Chapter 17

Advanced Artificial Vision and Mobile Devices for New Applications in Learning, Entertainment and Cultural Heritage Domains

In this chapter, the challenges posed by mechatronics and education [HAB 06] are addressed in the field of advanced artificial vision technologies and mobile devices. In particular, the chapter presents the emerging technologies for mobile learning and introduces two novel research projects. State-of-the-art technologies and applications in mobile learning are presented in section 17.3. In section 17.4, a detailed description of two projects headed by the Artificial Vision and Real Time Systems (AVIRES) laboratory at the University of Udine for mobile learning, entertainment and cultural heritage domains is provided.

17.1. Introduction

In the past few years, mobile devices have been boosted by very strong technological innovations. Mobile devices can be considered as (Web-enabled) devices that are generally used not within a fixed location

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but have been conceived and designed to be portable and usable whilst on the move. Typical mobile devices include Web-enabled cell phones (mobile phones) and Web-enabled pocket-sized Personal Digital Assistants (PDAs) [W3C 05]. The first mobile phone appeared in police cars in Detroit in 1921 and in 1946 they had already reached the commercial service level. These devices communicate with each other with a single high-powered antenna installed on a skyscraper that allows a transmission range of about 100 km. Over the years the advent of transistors led to an impetuous leap in technology: the possibility of building smaller and sophisticated electronic components enabled phone companies to develop a large number of models, more usable, comfortable and with other rich features. For example, a smartphone is the term used to specify a new generation of mobile devices that let users have a large number of features and services. As reported in [GAR 11] the world's leading company in information technology research and advisory sold 440.5 million units in the third quarter of 2011 (up 5.6% from the same period of the previous year).

Another important aspect that is strongly connected with the diffusion of mobile devices is the innovation of the communication infrastructure. Nowadays the community is talking about the fourth generation of mobile networks with the goal of reaching a transmission data speed of 1 GB/s. The new, more reliable and faster network infrastructures have pushed more and more the mobile device companies to make new mobile phones that could take advantage of these resources and new services. The technological progress leads to the design and development of new, more sophisticated and innovative, mobile phones. While previously, mobile phones were equipped with a single physical keyboard, they are now equipped with a large liquid crystal display (LCD) screens and fast microprocessors that allow the users an excellent user-experience and the performing of tasks, such as multimedia processing and data logistics. In the past few years, smartphones have exploited the touch screen technologies introduced by PDAs and other handheld devices: the keyboard has been replaced by a screen that allows the user to interact with a graphical interface using fingers or other pointing devices. The PDA can be seen as the first generation of mobile devices/phones. The second generation is now represented by smartphones and tablets. A PDA is a handheld computing device that combines multiple functions and features, including telephone, fax, Internet and networking or other forms of different connectivity capabilities. These devices are mainly used by users who need to compute operations while moving, simply called "Mobile Computing". Before that such features were provided only by laptops or desktop computers. The PDA is the first step in a future trend that would be later defined as "technological convergence".

The next generation of mobile computing, represented at the forefront by smartphones, will foster the convergence of communication, computing and consumer electronics; three traditionally distinct industries with quite low interoperability. While previously, mobile phones were equipped with a simple address book and agenda, now a smartphone has several features, such as a camera, a voice control and so on. So, a smartphone can be seen as a mobile phone with computer capabilities that allows us to interact with computerized systems, send email and access to the Web [DIC].

According to [ZHE 05], the communication and computing environment is moving toward interacting with the physical environment or even becoming part of it. As mentioned by Mark Weiser [WEI 99], chief scientist at Xerox PARC and also considered the father of Ubiquitous Computing, in the 21st Century the technology revolution will move into "the every, the small and the invisible". That is what is really happening now. This leads to a real-world environment where the information processing moves to the background and the humans concentrate on the tasks, and not on the tool. In this sense, the technology should be considered as a tool to serve the needs of people, not something to depend on. Weiser [WEI 99] suggested that the deepest technologies are those that disappear ("Disappearing Technology"). They weave themselves into the fabric of everyday life until they are indistinguishable from it. The concepts of access anywhere and anytime from any device are intertwined with the progress of the network infrastructures and with the aspects of convergence. Furthermore, smartphones can be considered as a technological expression that offers a complete set of services, including those of a normal cell phone, PDA and wireless communication facilities.

According to Gartner's Press Releases [GAR 11], smartphone sales reached 115 million units in the third quarter of 2011, up 42% from the third quarter of 2010. Another kind of mobile device that reached a very significant success in the past few years, and whose features are very similar to a smartphone and a computer, is called a tablet. A tablet can be defined as a "flat" notebook uniquely composed of a touch screen where users interact through direct touching on the screen of the device. This new generation of computers is enjoying a great success: according to IDC [IDC 12] the sale of tablets is estimated at around 160 million devices in 2012.

Both smartphones and tablets have quite similar, though at the same time different, operating systems that support the devices just described. As shown in Figure 17.1, Symbian OS, Android OS, Apple iOS and Microsoft Windows Mobile OS are the most diffused operating systems.

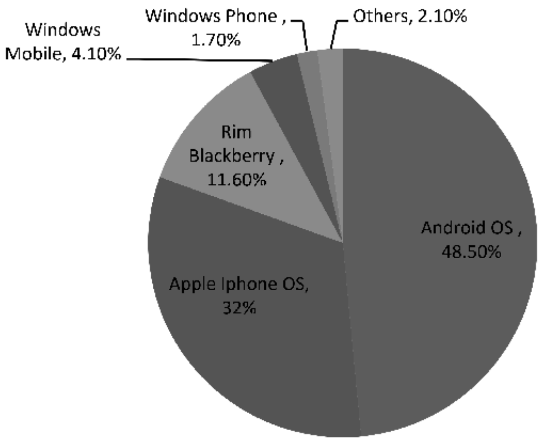


Figure 17.1. *Smartphones used by 50.4% of U.S. consumers, 48.5% of them use Android. For a color version of this figure please see www.iste.co.uk/mechatroneng.zip*

In 2009 the market leader was Symbian OS that covered the majority of Nokia devices. Symbian OS, heir to the operating system Electronic Piece Of Cheese (EPOC), was initially developed by a joint venture between Psion, Ericsson, Motorola and Nokia. However, in 2008 Nokia decided to buy all the shares of the other companies in order to become the only owner. Later, the transition of Symbian Foundation allowed for making for this operating system open source. Nevertheless, especially in the past two years, the Google Android operating system achieved a huge boost. In 2011 it accounted for 52.5% of smartphone sales to end users in the third quarter of 2011, more than doubling its market share from the third quarter of 2010. Certainly, a historical strategy was the purchase of the Motorola Mobility Company (August 2012), so Google definitively entered into the hardware market. Another company that is fighting for a slice of the market is certainly Apple Inc. In the past years, Apple Inc., led by its chief executive officer Steve Jobs, introduced a new and highly innovative device: the iPhone. It introduced a complete new generation of smartphones. The iPhone was the first mobile device that introduced a revolutionary way to conceive and design the phone in terms of the user's experience. The numerous applications, simply called "apps" and available in the "Apple store", have become the new interface which allows the user to have the maximum benefits using this newfangled mobile phone. Microsoft participates in this mobile device challenge as well. At the last Mobile World Congress, 2010, the company presented the new operating systems called Windows Phone 7. Compared with the previous versions of the operating systems, the marketing strategy was aimed at a consumer audience rather than an enterprise audience. Nevertheless, this operative system remains at sixth place with a total of 1,701.9 million units sold in the past year. As shown in Table 17.1 there are other operating systems, such as Research In Motion, (BlackBerry - RIM) and Bada (Samsung Electronics), that are placed in the mid range compared with Apple and Android.

Operating system	Units 3Q11	Share 3Q11 (%)	Units 3Q10	Share Q11 (%)
Android	60,490.4	52.5	20,544.0	25.3
Symbian	19,500.1	16.9	229,480.1	36.3
IOS	17,295.3	15.0	13,484.4	16.6
Research In Motion	12,701.1	11.0	12,508.3	15.4
Bada	2,478.5	2.2	920.6	1.1
Microsoft	1,701.9	1.5	2,203.9	2.7
Others	1,018.1	0.9	1,991.3	2.5

Table 17.1. *Main producers of smartphone operating systems*

Several studies have been conducted to verify the smartphones usage by age: according to Nielsen's studies [NIE 12b], during Q2 of 2012, the smartphone market is still growing. This growth is driven by increasing smartphone purchases: two out of three U.S. citizens who acquired a new mobile phone in the last three months chose a smartphone instead of a feature phone. Nielsen [NIE 12a] showed that teenagers between 13 and 17 years old demonstrated the most dramatic increases in smartphone adoption, with the majority of American teens (58%) owning a smartphone, compared to roughly a third (36%) of teens saying they owned a smartphone just a year ago. And they just seem to be getting younger. A study conducted in April 2012 by the Massachusetts Aggression Reduction Center showed that 20% of third grade students have cell phones while 83% of middle school kids have a mobile device. These information are significant considering the new proposals in education and in pedagogy that are spreading in these last years.

17.2. Chapter contributions

Mechatronics is defined as the science that studies how to make different disciplines interact together and it is strongly involved in the new learning and educational processes [HAB 08]. New generation mobile devices such as smartphones and tablets are new communication systems that introduce novel learning methods. In the past few years, mobile devices together with new educational methodologies have been adopted by schools, museums, etc., giving rise to the new concept of mobile learning. Despite the diffusion of such systems, there are only a few studies that show and study the efficiency and effectiveness of mobile devices for such purposes. In this chapter, the authors contribute to the research in mechatronics and education introducing the most relevant works for mobile learning and education and describing two recent research projects in such areas.

The project entitled "Image Processing Supports HCI in Museum Application" proposes an application to support users learning about paintings. It combines different state-of-the-art computer vision techniques together with augmented reality to display painting information through mobile devices. The main objective was to propose a novel user interface that allows users to interact with the paintings images captured by the mobile device to get information about the paintings themselves (e.g. author, characters and objects represented). Usability studies have been conducted with different classes of users to evaluate the effectiveness, efficiency and satisfaction in use of three different proposed designs.

The project entitled "Back to the future" is a three-dimensional (3D) image gallery developed to increase the knowledge of the cultural heritages and the history of a city. The application has been designed both for desktop and portable devices, such as smartphones and tablets. A 3D environment is presented and the user is invited to explore it as a kind of tridimensional game. 3D images of the most important places of a given city are presented and the user can see them using 3D glasses.

17.3. Mobile devices for education purposes

The diffusion of more and more sophisticated mobile devices, the innovations of the communication infrastructures and the new ways to use these devices lead to new aspects in education and pedagogy. Several studies investigate how these new technologies can support a new way to learn. A new very important concept is now widespread: mobile learning. It can be defined as any educational provision where the sole or dominant technologies are handheld or palmtop devices [TRA 05]. According to Roschelle [ROS 03], the attention should be focused toward the identification of simple things that technology does extremely and uniquely well, and to understand the social practices by which those new affordances become powerful educational interventions. Traxler [TRA 05] showed that mobile devices are now radically transforming social notions of discourse and knowledge, and are responsible for new forms of art, employment, language, commerce, deprivation and crime, as well as learning. With increased popular access to information and knowledge anywhere, anytime, the role of education, perhaps especially formal education, is challenged and the relationships between education, society and technology are now more dynamic than ever.

The new concept of m-learning can support a wide range of subjects from childrens education to higher education. For that it is important to know the most significant projects and research that have laid the basis for future studies. Mobile learning introduces several challenging aspects with respect to the traditional learning methods. So it is important to continue investigating its efficiency and effectiveness in education and pedagogy. In the following section, some of the most important and interesting projects that exploit mobile devices for education and pedagogy are described.

17.3.1. *Mobile learning for education*

17.3.1.1. *HandLer*

HandLeR was one of the first projects constructed by the University of Birmingham [SHA 00]. It was started in 1998, and was based on the theory of "learning conversation" with the characteristic to understand how people learn in multiple contexts over their lifetimes. The learning conversation was implemented using different scenarios that included a young boy of 11 years old on a school trip, a radiologist in his/her first academic year in neuroradiology and an elderly person who is rethinking and reorganizing the memories of a lifetime. The project was centered on the implementation of different interactive and portable personal computer contexts with the same features of a tablet (see Figure 17.2).

The main goal of the project was to implement different user contexts. For example, the software for the HandLeR school trip was developed through questionnaires and interviews with children of 11 and 12 years old, and the goal was to create an interactive style connected to the way of how the children learn in the field rather than using the same metaphor of the office desktop. It introduced a specific interface based on the concept of an animated mentor with the aim of helping the children and allowing them to easily learn and interact with it and with the new proposed contents. These experiments were limited by the technology available at that time, although it was a very important project as it stated the basis for other and future projects with similar goals. These experiments have underlined how portable are these types of devices. They showed that such devices allow the user to learn everywhere, one-to-one, with the capabilities to adapt to the knowledge and the learning style of the one who is learning: non-invasive, always available, adaptable to different contexts, persistent, useful and easy to use.

Figure 17.2. *HandLeR's interfaces example*

17.3.1.2. *M-learning*

M-learning was another important project in mobile learning lead by the English Skill Development Agency (LSDA) and other universities in the UK, Italy and Sweden. This project was performed to support students between 16 and 24 years old, with the characteristic to have lost his/her interest in learning and with unsatisfactory results in the educational system. A learning management system and the interface of a micro-portal were developed with the aim to provide access to the materials and the learning services through several devices, such as mobile devices, Web and TV. Moreover, an SMS system based on health arguments was also developed, with the goal to inform the users on different arguments as, for example, the dangers of drugs, a drive quiz and so on. The project results were satisfactory because it showed that mobile learning is an efficient tool that allows the users to reach places that other forms of learnability are unable to reach. Furthermore, these experiments have shown how it is better to provide different pieces of learning, rather than to offer the user a unique solution.

17.3.1.3. *MOBILearn*

MOBILearn was an European project which involved 24 industrial and academic partners from 10 different countries. The project started in January 2002 and ended in March 2005. The goals were to develop and evaluate a mobile learning architecture based on effective learning and teaching theories, which were based on a mobile system outside the scholastic environment. The objectives of this project were very wide: the main goal was to allow the users access to the knowledge in an ubiquitous way using innovative mobile interfaces. The project also introduced new learning models for mobile environments, new system architecture to support the making, the supply and the tracking of learning contents, new methodologies to adapt the content for mobile devices, such as smartphones and tablets, and finally new business models with the aim of providing a sustainable deployment of new technologies for mobile learning. The MOBILearn technology was tested in different contexts, for example, in a museum, on a university campus and for first aid.

17.3.1.4. *From e-learning to m-learning and mobile learning*

From e-learning to m-learning and mobile learning are the projects funded by the European Commission on the through "Leonardo Da Vinci" program and directed by Ericsson [SAM 06]. They aim to support education and professional training using mobile phones and other mobile devices. The major part of the users tested were students. The final evaluation questionnaire showed how they considered positively and funny mobile learning using mobile devices, although only 45% of participants improved with the quality of e-learning. The major problems encountered by the users were the frustration caused by connection problems (continued disconnections) and limitations on visualization due to the small size of screens [NIX 05]. Moreover, from e-learning to m-learning projects solved problems connected with course presentations on a PDA by using the Microsoft Reader Works application.

17.3.1.5. *Nintendogs*

Nintendogs is a learning project based on a game. It exploits the Nintendo DS Console as a context to create a set of several activities that involves two different classes of students. The main character of the game is a dog for which the students must take care of. The game also involves other activities as, for example, bringing the dog to canine exhibitions with the goal to winning money as the score. It is worth noticing how such activities lead the students to perform activities that are generally considered as boring. The students perform such activities to reach their objectives and collaborate with different students in different classes. These activities have the goal of stimulating the social interactions among students of different ages.

17.3.2. *Mobile learning for museums and galleries*

Mystery at the Museum is another project described by Cabrera *et al.* in [STO 05]. They describe the experience of designing a collaborative learning activity for a traditional historical/cultural museum involving small groups of students through mobile handheld devices. Any group is partially informed of the task that they must complete and it receives additional information through a mobile device. For instance, given different brainteasers, the students have to share their answers among all the members of the groups to achieve the final goal. MyArtSpace [VAV 09] allows children, who are visiting a museum with their classmates, to conduct a research connected to the museum. Before visiting the museum, the teacher informs the students about the rules and the goals of the "game" and asks them a main question that students must answer after or during the visit. In this case, the mobile device is represented by a mobile phone used by a student to collect photos, audios, videos and other notes. The data collected are also used during classes to create and share image and video galleries with other students. Gidder [PIE 08] is another interesting project developed for museum purposes. The main project goal is to support collective knowledge within a class and in the museum. Before visiting the museum, students are required to work in groups using the Wiki system. The objective is to prepare some notes about the most interesting paintings they found and to discuss about the exhibition. During the fruition of the paintings session inside the museum, students share and send information to the wiki system and post it on the blog. The collected data are then discussed by all participants during classes. Finally, City [GAL] is a system that allows three users to communicate and, visit at the same time, the Charles Rennie Mackintosh room at the Lighthouse Centre for Architecture, Design and the City in Glasgow. The visitor uses a PDA to interact with the environment and with the capabilities to share with other users his/her position on the map of the gallery. The other two remote users, using a Web application or a virtual reality environment, can share information with users inside the gallery and communicate in real time using an audio channel.

17.3.3. *Mobile learning for workplace, professional development and training*

It is worth introducing some projects that are not strictly connected with mobile learning in education but which concern work places, professional development and personal training. MeduMobile [SCH 06] uses the video communication technology available on mobile devices and notebooks to support medical students and teachers. The main purpose was to train new students in different contexts as, for example, to improve the relationships between medical staff and patients. These activities were filmed and transmitted in real time to the students at the Charite' campus.

Flex-Learn [GJE] is a project of the Danish University of Education that aims to support drivers of heavy/long vehicles using different multimedia displayed on mobile devices. These multimedia involve videos, audios, text overlays, etc. The main characteristics of this platform is that users can interact with it, making notes and highlighting favorite content. Know Mobile [SMØ 03] was one of the first projects in the medical research field that aimed to explore how to use mobile technologies and support strategies of Problem-Based Medicine (PBL) and Evidence-Based Medicine (EBM) after the reform of the medical educational system in Norway. One of the main research goals was to investigate the field of the "just in time" in a medical concept, to support medical personnel who must always receive the most updated information (e.g. during an intervention). Chittaro *et al.* [CHI 11] proposed an adaptive Web-based information system called Presydium (Personalized Emergency System for Disabled Humans) that provides tailored instructions in the field of helping medical first responders in dealing with disabled persons. In [BUT 10] the authors developed an adaptive fitness game for mobile devices that takes into account users' heart rate, age, fitness level, etc., and supports them in exercise at the optimal intensity to gain cardiovascular benefits. This new training system introduced a new way to learn through a mobile device so that the user is completely informed about his/her health status and the best exercise to maintain a good fitness level.

17.4. Image processing supports HCI in museum application

In this section, a novel information visualization technique for mobile devices is presented. The objective of the developed application was to enhance museum paintings consumption displaying additional information to the images acquired by the device's camera [FOR 09] through augmented reality. In particular, the main goal is to display additional information on the paintings' characters images acquired by the mobile device. The proposed information visualization technique exploits the most recent algorithms developed in the fields of image processing and computer vision [FOR 05] to introduce a novel way to display augmented reality contents on mobile devices. In particular, the case study concerned usability evaluation of such techniques designed for a traditional, historical and cultural museum. The system introduces a novel method to learn and educate people about art, in a multimedia museum [FIN 12], through mobile devices. At the time of writing this book there are no similar works where the end user is supported by an augmented reality technique to visualize information related to a painting's characters. In [VLA 01] and [DAH 02] the mobile "archeoguide" application has been introduced to reconstruct historical sites. Takacs *et al.* [TAK 08] proposed an outdoor augmented reality system for mobile phones using Loxel-based visual feature organization. Despite this, there are several studies that show how to correctly visualize information on mobile devices. In [CAR 07] and [BUR 07] two different approaches for geographical map visualization on mobile devices are introduced. Several designs have also been proposed for Personal Information Management (PIM) devices [ROB 08].

Usability evaluation of information visualization techniques for mobile devices is a fairly recent research area. Despite desktop software products some base rules have been defined to achieve good usability results; there are no clearly defined methods that could also be applied to mobile devices interface designs. This is especially true for augmented reality applications, since only the recent developments in sensor [PIC 09] and device capabilities have allowed us to process and display contents in real time. The task to achieve the given goal was hard, since there are no strict and well-defined methodologies that could be exploited to conduct usability evaluation studies for such systems. As pointed out in [STO 05], there are three fundamental difficulties reported in the literature [KJE 04] regarding usability studies: (1) it is hard to provide realistic studies that capture all the relevant situations; (2) it is difficult to apply standard evaluation methods such as observation and thinking aloud; and (3) the data collection procedure is very complicated and the control over the environment is very limited. Laboratory evaluation studies help to deal with such problems, but at the same time they introduce a lack of realism. In the literature several approaches have been proposed to recreate or simulate the real context of use. Most of the times the proposed solutions are almost impossible to achieve since it is very hard to realistically recreate the context and the surroundings within restricted laboratory spaces. Usability evaluations have been performed in laboratory-based settings by simulating activities of typical users with a considerable degree of realism. To reach the proposed goal and to evaluate the performance of the proposed system with respect to a simulated–real scenario, a dataset of paintings has been built by taking pictures of paintings available from the Internet. The same paintings have been printed out and arranged within the laboratory space to evaluate the performance of the system within a simulated–real scenario. To achieve the best usability performances three different designs have been proposed and evaluated by means of standard evaluation methods.

To achieve the proposed objective three main goals have been reached: (1) recognize each single painting within the museum dataset, (2) find the transformation function between the real world and the device world and (3) display augmented reality information in a way that would be useful and unobtrusive. Each of them has been addressed by a single module of the entire system that will be described in the following sections.

17.4.1. *System description*

The objective of the proposed technique is to enhance museum paintings consumption by displaying additional information to the current acquired image by means of augmented reality. The overall system can be grouped into two main phases: (1) off-line signatures computation; (2) online signature computation, matching and information visualization. Image processing and computer vision algorithms [FOR 05] are exploited by the first module of the entire system to output valuable information that could be used to design the information visualization technique. Thus, the three image processing and computer vision system's modules are defined by: (1) the boundary detector module, (2) the signature computation and signature matching module and (3) the homography computation module. Only when the homography transformation from the initial world coordinate system to the current device coordinate system is fairly estimated, can the Human Device Interface (HDI) module be used to provide augmented reality information to the end user.

The boundary detector module extracts only the relevant painted region of a given image and aligns the image boundaries such that they are orthogonal to each other. The signature computation module extracts two different visual-based features from such relevant regions to compute a discriminative signature [MAR 12]. Then, the computed signatures are stored in a dataset that is used for comparison with real-time acquired images. These two steps mainly define the off-line phase. The online phase exploits the same two modules and, in addition to them, the signature matching and the HDI modules are used to achieve the given goal. Given a valid signatures match computed by the signature matching module, the homography computation module is in charge to estimate the homography transformation between the original image and the acquired image. The estimated homography transformation is finally exploited by the HDI module to introduce the novel information visualization technique.

17.4.2. *Boundary detector*

The boundary detector module has to extract only the relevant painting area from a given image acquired by the device sensors. It exploits the Hough Transform (HT) to achieve the goal. Each frame F processed by the camera is initially converted from the RGB color space to the standard eight bit grayscale. The transformed image F^G is then convoluted with a Sobel filter to get the edges image F^E used to compute the HT accumulator space. The HT technique parametrizes lines by considering points as a function of an angle normal to the line passing through the origin of the image. Thus, given any point (x, y) of the image F^G, its polar coordinates transformation is computed as:

$$\rho = x\cos(\theta) + y\sin(\theta) \quad [17.1]$$

where ρ is the length of the line normal to the line passing (x, y), and θ is the angle of the line normal. The HT accumulator space F^A can be computed by counting the ρ and θ values for all the points (x, y). Given the computed accumulator space F^A, the goal is to extract only the relevant painting image region F^R. This is achieved by computing the smallest area – enclosed by the detected lines intersections – of the image that is at least bigger than s times the whole image area. Even this is not guaranteed to give perfect results – since multiple lines can be detected or the whole painting area is not visible – this is enough for the given purposes.

17.4.3. *Signature computation*

Given the relevant frame region F^R, the signature computation module has the goal to extract visual-based features to compute a discriminative signature. The signature computation and matching module can be grouped into two submodules: (1) the image transformation and feature extraction and (2) the signature computation.

Given the relevant painting region F^R, two kinds of features are extracted: (1) Speeded-Up Robust Features (SURF) and (2) Pyramid Histogram of Oriented Gradients (PHOG). Before extracting such features F^R is transformed as:

$$F^{R'} = TF^R \quad [17.2]$$

such that the detected region boundaries are orthogonal to each other. The given region $F^{R'}$ is also projected to the HSV (hue, saturation, value) color space to achieve illumination and color invariance.

SURF features allow us to detect interesting points in a given image that are highly discriminative and robust to several issues, such as image rotations and scaling. SURF features are extracted from the given painting region $F^{R'}$ by exploiting the standard integral image representation that allows us to achieve lower computational costs. After detecting the interest points $F^{R'}_{S_p}$, the SURF feature descriptors $F^{R'}_{S_d}$ are computed as the sum of the Haar wavelet response around each of them. Then the PHOG feature is computed. The PHOG feature exploits the histogram of the oriented gradient descriptor and the spatial image pyramid representation to capture information about the shape and the whole appearance of the given region $F^{R'}$. A PHOG matrix $F_P^{R'} \in \mathbb{R}^{m\times 3}$ is extracted by concatenating the PHOG histograms extracted from the three image channels. m represents the total number of histogram bins computed by exploiting the original weighted combination of histograms extracted at the different levels of the spatial pyramid representation. Thus, given a frame F, the signature $\hat{F}$ is defined as $\hat{F} = \langle F_S^{R'}, F_P^{R'} \rangle$. During the off-line phase each computed signature is stored in a dataset that is used for comparison during the online phase.

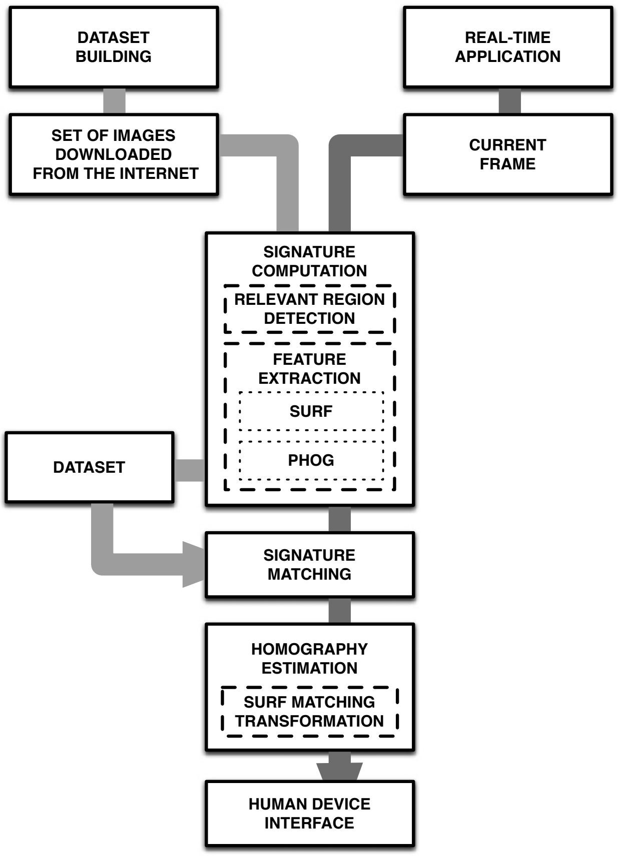


Figure 17.3. *Proposed system*

17.4.4. *Signature matching*

During the online phase the signature matching module is exploited to identify if there exists a match between the query signature, say $\hat{Q}$, with one of the previously computed signatures that are stored in the paintings dataset. Let $\hat{Q}$ and $\hat{I}$ be the paintings signatures of the query painting Q and the dataset painting I, respectively. To identify a valid match between the two signatures a linear combination of two distance measures computed between the signatures features is exploited.

Let i, j be a match between two SURF feature descriptors, such that the distance:

$$d_{l^2}(Q^{R'}_{S_{d,i}}, I^{R'}_{S_{d,j}}) = \|Q^{R'}_{S_{d,i}} - I^{R'}_{S_{d,j}}\|_2 \qquad [17.3]$$

is lower than a fixed threshold Th. $Q^{R'}_{S_{d,i}}$ and $I^{R'}_{S_{d,j}}$ are the ith and the jth SURF features descriptors of the paintings' signatures SURF features $\hat{Q}$ and $\hat{I}$. The overall SURF features distance is computed as:

$$d_{SURF}(Q^{R'}_S, I^{R'}_S) = \frac{1 + \sum_{i,j \in matches} d_{l^2}(Q^{R'}_{S_{d,i}}, I^{R'}_{S_{d,j}})}{count(matches) + \epsilon} \qquad [17.4]$$

where $matches$ are the matching SURF features descriptors.

PHOG features distance is computed by exploiting a linear weighted χ^2 distance as proposed in [MAR 12]. Given the PHOG feature matrices of two signatures $Q^{R'}_P$ and $I^{R'}_P$, the PHOG distance is computed as:

$$d_{PHOG}(Q^{R'}_P, I^{R'}_P) = \sum_c \lambda_c \chi^2(Q^{R'}_{P,c}, I^{R'}_{P,c}) \qquad [17.5]$$

where $Q^{R'}_{P,c}$ and $I^{R'}_{P,c}$ are the PHOG feature vectors computed for the two signatures on image channel c. λ_c is the normalization weight.

Finally, a query signature $\hat{Q}$ and a dataset signature $\hat{I}$ are classified [MIC 12] by computing the minimum $d(\hat{Q}, \hat{I})$ distance, such that:

$$\begin{aligned} d(\hat{Q}, \hat{I}) \quad &= \quad \alpha d_{SURF}(Q^{R'}_S, I^{R'}_S) + \\ &\quad\quad \beta d_{PHOG}(Q^{R'}_P, I^{R'}_P) \end{aligned} \qquad [17.6]$$

where α and β are the normalization weights.

17.4.5. *Homography estimation*

The homography estimation module is used to compute the homography transformation matrix that allows us to display a painting characters' additional information to the device display. To achieve such a goal the module exploits the feature matching technique proposed in [BRO 06]. Since the initial transformation T is applied to region F^R, its boundaries are orthogonal to each other and, as for small changes in image position, the feature transformation is affine, SURF features have been exploited to reach the task.

Let Q and I be two matching painting images such that $I = \arg\min_I d(\hat{Q}, \hat{I})$, where Q and I are the query painting and the dataset painting, respectively. Given all the matches q, i between SURF feature descriptors (see section 17.4.4), the goal is to estimate the homography transformation $H^{Q,I}$ such that $Q^{R'}_{S_p} = H^{Q,I} I^{R'}_{S_p}$. Since the technique proposed in [BRO 06] has been exploited, the readers are asked to refer to [BRO 06] for further details about the estimation of $H^{Q,I}$. Given the matrices $H^{Q,I}$ and T, it is possible to compute the inverse transformation such that any content given in the original coordinate system can be displayed and aligned with respect to the current acquired image.

17.4.6. *Human device interface*

Given the homography transformations that allow us to overlap content to the currently acquired image, the objective is to design a novel information visualization technique to allow end users to reach the content/information related to a character in a painting by interacting with the augmented reality displayed information. Standard human–computer interaction methods have been exploited such that the end users could find the correct way to interact with the user interface and access the information without any cognitive effort. To reach such a goal three designs have been proposed and implemented respecting the so-called usability "golden rules".

Three different user interfaces have been designed and evaluated exploiting the standard usability evaluation methods that allowed us to identify the best design among them. The three proposed user interfaces have been designed as follows (see also Figure 17.6):

1) Painting characters' edges are highlighted with the same color and their names are shown close to themselves. The end user can access character information by selecting the displayed label.

2) Painting characters' edges are highlighted with the same color as before, but name labels are replaced by blinking white circles. The end user has to select the circle to access the character information.

3) Characters' edges are displayed with different colors, and characters' silhouettes are overlapped with semi-transparent colored and blinking silhouettes. The end users have to select the semi-transparent colored silhouette to access the character information.

The proposed information visualization techniques have been designed according to the software engineering process. Such iterative and trial-and-error processes takes place between the designers and the end users. The main advantages of using it are: (1) it is available from the early stages as a low-functionality version of the product; (2) each prototype can be tested with end users at every stage; and (3) it allows us to understand if requirements are correct and if the design and development process is on the right path, then the risk of designing an unusable product is minimized.

17.4.7. *Experimental results*

According to [CHE 00] usability testing and controlled experiments are the backbone of prototype evaluation. To evaluate the proposed designs two types of tests have been performed: (1) inspection tests (usability inspection is the generic name for a set of cost-effective ways of evaluating user interfaces to find usability problems [NIE 94]) and (2) end user tests. Inspection tests have been performed by usability experts without the direct involvement of the end users. Such a technique is used throughout the overall design process.

Two types of inspection tests have been exploited: (1) *heuristics* tests, that is analytical evaluation techniques that provide opinions, and (2) *cognitive walkthrough* tests, where the HCI experts examine the elementary actions that end user needs to take to achieve a given goal. Evaluators aim to reconstruct the mental processes that end users build during their tasks.

According to [BOR 97], working with end users is a very important task in usability studies. As described in [NIE 93] to reveal about 80% of all usability problems just five testers are required. Faulkner [FAU 03] shows that five participants are not sufficient to detect all the usability issues while 60 of them – randomly selected as sets of five – can detect 99% of the issues.

To evaluate the proposed system 10 users have been tested for any interface with a total of 30 users (see Figure 17.4). To increase the end users interests they were paid for each session test. Relevant end users' skills are shown in Figure 17.5.

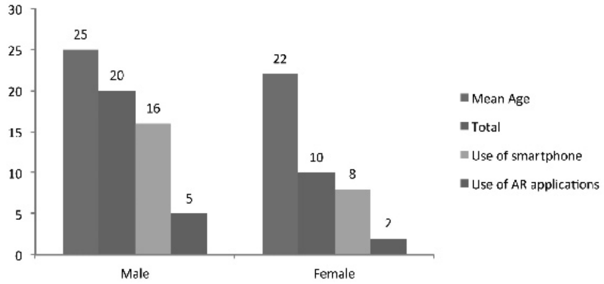
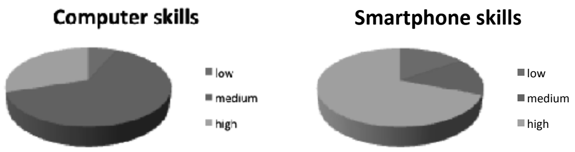


Figure 17.4. *Testers' profiles. A total of 30 testers have been selected to perform the required task. For a color version of this figure please see www.iste.co.uk/mechatroneng.zip*



a) b)

Figure 17.5. *End users relevant skills: a) computer skills; b) smartphone skills. For a color version of this figure please see www.iste.co.uk/mechatroneng.zip*

According to [BEV 94], to evaluate the usability performance it normally requires providing at least one measure for each of the quality of use: (1) effectiveness, (2) efficiency and (3) satisfaction. Effectiveness is defined as the measure that relates the goals of using the system to the accuracy and completeness with which these goals can be achieved. It was measured as the number of errors (i.e. wrong touches) occurred during the tasks. The efficiency relates the effectiveness achieved to the expenditure of resources. It was measured as the time spent by the user to complete the task. Finally, the users satisfaction is defined as the state of gratification achieved at the end of (or during) the interaction with the system. It was measured by considering both the comments (negative or not) provided during the task and the final debriefing questionnaire that reported open and Likert scale questions. Session tests were performed in a laboratory where a 2×1.5 m painting is shown. A four inch (display) Samsung smartphone device with Android OS has been used during evaluation tests. The data of the tests were recorded using a video camera placed behind the user. During the briefing, participants were informed about the purposes of the test, the task and its duration. The users were also asked to fillout a screening questionnaire so that information about users' profiles can be obtained. The "think-aloud" technique has been exploited during test sessions, each of which lasts about 15 min. During the tests the end users were asked to perform a task and to verbalize whatever came into their mind during the performance. After each test a debriefing is exploited to investigate unusual or interesting events that occurred during the session. Statistically significant differences in time, error rate or satisfaction are obviously a plus, but observations recorded during the tests became the basis for refinement or redesign, leading to better implementations, guidelines for designers and refinement of theories.

The three proposed information visualization techniques are shown in Figure 17.6. The first user interface (see Figure 17.6(a)) has been deeply evaluated with the support of end user testings. Six participant out of 10 completed the given task with an average execution time of 8 min 33 secs. As shown in Figure 17.7(a), out of the four users that failed the test, 25% of them selected different areas other than the selectable label; 25% selected the menu button; and the remaining 50% did not achieve the given task at all. After debriefing, 90% of the participants were satisfied about the application but 40% of them stated that the user interface was not clear and cognitively expensive.

The second designed user interface is shown in Figure 17.6(b). After experimental test sessions, only one tester out of 10 failed the test selecting the menu button. A total of 90% of the testers stated that the proposed user interface was clear and was easy to reach the information related to a character. One single tester suggested to display the white circles with different colors. As shown in Figure 17.7 the second designed user interface achieves the best performance both in terms of success rate and average execution times. The average execution time required to achieve the given goal is about 4.1 min.

Finally, the third designed user interface (shown in Figure 17.6(c)) achieved the worst results. Only one tester successfully completed the given task. According to a debriefing questionnaire inspection, 70% of the participants stated that the interface was unclear and 80% of them had difficulties in recognizing the silhouette as a selectable element. Almost all the testers said that the character recognition was difficult due to the overlapping of the colored silhouette.

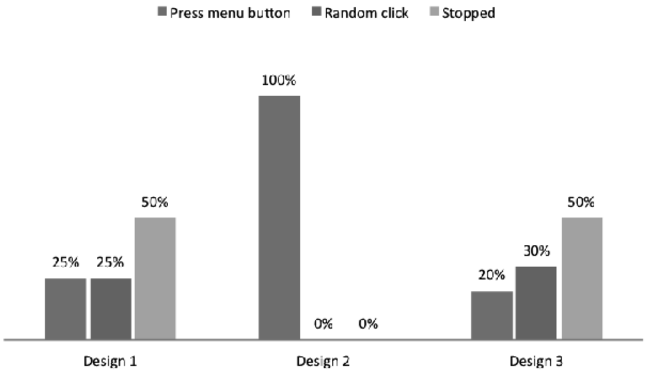
a) b) c)

Figure 17.6. *Proposed information visualization techniques: a) painting character's edges are highlited using colors. Characters' names are used as selectable elements to access character information; b) painting characters' edges are highlighted using coulours as in design 1. Characters' names are replaced by blinking white circles that are used as selectable elements to access character information; c) painting characters' edges and silhouettes are highlighted using different colors. Characters' silhouettes are used as selectable elements to access character information*

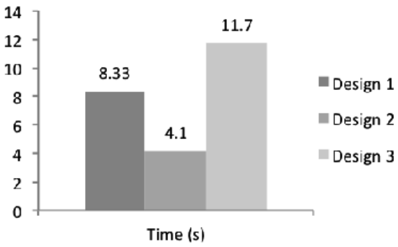
Figure 17.7 shows that many of the testers that did not achieve the given goal stopped in the grip of frustration and panicked, while just a small percentage of them had randomly touched the screen or selected the menu button.

17.5. Back to the Future: a 3D image gallery

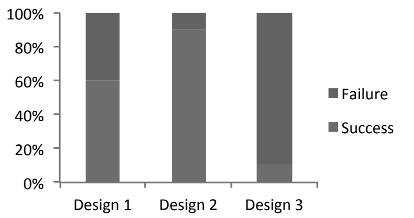
Back to the Future is a project that aims to propose an innovative and futuristic interface to visualize old historical images elaborated and transformed to be displayed in 3D. The developed system has been adapted and tested for different platforms, such as PCs, notebooks, smartphones and tablets supported by Fash Player technology. The system has been mainly developed using HTML 5, Adobe Flash and Papervision. Adobe Flash is a graphical software that allows us to create vector animations on a timeline and it is supported by the scripting language called Adobe Actionscript (AS), which allows developers to create more complicated dynamical applications. Among other characteristics of Adobe Flash, one of the more interesting is the possibility to connect the entire environment with external libraries. To display the 3D images, a dynamical and interactive environment has been created using Papervision 3D. Papervision 3D is simply an extension library that allows us to create a 3D scene inside the flash movie.



a)



b)



c)

Figure 17.7. *Evaluation results: a) most relevant user interface issues: menu button selection, random click on non-selectable area and stopping to reach the given goal; b) average execution time; c) Success and failures. For a color version of this figure please see www.iste.co.uk/mechatroneng.zip*

17.5.1. *System description*

The *Back to the Future* application, as a flowchart is represented in Figure 17.8, starts with a brief animated introduction, played along with a soundtrack of music; the music can be turned off or on by the user using the respective links on the screen interface (see Figure 17.9(a). In the following, a time machine is presented, and the user is invited to enter into the 3D environment by selecting a linked image represented by a gleaming diamond (see Figure 17.9(b).

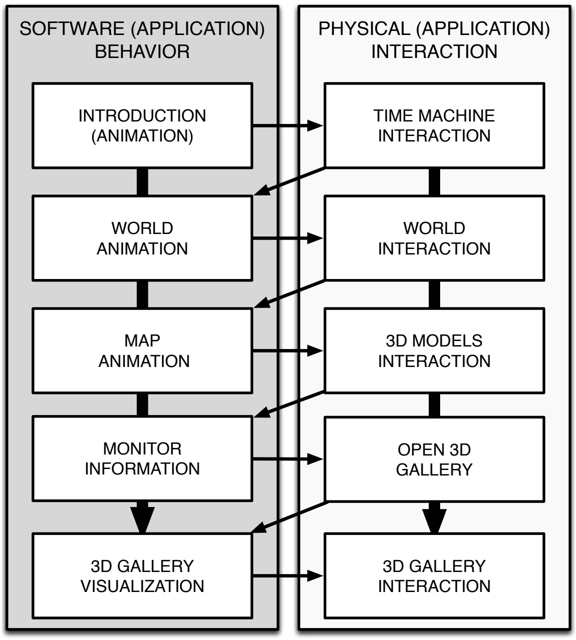
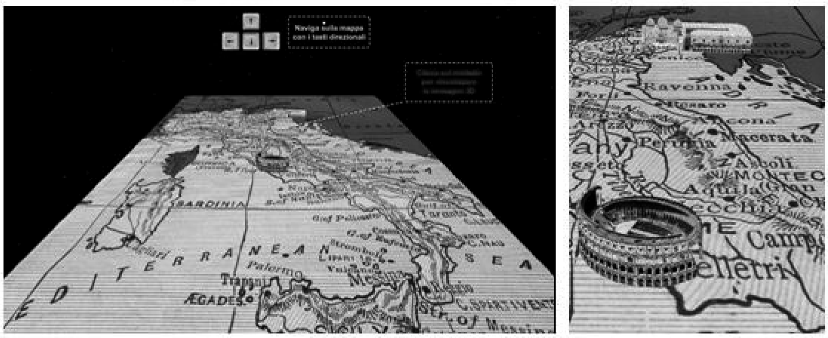


Figure 17.8. *System interaction flowchart*

Figure 17.9. *a) Back to the future introduction (from the Italian version); b) future machine; c) globe rotation*

After the user clicked the red diamond, an animation is shown and a 3D globe (Figure 17.9(c) starts rotating. Then an interactive map of Italy is presented (Figure 17.10(a). The map is shown in a vertical position and after clicking on it, the map moves to a horizontal position presenting the 3D clickable miniatures of two of the main important Italian monuments: Rome's Coliseum and Venice's ST mark's square (Figure 17.10(b).



a) b)

Figure 17.10. *a) Interactive map of Italy; b) 3D models of the monuments*

The map can be moved using the buttons at the top or by scrolling the mouse if the user is using a normal PC. Both the map and the monuments are 3D reconstructions created as follows: (1) a 3D shape (e.g. a rectangle) has been created using Papervision, then (2) a *.dae* model has been pasted. "*.dae*" models are 3D images downloadable from Google's archives. If the user clicks or touches the models, the map moves to the bottom of the window and a miniature image and a description of the monument is presented (see Figure 17.11). Then, if the user clicks on the miniature, a carousel gallery of 3D images is shown (see Figure 17.12). The user can move the images by simply moving the mouse or cursor on the left or on the right, or touching them if the user is using a tablet or a smartphone. The images can be viewed if the user uses the right 3D glasses for stereoscopy images. The user can go back to the 3D representation of the map by simply clicking on the exit button positioned on the top of the screen's interface.

Figure 17.11. *Display information about the selected content*

17.5.2. *Testing and evaluations*

To evaluate the effectiveness, efficiency and satisfaction of the proposed system, usability tests have been performed. Specifically, user testing has been exploited: they are usability tests entirely based on the evaluation of the system by real potential users of the system. As described in [NIE 93] just five testers are required to reveal about 80% of all usability problems. In the proposed system, a total of 15 users composed of eight males and seven females aged between 20 and 30 years old have been tested. Participants have been divided into three groups: (1) the first group evaluated the application on a desktop PC, (2) the second group evaluated the application on a 10.1 inches Android OS Asus tablet and (3) the third group exploited a four inches Samsung smartphone device with Android OS. Before testing, the users were informed about the goals of the test with some general instructions both on the application and the requirements to complete the test. They were asked to fillout a screening questionnaire so that information about participants profiles can be obtained. The think-aloud protocol was also used during the test sessions. At the end of the test, another questionnaire was proposed to the user to investigate the possible applications' issues. As reported (shown in Figure 17.13) 80% of the participants were satisfied with the system without having found particular problems. The remaining 20% found problems mainly connected to how to move the carousel of images and how to come back to the image description. In the first group, no participants have encountered usability problems. In the second group, only one user had a problem about how to come back to the description of the image once he/she entered the images carousel. In the third group, a user found problems on how to move the images of the carousel. Finally, among the comments section of the questionnaire we have received some useful information to improve the parts of the application that gave unsatisfactory results to the user. For example, three users out of 15 suggested improving the visibility of the link button (the gleaming diamond) to continue the animation maybe with a larger button or introducing a blinking effect. Lastly, another participant suggested highlighting the 3D images when the mouse is over them.

Figure 17.12. *3D gallery of images of the selected object*

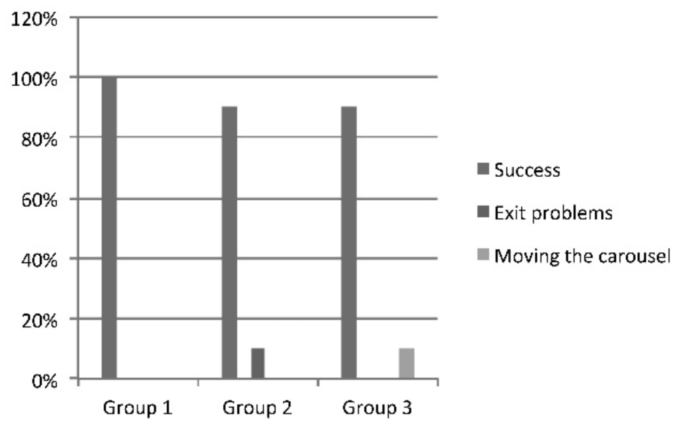


Figure 17.13. *Evaluation of the system by the users*

17.6. Conclusions and future works

Over the past years, mobile devices have been boosted by relevant technological innovations. Mobile devices have been conceived and designed to be portable and usable while on the move, and recent communication technologies have allowed them to download content from the network every time. The diffusion of sophisticated mobile devices, the innovations of the communication infrastructures and the ways these devices are exploited lead to new aspects in education and pedagogy. Several of these studies have been introduced in the chapter emphasizing the most important concept that is now widespread: mobile learning. Mobile learning is a very interesting emerging topic in the mechanical and electrical research fields. The concept of mobile learning supports a wide range of topics and introduces several challenging aspects to the traditional learning methods. Different challenges related to the mobile learning concepts have been addressed by two proposed works. The works aim to improve the knowledge about paintings and historical buildings through mobile learning. The main objective of both applications is to ease the consumption of contents displayed through mobile devices. The results achieved by the two works show that the task of learning through mobile devices can be eased by exploiting HCI design methods.

The results achieved by the proposed systems inspired different enhancements and future works. The museum application is at its first stage of the software engineering process and new features will be introduced to enhance the navigation and the content display tasks. A painting geo-localization system and the 3D techniques used in the image gallery application will be exploited and merged to display 3D contents to the users. Supported by the interesting results achieved by the two described works, the AVIRES team is now leading other projects that involve the mobile learning, especially for museums and exhibits. “The Pantheon” is a novel mobile-based application focused on the famous artist Antonio De’ Sacchis. Information about the artists and their works, together with connected points of interests (e.g. museums and churches), are provided with the goal to improve and ease the visitor’s tasks and to provide relevant and connected information about different works. The proposed application is conceived to be available for both smartphones and tablets, thus introducing different HCI challenges.

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