Evaluation of a web recommender system in electronic and mobile tourism

Damianos Gavalas* and Michael Kenteris

Department of Cultural Technology and Communication,
University of the Aegean,
University Hill, GR-81100, Mytilene, Lesvos, Greece
E-mail: dgavalas@aegean.gr
E-mail: m.kenteris@ct.aegean.gr
*Corresponding author

Abstract: Recommender systems are software frameworks that employ a specific type of information filtering technique, aiming at recommending information items or social elements that are likely to be of interest to the user. Herein, we present the evaluation results of the recently prototyped tourism recommender system (TRS). We followed a formal evaluation process to validate the usability of two versions of the TRS by users in realistic environments; the first is a typical web recommender system (wTRS), while the second is a system that enables tourist content recommendations addressed to mobile users (mTRS). The usability evaluation tests have been undertaken at the municipality of Mytilene, Greece.

Keywords: web recommender systems; wTRS; web engineering; electronic tourism; mobile tourism; mobile guides; context-awareness; user profile; user evaluation; field trials; sensor networks.

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Biographical notes: Damianos Gavalas received his BSc in Informatics from the University of Athens, Greece, in 1995, and MSc and PhD in Electronic Engineering from the University of Essex, UK, in 1997 and 2001, respectively. Currently, he is an Assistant Professor in the Department of Cultural Technology and Communication at the University of the Aegean, Greece. He has served as TPC member in several leading conferences and guest-editor in highly ranked journals in the field of mobile and wireless communications. His research interests currently include mobile and pervasive computing, mobile ad-hoc and wireless sensor networks and optimisation algorithms.

Michael Kenteris received his MEng in Electronic and Electrical Engineering from the University of Loughborough, UK in 1997 and MSc and PhD from the University of the Aegean, in 2004 and 2010, respectively. His research interests include mobile applications, ICT technologies in tourism, usability and quality of experience, social networks, web science, and geo-spatial representation.

1 Introduction

Recommender systems use the opinions of a community of users to assist individuals identify content of interest from a potentially overwhelming set of choices. Recommender systems use details of the registered user's profile and opinions and habits of their whole community of users and compare the information to reference characteristics to present the recommendations (Adomavicius and Tuzhilin, 2005; Ricci et al., 2011). Typically, a recommender system compares a user profile to some reference characteristics, and seeks to predict the 'rating' or 'preference' that a user would give to an item she has not yet considered. These characteristics may correspond to an information item [content-based approach (Pazzani and Billsus, 2007)] or the user's social environment [collaborative filtering approach (Ekstrand et al., 2011)].

Recommender systems have originally found success on e-commerce websites to present information on items and products that are likely to be of interest to the reader (e.g., films, books, news, web pages etc). Lately, they have been increasingly employed in the field of electronic tourism (e-tourism), in the context of guides providing recommendations for points of interest (POIs) that match user preferences, typically consolidated in 'user profiles' (Kabassi, 2010; Werthner and Ricci, 2004). The most commonly used methods to build a user profile enable extraction of user data:

- explicitly, e.g., rating content within a given scale, ordering content from the most to the least interesting item, statement of preference among various content items, statement of favourite content items list, etc.
- implicitly, e.g., recording pages visited by the user (also taking into account the visit duration and visit recurrences), monitoring the content selection behaviour of users and analysing the interests of their social network (e.g., the list of user contacts in a social network), etc.

Existing recommendation systems in e-tourism typically emulate services offered by tourist agents where prospective tourists refer to seeking advice for tourist destinations under certain time and budget constraints (Berka and Plößnig, 2004; Ricci, 2002). From a technical point of view, e-tourism recommendation systems use content-based approaches whereby a user states her needs, interests and constraints based upon selected parameters. The system then correlates user choices with catalogued destinations described using the same list of parameters.

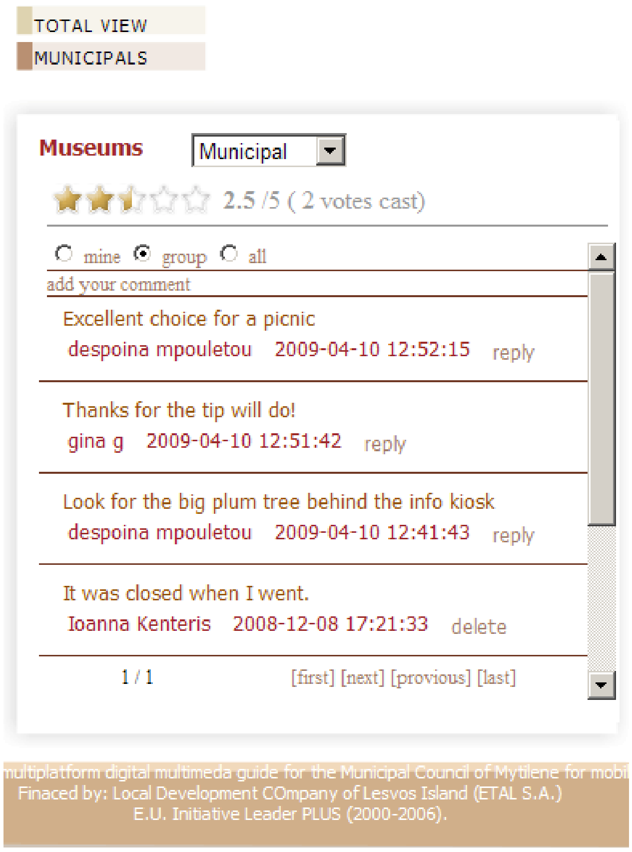
A relatively recent development in e-tourism lies in the use of mobile devices as a primary platform for information access; when coupled with recommender systems technologies, those devices can become key tools for mobile users both for leisure and business applications. Recommendation techniques can increase the usability of mobile systems providing personalised and more focused content, hence limiting the negative effects of information overload (Ricci, 2011). Mobile recommender systems may also take advantage of usage and application context in providing improved, context-aware recommendations (Adomavicius and Tuzhilin, 2011; Kenteris et al., 2010).

Formal evaluations used to assess the experience of users while accessing an information system, is of critical importance to measure the success and perceived usefulness of web and mobile recommender systems. Yet, although some papers have dealt with the automated evaluation and comparison of 'traditional' web recommender systems (Herlocker et al., 2004), very little has been done in executing formal user trials and evaluation tests. Even more so, when user evaluations of mobile recommender systems are concerned.

This article presents the user evaluation results referring to our tourism recommender system (TRS), explicitly designed for electronic and mobile tourism (m-tourism) applications[1]. The architectural specifications of TRS have been introduced in Kenteris et al. (2010). The user evaluation follows a structural process to validate the usability of TRS, measuring several quantitative and qualitative attributes. The evaluation has been exercised upon two separate versions of TRS: a typical web recommender system (wTRS) used in the domain of e-tourism, and a mobile recommender system (mTRS) used in m-tourism. The field trials and usability evaluation tests have been undertaken at the municipality of Mytilene, Greece.

The remainder of the article is structured as follows: Section 2 provides a brief introduction in the architecture and functionality of the TRS. Section 3 comprises the main part of the paper, detailing the user evaluation process for both wTRS and mTRS and presenting the quantitative and qualitative results derived from the evaluation tests. Section 4 discusses issues raised by evaluators and recommendations for enhancements and improvements. Finally, Section 5 concludes the paper and draws directions for future research.

Figure 1 Personalised recommendations to wTRS users for archaeological sites based on information collected by peers (see online version for colours)



2 The TRS

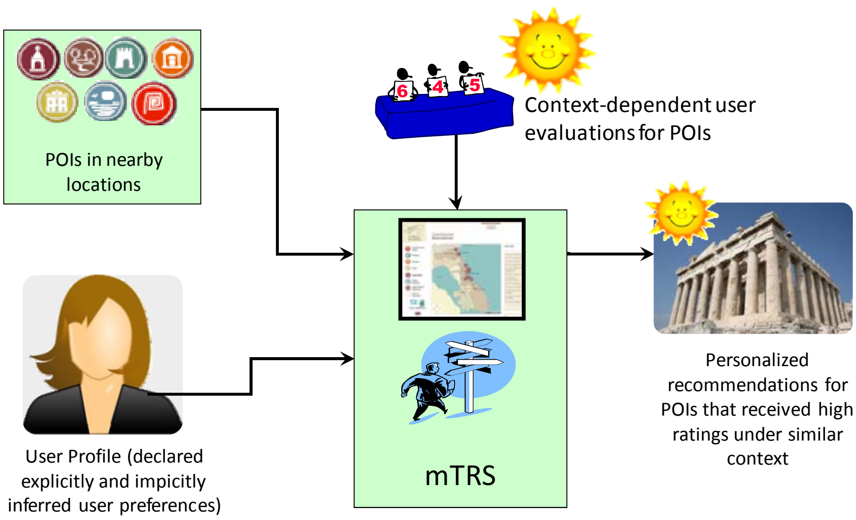
TRS is based on MyMytilene (Kenteris et al., 2009), a web-to-mobile (Kenteris et al., 2011) tourist framework which allows tourists to use the web in order to dynamically 'build' customised mobile standalone guides that run on any mobile device offering tourist information. In the original prototype, users manually chose content items (information about POIs) after browsing all available tourist content; the chosen content items were later included in the mobile guide application and adapted to the user's mobile device (depending on the device's screen size and resource constraints).

TRS incorporates numerous extensions mainly addressing various aspects of m-tourism personalisation (Kenteris et al., 2010). First, it allows users to collaboratively contribute in uploading and sharing with peers tourist-related information, such as ratings, comments and multimedia content relevant to POIs. Through employing collaborative filtering techniques (Ekstrand et al., 2011), we enable the delivery of personalised tourist content recommendations based on the ratings and evaluations of peers with similar preferences. These features are consolidated within a web recommender system (wTRS) (Kenteris et al., 2010).

Figure 1 shows a screen where a particular user is recommended archaeological sites-related content based on the profiles of her peers and another displaying comments uploaded by peers.

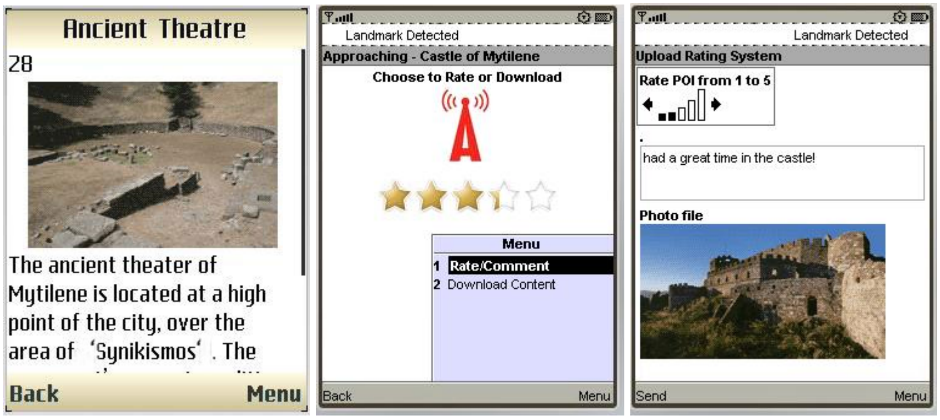
It is now widely accepted that the mobility element raises challenges, yet also important opportunities for service personalisation (Kabassi, 2010). For instance, a recommender system may evaluate user input and uploaded content with respect to user context, e.g., the user's device type and location at the time she uploaded content. Similarly, content recommendations may depend not only on the user interaction history but also the user's location and context, e.g., current local weather conditions or places already visited by the user. Furthermore, mobile tourist applications may utilise innovative services which support direct communication and social interaction between tourists sharing similar interests and situated at nearby locations.

Figure 2 Functional elements of mTRS (see online version for colours)



While a substantial body of research has already been performed in the area of recommender systems, most existing approaches do not take into account any additional contextual information (Adomavicius and Tuzhilin, 2011). Along this line, TRS enables context-aware tourist recommendations to mobile users. In particular, it introduces the concept of 'context-aware rating' to denote the higher credibility of users that upload reviews, ratings and comments while onsite (via their mobile devices) in comparison with others that perform similar actions through standard remote web interfaces. The mobile tourism recommender system (mTRS) assigns different weights to content provided by tourists depending on the technology infrastructure used by tourists. Hence, the mTRS captures context-aware user evaluations and ratings and uses such data to provide recommendations to other users with similar interests. Furthermore, the mTRS delivers several innovative personalised recommendation services to mobile users, taking into account contextual information such as the user's location, the current time, weather conditions and user's mobility history (e.g., POIs already visited by the user). The functional elements of mTRS are illustrated in Figure 2.

Figure 3 Screenshots of the mobile application, (a) typical content item page (b) incoming proximity detection of a user (c) user rating and commenting screen (see online version for colours)



(a) (b) (c)

Recognising that tourists often labour to interact with a remote tourist portal while on travel due to lack of networking infrastructures or even avoid mobile data communications due to high roaming charges, the mTRS enables the use of cost-effective wireless sensor network (WSN) installations (Arampatzis et al., 2005) around tourist sites for providing mobile users convenient and inexpensive means for uploading tourist information and ratings about POIs via their mobile devices. The mTRS regards sensor nodes[2] as inexpensive distributed network access points deployed around POI areas that provide the necessary infrastructure for tourists to upload multimedia content (text, photos, etc.) to remote tourist portals. Within this approach, tourists located in the vicinity of a POI are discovered and prompted to connect to a remote content server (portal). The user then performs a Bluetooth handshake with the sensor node in order to establish connection. Once in sync with the node, the application receives the POI ID and the user is prompted to rate the POI (see Figure 3). The user may also upload photos taken from her mobile device to her personal profile web pages. At a later stage the sensor node forwards the data received from the user's mobile device to the sink (either directly or via multiple intermediate nodes) and the sink in turn transmits the data to the remote server (tourist portal). The sensor nodes may also transmit, along with the user rating and commenting data, environmental parameters values (e.g., temperature, humidity and light measurements) as well as their GPS locality. This allows the provision of up to date local environmental information to users interested in visiting nearby POIs.

3 The usability evaluation

The usability experiments involved 15 testers. The ages of the participants varied from 15 to 43 years old; nine were female and six were male. The tests were conducted around the city of Mytilene, in Lesvos island, Greece, using POIs located within the Municipality of Mytilene. All participants had been residents of Mytilene for some time (but were not locals) and were familiar with the position of the POIs and the surrounding area and were therefore able to gives us feedback and ratings regarding the list of recommended POIs without actually having to visit them.

Each participant initially preferred to use their own mobile phone device as a test tool (after downloading and installing the myMytilene guide application on it). That was feasible for participants' devices that supported the Location API (JSR-000179 Location API for J2ME); in fact, this is common place, given that the Location API is supported by the majority of Java-enabled phones. However, in cases where a participant's mobile device did not support the Location API, a Nokia N95 Smartphone was provided to participants to test the system. All participants had used mobile applications (e.g., address book, phonebook, games) in the past but only three participants had used a mobile tourist guide in the past.

Each usability test session comprised four parts:

a an oral introduction to the scope of the session

b the web platform testing task

c the mobile application on-site testing task

d interview and filling-in of questionnaires.

During the introductory stage, users were briefed on the tasks which would be set for them, and were also introduced to the web and mobile application. The introduction took place in the premises of the University of the Aegean, where a brief introduction on the overall system was presented. In particular, we introduced the functionality of the web application to the testers and demonstrated the functionality of the mobile application. Following this, we placed each tester on a lab's PC so they could use the web application themselves. The web platform testing phase involved a series of tasks, wherein the users had to

a use the web tourist platform to choose eight POIs by browsing

b create a personal profile, i.e., feed data in regards to participant's age, sex, educational level, interests related with available sightseeing options, duration of stay at the destination, daily time allowance for sightseeing c add the recommendations of the wTRS platform to their selection

d download the mobile application.

The complete task list set is shown in Figure 4.

Figure 4 Set of tasks assigned to participants to be repeated twice

Task list for use with the web platform:

1. Browse the main web application menu and map system.
2. Choose 3 POIs directly from the map.
3. Browse the POIs content get to know your POIs and select another 5
4. Continue to the download section.
5. Fill in the form for the new user
   a. Fill in your correct details (this info is kept private)
   b. Answer profile questions (honestly!)
6. Enter your "profile" area.
7. Select the "Recommend content" menu
8. Accept the POIs which are recommended for you for all categories
9. Choose your mobile phone (if not in list, ask researcher for a device)

Figure 5 Some of our testers in the process of the experimental test briefing (see online version for colours)

It is noted that, prior to conducting the evaluation tests, we created 15 user stereotypes in order to enable the TRS to provide reliable and suitable recommendations in cases that only a few users (with profiles similar to the participant's profile) had interacted with the content system to implicitly provide usage data. The user stereotypes simply associated user attributes (age, educational level, gender, profession, etc.) with relative preferences. For instance "women, adults, archaeologist enjoy visiting archaeological sites" or "underage males prefer visiting toys museums and aquariums". In case that the participant's profile did not exactly match any of the available stereotypes, it was associated to the closest one (using a Hamming distance-based vector proximity metric).

The experimental and field studies revealed a high degree of satisfaction among participants in terms of the amount and quality of the available tourist information. Most users found the platform simple to use for locating and getting recommended content from the web application. Upon loading it onto their mobile phone, the users thereafter roamed around the municipality POIs in order to use the mobile application to rate POIs and get their next POI recommendations.

Both test sessions ended with an interview (following a verbal protocol) and the completion of short questionnaires. The questionnaire contained a free-text space for comments and predefined statements, many adopted from Ricci and Nguyen (2007) (based upon the Post-Study System Usability Questionnaire) (Lewis, 1995). Participants answered questions using a seven-point Likert scale where 1 translated to 'strongly disagree' and 7 to 'strongly agree'.

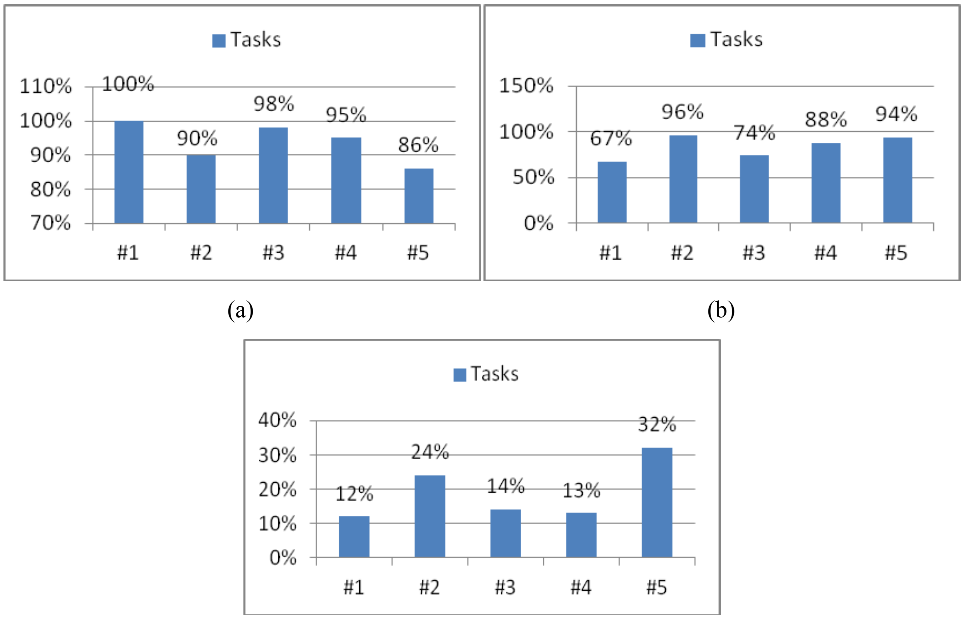
Table 1 Compilation of questionnaire statements ratings related to the web-based recommender system

Statements		*Average*
1	Overall, I'm satisfied with the easiness and friendliness of the system	5.8
2	I can effectively complete my work using this system	5.5
3	I feel comfortable using this system	5.2
4	Information on using the system (such as online help, on-screen messages, and other documentation) was clear	4.3
5	The information provided the system was easy to comprehend.	5.9
6	The information on the system screens was clearly organised.	5.4
7	I enjoyed using the system interface	5.3
8	This system provides all the functions and capabilities I expected it to have	5.4
9	This system was simple to use	5.9
10	I can quickly complete my work using this system	5.7
11	Learning to use this system was easy	5.1
12	It was easy to find the information I needed	6.7
13	The information effectively helped me complete the task and scenario	4.9
14	The system interface is pleasant	6.1
15	I found it useful to add recommended POIs to my selection	5.5
16	Recommended POIs matched my interests	6
17	Overall I' m satisfied with this system	6.6

3.1 Usability testing of the web-based recommender system

Table 1 (referring to the wTRS) portrays the testers' average ratings of the questionnaire statements (we have used a 0–7 rating scale for each statement). These ratings expressed the participants' evaluation of the web recommender system and confirmed our conclusions drawn from the observations of users' interaction. In particular, participants effectively and quickly located content of interest and found the recommendation of POIs in the scope of the types of POIs they were interested in.

Figure 6 Quantative measurements referring to the evaluation of the web application, with respect to (a) effectiveness (%), (b) efficiency (%), and (c) learnability (%) (see online version for colours)



(a) (b) (c)

Note: Those measurements refer to the task list shown in Figure 4.

3.1.1 Quantitative evaluation results for wTRS

Out of the generic quantitative usability attributes identified in Goldman et al. (2004) and Zhang and Adipat (2005), we have measured those that fit in the nature of our dual electronic guide (i.e., web and mobile) application:

- Effectiveness: the percentage of tasks completed.
- Efficiency: time needed to solve tasks in comparison to a pre-defined 'task completion time goal'.
- Learnability: the improvement in task performance in the second trial.

From the set of ten tasks (see Figure 4) related with the evaluation of the web application, we have combined them into five measurable tasks below:

1 Task #1: use of the web application (Steps #1, #2, #3 combined).

2 Task #2: use of the download section (Step #4).

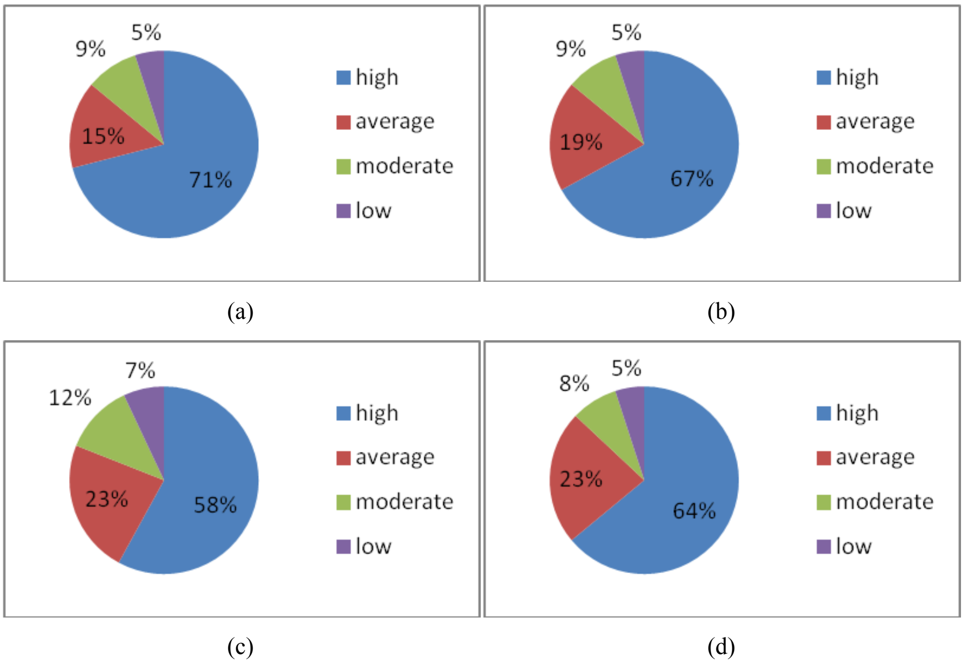
3 Task #3: fill in the form for the new user with correct details and answer profile questions (Step #5a, Step #5b).

4 Task #4: accept the POIs which are recommended for you for all categories (Steps #6, #7, #8).

5 Task #5: install application using Bluetooth (Steps #9, #10).

Figure 6 shows the quantitative results for the evaluation tests of the web system. Overall, the effectiveness was high (i.e., most tasks were completed successfully) apart from some problems dealt with in Task #2 where users were unsecure of using the download section and in Task #5 when participants tried to install their customised applications to their mobile device. The participants carried out the tasks assigned to them quite efficiently (i.e., within the given time limit); in tasks where the participants encountered problems (Tasks #2 and #5), most participants recompleted their tasks considerably faster (hence, increased learnability).

Figure 7 Measurement of qualitative usability attributes of the wTRS, (a) user satisfaction (b) simplicity of use (c) comprehensibility (d) perceived usefulness (see online version for colours)



3.1.2 Qualitative evaluation results for wTRS

Upon completing these tasks participants were called one-by-one for an interview in which they were asked to fill in a questionnaire sharing their experience with the use of the web and mobile recommender systems. Indeed, from the compilation of the interviews and the processing of the questionnaires, we measured several *qualitative* usability attributes, such as:

- *user satisfaction*: the attitude of users toward using the application
- *simplicity*: the degree of comfort with which users find a way to accomplish tasks
- *comprehensibility*: how easily users can understand content presented on the mobile device
- *perceived usefulness*: to what extend the application has met its implementation objectives.

In particular, the participants rated these attributes in a 0–100 scale (0–24: low, 25–49: moderate, 50–74: average, 75–100: high). Figure 7 portrays the results referring to the web recommender system (wTRS).

The usability study confirmed the user satisfaction from the web recommendations. Overall, participants comprehended the web systems potential in delivering personalised tourists information and appreciated the systems capabilities. Besides, the evaluation results indicate that the participants perceived a high degree of usefulness from using our web system. That is, they argued that the system's recommendations strongly matched their preferences: being familiar with the recommended POIs, they felt they would appreciate visits to those POIs if they were newcomer tourists.

Figure 8 A user evaluator uploading content through a deployed WSN infrastructure (see online version for colours)

Note: The SunSPOT node is shown on the top of the pillar, while the upper left part of the picture illustrates the sink which receives and forwards the tourist content to the remote web server.

3.2 Usability testing of the mobile recommender system

Having completed the web platform evaluation, we met the participants at the front entrance of the archaeological castle of Mytilene. Prior to that, a total of 20 sensor nodes were placed around the archaeological site entrance, within ~25 to 40 meters radius from each other, depending on the morphology of the ground terrain[3]. Figure 8 shows a participant next to a sensor node placed onsite, near the entrance of the Castle of Mytilene and – in the upper-left-hand corner – the sink node to which all sensor nodes' data were addressed to. The sink node forwarded collected data to the mTRS web server.

The mobile evaluation involved a set of tasks, repeated twice, shown below:

Figure 9 Task list for the participant to use with the mobile application

Task list for use with the mobile platform:

1. Walk into the scanning radius of the sensor node field
2. Accept the mobile applications automatic notification of approaching a POI.
3. Rate the POI
4. Write a comment
5. Upload to mTRS a photo taken from the smartphone's file system
6. Request recommendations for the next POIs to visit.

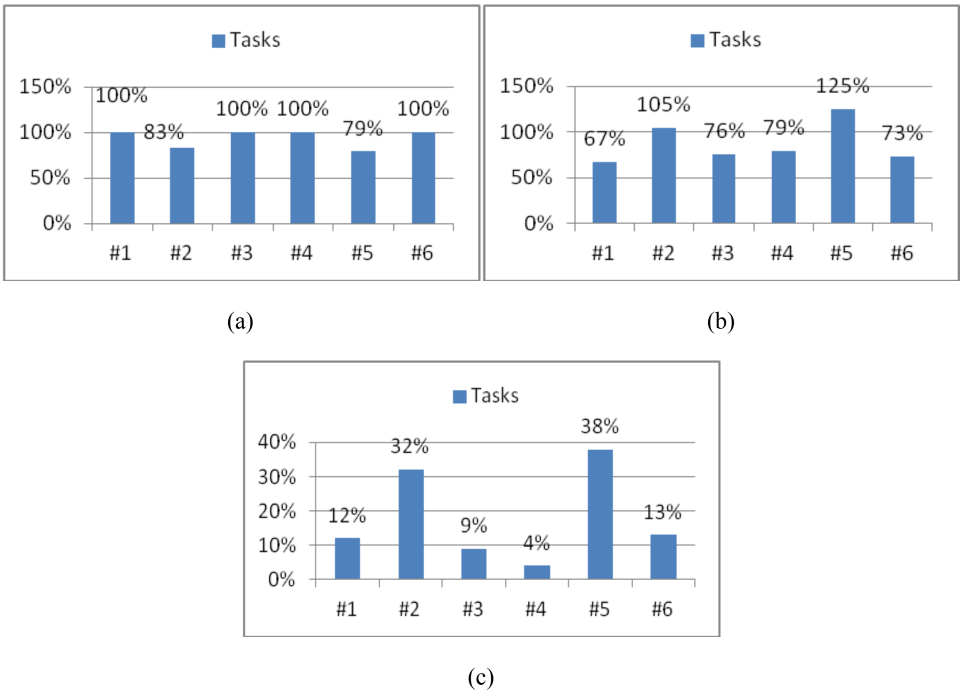
3.2.1 Quantitative evaluation results for mTRS

The evaluation of the main on-site tasks with the intention to evaluate the mTRS was carried out by the same participants. Figure 10 shows some of our participants after they had uploaded their personalised application to a mobile device.

Figure 10 Some of our testers just before going to the testing site for our field trials (see online version for colours)

After running the installed application on their devices, the users followed the task list assigned to them (see Figure 9). While performing those tasks participants were observed and data was collected. Figure 11 summarises these results in terms of quantitative usability attributes measurements (effectiveness, efficiency and learnability, as defined above).

Figure 11 Quantative measurements the mobile application of (a) effectiveness (%), (b) efficiency (%) and (c) learnability (%) (see online version for colours)



Note: Those measurements refer to the task list shown in Figure 9.

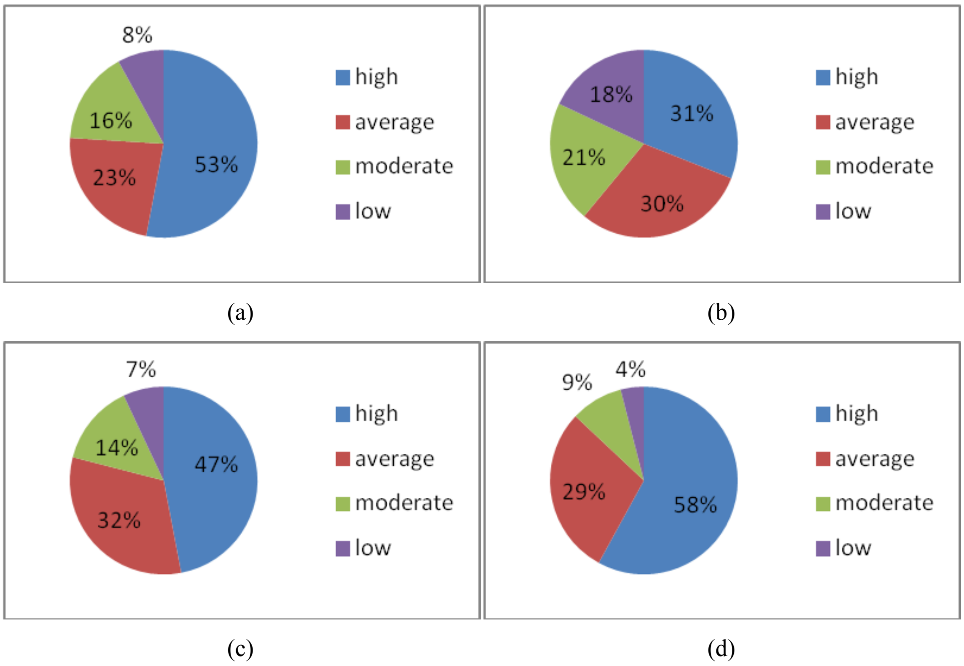
As for most participants, problems were mainly dealt with in Tasks #2 and #5 in the completion of the mTRS evaluation task list. In Task #2 participants had to accept the mobile applications automatic notification of approaching a POI and hence perform a Bluetooth handshake between their mobile phone and a nearby sensor node in order to continue to the following tasks of rating etc.

In Task #5, problems arose when users took photos of their visit to the POI using high resolution camera phones. When uploading large picture files, they experienced long delays, which frustrated several participants (a solution to this problem would be to enable the mobile applications modify the image sizes prior to uploading). Besides, network disconnections were frequent due to users mobility (i.e., their detachment from the nearby sensor node).This would be a case to look at in the future, e.g., cross-network connectivity and use of WSNs for feeding mTRS with contextual information.

3.2.2 Qualitative evaluation results for mTRS

As of the mobile recommender system (mTRS), participants were rather satisfied and found our mobile system fairly simple to use except in handling problems related with the Bluetooth handshaking between their mobile device and sensor nodes (several participants requested assistance from the evaluators to perform the handshake; this explains the relatively low users' rating for the simplicity of use). However, users realised the overall system potential and had a fairly high appreciation of its usefulness in m-tourism cases. Figure 12 illustrates those qualitative data results.

Figure 12 Measurement of qualitative usability attributes of the mTRS, (a) user satisfaction (b) simplicity of use (c) comprehensibility (d) perceived usefulness (see online version for colours)



4 Issues raised by evaluators and recommendations for enhancements/improvements

Overall, participants appreciated the use of the recommender system as it adapted the application's content to fit participants' personal preferences; also, the fact that the application could function on their personal mobile devices brought an added perception of familiarity to them. They also realised the business perspectives of including advertisements through the web and the mobile applications.

A number of directions for future enhancements of the TRS platform were suggested:

- recommendation of *routes* to follow (i.e., ordered lists of POIs) rather than (or in addition to) a list of possible POIs to visit
- cater for non-intrusive notifications for nearby POIs when moving in proximity to deployed sensor nodes
- provide more transparent and reliable communication facility for uploading content
- prevent prolonged uploading delays either by prohibiting uploads of large pictures or by automatically reducing image sizes
- participants appreciated the capability to rate POIs; some of them though found it annoying to be interrupted with a whole screen message while using the application and suggested the use of more discrete notifications

- some participants expressed interest in being able to access the public profiles of other users with similar views for a POI, i.e., those that provided similar ratings and communicate (asynchronously) with them
- several users expressed interest in knowing the percentage of users who actually visited and positively rated each POI
- participants would like to have access to representative comments from other users.

5 Conclusions and future work

The unique features of mobile devices (limited hardware and communication resources, unreliability of wireless networks, changing context, etc.) places obstacles in the formulation of usability guidelines for mobile application developers. As a result, usability testing of mobile applications continues to represent an emerging research area that faces a variety of challenges. Traditional guidelines and methods employed in usability testing of desktop applications are not directly applicable to a mobile environment (Ricci et al., 2011; Zhang and Adipat, 2005).

We have conducted thorough user evaluation tests to validate the usability of our prototype and capture problems dealt with in real deployment. The strategy followed in this particular evaluation had to adhere to the nature of the evaluated application. Thus, we have used experimental testing in laboratory environments for the evaluation of the wTRS as it made it easier to measure usability attributes and interpret results, while also making it possible to use video or audio recordings to capture participants reactions, including emotions (Buyukkokten et al., 2002; Ricci, 2002). In contrast, we favoured field studies in a realistic environment for the evaluation of the mobile recommender system (mTRS) as it made it possible to take the dynamic mobile context into consideration, which is difficult to simulate in laboratory experiments (Kjeldskov and Stage, 2003). In particular, field tests were performed to assess the functionality and usability of the mobile application with respect to controlled parameters, e.g., connectivity, camera and uploading of content from certain devices, etc. The results taken from usability tests were processed in order to extract quantitative data. Also, field tests were commissioned to extract both qualitative and qualitative data.

The TRS was evaluated on the basis of a multitude of quantitative (e.g., effectiveness, efficiency, learnability) and qualitative (e.g., user satisfaction, ease of use, comprehensibility, perceived usefulness) criteria based on a combination of evaluation methods (compilation of oral interviews, processing of questionnaires, analysis of video recordings, task completion time measurements, etc).

The usability test results referring to the wTRS portrayed high effectiveness and efficiency. High effectiveness indicates that most participants successfully completed their assigned tasks, while high efficiency shows that the tasks were completed within the anticipated time brackets. As for tasks with relatively low efficiency, the repetition of the same tasks showed increased learnability (i.e., ability to perform the task much faster in the second attempt).

The user evaluation of mTRS by mobile users was conducted in a real archaeological setting (the middle-ages castle of Mytilene). The field trials were performed with particular success, although some problems arose. The problems that were mostly associated with the communication between the users' mobile devices and the scattered sensor nodes. The problems were mainly due to Bluetooth technology shortcomings (limited bandwidth and range and non-transparent connection establishment due to the handshake); network disconnections occurred due to user's mobility (i.e., their detachment from the nearby sensor node), while several participants were frustrated when attempting to upload large photos due to the increased upload time. Those problems questioned the appropriateness of Bluetooth as communication infrastructure in a wide scale (Vergetis et al., 2005). The use of 802.15.4-compliant devices could provide an effective alternative to Bluetooth for communicating with WSN installations. However, practical issues dealt with the field deployment of WSNs (e.g., careful consideration of local conditions, equipment safeguarding, validation of gathered data, etc.) need to be investigated and answered first (Barrenetxea et al., 2008).

As a future work, we plan to incorporate several of the evaluators' proposed enhancements into our prototypes. We also plan to execute usability tests of the enhanced version of TRS by a larger number of participants. Finally, the mTRS will be evaluated on several POI sites representing a variety of terrain morphology.

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Notes

1 The term e-tourism mirrors the diffusion of ICTs in all processes and value chains in the tourism, travel and hospitality industries (Buhalis, 2003). Despite its broad definition, it is commonly linked to the use of standard web applications by tourists. M-tourism represents a relatively new trend within the context of e-tourism that concerns multimedia guides on mobile devices (e.g., mobile phones, PDAs), either standalone or web-based. The m-tourism applications enhance user experience offering audiovisual content, integration of location-aware interactive maps and services, etc. (Kenteris et al., 2011).

2 Sensor nodes are computational nodes of small dimensions and of very low cost shipped with embedded sensors to record measurable parameters such as temperature, humidity, acceleration, etc. WSNs represent a modern wireless technology whereby nodes communicate with each other over a wireless connection and push collected data to a processing element (sink). A basic principle of WSNs is that they do not require a stable network infrastructure to operate. Namely, WSNs enable self-configuration and self-organisation of an infrastructureless ad-hoc network topology.

3 In our implementation we used 20 SunSPOT sensor nodes of Sun Microsystems (SunSPOT project). SunSPOTs are equipped with a processor (32 bit risk clocked at 180 MHz), an IEEE 802.15.4-compatible radio transceiver, a rechargeable battery (3.7 V 720 maH) and three embedded sensors (accelerometer, temperature and light sensor). Each SunSPOT hosts a Squawk Java VM and may execute Java ME applications. Additional sensors and modules may be also attached to sensor boards. In our testbed, we attached 512 Kbps BlueSMiRF Bluetooth modems and GPS modules to SunSPOT devices. Furthermore, SunSPOTs enable ad hoc connections with transfer rate of 250 Kbps which allows fairly fast upload of low to middle resolution graphics. The transmission range of SunSPOTs in clear terrain is around 100 m; hence, depending on the terrain's morphology, a 'grid'-like coverage with SunSPOT nodes placed within a distance of 30–50 m (that is less than 10 nodes per hectare) should be sufficient to guarantee connectivity even in the event of failure of a relatively large number of nodes.