

Innovative IoT-aware Services for a Smart Museum

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ABSTRACT

Smart cities are a trading topic in both the academic literature and industrial world. The capability to provide the users with added-value services through low-power and low-cost smart objects is very attractive in many fields. Among these, art and culture represent very interesting examples, as the tourism is one of the main driving engines of modern society. In this paper, we propose an IoT-aware architecture to improve the cultural experience of the user, by involving the most important recent innovations in the ICT field. The main components of the proposed architecture are: (i) an indoor localization service based on the Bluetooth Low Energy technology, (ii) a wearable device able to capture and process images related to the user's point of view, (iii) the user's mobile device useful to display customized cultural contents and to share multimedia data in the Cloud, and (iv) a processing center that manage the core of the whole business logic. In particular, it interacts with both wearable and mobile devices, and communicates with the outside world to retrieve contents from the Cloud and to provide services also to external users. The proposal is currently under development and it will be validated in the MUST museum in Lecce.

Categories and Subject Descriptors

C.2.1 [Network Architecture and Design]: *Wireless communication*

C.3 [SPECIAL-PURPOSE AND APPLICATION-BASED SYSTEMS]: *Real-time and embedded systems*

C.5.3 [Microcomputers]: *Portable devices (e.g., laptops, personal digital assistants)*

D.2.11 [Software Architectures]: *Domain-specific architectures*

H.2.8 [Database Applications]: *Data mining, Image databases*

I.2.10 [Vision and Scene Understanding]: *Modeling and recovery of physical attributes, Video analysis*

I.4.8 [Scene Analysis]: *Object recognition*

General Terms

Algorithms, Management, Design, Experimentation.

Keywords

IoT architecture; Embedded systems; Smart Museum; Artwork recognition; Localization; Android; Cloud.

1. INTRODUCTION

The Internet of Things (IoT) is leading to the development of a plethora of smart objects that are intended to sense environmental parameters and human beings' behavior, in order to provide advanced services to the users. This trend aims at realizing smart environments able to capture, in a pervasive way, all useful information from the real world, and to automatically anticipate users' needs. The continuous attention towards this new vision puts an extraordinary stress on the so-called smart cities. They aim at increasing the effectiveness and efficiency of tourism, energy and water supply, healthcare, home and building automation, by integrating various systems through Information and Communication Technology (ICT) [1]. Among all the possible areas of applicability of ICT technologies, art and culture are becoming more and more interesting since they play an important role in human beings lives. Over the centuries, hundred of museums and art galleries have preserved our diverse cultural heritage and served as important sources of education and learning. However, visiting a museum could often be quite boring, because museum curators are not able to catch the tourists' attention properly. In particular, it is difficult to define in advance a tour for all the visitors, because interests may vary from person to person (e.g., from children to adults, students group from single visitor, casual visitor to fond-visitor). Interactive and personalized museum tours need to be developed. In this perspective, a significant contribution can be given by the IoT, which aims to create a better world for people, where smart objects around us know what we like, what we want and act accordingly without explicit gestures.

Together with the IoT vision, also the role of mobile and wearable devices is increasing. Mobile devices, such as smartphones and tablets, are almost ubiquitous in our society, since they are not only communication means, but also technological tools for controlling other devices and communicating information about users. For this reason, the trend to use them for interacting with smart environment is increasingly widespread.

Finally, another key element of the current digital world is the Cloud, which is becoming the main mean for sharing data, information, and events between services and users.

Taking into account these considerations, it could be possible to design and develop a smart system able to improve the user experience in a museum. The fundamental concept of the system should be the location-awareness, that is, all the provided services have to act according to the users' position and their movements. The capability to detect the location of each user can represent the base of more complex systems that involve several IoT-enabling technologies. For example, by tracking the visitors in the museum, a service could provide external users with real-time information about queues, and the environment itself could modify its status

according to specific events (e.g., the number of users in a room). Then, by placing Near Field Communication (NFC) totems in the internal areas, another service could automatically send a notification on visitors' smartphones about the opportunity to incrementally pay tickets to access specific rooms of the museum. Another interesting idea to improve the cultural experience of visitors could be to provide them with a smart wearable device that automatically recognizes the artworks they are admiring. By exploiting this opportunity, each user can benefit of several correlated services that allow him/her to send and share information in the Cloud (mainly through the smartphone), leading to the so-called Social Internet of Things (SIoT): vocal comments about his/her extemporaneous feelings, automatic posts on social networks with information about the particular artwork that is being admired, and so on.

In the literature, there are several works addressing the aforementioned issues, but none of them provides a flexible and scalable solution that can solve all the problems in one system. About indoor localization, in [2], the authors present a personalized smart control system that: (i) localizes the user exploiting the magnetic field of the smartphone, and (ii) controls appliances present at the user's location. On the other hand, focusing on the museum environment, some solutions have been recently proposed for interactive guides for enhancing cultural experience. An example is the system "SmartMuseum" [3], in which visitors can gather information about what the museum displays and customize their visit based on specific interests. This system, that integrates PDAs and RFIDs, brought an interesting novelty when first released, but it has some limiting flaws. In fact, researches demonstrated how the use of mobile devices on the long term decreases the quality of the visit due to their users paying more attention to the tool rather than to the work of art itself. Another example is the museum wearable [4]: it is a museum guide which in real-time evaluates the visitor's preferences by observing his/her path and length of stops along the museum's exhibit space, and selects content from a database of available movie clips and audio. However this system does not use any algorithm for visual analysis of understanding the surrounding environment. Furthermore, the visitor localization is based on an indoor infrared positioning system; this methodology allows the system to roughly estimate the position and therefore the content delivery may not be well suited for the visitor.

At the same time, research efforts have been made on the definition of techniques to automatically recognize objects, actions, and social interactions. Nowadays, local visual features (eg. SIFT, SURF, ORB) have been widely used for object recognition and image retrieval, due to their robustness to several geometrical transformations (such as rotation and scaling), occlusions and clutter [5].

Basing on the previously mentioned considerations and the current state-of-the-art, we propose a system able to provide the users with a real interactive cultural experience. In our system, the user is basically equipped with a smartphone and a wearable device able to capture videos and images. The actual business logic is, instead, managed by several location-aware services running on a processing center. The wearable device accomplishes two main tasks: it recognizes the artwork in front of the user by processing local visual features, and continuously localizes the user by leveraging a Bluetooth Low Energy (BTLE) infrastructure. The results of this twofold processing activity are sent to the processing center and then used by the location-aware services that are in charge to provide all the other features of the system. More in detail, they use a bidirectional communication

channel with the visitor's smartphone to provide cultural contents about his/her specific tour and information about the museum. They are also able to provide such information to external users and to interact with other heterogeneous technologies that control the status of the environment (e.g., a building automation system that manages lighting and thermoregulation of the museum). Finally, the users may also exploit their mobile devices to share information and feelings in the Cloud among family and friends.

The rest of the paper is organized as follows. Section 2 provides an overview on the architecture design. A more detailed description of the system is presented in Section 3. Conclusions and future steps are summarized in Section 4.

2. SYSTEM ARCHITECTURE DESIGN

Fig. 1 shows the overall structure of the proposed system architecture. It is composed of four main building blocks.

- The image processing algorithm: it runs on the wearable device and it is able to detect, in real-time, the artwork the user is observing. It has the capability to quickly analyze the video frames captured by the vision device and to identify the target object with high accuracy and reliability. The result of the processing activity is then sent to the processing center.
- The localization service: it is distributed between the wearable device and the processing center. The first one detects the current user's position and communicates it to the processing center. Here, the localization information is stored and made available to other services. The information is also used locally (on the wearable device) to speed up the image-processing algorithm.
- The processing center: it is the core of the business logic. It allows both the execution of the system services and their mutual interactions. First of all, it stores the current position of the users and provides this information to all interested services. For example, a specific service exploits this feature for providing external users with information about queues in the museum for accessing to specific artworks or sectors. Then, other services use the localization capability to modify the environment accordingly, so immersing the users in a real interactive environment. Finally, another key service receives the information about the artwork the user is observing and accesses, even exploiting the Cloud, the related cultural contents. Then, it provides such contents on the user's smartphone.
- The Android application: it allows the visitor to receive cultural contents about his/her specific tour, and to share

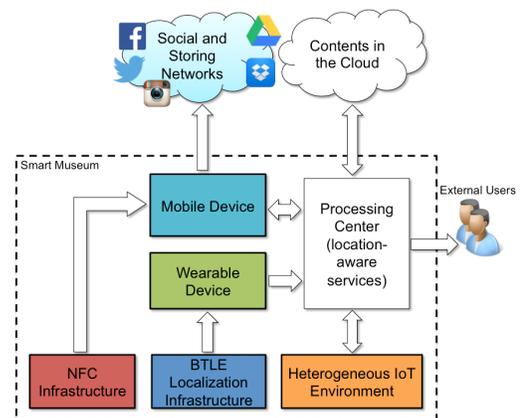


Figure 1. Overall system architecture.

multimedia information and personal feelings both in the Cloud and on the social networks. By exploiting recent auto-identification technology, such as NFC, it can also be used to pay “on the fly” incremental tickets during the cultural tour.

3. SYSTEM DETAILS

3.1 Localization

Several system components depend on the localization service. It consists of three main elements: (i) an infrastructure of wireless landmarks that periodically send localization information, (ii) a service installed on the wearable device that collects the information of the landmarks to determine its location, and (iii) the service running on the processing center that receives the location of the user and provides it to the other services. More specifically, the network of wireless landmarks consists of embedded devices equipped with BTLE interface and placed individually in the different rooms of the building. The choice of BTLE is mainly due to its low energy consumption in front of a communication range comparable with that of the traditional Bluetooth. In this way, the wireless landmarks can be battery powered, making the localization mechanism more flexible and less invasive. Each device of the BTLE infrastructure sends its location indication together with the Received Signal Strength Indication (RSSI) value. The service running on the user's wearable device collects location information from all the landmarks within its listening range and then determines the room in which it is located. To do so, it computes a proximity index d , for each landmark, using the corresponding value of the RSSI. The adopted formula is the following:

$$\text{RSSI} = -(10n \log_{10} d + A) \quad (1)$$

where A is the received signal strength at 1 m, n is a signal propagation constant depending mainly on the environment, and d is the distance from the sender [6]. The landmark that has the lowest value of d represents the user's current location.

3.2 Artwork recognition

In order to provide the visitor with information about the artwork s/he is looking at, we rely on an image classification algorithm.

Paintings on a wall can be heavily distorted by perspective and simple template matching techniques cannot thus be used. To match the framed artwork and its counterpart in the museum database overcoming this issue, we extract visual local features from the whole image by using Oriented FAST and Rotated BRIEF (ORB) descriptors [7]. In our initial experiments, the results showed that sampling keypoints only from a region of interest previously detected, i.e. a painting, did not provide sufficient results. This is mainly because a detection based on the shape of the object often incurs in false positives, like mismatching a window for a painting. In order to improve the quality of the matches, we process the keypoints using the RANSAC [8] algorithm for outlier rejection. To further improve the matching results, a first thresholding step is performed: using a threshold over the distances among ORB descriptors θ_s , we remove those matches that have a distance greater than θ_s . This allows the tuning of the method to different situations and primarily influences the recognition performance. Some examples of the matching process can be seen in Fig. 2. Since our approach samples keypoints in the whole image, we introduce a second thresholding step that discriminates frames effectively containing an artwork from frames where many keypoints are detected on architectonic details. We define the threshold θ_d over the ratio between matches that survived the previous pruning steps



Figure 2. Examples of Artwork recognition.

RANSAC and θ_s and the original amount of keypoints in the current frame. This allows the method to decide whether the current frame contains an artwork or not. Adjusting this threshold can render the method more robust to noise and clutter situations or increase its detection range, depending on the specific requirements of the museum.

Exploiting the location-awareness of our method, is possible to greatly reduce the computational requirements of the matching process and increase its accuracy. This is done by analyzing the localization information obtained by the BTLE infrastructure in each room and match the current frame against the templates of the artwork that belongs to the room where the user currently is.

3.3 Mobile services

A key element of the proposed system is a mobile application that interacts with both the services running on the processing center and the user's world in the Cloud. The first kind of interaction allows the user's mobile device to display the cultural contents related to the specific artwork the user is observing. These contents could be textual information or multimedia data. Moreover, according to the current user's position, also useful information about additional services of the museum could be provided. For example, a notification could inform the user that a NFC totem is available in that place to pay an additional fee for visiting other rooms of the museum. Furthermore, the application may also be able to share data and events related to the cultural experience of the user. In particular, it could allow to automatically post updates on the user's social networks, and to store multimedia contents in the Cloud. In this way, each user could live again his/her extemporaneous feelings at a later stage. To do so, the application exploits the proper Software Development Kits (SDKs), provided by the most popular Cloud services and social networks (e.g., Dropbox SDK, Facebook SDK, etc.). The high level methods of these SDKs allow to automatically login to the user's accounts and to share both textual and multimedia contents. The sharing process could be both manual and automatic: through the first approach the mobile device notifies the user about the detected event and give him/her the opportunity to choose whether the specific content should be shared or not; in the automatic approach, the application already knows what contents can be shared and where they should be sent.

3.4 Contents in the Cloud

Storing, organizing, and retrieving information and multimedia contents for each user is an expensive process from both the computational and memory point of view. For this reason, the Cloud seems to represent the solution that best suits this kind of

needs, as its storing and computing capabilities allow to process data more efficiently. In particular, in the proposed system, the Cloud accomplishes several tasks. First of all, it is accessed by the processing center whenever the running services need to retrieve cultural contents destined to the user's smartphone (e.g., detailed information on an artwork, augmented-reality elements to better appreciate the historical context of a sculpture, etc.). It is worth noting that, currently, the sources of cultural contents are predefined, meaning that the processing center knows in advance where to find the needed information. To further enhance the system, a semantic reasoner could be developed to automatically retrieve data from multiple sources in the Cloud and to infer additional information about the user by analyzing his/her interests on the social networks. Then, the Cloud is also exploited to maintain user profiling tools, which are useful to provide personalized services to the users. Finally, it is exploited to provide Internet users with real-time information about the museum. For example, localization information could be used to give information about queues in the museum for accessing to specific artworks or sectors. Moreover, external users could leverage statistical information about the cultural experiences of other users (e.g., the most viewed and appreciated artworks) in order to plan, for example, their tour in the museum.

3.5 Interactions with the IoT

One of the main tasks of the services running on the processing center is to adapt the status of the environment according to the information coming from localization service. Exploiting IoT-aware technologies, the environment could be modified in real-time in order to provide the user with a real interactive experience. As an example, imagine that the museum has a special room where an historical war is represented by a mechanical animation managed by several IoT actuators. To maximize the impact of this animation, the system could decide to activate it only when the number of visitors in the room is higher than a predefined threshold. In the same way, lighting, temperature and other physical characteristics of a room could be controlled to perform special 4D effects. Obviously, the IoT technologies able to provide these features could be extremely heterogeneous since they are often compliant to different standards and protocols. In order to efficiently interact with such a kind of technologies, the services of the processing center exploit a multi-protocol middleware that allows a transparent access to the underlying heterogeneous devices, hiding the low-level communication details. In particular, on the one hand, it provides the services with high-level APIs to communicate with the physical network, whereas, on the other hand, it is equipped with specific software modules that communicate with the IoT devices in accordance to the specific standards and protocols. The modular structure that characterizes the middleware allows to easily extend it to new technologies, so guaranteeing flexibility and scalability.

4. CONCLUSION

In this paper, we have presented an IoT-aware architecture for smart museum. It is substantially based on an indoor localization service that supports all the other services of the system. This service exploits a BTLE infrastructure and is distributed between a wearable device and a processing center, where the position information is stored. By exploiting the localization feature and a

vision system with image-processing capabilities integrated on the wearable device, the user automatically receives cultural contents related to the observed artworks. These contents are smartly collected by the processing center from the Cloud and could be used by the user's smartphone to share information and feelings on social networks. Moreover, the localization information is also exploited by other services to adapt the environment to the users' movements and to notify, on the users' smartphone, the availability of further services, such as NFC micro-payments in specific museum areas. Finally, statistical data inferred from the localization data could be used to provide information to Internet users. The whole architecture is currently under development, and it will be evaluated in the MUST museum in Lecce to better appreciate its effectiveness. The results of these evaluation tests will be the object of further scientific manuscripts.

5. ACKNOWLEDGMENTS

This work is partially supported by two projects: "PON04a2_D - DICET LivingLab Di Cultura e Tecnologia - INMOTO - OR.C.HE.S.T.R.A." and "PON01_02588 - HSEPGEST - Gestione di salute, sicurezza, qualità e protezione nei processi aziendali". Both national projects are funded by the Italian Ministry of Education, University and Research (MIUR).

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