International Journal of Multimedia and Ubiquitous Engineering
Vol.11, No.3 (2016), pp.11-22
http://dx.doi.org/10.14257/ijmue.2016.11.3.02

Context-Aware Information Systems for Public Spaces: The Public and Private Dichotomy. Overview, Challenges, and Experiments

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Abstract

Developing information systems that are able to present the content that is most appropriate for the interests of the target audience in public spaces is a very challenging task. However, this is also a central concern for advertisers and content publishers who are continuously trying to find appropriate strategies to get the attention of visitors that are potentially interested in their products or services. In this article, we provide an overview of some of the main challenges associated with this task. We also describe a system that combines information from individual user's interactions with contextual information to infer the general interests of the visitors to support socially aware content recommendations for individuals and groups in public spaces. Evaluation results from experiments performed in two distinct scenarios indicate that the proposed approach can be used to deliver personal and public content in public spaces and that people recognise its advantages over other traditional information systems used in public spaces.

Keywords*: ambient intelligence, context-awareness, public recommendations, socially aware computing, smart spaces, ubiquitous computing*

1. Introduction

Information systems in public spaces are increasingly common, and people are constantly overwhelmed by a huge quantity of information (*e.g.*, news, announcements, videos, photos, *etc.*). However, many of these systems are not succeeding. Many visitors often do not pay sufficient attention to them because the content is not in accordance with their interests, is not presented in the appropriate context, or is not delivered using appropriate devices. Traditional approaches that cyclically or randomly deliver the same content are not appropriate. The frequent presentation of the same content will solve the problem of presenting the information to people that are interested in it, but it will also be annoying and will likely present unexpected or misplaced content, leading to disaffection of users. Consequently, the system will fail. Because of that, advertisers and content publishers are continuously looking for new approaches and strategies to better promote their services and products and thus deliver them to people who are potentially interested. To succeed, systems that present or deliver content to people in public spaces must be aware of the people's interests, expectations, and their social context so it will be possible to deliver appropriate content and adequately correspond to the needs of both content publishers and the potentially interested audience.

The current proliferation of mobile computing devices and large displays in public spaces have created new opportunities to develop systems that attempt to discover the best advertising strategies to capture users' attention and reach the target audience that is potentially interested in their products or services. However, to be successful, these

ISSN: 1975-0080 IJMUE

devices should be designed to automatically reflect both the environment in which they are placed and the actions of the people around them [1].

This article provides an overview of some information systems that are developed to deliver information for people in public spaces and that, in one sense or another, have been deployed to infer the interests of the visitors of a public space and to present the content that is representative of their interests. It explores the key challenges involved and some available alternatives. It also describes some experiences we perform with a system that explores users' individual interactions and contextual information rules to support socially aware content presentation to fit users' interests in public spaces best. Evaluation results from these experiments suggest that our approach presents some advantages over most information systems usually used in public spaces and that it could be used to deliver content for individuals and groups in public spaces. However, they also have shown that people do not become significantly involved in the interaction with the system, and that it will require more appealing engagement strategies to increase the level of involvement and interaction with the system.

2. Related Work

Here, we review some systems that, in one sense or another, have been deployed to deliver appropriate content for people in public spaces. First, we discuss research on systems that combine personal mobile devices and public displays to infer users' interests. We discuss the problem of using public displays to present relevant and contextualised content to visitors. Second, we discuss research on content recommendations for groups in public spaces.

Several information systems that try to provide personalised information for individual users or groups in public spaces have been presented and discussed. Some of them rely on the users' personal mobile devices to support the interaction with public displays. The BluScreen [2] collects audience statistics by exploiting Bluetooth to detect the presence of people. It includes a public display, which selects and displays ads in response to users detected in the audience. It uses Bluetooth-enabled devices for identifying users, and it explores the historical information of past exposure of users to certain sets of ads. Its main goal is to select the best content to maximise exposure to the current audience so that the ads are preferentially shown to those users who have not seen them yet. PervAds [3] tries to maximise the relevance of the ads sent to potential customers based on user profiles. The relevance of each ad is determined by semantically matching the profile and the context to the user. In this system, ads are received in the users' mobile devices, and users are able to have some control related to the pertinence of the ads they receive. Muller [4-5] described a mechanism to adapt ads to the interests of the audience in public spaces. Each ad has a set of keywords, and the history of all ads the user has shown interest in is maintained. The ad is shown as a coupon that users can capture with their mobile phone cameras and show to the cashier. The coupon contains a code that identifies the place and the date the user has seen the ad. This code is fed back into the system, and it is used to influence the decision on which content to present in the display. The combination of personal mobile devices and public displays was also used in other research [2, 6]. They presented a concept to allow people to influence public content, such as songs, news, *etc.*, individually, based on the Bluetooth functionality in their mobile devices. Users define their preferences and store them encoded in the Bluetooth name of their mobile phone. In [7] authors explore the creation of a public display system that evaluates the relevance of content from web sources and selects the most appropriate content according to a dynamic tag cloud that incorporates place definitions but is also sensitive to the people around the display. In this system, users interact with the display using

keywords in their Bluetooth devices. The NFC technology is also used in many systems. Typically, NFC tags are placed in or on objects and are used to provide a link between the content publishers and the target audience through mobile devices [8-9]. An advertising system using NFC is described in [8]. It combines public displays and mobile devices and explores personal user profiles and explicit input from users in order to provide appropriate content. In this case, static displays, such as paper posters, and dynamic displays have been augmented with NFC tags to allow direct interaction with a smartphone. They rely on the users' mobile devices to store information about their owners, their activities, and to let them interact directly with information on the displays. The content delivered depends on the personal user profiles and the current activities of the users.

Usually, approaches to recommender systems deal with two types of entities: users and items. The user entity is usually a user profile that is based on either manual user input of preferences or automatic user modelling (*i.e.*, deriving user preferences based on a user's history of content consumption). The item entity is typically characterised with a set of metadata that is usually supplied by the source; however, in some cases, this information is extended with other information that is inserted by users. These entities are the basis of the three main recommendation techniques in use today: content-based recommendations, collaborative recommendations, and hybrid approaches that normally depend on extensive data about both. How they are used differs between the three techniques. In content-based recommendations (*e.g.*, [10-11]), the system suggests items that best fit a specified set of criteria on users' profiles. On collaborative recommendations (*e.g.*, [12-14]), the system makes recommendations based on information that similar people liked in the past. These systems try to predict the utility of items for a particular user, based on the items previously rated by other users. To avoid certain limitations that are associated with content-based and collaborative systems, hybrid approaches have emerged (*e.g.* [15-16]). However, traditional recommendation systems, usually designed to recommend content to individuals, are not able to appropriately make recommendations for groups; thus, research on group-based recommendations has attracted more attention recently (*e.g.* [17-19]). These approaches are targeted to online groups and usually combine the profile of each user in a group to build a group interest profile or combine the recommendation list of each member to make group recommendations. In fact, recommender systems require a significant level of user involvement because they require explicit feedback from the user. They often require a user profile defined by the user.

Several systems attempt to provide personalised content to users in public spaces. Some provide personalised content to individuals, while others recommend content for groups. When content is targeted to individuals, many systems make use of user profiles to define the best content to deliver. When the content is targeted to groups instead of individuals, some approaches base decisions on users' identification, individual profiles, or some types of explicit feedback or past actions. However, people who frequent public spaces are very heterogeneous. Frequently, they visit a single time, and building individual user profiles or collecting some type of user feedback or information about user history is not achievable.

3. Challenges

Deploying context-aware information systems for public spaces poses many challenges that are not usually found when developing information systems for media or online media, and this may limit their applicability and success. The singularities and specificities of these environments make them very rich in interaction mechanisms and create new opportunities for several innovative applications; however, at the same time,

they also create additional challenges. Here, we consider major research challenges that we must overcome before achieving this goal.

3.1. Difficulty to Recommend for Groups in Public Spaces

Many common strategies to identify users' individual interests make use of personal mobile devices. In these approaches, users' interests are usually easy to identify because they result from the explicit interactions of the users or from user identification. In this case, it is possible to make associations between the user (device) and the services and/or products the user is interested in or build user profiles based on past user interactions. In fact, when the intention is to use information about users' individual interests, they can be easily obtained through simple interactions through their mobile devices. Based on this information, the system is able to make individual recommendations. If the purpose is to make recommendations for groups instead of individuals, this task is much more complex. In these scenarios, the identification of their interests is not easy or obvious. Many of these people may not be able to interact with the system to expose their interests; therefore, it is more difficult to obtain information about their interests. Thus, novel strategies are required to infer the general interests of the visitors and to be aware of the activities and characteristics of the place because, without knowing the visitors' preferences and interests, it is not possible to make appropriate decisions about what content to present at each moment.

3.2. Inferring Group Interests in Public Spaces

When a user visits a public space, he or she expects relevant information to be recommended that should be according to his or her particular interests and expectations. This is not a complex task when recommendations are made for individuals instead of groups in public spaces. In many systems, the interests of the users are previously defined in the form of some type of user profile and/or some type of explicit user interactions, and the system selects information according to it. However, when recommendations are made for groups, this could be a very complex task because recommendations are public, because all people can see them, and because they are targeted for groups instead of individuals. This raises some specific challenges. First, it is important to infer the general interests of the visitors and build some type of place social model. This model should incorporate the dynamic nature of the interests of the visitors and should be dynamic over time. Second, in common recommender systems, content is usually presented once and afterwards the system assumes the user is no longer interested in the same content; however, in public displays, the same content may be presented one or more times depending on its relevance to the current environment and target population.

3.3. Balance between Content Publisher Desires and Visitor Interests

Usually, there are two viewpoints from the perspective of the relevance of the content that should be delivered. On one hand, the place owner has goals and expectations about the content to be presented to the visitors and should play an active role as a driver of the system behaviour or have some type of control over its behaviour. On the other hand, the visitors are the main consumers of the content and should be provided with mechanisms to influence the system information behaviour. Both perspectives should be central in the definition of the system behaviour, and they should be correctly balanced in order to maintain the interests of visitors but also to maintain the display behaviour expected by the display owner. This combination of interests in a common representation builds a characterisation of the place and represents the social environment of the public place, and it should be one of the main drivers of the system behaviour. Because public places are characterised by a high diversity of visitors in number, frequency, interests, and expectations, they are very dynamic and heterogeneous environments. Thus, instead of

considering individual contributions per se, it is important to consider the combination of the multiple contributions over time, allowing the characterisation of the social environment of the location, thus benefiting from synergies between them and serving the community as a whole instead of each individual interest at a time.

3.4. Difficulty to Obtain User Preferences and Feedback

If the information is delivered through mobile personal devices, users are able to have some control over the content that is presented, namely explore, ignore, give feedback, *etc.* If the information is presented through public displays for groups instead of individuals, people are very limited in their ability to influence the display decisions. Public display systems are not conceived to provide traditional interaction mechanisms or to be under the control of a single user. Unlike what happens in traditional recommendation systems, which assume some type of collaborative process with users where the user will somehow be in control of the selection process, in systems that make group recommendations using public displays, users are very limited in the way they can influence the selection process. Of course, the system can provide specific tools to be used by the display manager to specify his interests and have some control over the system, but the same mechanisms are not suitable for visitors. Visitors should be provided with more intuitive, non-obstructive, and easy-to-use mechanisms to interact with the system. Although there are no well-accepted techniques for supporting spontaneous interaction between users and public displays, most common techniques in use today are supported by personal mobile devices. Their communication capabilities provide an appropriate means to expose their interests through simple and non-overburdening configurations.

3.5. Which Contextual Information to Use and How to Use It

If the selected content is not aligned with the values, activities, practices, or commercial strategies of the location, its public presentation may become a source of embarrassment. To be valuable, content should be selected in accordance with the social environment around the display. This means the system should be aware of its surroundings and the interests and expectations of people that frequent the place. However, there are many challenges that should be overcome, namely which contextual information should be used and how it should influence the selection of content and the way content publishers specify the preferable context in which to present the content.

3.6. Avoid Useless Content

When the content is delivered through personal mobile devices (*e.g.*, smartphones) of the users, they can easily choose to ignore the content presented through simple actions that they can make to control the device. However, if the content is presented through public devices in public places (*e.g.*, large public displays) where all people can see it, the lack of mechanisms to play some type of direct and explicit control over the content that is presented in the public display can lead to situations where inappropriate or useless content is presented. In these cases, systems should be able to properly interpret the information from the user' interactions and properly process them to respond in a timely manner with the most appropriate content.

3.7. Protect Users' Privacy

Large public displays are very common as part of the information systems for public places. However, the public nature of these devices makes them unsuitable for presenting sensitive information. Even if such a display is public, its use can be of a private nature like personal interactions that allows private information to be shown on the display (*e.g.*,

presenting personal photos or videos, access to a specific content, *etc.*). The personalisation of these devices presents a number of design challenges, in particular how best to provide personalisation without unduly compromising viewers' privacy [20]. Even in the case where a specific content is to be made public, it is generally undesirable that the association between the content and the users that interact with it should be perceptible. This means that while working on large displays in public places, users' privacy should be a central concern. In addition, public display systems should give users the freedom to interact with them spontaneously without the fear of exposing sensitive information.

4. Context Aware Recommendation in Public Spaces

The interests of the individual visitors can be easily obtained through their explicit interactions that can be discovered using their mobile devices. Thus, it is not a complex task to answer to their requests and to recommend content according to their interests. However, if recommendations are targeted for groups instead of individuals, this could be a complex and challenging task. These recommendations are public because all people can see them, and they should be made according to the interests of the people who attend the same space and not according to the interests of a single visitor. Additionally, recommendations should be considerably improved if they are framed within the context provided by the additional contextual information associated with the place.

4.1. Individual and Group Recommendations in Public Spaces

A very common way to specify user preferences is using personal mobile devices. In these cases, there are several technologies to support them. Users are able to specify keywords denoting interest in some specific topic (*e.g.*, SMS, Bluetooth) or use read tags on products or objects (*e.g.*, NFC tags or QR codes). With this information, systems are able to answer appropriately to their interests. In these situations, it is possible to make associations between services and/or products and user interactions or to build user profiles based on users' recent and past interactions.

However, in public spaces, recommendations are usually public and targeted to groups instead of individuals. In these scenarios, identifying the general interests of people that frequent that space is central because, without being aware of the activities and characteristics of the place and without knowing the preferences and interests of the users that visit that space, it is not possible to make appropriate decisions about what content to present at each moment. In this scenario, the owner's guidelines and information concerning the visitors' individual interactions are important indicators. When combined, this can play an important role in the characterisation of the place's interests. Using this knowledge will make it possible to build a place characterisation that can be used to support decisions regarding which content is more appropriate for the target population at each specific moment. In other words, this means that individual users' interactions can be used to infer the general interests of the visitors. This approach allows the system to deliver content that is representative of the interests of the people who visit a specific place (and thus perhaps have similar interests) even without having interacted with the system. Using information related to the history of visitors' past interactions, the topics they interact with, the number of times each topic is accessed, when they interact, the recent items presented, *etc.*, the system infers the general interests of the visitors at each moment. This information can be combined in a dynamic model to represent the social interests at the location. Additionally, the period that validates the social interests can be adjusted to make the model more or less dynamic. A short period makes the model more dynamic. Its behaviour is mostly dependent on recent interactions. A long period makes the model less dynamic, incorporating user interactions in its behaviour that happen for a long period; consequently, it is less affected by recent interactions.

4.2. Context and Context-Awareness

The relevance of the content is strictly connected to the context of the place where it will be delivered. The same content may be very suitable in one place at a specific moment and may be unsuitable in a different place or even unsuitable in the same place at a different moment. The context of the place where the content is presented is a determinant to support the decisions about which content is more appropriate to recommend for each group at each moment. However, it is also important to consider the characteristics of the content and the viewpoint of the content publisher (or the owner) because it will be possible to frame the content in the context where it will be presented. This approach can be implemented by assigning a set of contextual rules for the content. Contextual rules allow the most appropriate context in which to present the content to be specified (*i.e.*, the preferable conditions under which the content will bring the highest benefit. Target places, the temporal pertinence of the content, the main topic the content is associated with, the priority of the content, revenue, characteristics of the place (*e.g.*, the location, nature of the place, *etc.*), or even weather may help to identify the best moments to deliver the content.

5. Presenting Personal and Public Content in Public Spaces

As part of our work on this topic, we have developed a system that is able to make personal and group recommendations in public spaces. There are five main sub-systems in the system architecture: a web portal, a content server, a large display to present public content, a smart poster, and a mobile application that allows users to visualise the content they request. This design has evolved throughout multiple iterations, and its final architecture is represented in Figure 1.

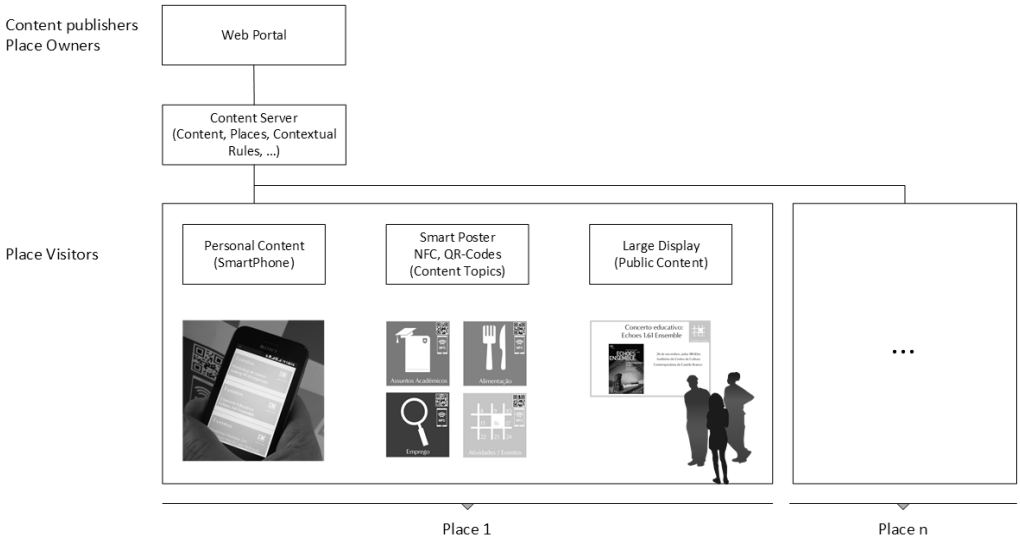

Figure 1. System Architecture and Technologies

Web portal: It provides the interface to manage places, configure displays, and associate smart poster NFC tags and QR codes to content topics. It also provides support to manage the content, namely inserting items (*e.g.*, title, description, image to present on the personal smartphone, image to present on the public display, main topic, priority level, start date, end date, target places, and preferable days and periods to present the content) and context rules (to specify the most appropriate context to present the item).

Content server: The content server contains the logic associated with the content and places. It is also responsible for the scheduling of the items to present in the public display and the scheduling of the items to deliver to each mobile device.

Smart poster: The smart poster is a poster that contains figures that are associated with the main topics of the content. It uses an NFC tag and/or a QR code to provide a link between the figure of the topic and the associated content in the content server.

Personal content (smartphone): This application is responsible for the interaction with the smart poster reading the NFC tag or the QR code (the user selects the method, if available). It is also responsible for the communication with the content server to obtain the items that are associated with the NFC tag or QR code to interact with and presents them in a list according to their relevance. The relevance of each item is determined considering the context where the item is displayed, the topic the user read (associated with the NFC tag or QR code), the recent history of selected items in the users' smartphones, and the set of contextual rules specified by the content publisher for each item. These rules include location, history of recent interaction (topics, items, and users), the period in which the item is valid, the preferable period to display the item, and the priority level of each item. When users select a specific item from the list in their mobile phones, a new screen with details about the selected item is presented and the users are able to share it through email or social networks (*e.g.*, Twitter and Facebook).

Although NFC interactions are more spontaneous and less intrusive to the users (every time they want to interact with the smart poster, they only need to tap the intended topic), we have decided to provide support for interactions through QR codes primarily because NFC technology is not yet common in many smartphones.

Public content (large display): The large display presents the items in which people are most interested. The selection of the items is supported by the social interests by location, according to the pool of available items to be presented in that specific place and their contextual rules. We calculate the relevance of each item, considering the recent social characterisation, and we verify its contextual rules and the history of the presented items to avoid the presentation of the same content too often. Items with low values of relevance, which are consequently not presented in the display, are included in the pool of items to be presented when there are not enough items that satisfy the required contextual rules to complete the queue. The combination of these conditions allow making a pool of items that is continuously updated according to the changes in context, social characterisation of the location, and display history.

6. Experimental Work and Evaluation

The evaluation of this system comprised two user studies to assess its overall operation in a real-world scenario. The goal was to evaluate different aspects of the proposed model in different scenarios, namely:

- whether results are influenced by the nature of the public space,
- how users perceive the relevance of the personal and public content presented in the smartphone and public display,
- how they perceive the sensitivity of the system to their interactions, and
- whether they uncover meaningful opinions about the relevance of the items presented in the public display.

In both experiments, two different data gathering techniques to collect qualitative and quantitative data were used. The first was a questionnaire to obtain quantitative ratings on a set of questions about the system usage (each question of the questionnaire was evaluated on a four-level scale (good, sufficient, poor, and bad) and a 'don't know' option.). The second was through direct observations made during the experiments to obtain qualitative data. In both cases, usage logs were also collected during the experiment time.

6.1. Experiments

The first experiment was performed in a common area of a technology company, which is frequented by their workers and occasionally visited by other people outside the company. The system included a smart poster showing three topics of content (food, technology, and telecommunications) and a public display presenting content. In this case, the system only provided support to interactions through NFC. The experiment was carried out for a week between 9 am and 6 pm on working days.

The second experiment was performed in the common area of a school of technology. The system was installed in a transient place where students, teachers, and staff walk by on their way to classes and the dining hall. The system was configured with four topics (academic issues, events, food, and jobs) and users are able to interact with the smart poster using NFC or QR codes. The experiment was carried out for three working days between 9 am and 6 pm. The system included a smart poster and a public display (see Figure. 2a and 2b). When a user interacts with the smart poster using a smartphone camera to read the QR code or tap the intended topic to read the NFC tag, a list of items is presented in the smartphone (see Figure 2c). If a specific item is selected, a new menu with detailed information about the item is presented (Figure 2d). This experiment is described in more detail in [21].

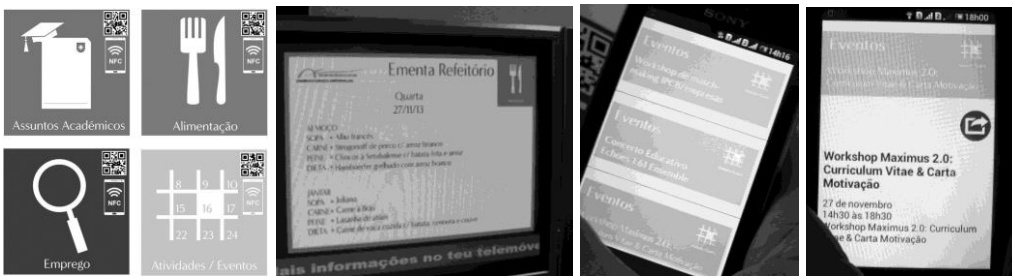

Figure 2. a) Smart Poster, b) Public Display, c) List of Items, d) Information about a Specific Item

6.2. Results and Discussion

The number of distinct users who interact with the system in both experiments is relatively low (four users in the first experiment and eight users in the second experiment. They realised 147 interactions with the smart poster; therefore, new evaluations with a higher number of users are required. However, the results that were obtained from the questionnaire (13 valid questionnaires) and the direct observations allow us to make some initial conclusions.

The users' opinions are similar in both experiments. This may suggest that the results are not dependent on the specific place where the experiment was conducted. All the respondents agreed that they did not have difficulties understanding the system. They all interacted with the system spontaneously and without help and 85% of the respondents stated the content was presented in the personal mobile device with good clarity and readability. The relationship between individual user's interactions and the public content presented on public display is not clearly perceived by the visitors. Although users recognise the appropriateness of the content presented in the public display, it is not clear whether this is only a consequence of the set of available items and contextual rules, or whether it is also a consequence of the personal interactions via personal mobile devices. All of the respondents stated that the content presented in the public display is relevant.

The advantages of this system over the most common information systems usually used in public spaces (*e.g.*, paper posters or cyclic content in public displays) are recognised by all the respondents. It is important to note that the results can be influenced

by the system configuration. It can be configured to adjust its behaviour to be less or more reactive. More reactive indicates that the system includes a more immediate influence on recent interactions and, consequently, a more perceptible relation between users' personal interactions and the public content on the display.

7. Conclusions and Future Work

This work has discussed the overall issue of how to present appropriate content for individuals and groups in public spaces. We have analysed different strategies, particularly those that explore user's individual interactions to support content selection to be delivered to people in public spaces. Based on these assumptions, we have developed and evaluated an information system that explores the interactions of each visitor, combined with contextual information rules, to support socially aware content presentation to fit the visitors' interests in public spaces. This system allows individual users to receive content they are interested in through simple interactions with a smart poster. In addition, it uses information from individual users' interactions to characterise the social interests of the place and to infer the general interests of the visitors, thus allowing the system to deliver content that is representative of the interests of the people who visit.

To evaluate the proposed approach, we have performed two experiments in different scenarios. Overall, the positive results obtained during the evaluations suggest that this is a viable approach to the problem of delivering content for individuals and groups in public spaces. The results showed that visitors recognise the advantages of this system over traditional information systems usually used in public spaces. They also show that users easily interact with the system to receive content related to their interests and that the content is presented with clarity on their mobile phones. In addition, they recognise the relevance of the content presented on the public display. Despite this, a more in-depth study is needed. We need to perform more experiments with different audiences and to obtain more significant statistical results in order to analyse how interactions generated by nearby users influence the perceived relevance of the public content presented on the display. In addition, another goal is to uncover whether the perceived relevance of each item is only a consequence of the set of available items or whether different configurations of the social interests or actions of the users that interact with the system may affect the perceived relevance of the items.

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