile than others to visit certain artworks when they have to walk large distances.

For the PMTMD only the availability aspect is taken into account because this is a crucial aspect for a physical museum tour to work properly.

The algorithm

We propose an algorithm for removing unavailable (non-exposed) artworks from the set of tour artworks. This algorithm has a set of artworks as input and outputs a set of available and a set of unavailable artworks. The set of available artworks is used for the museum tour and the set of unavailable artworks are the artworks that are filtered out and hence are not available in the tour. These unavailable artworks are not removed from the system such that they can still be accessed by the system. Information about the location of each artwork is used to verify the availability of the artwork. For the Rijksmuseum artworks with a location starting with "PH-" are available to the visitor. "PH-" refers to the Philips wing of the Rijksmuseum which is at the moment of writing the part of the Rijksmuseum that is open for visitors. The location data is retrieved from the CHIP RDF repository such that it is available for use in the PMTMD. Algorithm 6-1 and Figure 6-2 show the algorithm.

```
for each artwork a ∈ tourartworks
    if a starts with "PH-"
        add a to availableartworks
    else
        add a to unavailableartworks
    output -> availableartworks, unavailableartworks
```

Algorithm 6-1 Filter unavailable artworks

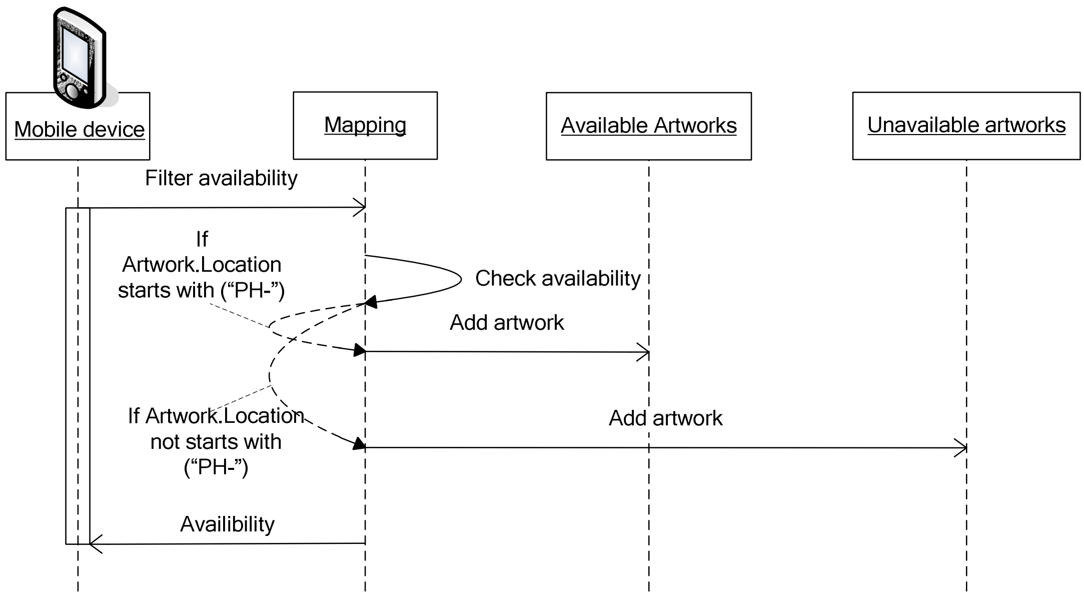

Figure 6-2 Sequence diagram: Filter unavailable artworks

6.2 Tour artwork ordering

The set of artworks initially has no specific ordering; however the artworks must be ordered such that a logical route through the museum can be presented to the user. We propose an ordering algorithm which uses distances between the artworks in the tour to determine a logical route. The distances between the artworks are calculated using the routing framework which is presented in section 8.1.

The algorithm

The ordering algorithm we propose uses a set of available artworks as input. All artworks must be available because their locations within the museum are used in the ordering algorithm. The algorithm delivers an ordered set of tour artworks.

We determine the artwork that is closest to the starting point of the tour. Then we put the closest artwork in the set of ordered artworks and remove it from the available artworks. After that we repeat this process by taking the closest artwork as starting point for the next iteration. Algorithm 6-2 and Figure 6-3 show the ordering process.

```
start = tourstartpoint
for each artwork a ∈ availableartworks
    for each artwork a2 ∈ availableartworks
            distances.add distance from start to a2
    closestartwork = get minimum from distances
    add closestartwork to orderedartworks
    remove closestartwork from availableartworks
    start = closestartwork
output -> orderedartworks
```

Algorithm 6-2 Tour artwork ordering

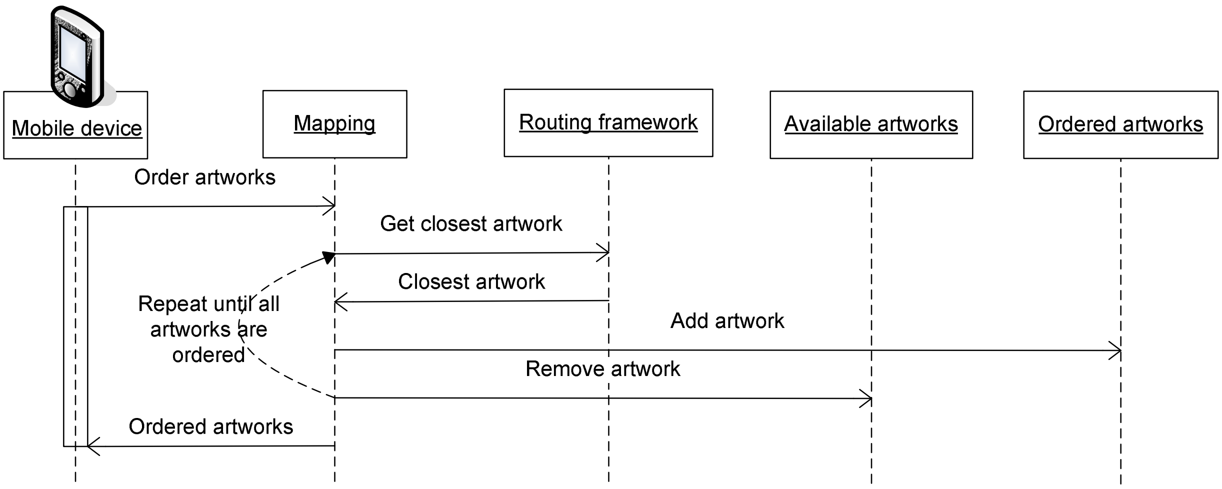

Figure 6-3 Sequence diagram: Tour artwork ordering

6.3 Apply constraints

A virtual tour can contain a large number of artworks which would lead to a long museum tour. From the museum tour overview of section 2.1 we learned that a good museum tour is not too long. Therefore we limit the number of artworks in the tour according to a set of constraints which are created from user input. These constraints can be anything that filters out artworks leading to a smaller set of artworks. Possible constraints are: "The tour must contain 6 artworks.", "The tour must take no longer than 45 minutes", "The distance between tour artworks may not be more than 100 meters", "The maximum walking time between tour artworks may not be more than 5 minutes".

For the PMTMD we have chosen to offer functionality to the user to apply a constraint which sets the number of artworks and a constraint which sets the tour duration (requirements 3.1 and 3.2). Applying the constraints can be done before starting the museum tour or during the museum tour. Applying constraints during the museum tour might lead to a more precise estimation of tour properties such as the duration. On the other hand it can be confusing for the user if the number of artworks in the tour changes during the tour. Therefore we have chosen to apply the constraints before starting the museum tour.

We now propose methods to limit the number of artworks in the tour by setting the number of artworks and by setting the tour duration.

Set number of artworks
The user chooses the number of artworks he or she wants to visit during the museum tour. This is a number between one and the number of ordered artworks. If the number that was chosen by the user is smaller than the number of ordered artworks: the system determines which artworks should be filtered out. From the resulting set of artworks the estimated tour duration is calculated and given to the user, the tour duration and the number of artworks are synchronized (requirement 3.3).

For estimating the duration of the tour, information about the visitor's behavior is needed. The information that is needed is: the time a user spends at each artwork and the time that is needed to walk from one tour artwork to the other. A summation of the times spent at all artworks in the museum together with the walking times lead to an estimation of the total tour duration.

The time that a user spends at an artwork differs per user; this makes the estimation of the total duration more difficult. We have solved this by adding the time a user spends at each artwork in previous museum tours to the User Model (this time must be higher than 10, otherwise it is not added to the User Model because we do not consider visits of less than 10 seconds to be real visits). From these times, called attraction power in the User Model, an average time is calculated which is used to estimate the tour's duration. This average is personalized for each user and is adapted automatically by the application. The calculation of the average is trivial: the sum of all times is divided by the total number of artworks visited. If the user has not done any previous museum tours, an average time for the general museum user is used to estimate the tour duration. An average time suffices here because only an estimation of the duration is needed. For the PMTMD we use an average of 5 minutes per artwork.

The time that is needed for a user to walk from one artwork in the tour to another depends on different aspects; the crowdedness in the museum, the walking speed of the user, whether the user takes stairs or elevators. These aspects make it rather difficult to calculate the walking time. For the mobile application we use a walking speed that is average for all museum visitors; this walking speed we then use together with the distance between the artworks to calculate the walking time. For the PMTMD, we use an average walking speed of 1 meter per second.

We calculate the estimated tour duration using the equation from Equation 6-2. This equation leads to the following algorithm (Algorithm 6-3):

```
averagewalkingspeed = 1
walkingtime = 0
for i = 0 to #orderedartworks
    distance = distance from orderedartworks[i] to orderedartworks[i+1]
    walkingtime = totalwalkingtime + (distance / averagewalkingspeed)
duration = (avgtimeatartwork * #orderedartworks) + walkingtime
output -> duration
```

Algorithm 6-3 Estimate tour duration

$$Dur = \left(AvgT_{artwork} \cdot \#M \right) + \sum_{i=1}^{\#M} \left(\frac{Dist\left(Pos_i \ , \ Pos_{i+1}\right)}{Avg_{wspeed}} \right)$$

Where:

Dur	:	*Estimated duration of the mobile museum tour in seconds.*
$AvgT_{artwork}$	:	*The average time a user spends at an artwork in seconds.*
Pos_n	:	*A position in the museum. A position can be either an artwork or the start or end point of the museum tour.*
$Dist\left(Pos_i \ , \ Pos_{i+1}\right)$	:	*Distance from the* i_{th} *position (current) to the* $i+1_{th}$ *position(next) in meters.*
Avg_{wspeed}	:	*Average walking speed of museum visitors in meters per second (m/s).*
$\#M$	:	*Number of artworks in the PMTMD which is set by the user.*

Equation 6-2 Estimate tour duration

We now propose the algorithm that sets the number of tour artworks from which the estimated duration is calculated.

The Algorithms

When setting the number of artworks, the user gives a preferred number. We then remove artworks from the set of tour artworks as long as the number of preferred artworks is smaller than the tour artworks. The input of the algorithm is the set of ordered artworks and the preferred number of tour artworks. The algorithm delivers a set of tour artworks and a set of filtered out artworks.

Removing the artworks is done using the artwork ratings in the first place and their locations in the second place. First the least popular artworks are removed from the set of ordered artworks. With least popular artworks, the artworks with the lowest rating are meant. Artworks which are not rated yet are given a temporary average rating such that they are not immediately removed from the tour. Secondly, if there are more artworks with the lowest rating than the number of artworks that should be removed, we remove artworks which are most off-route. An artwork is most off-route if the total distance that is needed to visit it is largest. This off-route distance is calculated using Equation 6-3.

The algorithm for removing artworks is shown in Algorithm 6-4 and Figure 6-4.

Assume artwork 'a', 'b' and 'c' are consecutive artworks in a route where 'a' is the first artwork, 'b' is the second artwork and 'c' is the third artwork.

$$TotalDist = \left(Dist\left('a', 'b'\right) + Dist\left('b', 'c'\right)\right) - Dist\left('a', 'c'\right)$$

Where:

$TotalDist$ *: Total distance needed to visit the artwork.*

$Dist\left(i, j\right)$ *: Distance from artwork i to artwork j.*

Equation 6-3 Calculating distance between artworks

```
tourartworks = orderedartworks
while #tourartworks > #preferredartworks do
    #artworkstoremove = #tourartworks - #preferredartworks
    lowestratingartworks = getlowestratingartworks from tourartworks
    if #artworkstoremove >= #lowestratingartworks and
      #lowestratingartworks > 0
           for each artwork a ∈ lowestratingartworks
                  add a to filteredartworks
                  remove a from tourartworks
    else
           for i = 0 to #artworkstoremove
                  mostoffroute = getmostoffrouteartwork from tourartworks
                  add mostoffroute to filteredartworks
                  remove mostoffroute from tourartworks
output -> tourartworks , filteredartworks
```

Algorithm 6-4 Set number of artworks

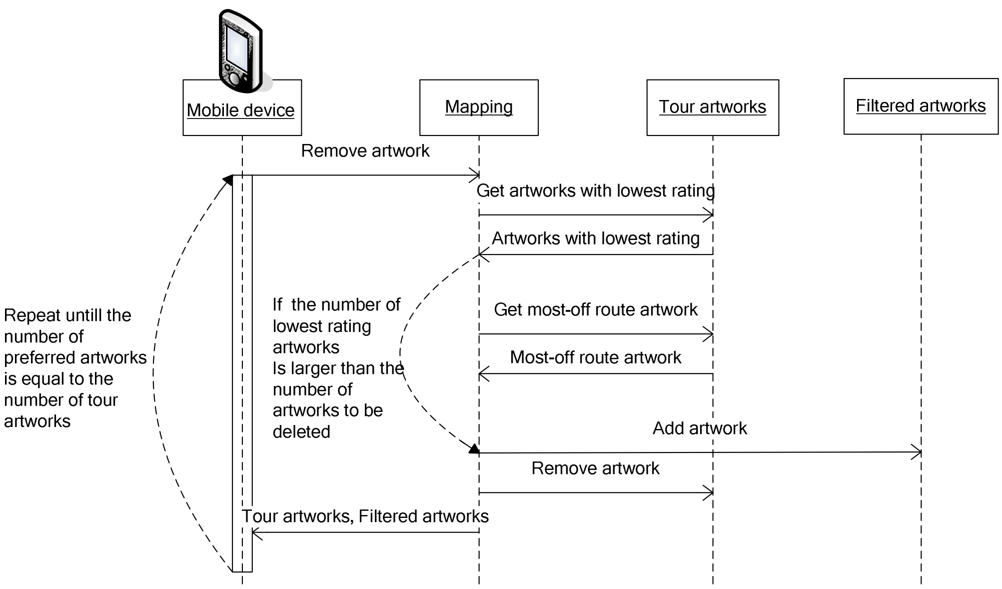

Figure 6-4 Sequence diagram: Set number of artworks

Set tour duration

Besides the number of artworks, the user can also choose to set the tour duration. While setting the tour duration, the number of artworks in the tour is estimated according to the preferred duration. The tour duration can be a value between the time needed to visit one tour artwork and the time to visit all artworks from the virtual tour minus the unavailable artworks.

The tour duration in the PMTMD is not used as a hard deadline which should be met by the user but is used to set the preferred tour duration. When a deadline should be met, the user is focusing too much on the time aspect which is not in the nature of a museum visit.

The Algorithm

This algorithm uses the set of ordered artworks as input and outputs a set of tour artworks and the filtered out artworks. As long as the estimated duration is larger then the preferred duration (which is given by the user), an artwork is removed from the tour artworks. This artwork is placed in the set of filtered artworks. The algorithm for setting the tour duration is shown in Algorithm 6-5 and Figure 6-5.

```
1. tourartworks = orderedartworks
2. estimatedduration = get estimated duration using ordered artworks
3. while (estimatedduration > preferredduration
4.     tourartworks = get tour artworks from setting number of artworks one
       less
5.     add removed artwork to filteredartworks
6.     estimatedduration = get estimated duration using ordered artworks
7. output -> tourartworks , filteredartworks
```

Algorithm 6-5 Set tour duration

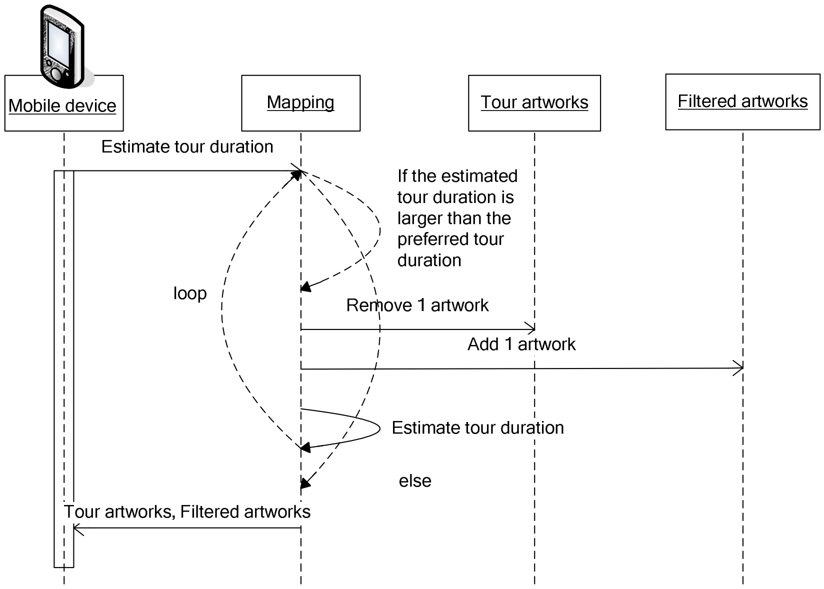

Figure 6-5 Sequence diagram: Set tour duration

6.4 Implementation of the mapping

The mapping from the virtual tour to the physical tour is applied during the tour setup. The tour setup screen is shown in Figure 6-6. The number of artworks that are filtered out because they are currently not exposed is given on top of the tour setup screen. Furthermore, the user has the possibility of setting the number of artworks and the tour duration. When pressing the up or down button to change the number of tour artworks or the tour duration, the mapping is applied such that the tour artworks and a set of filtered artworks are determined. Now the user can choose to start the tour with the set of tour artworks or the user can see which artworks are filtered out by the system. From the filtered out artworks it is also possible to retrieve a description by pressing the description button in the bottom right corner.

When changing the number of tour artworks, the estimated tour duration is calculated and shown in the tour setup screen. And when changing the tour duration, the estimated number of tour artworks is shown in the corresponding text field. The number of artworks in the tour can be at least one and at most the number of tour artworks from the virtual tour minus the unavailable artworks. After pressing the decrease or increase tour duration buttons, the number of tour artworks is estimated.

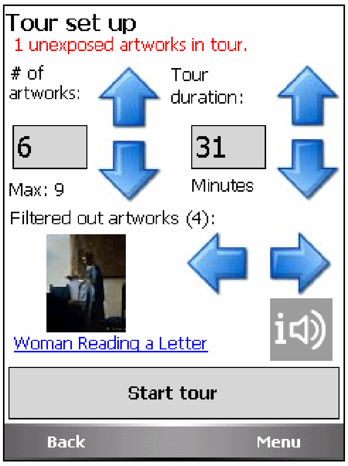

Figure 6-6 Tour set up

When guiding the users to artworks, users might not strictly follow the order of artworks which we propose during the tour set up. Therefore, we adapt the tour to the behavior of the user and reorder the route during the tour. If an artwork is visited which is not the next tour artwork, the artworks are reordered such that the most logical route is given starting from the current artwork.

7 USER POSITIONING

RFID technology is used to implement user positioning in the PMTMD application. An RFID reader which is connected or embedded in the mobile device is used to read RFID tags. Passive RFID tags are placed on the labels next to the paintings. When a user moves the mobile device close to a label, the tag is read and the system receives input from the RFID reader.

Each RFID tag is coupled to an artwork. If a tag is scanned, the system recognizes which artwork was scanned (requirement 4.5). The system uses the location of the corresponding artwork to update the user's location in the museum. Figure 7-1 shows the internal actions when scanning an RFID tag.

The PMTMD must be usable when an RFID tag or reader is not available. Therefore it is possible to manually select an artwork such that the current user's position is updated.

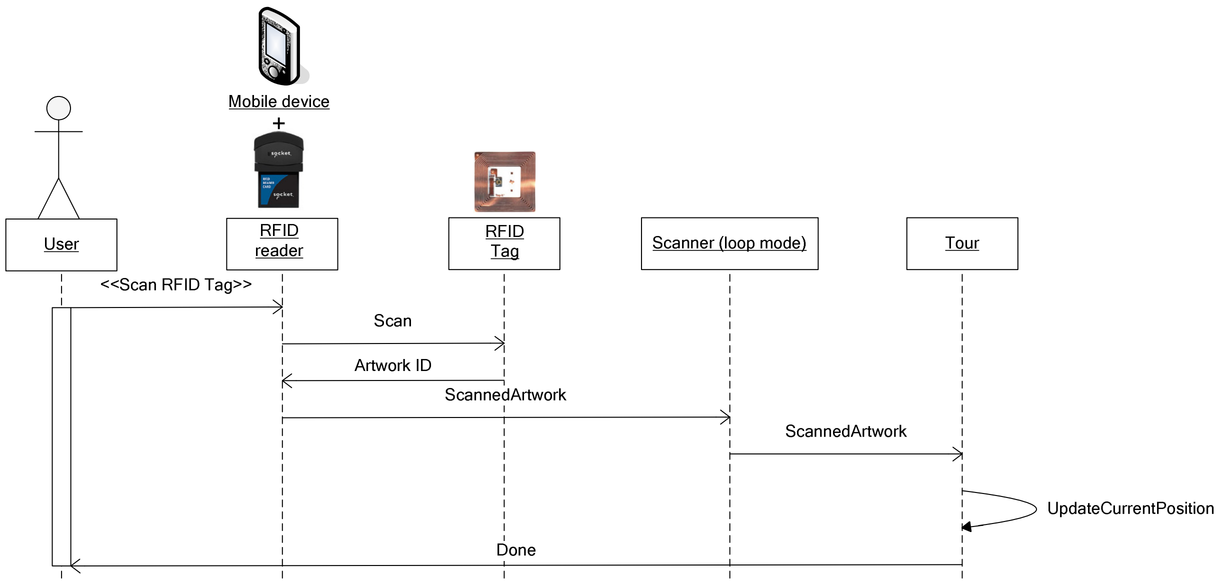

Figure 7-1 Sequence diagram: Scan RFID tag

7.1 User positioning implementation

In the PMTMD application, the RFID reader is only used while performing the tour. Scanning an RFID tag will show the artwork description screen (Figure 7-2), here information about the scanned artwork is shown. Furthermore, the User Model is updated, the scanned artwork is added to the sequence of visited artworks and the attraction power of the artwork is measured. The attraction power is measured by tracking the time that the user spends in the artwork description screen. We assume that the user is done visiting an artwork when he or she requests the next artwork in the tour. When no scanner is attached to the mobile device, the user can also manually go to the artwork description screen which simulates an RFID tag read action.

We implemented an abstraction of an RFID reader interface where we support the two main brands of currently available RFID readers: Socket Mobile and SDiD. The drivers of these readers are embedded in the PMTMD as separate libraries. A class interface is delivered with the code which enables future developers to easily implement and add other RFID readers or standards. The reason for implementing such an abstract interface is because there is currently no communication standard for RFID reader technology and Windows Mobile 5 does not provide native support for RFID readers.

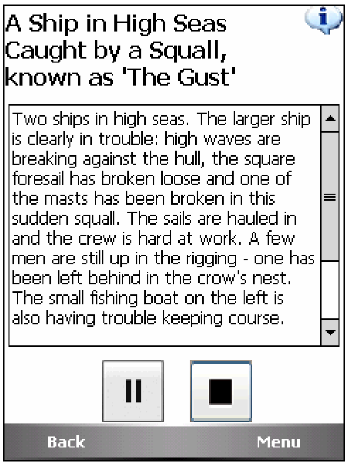

Figure 7-2 Artwork description

8 USER GUIDANCE

In the mobile museum tour, the set of artworks is ordered. Using this ordered set of artworks, we suggest a route through the physical space of the museum. Suggesting such a route is not trivial. For example, the physical space of the museum consists of rooms, doors and walls which all must be taken into account. We now present a framework to generate routes through the museum (requirement 4.3). This framework is used to calculate the routes and offers user adaptation by making the routes dynamic.

8.1 Routing framework

The route calculation algorithm needs to know the locations of all tour artworks. Furthermore information about where the user can walk and the starting point of the route is necessary. In order to couple this information together, we have created a routing framework which is a virtual version of the museum. This routing framework consists of floors, rooms, doors, artworks and waypoints. The floors, rooms, doors and artworks represent the corresponding physical objects of the museum. Waypoints are used to inform the routing algorithm where a user can go. A more detailed description of every object of the routing framework and their relations is now given.

Floor

In the physical space a museum can consist of one or more floors, these floors are connected to each other by stairs, elevators or even escalators. The PMTMD contains each floor of the physical museum and connects these floors. Each room, door, artwork and waypoint is assigned to exactly one floor.

Room

The rooms of the physical museum that can be reached by visitors are also contained in the routing framework. Rooms are connected to other rooms using doors. Each artwork and waypoint is assigned to exactly one room.

Door

The doors supply the routing framework with information about which rooms can be reached from other rooms. Each door is connected to the other doors in the room. A door can also be connected to artworks and waypoints which are in the same room, such that a user can be guided from a door directly to a position within the room.

Artwork

Artworks in the routing framework resemble the physical museum artworks and are connected to exactly one floor and one room. Artworks can also be connected to doors and waypoints which lead the user to the artworks.

Waypoint

In the physical museum, users cannot walk through walls; thus it must not be possible in the virtual museum. Waypoints in the mobile application are used to provide information about where the user can go within a room to the routing algorithm. Especially for the visualization of a route on the museum map, these waypoints are necessary. Often, all artworks can be reached directly from the doors of the rooms they are in, however for odd shaped rooms, waypoints are absolutely necessary to prevent guiding a user through walls. Waypoint can be connected to other waypoint, artworks and doors.

8.2 Route calculation

The route is calculated after updating the current user position. This makes the calculation of the route dynamic and does not limit the user to visit non tour artworks.

The algorithm

The actual calculation of the route is done in different phases: when starting a tour a trace[1] is calculated from the current user position to the first artwork in the tour, then a trace is calculated from the first artwork until the second artwork in the tour. This sequence is repeated until a trace is calculated from the last artwork to the end point of the tour. Finally all these traces are merged together, leading to a route from the start point to the end point passing all tour artworks.

The calculation of each trace is divided in two separate parts: First the trace is calculated on a high level (room level) which only takes into account which rooms and which doors should be visited in order to go from the begin point of the trace to the destination point of the trace. These begin and destination points can be artworks or waypoints. This high level calculation delivers a sequence of doors which should be visited in order to reach the destination.

The high level calculations provide a list of consecutive doors to go from one place to the other. The next step is a more low level (waypoint level) calculation which takes into account the waypoints and artworks that can be found within the physical space of the museum. The low level algorithm first determines a trace from the begin point to the first door and then from each following door in the sequence to the next. Finally a trace is calculated from the last door in the sequence to the destination point. All these traces together form the final route through the museum which now consists of artworks, waypoints and doors.

[1] A list of artworks, doors or waypoints which form a path through the museum.

Both high and low level trace calculations use breadth-first search to determine the trace. This search algorithm is easy to implement and is fast enough for use in the PMTMD. The outcome of both calculations is a set of traces of different lengths; we implemented an algorithm that determines the shortest trace from the set of traces. The reason for dividing the route calculation in a high and a low level is made because of optimization matters. If only the low level calculation is used, the algorithm must search through all waypoints, artworks and doors at once, leading to a slow algorithm. The use of two level calculations decreases the number of calculations significantly.

Figure 8-1 shows the actions that occur when calculating a route.

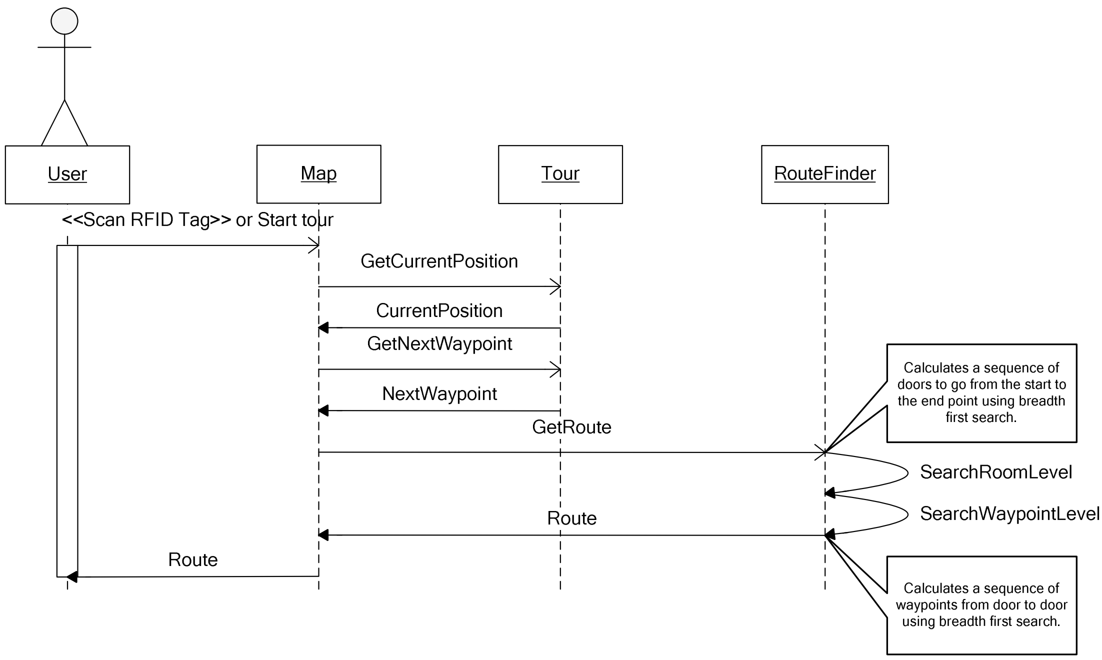

Figure 8-1 Sequence diagram: Calculate route

8.3 User guidance implementation

The PMTMD application guides the user though the museum (requirement 4.3). The user is guided from his or her current position to the next artwork in the tour (requirement 4.1). The rooms of the previous, the current and the next artwork in the tour (Figure 8-2) are given to the user. The user can use this information together with the labels on the museum walls to go to the next artwork. The user can also use the museum map together with a route from the current position to the next artwork (Figure 8-3).

Figure 8-2 Location in tour progress screen

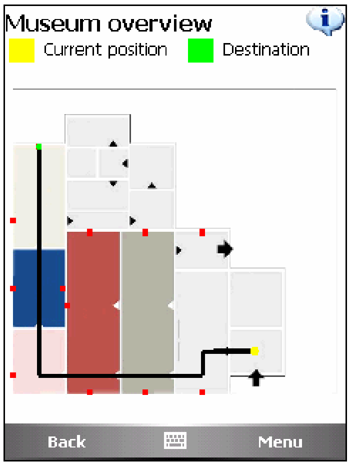

Figure 8-3 Museum map

Some users do not strictly follow the order of artworks that is proposed by the PMTMD. They want to visit artworks in a different order or even artworks that are not in the tour. For these users, we have built in an adaptive form of user guidance; when the user scans other artworks than the next, the current position is set to that artworks and the order of the artworks is recalculated. The user is given a logical route through the museum and can continue the tour. The tour adapts to the user's behavior, we call this: adaptive user guidance. While recalculating the renewed artwork order, only the unvisited tour artworks are used; the artworks that were already visited remain visited. The downside of reordering is that the next tour artwork might change, which might confuse the user.

9 CONCLUSION

More and more museums offer multimedia tours or other museum tours on mobile devices to their visitors. Most multimedia tours only offer basic information about exposed artworks. These tours are static and not personalized. The PMTMD includes dynamic and personalized functions and is therefore different from other tours. It is an exciting mobile museum tour which triggers visitors to return to the museum.

During this master project we moved the museum experience from the virtual space to the physical space. We proposed a method to import tours from the web server to the mobile device and to synchronize user data on the mobile device with the CHIP demonstrator. While moving from the virtual to the physical space, physical aspects of the museum are considered. We presented a mapping mechanism for this conversion. Furthermore, we tried to capture innovative new functionality for mobile museum tours like user guidance and user positioning. User guidance and user positioning are used to offer museum visitors a dynamic tour experience.

To discover what a good museum tour should contain, we created a list of properties. These properties are derived from exploring different museum tours in the Netherlands. After choosing a scenario and creating a set of requirements for the PMTMD, we considered technologies used for the scenario. We compared several properties of mobile technologies and selected the technologies that are appropriate for a mobile museum tour.

We proposed a method to import and synchronize tour and user data on a mobile device. This method allows users to import tours and the User Model from the CHIP demonstrator application to the mobile device. The mobile User Model is used to store user behavior during the tour and can be synchronized with the web server to update the User Model. The method uses a translation from the RDF data to XML such that it can be used on the mobile device. The communication is done using an active Internet connection. After importing a tour, the tour must be mapped to the physical space. We propose a mechanism to map a virtual museum tour to a physical museum tour. This mapping mechanism filters out non exposed artworks and proposes an ordering of the tour artworks with respect to their locations. The artworks are ordered such that a logical route through the museum can be given. The mapping also allows the user to limit the number of artworks in a tour. The ordering algorithm used during the mapping process is also used to provide dynamic user guidance.

We proposed a method to retrieve the user’s position in a museum which can be used in combination with a mobile device. We presented a method that uses RFID technology to determine the user’s position. The current position of the user in the museum is used for guiding the visitor to the physical location of artworks. We propose a method for user guidance in a mobile museum tour which uses the museum map and specifies rooms, doors, waypoints and artworks such that a route line can be drawn.

By creating the PMTMD, we have implemented a personalized museum tour on a mobile device. We believe that the PMTMD improves the museum experience by offering innovative features to the user.

9.1 Future work

The current PMTMD application implements the RFID reader scenario as described in section 2.2.2. This scenario implements basic museum tour functionality on a mobile device and extends this with user guidance and user positioning. The tour can be extended with several other features which we describe in this section.

Wireless communication in the museum

A wireless communication technique such as Bluetooth or Wi-Fi can be used to share data between devices. This can provide social functionalities like sharing tours with friends or sharing notes about artworks. Hotspots like in scenario 2.2.5 can be used for an implementation using wireless communication.

Online tour

The PMTMD is an offline tour, there is no network connection when performing the museum tour. An Internet connection might extend the PMTMD with interesting functionalities. When having an online tour, the User Model can be updated during the tour and social functionalities can be provided using the Internet. For example, a social functionality that shows the number of users (or friends) at artworks can be implemented.

Multiple client applications

The PMTMD runs on Windows Mobile. To support a larger spectrum of devices, clients for other operating systems can be implemented. For instance to support more smart phones: a Symbian client can be developed or to support iPhones: an implementation for MacOS X can be created.

Dynamic adaptation

In the future more dynamic scenarios might be wanted which for example can dynamically extend the set of tour artworks or can give recommendations during the tour. More dynamic user guidance can be required which provides alternative routes through the museum or which can adjust the route in case of heavy crowdedness around artworks. To provide such dynamics, more data must be available to the PMTMD.

Interface improvements

The interface of the PMTMD has been set-up primarily to be functional and usable. Special attention is dedicated to support a small touch screen controlled by a human finger in stead of a stylus. Less attention was devoted to create a nice look-and-feel for the user. When introducing the PMTMD to the public it will be necessary to improve the looks of the application to enhance the user's experience. For instance icons can be used on buttons instead of text, or a general skin can be used to enhance the overall look and feel and change the windows-like interface to a more professional design. Another interesting point is the adaptation of the user interface to the device properties such as the screen layout (landscape or portrait).

10 BIBLIOGRAPHY

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11 ACKNOWLEDGEMENTS

In the first place we thank Lora Aroyo for accepting us for this master project, providing us with many ideas and guiding us through the entire project. We appreciate all valuable input, even when we received it by e-mail at night or very early in the morning.
We furthermore thank all CHIP members and Rijksmuseum employees who helped us in many ways during our project; Natasha Stash for helping us with the implementation; Yiwen Wang for her creative input and Lloyd Rutledge for his help and hospitality when we were at the Rijksmuseum Amsterdam.
Thanks to Geert-Jan Houben for providing us with directions for writing our thesis and organizing the Tuesday morning meetings from which we received useful feedback. Also thanks to all other attendees of the Tuesday morning meetings.
Thanks to the members of the Databases and Hypermedia department, especially Paul de Bra for pointing us to the exciting project and Riet van Buul for answering all our questions and helping us with practical issues.
Finally we thank everybody else who supported us during this project.

Rody van Sambeek and Yuri Schuurmans

Eindhoven University of Technology
July 2007

A. APPENDIX: PMTMD SOURCE CODE AND BINARIES

Code and binaries of the PMTMD can be found at:
http://www.chip-project.org/mobileDemo/PMTMD/

B. APPENDIX: MUSEUM TOUR EXPLORATION TABLES

Tour properties

Table B-3 Tour properties

	Multimedia tour at Van Gogh Museum Amsterdam	**Multimedia tour at Frans Hals Museum Haarlem**	**Multimedia tour at Netherlands Architecture Institute Rotterdam**	**Audio tour at Rijksmuseum Amsterdam**	**Human Guided tour at Rijksmuseum Amsterdam**	**Online tour Tate Britain at http://www.tate.org.uk/britain/explore/**
1.1. Theme	Life of van Gogh	Nicolaes Berchhem	'GeWoon Architectuur'	None	The Masterpieces	None
1.2. Number of participants	1	1	1	1	4	1
1.3. Number of artworks	20	25	11	10	15	30
1.4. Duration	1:30	1:15	1:00	1:00	1:30	0:45
1.5. Languages	Dutch, English	Dutch	Dutch	Dutch, English, German, French, Spanish, Italian, Russian, Japanese and Mandarin	Dutch, English, French, German	English
1.6. Personalization	None	Different multimedia tours for different aged people	None	Different audio tours for different aged people	Selecting artworks according to user input before start and during the tour	None
1.7. Platform	PDA	PDA	PDA	Audio player	Human guide	Webpages
1.8. Tour explanation	Explanation of functions by desk personnel, small audio and video instructions when starting the tour	Explanation of functions by desk personnel	Explanation of functions by desk personnel, small audio and video instructions when starting the tour	Explanation of functions by desk personnel	Introduction at the start of tour by the human guide	Textual explanation
1.9. All artworks featured	No	No	No	No	Yes	Yes

Physical space

Table B-4 Physical space

	Multimedia tour at Van Gogh Museum Amsterdam	Multimedia tour at Frans Hals Museum Haarlem	Multimedia tour at Netherlands Architecture Institute Rotterdam	Audio tour at Rijksmuseum Amsterdam	Human Guided tour at Rijksmuseum Amsterdam	Online tour Tate Britain at http://www.tate.org.uk/britain/explore/
2.1. Museum units	Different compartments in one area	Rooms	Different areas on a wall containing exactly one Infrared label in one hallway with a few corners	Rooms	Rooms	Virtual Rooms
2.2. Unit size	Medium	Small	Small	Medium and Large	Medium and Large	Not applicable
2.3. User guidance	None	The current room number can be selected	Using Infrared tags to identify position of user	Enter the artwork number which is on the label	The guide directs the user through the museum	None

Locator

Table B-5 Locator

	Multimedia tour at Van Gogh Museum Amsterdam	Multimedia tour at Frans Hals Museum Haarlem	Multimedia tour at Netherlands Architecture Institute Rotterdam	Audio tour at Rijksmuseum Amsterdam	Human Guided tour at Rijksmuseum Amsterdam	Online tour Tate Britain at http://www.tate.org.uk/britain/explore/
3.1. Artwork locator	PDA tour labels showing artwork is in PDA tour	The user manually selects a room	Infrared label	Artwork labels with corresponding numbers	The guide knows the locations of the artworks	None
3.2. User locator	Static map without current location highlighted	Static map without current location highlighted	Dynamic map with last activated label highlighted	None	Tour guide	Static map showing museum layout

Content

Table B-6 Content

	Multimedia tour at Van Gogh Museum Amsterdam	**Multimedia tour at Frans Hals Museum Haarlem**	**Multimedia tour at Netherlands Architecture Institute Rotterdam**	**Audio tour at Rijksmuseum Amsterdam**	**Human Guided tour at Rijksmuseum Amsterdam**	**Online tour Tate Britain at http://www.tate.org.uk/britain/explore/**
4.1. Type	Audio, Video, Images, Textual, Games	Audio, Images	Audio, Video, Images, Textual	Audio	Audio, Gestures, Images	Textual, Images
4.2. Content focus	PDA	PDA	PDA and Artworks	Artwork	Artwork	Artwork images
4.3. Referring to (parts of) artwork	Never	Rarely	Rarely	Sometimes	Very often	Never

Interaction

Table B-7 Interaction

	Multimedia tour at Van Gogh Museum Amsterdam	**Multimedia tour at Frans Hals Museum Haarlem**	**Multimedia tour at Netherlands Architecture Institute Rotterdam**	**Audio tour at Rijksmuseum Amsterdam**	**Human Guided tour at Rijksmuseum Amsterdam**	**Online tour Tate Britain at http://www.tate.org.uk/britain/explore/**
5.1. Controls	Touch screen of the PDA using finger	Touch screen of the PDA using stir	Touch screen of the PDA using finger	Buttons on the audio player	Human interaction capabilities	Personal computer controls
5.2. Response time	Slow	Normal	Fast	Fast	Normal	Normal

C. APPENDIX: XML IMPLEMENTATIONS

```
<?xml version="1.0" encoding="UTF-8"?>
<Tour>
  <Name>Demo Tour</Name>
  <Museum>Rijksmuseum Amsterdam</Museum>
  <Type>My Tour</Type>
  <Language>English</Language>
  <User>
    <Username>rody</Username>
    <Password>140d3ea2b0c7a720b8fcc236deedd04f</Password>
  </User>
  <Navigation>
    <Map>
      <MapImages>
        <MapImage floor="Ground floor" id="0" type="jpeg">
          http://www.chip-project.org/museum/adam/maps/groundfloor.jpg
        </MapImage>
         <MapImage floor="1st floor" id="1" type="jpeg">
          http://www.chip-project.org/museum/adam/maps/firstfloor.jpg
        </MapImage>
        ...
      </MapImages>
      <Rooms>
        <Room id="1" name="Entrance" floorID="0" coordinate_left="802"
              coordinate_top="904" coordinate_width="189" coordinate_height="148">
          <Doors>
            <Door id="0" />
          </Doors>
          ...
        </Room>
        ...
      </Rooms>
      <Doors>
        <Door id="0" x="787" y="976" floorID="0">
          <ReachableDoor id="1" distance="280" />
          <ReachableDoor id="3" distance="354" />
          <Lineofsight id="4" type="waypoint" distance="84" />
          <Lineofsight id="5" type="waypoint" distance="103" />
        </Door>
        ...
      </Doors>
      <Waypoints>
        <Waypoint id="4" x="380" y="331" floorID="0" roomID="1" start="0" end="0">
          <Lineofsight id="11" type="door" distance="69" />
          <Lineofsight id="12" type="door" distance="46" />
          <Lineofsight id="13" type="door" distance="66" />
        </Waypoint>
        ...
      </Waypoints>
      <Artworks>
        <Artwork id="58" name="" x="498" y="1117" floorID="0" roomID="13"
                 rfid="1234567890">
          <Lineofsight id="45" type="waypoint" distance="57" />
          <Lineofsight id="1" type="door" distance="108" />
          <Lineofsight id="4" type="door" distance="118" />
        </Artwork>
        ...
      </Artworks>
    </Map>
  </Navigation>

  <TourArtworks>
    <Artwork ID="http://www.chip-project.org/Rijksmuseum#artifactsK-C-374">
      <Name>Meagre Company</Name>
      <Artist>Frans Hals</Artist>
      <Images>
        <Image type="jpeg" title="Image of Painting">
```

```xml
          http://www.rijksmuseum.nl/images/aria/SK/Z/SK-C-374.z
        </Image>
      </Images>
      <Descriptions>
        <Text title="RM Description">
          <![CDATA['Just to see that painting would make the journey
                    to Amsterdam worthwhile.' wrote Vincent van Gogh ...]]>
        </Text>
        <Audio title="Audio stream 1">
          http://www.rijksmuseum.nl/images/aria/SK/Z/SK-C-374.mp3
        </Audio>
      </Descriptions>
    </Artwork>
    <Artwork ID="http://www.chip-project.org/Rijksmuseum#artifactsK-A-4646">
      <Name>Still Life with Turkey Pie</Name>
      <Artist>Pieter Claesz</Artist>
      <Images>
        <Image type="jpeg" title="Image of Painting">
          http://www.rijksmuseum.nl/images/aria/SK/Z/SK-A-4646.z
        </Image>
      </Images>
      <Descriptions>
        <Text title="RM Description">
          <![CDATA[A large  turkey pie is the most eye-catching part of ...]]>
        </Text>
        <Audio title="Audio stream 1">
          http://www.rijksmuseum.nl/images/aria/SK/Z/SK-A-4646.mp3
        </Audio>
      </Descriptions>
    </Artwork>
    ...
  </TourArtworks>

  <NonTourArtworks>
    <Artwork ID="http://www.chip-project.org/Rijksmuseum#artifactsK-A-4830">
      <Name>Still Life with Gilt Cup</Name>
      <Artist>Willem Claesz. Heda</Artist>
      <Images>
        <Image type="jpeg" title="Image of Painting">
          http://www.rijksmuseum.nl/images/aria/SK/Z/SK-A-4830.z
        </Image>
      </Images>
      <Descriptions>
        <Text title="RM Description">
          <![CDATA[Willem Claesz. Heda painted this still life in 1635 ...]]>
        </Text>
        <Audio title="Audio stream 1">
          http://www.rijksmuseum.nl/images/aria/SK/Z/SK-A-4830.mp3
        </Audio>
      </Descriptions>
    </Artwork>
    ...
  </NonTourArtworks>
</Tour>
```

Figure C-1 XML implementation of the tour package

```xml
<?xml version="1.0" encoding="UTF-8"?>
<usermodel>
  <personal>
    <id>rody</id>
    <password>140d3ea2b0c7a720b8fcc236deedd04f</password>
  </personal>
  <websiteModel>
    <ratings>
      <rating>
        <artwork_id>artifactsK-C-251</artwork_id>
        <artwork_rating>0,5</artwork_rating>
      </rating>
      <rating>
        <artwork_id>artifactsK-C-5</artwork_id>
        <artwork_rating>-0,5</artwork_rating>
      </rating>
      <rating>
        <artwork_id>artifactsK-A-1848</artwork_id>
        <artwork_rating>-1</artwork_rating>
      </rating>
    </ratings>
    <toursfollowed>
      <tour>
        <id>1</id>
        <totaltimespent>870</totaltimespent>
        <sequence>
          <artwork>
            <id>artifactsK-A-4646</id>
            <attractingpower>105</attractingpower>
          </artwork>
          <artwork>
            <id>artifactsK-C-251</id>
            <attractingpower>81</attractingpower>
          </artwork>
          <artwork>
            <id>artifactsK-C-5</id>
            <attractingpower>34</attractingpower>
          </artwork>
          <artwork>
            <id>artifactsK-A-1848</id>
            <attractingpower>12</attractingpower>
          </artwork>
        </sequence>
      </tour>
    </toursfollowed>
  </websiteModel>

  <mobileModel>
    <ratings>
      <rating>
        <artwork_id>artifactsK-C-251</artwork_id>
        <artwork_rating>1</artwork_rating>
      </rating>
      <rating>
        <artwork_id>artifactsK-C-5</artwork_id>
        <artwork_rating>0</artwork_rating>
      </rating>
      <rating>
        <artwork_id>artifactsK-A-1848</artwork_id>
        <artwork_rating>-1</artwork_rating>
      </rating>
    </ratings>
    <toursfollowed>
      <tour>
        <id>First Tour</id>
        <totaltimespent>2130</totaltimespent>
        <sequence>
          <artwork>
            <id>artifactsK-A-4646</id>
            <attractingpower>50</attractingpower>
```

```
        </artwork>
        <artwork>
          <id>artifactsK-C-251</id>
          <attractingpower>92</attractingpower>
        </artwork>
        <artwork>
          <id>artifactsK-C-5</id>
          <attractingpower>215</attractingpower>
        </artwork>
        <artwork>
          <id>artifactsK-A-1848</id>
          <attractingpower>202</attractingpower>
        </artwork>
      </sequence>
    </tour>
  </toursfollowed>
 </mobileModel>
</usermodel>
```


Figure C-2 Mobile User Model XML example


```
<?xml version="1.0" encoding="utf-8" ?>
<Tours>
  <Tour>
    <Name>First Tour</Name>
    <Museum>Rijksmuseum Amsterdam</Museum>
    <Type>My Tour</Type>
    <NumberOfArtworks>12</NumberOfArtworks>
  </Tour>
  <Tour>
    <Name>Second Tour</Name>
    <Museum>Rijksmuseum Amsterdam</Museum>
    <Type>My Tour</Type>
    <NumberOfArtworks>19</NumberOfArtworks>
  </Tour>
  <Tour>
    <Name>The Masterpieces</Name>
    <Museum>Rijksmuseum Amsterdam</Museum>
    <Type>Rijks Tour</Type>
    <NumberOfArtworks>7</NumberOfArtworks>
  </Tour>
</Tours>
```


Figure C-3 Tour overview XML example

D. APPENDIX: TECHNOLOGY EXPLORATION PROPERTIES TABLES

Legend: ✓ = all, × = none, ○ = some

Table D-1 Application types

Application types		
	Standalone application	**Web application**
Supports text	✓	✓
Supports audio	✓	×
Supports video	✓	×

Experiments with both application types showed us that standalone applications support text, audio and video. Web applications only have text support; if audio and video support is required, the user must install external plug-ins for the browser.

Table D-2 User positioning technologies

User positioning / Interactivity					
	GPS	**RFID**	**Infrared**	**Location-based wireless**	**Bluetooth**
Indoor application	×	✓	✓	✓	✓
Additional hardware required	×	✓	✓	✓	✓
Additional hardware costs estimation	×	Low	Low	High	High

According to [15], GPS cannot be used for indoor environments; they mention indoor implementations using Infrared, location-based wireless and Bluetooth. They also mention hardware that is required to use such a user positioning system. For user positioning with Infrared, hardware sensors are needed which are relatively low cost. For location-based wireless and Bluetooth implementations, expensive access points are needed.
In [14] a technique using RFID for indoor positioning is described. They use passive tags with stationary readers. To keep the hardware costs minimal for a museum, this can be done the other way around with portable RFID readers and stationary passive tags.

Table D-3 Device classes

Devices classes				
	PDA	**Smart phone**	**Mobile phone**	**PMP**
Resolution	320x240 - 640x480	320x240	128x160 - 240x320	× - 320x240
Storage space	64 - 4096 MB	64 - 4096 MB	32 - 2048 MB	1 GB – 80 GB
Supports standalone applications	✓	✓	×	×
Supports external custom hardware	✓	✓	×	×

The overview of device classes in [18], shows us the different resolutions and storage capabilities per device class. From specifications of mainstream devices from each class, the support of standalone applications and external custom hardware was extracted. With custom hardware, hardware which uses third party drivers is meant.

Table D-4 Operating systems

Operating systems					
	PalmOS	**Windows Mobile**	**Symbian OS**	**Embedded Linux**	**Blackberry**
PDA	6.1 %	62.1 %	5.6 %	0.7 %	18.1 %
Smart phone	Unknown	17 %	51 %	23 %	Unknown

The market shares for operating systems on PDA's as estimated by Gartner in [18] are shown in Table D-4. The remaining 7.4 percent is the total market share of smaller vendors.

TDG published the current market shares of smart phone operating systems in [17]; they also estimate that these numbers will be changed by 2010 and that Windows will be market leader by then. The numbers for the Palm and Blackberry operating systems are not specified and are in the remaining 9 percent.

Table D-5 Communication standards

Communication standards						
	WI-FI	**UMTS**	**GPRS**	**EDGE**	**Bluetooth**	**Infrared**
Speed	11 / 54 Mbps	2 Mbps	172 kbps	384 kbps	1 Mbps	4 - 16 Mbps
Range	100 meter	Not important	Not important	Not important	10 meter	1 meter

Press releases [19] and [11] show us the speed and range of each communication standard.