On-demand Loading of Pervasive-oriented Applications Using Mass-market Camera Phones *

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Abstract. Camera phones are the first realistic platform for the development of pervasive computing applications: they are personal, ubiquitous, and the built-in camera can be used as a context-sensing equipment. Unfortunately, currently available systems for pervasive computing, emerged from both academic and industrial research, can be adopted only on a small fraction of the devices already deployed or in production in the next future. In this paper we present an extensible programming infrastructure that turns *mass-market* phones into a platform for pervasive computing.

1 Mobile phone: A Platform for Pervasive Computing

Pervasive computing tries to make M. Weiser's vision [1] a reality by saturating the environment with computing and communication devices: the most of the infrastructure is often invisible and supports user's activities with an interaction model that is strongly human-centric. Today, almost fifteen years later, despite significant progresses in both hardware and software technologies, this vision is still not completely realizable or economically convenient.

Supporting the interaction between users and the environment can be greatly simplified if we relax the interaction model and include a personal device as the access medium. Mobile phones are the most obvious candidates: they are in constant reach of their users, have wireless connectivity capabilities, and are provided with increasing computing power [2]. Even better results can be achieved with those phones that are equipped with a camera. Instead of manually getting information or editing configurations, users can point physical objects to express their will of using them: taking a picture of the objects would suffice to setup the link with the offered services.

Relaying on an image acquisition device does not impose a strict limit to the share of possible users, since an always growing number of commercially available mobile phone is equipped with an integrated camera: according to recent studies [3], over 175 million camera phones were shipped in 2004 and, by the end of the decade, the global population of camera phones is expected to surpass 1 billion.

* This work is partially supported by the Italian Ministry for Education and Scientific Research (MIUR) in the framework of the FIRB-VICOM project.

Avvenuti M. and Vecchio A. (2006).
On-demand Loading of Pervasive-oriented Applications Using Mass-market Camera Phones.
In *Proceedings of the 3rd International Workshop on Ubiquitous Computing*, pages 39-48
DOI: 10.5220/0002501600390048

However, the acquisition of context-related information through images is not a trivial task, especially with resource-constrained devices. To ease the recognition process, objects can be labeled with visual tags readable by machines. Once decoded, visual tags either directly provide information about the resource they are attached to or, if the amount of information is too large, they act as resource identifiers that can be used to gather information from the network.

In this paper, we describe the design and the implementation of POLPO [1] (Polpo is On-demand Loading of Pervasive-Oriented applications), a software system that turns mass-market phones into a platform for the development of pervasive applications. With POLPO, a phone with a built-in camera and compatible with the Java 2 Micro Edition (J2ME) platform is able to get context information by decoding visual tags attached to real-world objects. POLPO supports dynamic loading and installation of custom applications used to interact with the desired resources.

2 Background and Contribution

In this section we summarize the most relevant solutions based on visual tags and the contribution of our system in this field.

Cybercode [4] is a visual tagging system based on a two-dimensional barcode technology. The system has been used to develop several augmented reality applications where the physical world is linked to the digital space trough the use of visual tags. Cybercode is one of the first systems where visual tags can be recognized by low-cost CCD or CMOS cameras, without the need for separate and dedicated readers. Each Cybercode symbol is able to encode 24 or 48 bits of information. The system has been tested with notebook PCs and PDAs.

In [5] the author presents a system that turns camera-phones into mobile sensors for two-dimensional visual tags. By recognizing a visual tag, the device can determine the coded value, as well as additional parameters, such as the viewing angle of the camera. The system includes a movement detection scheme which enables to use the mobile phone as a mouse (this is achieved by associating a coordinate scheme to visual tags). The communication capability of the mobile phone is used to retrieve information related to the selected tag and to interact with the corresponding resource. Tag recognition and motion detection algorithms were implemented in C++ for Symbian OS.

The Mobile Service Toolkit (MST) [6] is a client-server framework for developing site-specific services that interact with users' smart phones. Services are advertised by means of machine-readable visual tags, which encode the Bluetooth device address of the machine that hosts the service (Internet protocols addressing could be supported as well). Visual tags also include 15 bits of application-specific data. Once the connection has been established, MST servers can request personal information to the client to provide personalized services. Site-specific services can push user interfaces, expressed with a markup language similar to WML (Wireless Markup Language), to smart phones. MST also provide thin-client functionality: servers can push arbitrary graphics

[1] The Italian name for the *octopus vulgaris*, a cephalopod of the order *octopoda*, probably the most intelligent of the invertebrates.

to the phone's display which in turn forwards all keypress events to the server. The client-side is written in C++ and requires Symbian OS.

A similar approach is described in [7], where the authors propose an architecture for a platform that supports ubiquitous services. Real-world objects are linked to services on the network through visual tags based on geometric invariants that do not depend on the viewing direction [8]. But differently from other solutions, image processing does not take place on the user's device: pictures are sent to a server where they are elaborated and converted into IDs.

Instead of using two-dimensional barcodes, an alternative way of performing object recognition is the one based on radio frequency identification (RFID): small tags, attached to or incorporated into objects, that respond to queries from a reader. However this solution, that can be useful in many pervasive computing scenarios, is not particularly suitable when the interaction is mediated by mobile phones, that lack the capability of reading RFIDs.

In our opinion, currently available solutions present two major drawbacks: i) they are limited to specific hw/sw platforms (i.e. Symbian OS), excluding most of the models of mobile phones already shipped and in production in the near future; ii) the software needed to interact with the environment is statically installed onto the mobile phone and cannot be dynamically expanded, e.g. to interact with new classes of resources. We designed and developed a system for pervasive computing based on visual tags that overcomes these constraints as follows.

Compatibility with J2ME. The system runs on devices compatible with the J2ME platform. This environment is quite limited in terms of both memory and execution speed, but also extremely popular (nearly all mobile phones produced). This required the implementation of a pure Java decoder of visual tags for the J2ME environment.

Downloadable Applications. Our system is based on the idea that the interaction with a given class of resources, e.g. printers, public displays, etc., takes place through a custom application. New custom applications can be downloaded from the network and installed onto the user's device as needed. This brings two advantages: i) the classes of resources that can be used do not have to be known a priori; ii) the user's device, that is resource constrained, includes only the software needed to interact with the services actually used.

The J2ME platform comprises two configurations, few profiles, and several optional packages. The J2ME configurations identify different classes of devices: the Connected Device Configuration (CDC) is a framework that supports the execution of Java application on embedded devices such as network equipment, set-top boxes, and personal digital assistants; the Connected Limited Device Configuration (CLDC) defines the Java runtime for resource constrained devices as mobile phones and pagers. Our systems runs on top of the version 1.1 of the CLDC, that provides support for floating point arithmetics (unavailable in version 1.0). The adopted profile is the Mobile Information Device Profile (MIDP) that, together with CLDC, provides a complete Java application environment for mobile phones.

3 System Architecture

POLPO requires that physical resources are labeled with visual tags, and that a program providing access to POLPO functionalities is installed onto the user's device. This program has the following primary functions:

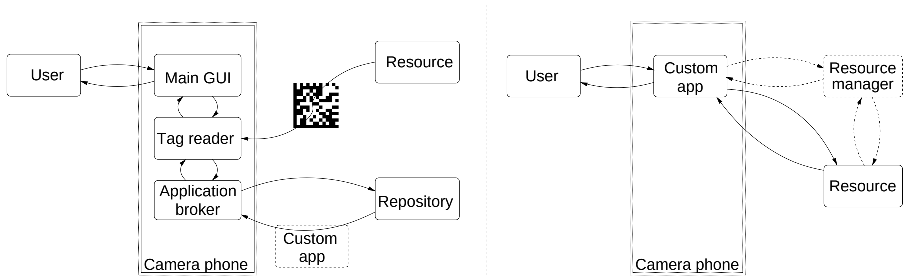
– *Decoding of visual tags.* The image captured with the built-in camera is processed to extract the data contained into the visual tag.
– *Management of custom applications.* The program downloads and installs the custom application required to interact with a resource. Usually, resources of the same kind share the same custom application (i.e., a single application is used to interact with all printers, another is used with public displays, etc).
– *Management of user's personal data.* In many cases, applications need information about the user to provide customized services. For this reason, the software installed on mobile phones includes a module that manages user's personal data and stores them into the persistent memory. Managed data comprise user's name, telephone number, email address, homepage, etc.

Each resource is identified and described by a Data Matrix visual tag. Data Matrix [9] is a two-dimensional symbology containing black and white square data modules. It includes a finder pattern composed by two solid lines (called handles) and two alternating black and white lines on the perimeter. The maximum amount of data that can be encoded into a symbol is, according to the specification, equal to 2335 characters or 1556 bytes. Reed-Solomon codes are used for error correction. Data Matrix has been released to the public domain and is now covered by an ISO standard. Other similar symbologies include PDF417, Maxicode and QR Code [9].

Most of the existing systems use visual tags to associate an ID to a physical resource. Then, after having extracted the ID from the visual tag, the mobile device has to retrieve from the network the information needed to interact with the resource. This is usually accomplished by connecting to a well-known server where IDs are mapped to relevant information. On one hand this approach requires a minimal amount of information to be coded into the visual tag (just the ID). On the other hand the mobile device has to connect to a server, usually through a GPRS/GSM connection, with related costs and communication latency.

With POLPO, a visual tag does not contain only an ID. Instead, whenever possible, it acts as a sort of visual database that contains all information needed to interact with the resource. In particular, each symbol contains a tuple *(AppName, RepoURL, InitMsg)* where *AppName* is the name of the custom application that has to be used to interact with the selected resource, *RepoURL* is the location of the repository of applications, and *InitMsg* contains the initial parameters for the application. The format of *InitMsg* depends on the type of the resource. For example, if the resource is a printer, *InitMsg* may contain the model, printing capabilities, IP address, and port number.

Since all needed information is directly extracted from the visual tag, the mobile device does not have to contact a server. This solution is not feasible if the amount of information that has to be encoded into a visual tag is too large (the decoding process may become too computationally intensive and less robust). In these cases, the visual tag contains an URL that points to the needed information.



(a) System architecture (b) Interaction can be mediated by a manager

Fig. 1. System architecture and interaction with a resource.

Figure 1(a) shows the main components of the system and the way they interact. The *main GUI* visualizes a viewfinder that is used to center the tag and take a picture of it. Then, the image is passed to the *tag reader* module that extracts the stored information. The *application broker* module receives from the tag reader the name of the *custom application* to start, the location of the application's repository, and initial data.

Usually, once started, the custom application uses the network to interact with the resource. Nevertheless, if the resource is not provided with computing/communication abilities, interaction can occur through a resource manager (as shown in Figure 1(b)). For example, let us suppose that a visual tag is attached to a door of an office, and that a user, by taking a picture of the tag, can leave a virtual note to the owner of the office. Since a door is not provided with any computing power, the custom application running on the phone communicates with an ambient-server that represents the resource.

4 Downloading of New Applications and Passing of Parameters

Applications for MIDP devices, such as mobile phones, are packaged in form of *jar* archives. Each archive contains a *MIDlet suite*, i.e. a set of one or more *MIDlets*, Java programs defined as extensions of the MIDlet class. A MIDlet's life-cycle is managed by the application management software (AMS), that is part of the software operating environment of the device. Installation of a MIDlet suite usually occurs by downloading the archive through a GPRS/GSM connection, according to a standard procedure called *over-the-air provisioning* (OTA). Custom applications that extends POLPO's functionalities are MIDlet suites that are downloaded and installed according to this procedure. The only difference from standard MIDlets consists in the way they receive the parameters extracted from visual tags.

The application broker and custom applications belong to different suites and direct communication is not possible (in the MIDP environment only one application at time can be in execution, and method invocation is not allowed between classes that belong to different suites). To overcome these constraints, we adopted a solution based on shared information stored in the persistent memory. In the MIDP programming environment the basic storage abstraction is the record store, a collection of records. A record store is referred by a name, and a record is simply an unstructured array of bytes identified

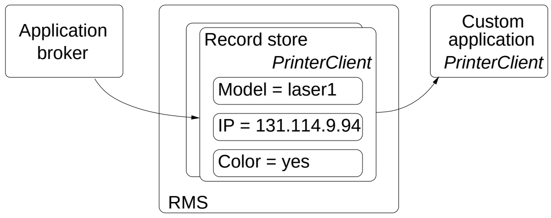


Fig. 2. Passing of parameters.

by a unique number. The Record Management System (RMS) is a set of classes that provides methods to create/destroy record stores and to save/retrieve records in a record store. As shown in Figure 2, the application broker creates a record store that has the same name of the custom application that is going to be installed and writes into the records the initial parameters that have to be passed to the application. When the custom application is executed, it looks for a record store having the same application's name and, if any, reads the data.

With the exception of the initialization phase, custom applications can be designed according to the standard J2ME guidelines. Therefore, programmers can make use of all libraries provided by the Java runtime to build graphical user interfaces, to store data into the persistent memory, or to communicate with external components through the network or SMSs.

Since POLPO is based on the Java platform, execution of applications downloaded from the network is safe. In fact, applications are executed in a sandbox and the JVM security manager grants the privileges to access specific APIs on the base of levels of trust. Moreover, the bytecode verification process guarantees that the application does not perform any dangerous operation.

5 The Decoding Algorithm

We implemented an algorithm to decode Data Matrix tags that is compatible with the MIDP platform. Figure 3 illustrates the main steps of the process that localizes the visual tag within the image. First, the RGB color image is converted to a gray-scale image (Data Matrix symbols do not make use of colors). Then, the image is converted to black-and-white through an adaptive threshold. To limit the computational overhead, the threshold is set to the mean of the maximum and minimum values of luminance of the image.

The next step consists in determining all groups of neighboring pixels that have the same color. After the image has been divided into black or white regions, it is necessary to identify the handles, i.e. the black solid bars that form two sides of the symbol. This is done by determining some properties of each region and applying few empirical rules (the candidate black area must be contained in a larger white area, the perimeter of the candidate area must be larger than the others, etc.). The longest two segments in the selected area are considered as the best approximation of the handles, and a precision alignment technique is used to compensate the barrel distortion caused by the camera

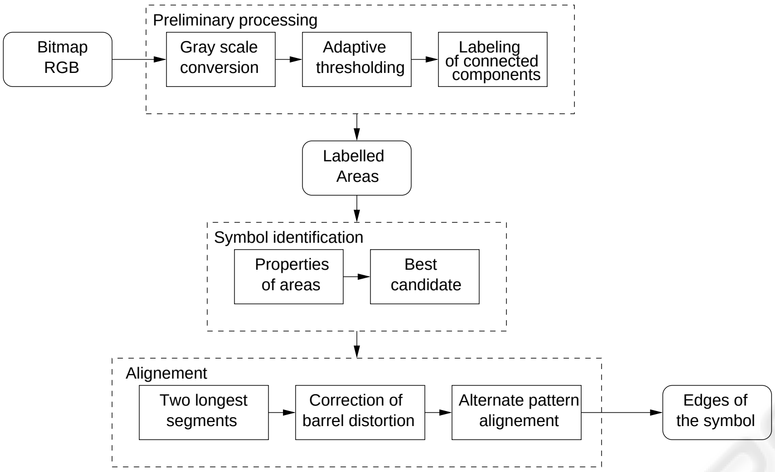


Fig. 3. Recognition algorithm.

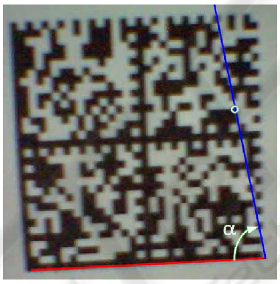


Fig. 4. Finding the alternate pattern.

lens. To find the alternating pattern that forms the other two sides of the symbol, we adopted the following procedure. Let us call P the end point of one of the handles. A line is traced from P to each point of the border of a black area that is part of the symbol. Then, the line that has the highest value for α is selected, where α is the angle between the line and the handle (Figure 4). The same procedure is executed for the other handle, and the intersection of the two selected lines is used to determine the missing corner of the symbol.

Once the position of the symbol is known, the algorithm determines the number, dimension and position of modules. This is done by locating the center of the modules of the alternating pattern and building a sampling grid. Data modules are sampled at their predicted center: black is a one, white is a zero. Groups of eight modules are converted into 8-bit symbol characters, according to a positioning scheme defined by the Data Matrix specification. Finally, after Reed-Solomon error correction, data is converted according to a specific encoding scheme.

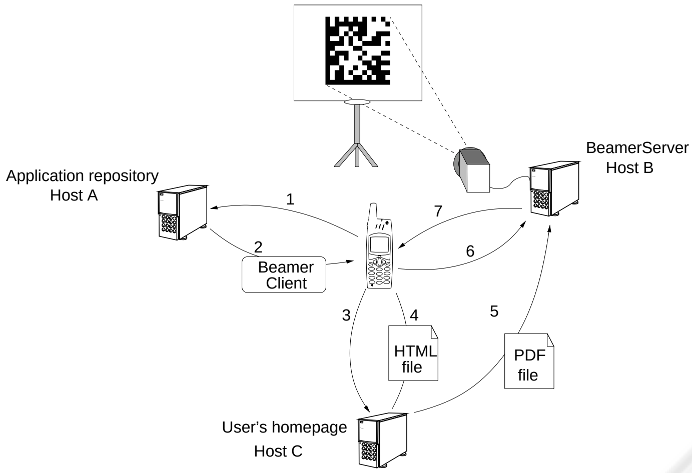


Fig. 5. Video projector application.

6 Demonstrator Application

We developed a complete test application to demonstrate the architecture and the implementation of the POLPO system. The idea is to allow a user equipped with his mobile phone to setup a slide show just by looking at, and taking a picture of, the projector situated in a meeting room. We assume that the presentations are available through the Web, for example at the user's home page. On his arrival, the user selects the projector by taking a picture of its screen, where a visual tag is displayed. Then the system retrieves the list of available presentations and the user is asked for the one to show. After the presentation has been started, the user can use his mobile phone as a remote control to visualize the next/previous slide or another presentation.

For such a scenario, Figure 5 shows the components involved and how they interact with each other. The application that controls the projector is made up of two parts: a suite composed by a single MIDlet, *BeamerClient*, that is executed on the mobile phone and provides the graphical interface, and a server, *BeamerServer*, that is executed on the computer connected to the projector and that displays the presentation. The system works as follows.

i) The Data Matrix tag that is initially displayed by the projector contains the URL of the repository of custom applications (Host A), the name of the custom application that must be used to interact with the projector (BeamerClient), and the set of initializing data (that consists of the name of the machine that controls the projector, Host B). When the tag is decoded, the application broker (running in the mobile phone) creates an entry in the RMS where it stores the address (Host B) that the BeamerClient application has to use to interact with the projector. The BeamerClient.jar archive is downloaded from Host A and installed.

ii) Once started, BeamerClient looks in the record store for an entry that contains the name of the machine that controls the projector. BeamerClient also needs the URL of

the page that contains the links to the presentation files. To this aim it prompts the user for the address (to make this task easier, the field is pre-filled with the URL of the user's homepage that is part of the personal data, so that a minimal amount of information has to be edited).
iii) BeamerClient starts an HTTP connection and downloads from Host C the text of the page that contains the presentations. Then BeamerClient parses the HTML file: all `href` tags that point to files with a given extension (pdf in our implementation) are considered as links to presentation files. The list of available presentations is built and shown to the user who can select the one to visualize.
iv) The URL of the selected presentation is sent to BeamerServer, which retrieves the pdf file and starts the presentation. Finally, BeamerClient shows a GUI that allows to change the page displayed or the presentation: each command is forwarded to the BeamerServer which acts consequently.

Screenshots and a video of the demonstrator application are available at the following address: `http://vecchio.iet.unipi.it/polpo`

7 Lessons Learned and Implementation Issues

In many cases, the portability of the Java language and the richness of the J2ME API allowed us to develop the POLPO system in a relatively short time. For example, the installation of a new application can be performed by calling the *platformRequest()* method of the MIDlet class and passing as argument the URL of the jar archive. This activates the AMS which starts the OTA installation procedure.

Nevertheless, in few cases, we found the application model of the MIDP profile rather inflexible. In particular, the major issues came from two restrictions: i) a MIDlet has no way to know if a given MIDlet suite is already installed or not; ii) a MIDlet is not allowed to start a MIDlet that belongs to another suite.

The first restriction can be faced in two ways: either the application broker always downloads and installs a custom application, possibly overwriting a previous installation, or the application broker manages a list of already installed custom applications. Both solutions are not completely satisfactory: the former leads to unnecessary traffic (e.g., BeamerClient has to be reinstalled every time the user interacts with a different projector), the latter suffers of possible inconsistency of the application list (while custom applications are installed by the application broker, the deletion is directly managed by the user).

The second restriction does not allow the application broker to automatically start a custom application after the installation procedure. Therefore, the user has to manually navigate through the set of installed applications and select the appropriate one.

During the implementation, we experienced some problems because of the Mobile Media API (MMAPI) optional package, that enables easy access and control of multimedia resources. In particular, the problems were due to the implementation of the *getSnapshot()* method which must be used to capture pictures through the camera in a platform independent way: two models of mobile phones that we used were equipped with VGA cameras, but they were able to capture images only with a resolution of

160x120 pixels (instead of 640x480 as possible with native applications). This problem is also described in [10].

The size of the Data Matrix decoder is approximately 4400 lines of code, while the size of the main GUI and the application broker together is less than 1000 lines of code. Once compiled, the size of the jar archive that includes the GUI, the decoder, and the application broker is approximately 70KB (without obfuscation). The jar of the BeamerClient is less than 10KB.

8 Conclusion

Until the coming of new technologies able to modify the way users interact with the world that surrounds them, mobile phones will remain the platform of choice for the development of pervasive applications. While some research has already been done on how using camera phones as a platform for pervasive computing, we believe that POLPO is a step forward in the direction of delivering site-specific services to the real-world: since it is based on the J2ME platform, the share of end users is significantly larger than the one offered by other systems.

In addition, as far as we know, POLPO is the first platform that supports dynamic downloading of new applications on mobile phones. The expandability of the software installed on the user's device is a key factor in a pervasive computing scenario: the set of services available to the users must grow as new devices or software systems are added to the environment. If the functionalities of the system are statically defined, users are forced to upgrade their devices continuously.

References

1. Weiser, M.: The Computer for the 21st Century. Scientific American **3** (1991) 94–104
2. Abowd, G., Iftode, L., Mitchell, H.: The smart phone–a first platform for pervasive computing. IEEE Pervasive Computing. Special Issue: The Smart Phone: A First Platform for Pervasive Computing **4** (2005)
3. http://www.infotrends-rgi.com.
4. Rekimoto, J., Ayatsuka, Y.: Cybercode: designing augmented reality environments with visual tags. In: DARE '00: Proceedings of DARE 2000 on Designing augmented reality environments, New York, NY, USA, ACM Press (2000) 1–10
5. Rohs, M.: Real-world interaction with camera-phones. In: 2nd International Symposium on Ubiquitous Computing Systems (UCS 2004), Tokyo, Japan (2004) 39–48
6. Toye, E., Sharp, R., Madhavapeddy, A., Scott, D.: Using smart phones to access site-specific services. IEEE Pervasive Computing **4** (2005) 60–66
7. Iso, T., Isoda, Y., Otsuji, K., Suzuki, H., Kurakake, S., Sugimura, T.: Platform technology for ubiquitous services. (NTT Technical Review) 82–88
8. Iso, T., Kurakake, S., Sugimura, T.: Visual-tag reader: image capture by cell phone camera. In: Proceedings of International Conference on Image Processing (ICIP). (2003)
9. International Organization for Standardization/International Electrotechnical Commission: (International Symbology Specification - Data Matrix, Bar code symbology – PDF417, Bar code symbology – QR Code, International symbology specification – MaxiCode)
10. Tierno, J., Campo, C.: Smart camera phones: Limits and applications. IEEE Pervasive Computing. Special Issue: The Smart Phone: A First Platform for Pervasive Computing **4** (2005)