

Forthroid on Android: A QR-code based Information Access System for Smart Phones

Tasos Alexandridis, Paulos Charonyktakis, Antonis Makrogiannakis,
Artemis Papakonstantinou, and Maria Papadopouli
Department of Computer Science, University of Crete &
Institute of Computer Science, Foundation for Research and Technology - Hellas

Abstract—The Forthroid is a location-based system that “augments” physical objects with multimedia information and enables users to receive information about physical objects or request services related to physical objects. It employs computer-vision techniques and QR-codes. We have implemented a prototype on Android platforms and evaluated its performance with systems metrics and subjective tests. We discuss our findings and challenges in prototyping on Android OS. The analysis indicates that the network and the server are the main sources of delay, while the CPU load may vary depending on the specific Forthroid operation. The preliminary subjective test results suggest that users tolerate these delays and the offered services can be particularly useful.

I. INTRODUCTION

The emergence of wireless networks and their continuous deployment world-wide has triggered a fast growth of location-aware and pervasive computing services and applications. We designed and evaluated the Forthroid, a location-based system and set of services, that enables users to obtain multimedia information about specific points of interest using their mobile phones and provides users with services related to physical objects (e.g., a printing service). The Forthroid can be easily deployed and used in indoor and outdoor environments, such as museums, campuses, and metropolitan areas.

The Forthroid uses QR-codes, which are two-dimensional barcodes that can encode various types of information. QR-codes can be attached to physical objects. Already in several metropolitan areas, such codes have been placed, e.g., in stores, at the entrance of buildings to provide floorplan information, on walls for announcing upcoming events. An example of usage of the Forthroid is illustrated in Figure 2.

The Forthroid architecture consists of QR-codes (associated with physical objects in proximity), Forthroid clients, that run on Android smart phones, and the Forthroid multi-threaded server. A Forthroid client may scan QR-codes (associated with a certain point of interest) and communicate with the Forthroid server via the Internet in order to retrieve multimedia information or request services associated with that point of interest.

Although the community has proposed similar QR-code information access systems [1]–[5], to the best of our knowledge, there are no real-world studies that evaluate their performance.

The Forthroid builds on our earlier work, the PhotoJournal [6]. The PhotoJournal is a novel location-based media sharing

application that enables users to build interactive journals that associate multimedia files with locations on maps and share this information with other users.

The contribution of this paper is twofold: it presents the design and architecture of the system, and its performance evaluation using subjective tests and system metrics, such as the delay, distance estimation error, battery consumption, and CPU load. Moreover, it discusses some of the main challenges that programmers often face, when developing similar applications.

This paper is organized as follows: Section II presents related work, while Section III focuses on the architecture of the system. The performance of the system and the user study are discussed in Section IV. Finally, Section V summarizes our main conclusions and future work plans.

II. RELATED WORK

The community has developed several exciting location-aware and mobile computing applications. For example, the CoolTown project [7] of the HP labs is a location-aware ubiquitous system that explores opportunities provided by the convergence of Web technology, wireless networks, and portable client devices to support “web presence” for people, places, and things. The web technology is used in order to provide ad hoc access to services, based on techniques of embedding and recovering URLs in visual codes located on objects and in places.

Several mobile computing applications have been using barcodes [1]–[5]. For example, Ljungstrand *et al.* [3] proposed barcode stickers, which can be attached to physical objects. Barcode stickers map web pages to physical representations and enable users to access the web by scanning an attached barcode.

A comparative performance analysis of several vision-based distance estimation algorithms is presented by Maida *et al.* [8]. The authors developed a hybrid approach to distance estimation, that mixes an iterative and an analytical method for pose estimation. Their approach is compared to several sophisticated vision-based algorithms. The execution time of their hybrid approach is $112\mu\text{s}$ for one pose estimation and the mean distance error is 7.2mm for a distance of 1m.

Several systems that use distance estimation algorithms with functionality similar to the Forthroid have been proposed. Sony developed a new type of marker named CyberCode [1],

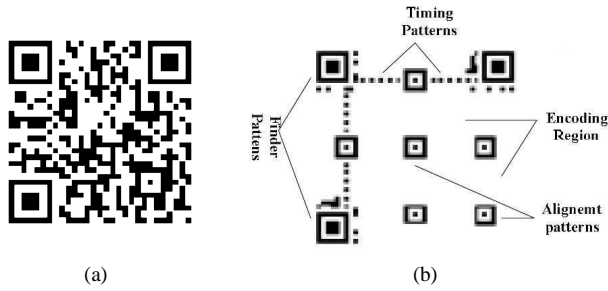


Fig. 1. (a) A typical QR-code. (b) The main components of a QR-code.

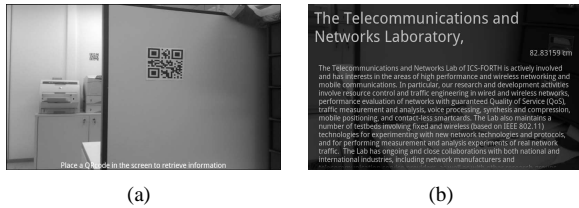


Fig. 2. (a) A user scans a QR-code in order to retrieve information about a point of interest at the Telecommunications and Networks Laboratory (FORTH). (b) A screen snapshot of the information returned to a user for a specific point of interest.

along with a visual tagging system with tracking capabilities. Ordinary mobile phones can easily recognize CyberCode tags, enabling the estimation of the 3D position and orientation of the camera relative to the tag. TRIP [2] is a computer vision system which uses printable 2D circular markers for the identification and location estimation of objects. Evaluation results indicate that the recognition is successful on 98% of the cases and the average error is less than 3cm. TRIP can identify entities within 3 meters distance.

Rukzio *et al.* [4] proposed the idea of user interaction through a mobile device with services that are related to a poster. The “interaction” between a mobile device and a poster uses cameras and near-field networks (e.g., WLANs, bluetooth), or user input. Rohs *et al.* [5] utilized 2-dimensional visual codes, similar to QR-codes, in order to retrieve object-related information and functionality. Their recognition algorithm can detect multiple codes simultaneously and compute the coordinates of the target in the coordinate system induced by the code. However, none of these papers provide any performance analysis study of their proposed system.

III. SYSTEM ARCHITECTURE

The Forthroid utilizes QR-codes, which are entities of the Forthroid architecture, and their main components, namely, the finder patterns, timing patterns, alignment patterns, and the encoding region (as shown in Figure 1). A unique identifier is encoded in each QR-code. The Forthroid defines and uses two QR-code types, namely, the “information-aware” and “action-aware” QR-codes. The information-aware QR-codes are attached to points of interest and associate them to specific multimedia information, while the action-aware QR-codes map the corresponding point of interest with certain services that can be provided to users.

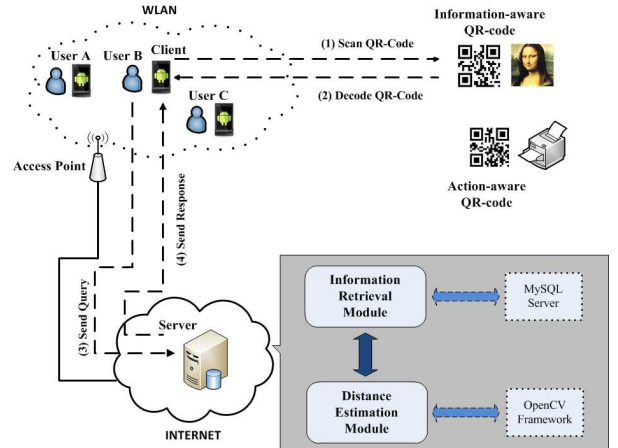


Fig. 3. The Forthroid architecture.

The Forthroid architecture employs the client-server paradigm: it consists of the application that runs on the mobile device (client) and the server. The client uses the ZXing API and the Barcode Scanner open-source application provided by Google, for scanning and decoding QR-codes. The server consists of two modules, namely, the information retrieval, and the distance estimation module. To support information retrieval, the server deploys a MySQL database that contains information regarding all points of interest, while the OpenCV framework is used to perform the distance estimation. The server is multi-threaded and able to support a significant number of clients/requests.

Figure 3 illustrates the general architecture of the Forthroid. A user holding an Android smart phone points to a QR-code (which is associated with a point of interest, for example a painting). The Forthroid mobile application detects the QR-code and decodes its unique identifier locally. A query for that point of interest is formed, containing the identifier of the specific QR-code and the captured image. The client sends the query to the server via the Internet. The server receives the query and determines the type of the QR-code based on the enclosed identifier. If the type corresponds to an information-aware QR-code, the information retrieval and distance estimation modules are invoked. The information retrieval module accesses the database to retrieve the appropriate information and the distance estimation module performs camera calibration. The server forms a response that contains the multimedia information about the point of interest and the estimated distance (between the smart phone and the QR-code). Finally, the response is sent back to the client.

In the case of an action-aware QR-code, action-specific operations are performed by the server. Currently, we have designed and evaluated the printing service: when a user scans a QR-code, which is attached to a printer, a list of all the points of interest he/she has visited is displayed. The user can then choose an item from this list and information about this item at the Forthroid server will be sent to the printer. In order to support the printing service, the Forthroid needs to keep track

TABLE I
VARIOUS EVENT TYPES. THE TERM T_i INDICATES THE TIME THE EVENT i WAS RECORDED AT THE CORRESPONDING MONITOR

Time	Event description
T_1	client successfully decodes a QR-code
T_2	client unicasts the query to the server
T_3	server receives the query
T_4	server sends back the response
T_5	client receives the response from the server
T_6	client displays the response to the user

TABLE II
DIFFERENT DELAY TYPES AS MEASURED BASED ON THE RECORDED EVENT TYPES

Delay	Time
Server	$T_4 - T_3$
Network	$T_5 - T_4 + T_3 - T_2$
Android client	$T_2 - T_1 + T_6 - T_5$
Total	$T_6 - T_1$

of the points of interest each client visits. Each time a client sends a query requesting information for a point of interest, the server creates a new entry in the database with the IP of the client and the identifier of the point of interest. Since IPs are dynamically assigned and a new client may have the same IP as an old one who “left” the network, these entries expire after a certain period of time.

The main operations of the Forthroid take place during two distinct periods, namely, the preview, and the query period. During the preview period, the Forthroid client uses the mobile camera to *continuously* scan the area in order to detect and decode a QR-code. The query period includes the client-server communication and the display of the results on the screen of the smart phone.

The distance of the smart phone from the plane that the QR-code is attached is estimated by camera calibration techniques. Camera calibration addresses the problem of determining matrix M of Eq. (1), that projects a 3D point P from the world coordinate system to a 2D point p in the image coordinate system [9]:

$$p = MP \quad (1)$$

where M is the 3x4 *projective or complete camera calibration matrix*. Eq. (1) can be further decomposed into:

$$p = K[R|t]P \quad (2)$$

where K is the 3x3 matrix of the *intrinsic* parameters, which are camera specific parameters and $[R|t]$ is the 3x4 *joint rotation and translation matrix*, which constitutes the matrix of the *extrinsic* parameters. Extrinsic parameters describe the position of the camera in terms of orientation and translation with respect to the world coordinates. In order to estimate the extrinsic camera parameters, correspondences between points in the world coordinate system and in the image must be

first identified. Once correspondences are extracted, the camera matrix M can be estimated using several methods for camera calibration, such as Least Squares Methods [10], nonlinear estimation methods [11], and iterative algorithms [9].

The corners of the finder patterns were used as the calibration pattern. 36 correspondences are created where each correspondence reflects to a corner of a finder pattern square. The upper-left corner is used to define the origin of the world coordinate system.

We divided the camera calibration process into two parts: the intrinsic parameters calibration, which is carried out only once, and the extrinsic parameter estimation. The intrinsic camera calibration was done using the MATLAB Calibration Toolbox [12]. When a query arrives at the server, extrinsic parameter calibration is performed in order to estimate the distance of the smart phone from the QR-code. This process consists of the following steps:

First, the image is rotated counterclockwise so that the position of the finder patterns in the image matches the position of the finder patterns in the actual QR-code (lines passing from the centers of the finder patterns form a “T” shape). The angle of rotation is included in the client query. It is estimated by inspecting the position of the centers of the finder patterns in the captured image.

Then, the corner detection procedure is carried out in order to create the world to image correspondences. The Harris corner detection algorithm [13] is applied in the three finder patterns of the QR-code. Specifically, Harris corner detector is expected to find the twelve corners that correspond to the corners of the three squares inside each finder pattern. The resulted correspondences are then used for extrinsic parameter estimation. After the extrinsic parameters are successfully found, the camera center C (i.e. the 3D world coordinates of the location of the camera) can be determined by [14]:

$$C = -R^{-1}t \quad (3)$$

The distance of the user from the QR-code is estimated using the Euclidean distance from the camera center to the origin of the world coordinate system.

IV. PERFORMANCE ANALYSIS

To evaluate the performance of the Forthroid, empirical-based measurements and subjective tests were performed. Specifically, first we measured the delay, the distance estimation error, and the battery consumption of the Forthroid running on the Android device. Then, we performed a preliminary subjective study in the premises of our lab.

The testbed includes an HTC Nexus One smart phone that runs Android 2.2 and a server, which is a 2.66 GHz Core 2 Duo Dell Desktop with 2048 MB RAM and the Linux Ubuntu Operating System. The server is connected via FastEthernet and the smart phone (client) is connected via IEEE802.11 to the ICS-FORTH infrastructure network.

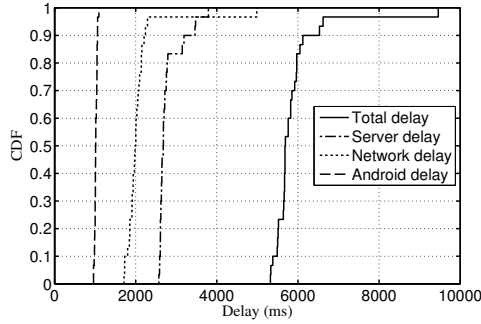


Fig. 4. Cumulative distribution function of the various types of delays introduced in the system.

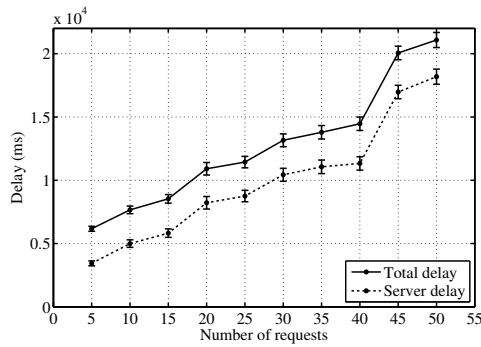


Fig. 5. Mean delay versus the number of concurrent requests with 95% confidence intervals.

A. Delay

As it is illustrated in Tables I and II, the overall delay (i.e., total delay) that a user experiences consists of the following components:

- 1) *Server delay*: it corresponds to the total time elapsed between the reception of a query by the server and the transmission of a response. Its dominant components are the distance estimation and the database access parts of the information retrieval.
- 2) *Network delay*: it includes the network and propagation delay.
- 3) *Android client delay*: it consists of the delay for the query generation and the delay for displaying the received data on the screen.

Specifically, to measure these delays, the events shown in Table I were defined. When a specific event occurs, our software invokes a system call in order to get the current system time in milliseconds. The various types of delays are then estimated according to Table II.

In the first evaluation phase, a Forthroid client scans an information-aware QR-code. This process was repeated 30 times. The resulted delay measurements are shown in Figure 4. The median values for the total, server, network, and android delay are 5.68, 2.68, 1.99 and 1.01 seconds, respectively. The variance is relatively small (as shown in Figure 4).

To study the impact of the number of simultaneous requests on the server and total delay, we used a desktop PC that

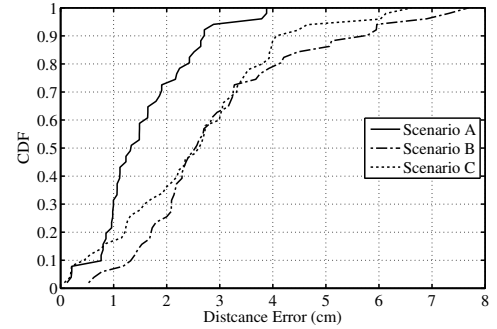


Fig. 6. Cumulative distribution function of the distance estimation error.

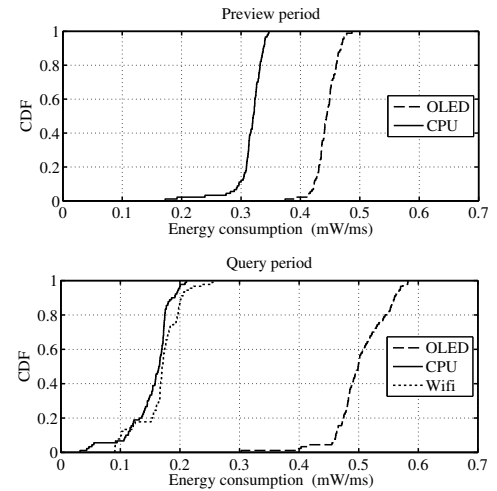


Fig. 7. Cumulative distribution function of the battery consumption during the preview and query periods.

sends to the Forthroid server a number of concurrent simulated queries for points of interest. We varied the number of concurrent requests from 5 to 50 (step of 5). Each experiment for a specific number of concurrent requests was repeated 10 times and the total and server delay were measured (as shown in Figure 5). A prominent increase in the delay occurs when the number of concurrent requests is 40 or more, due to the substantial increase of the memory required for processing all the requests (reaching the available one). As a result, some threads may have to wait for others to finish, increasing the server and the total delay.

B. Distance estimation

To test the accuracy of the distance estimation module, a range of distances from 40cm up to 2m was chosen. A QR-code is scanned at every 10cm in this range. The QR-code size is 11x11 cm. The distance of 40cm and 2m correspond to the minimum and maximum distance, respectively, for which the ZXing library was able to detect and decode the QR-code. The following scenarios were used for our measurements:

- **Scenario A**: The user is located in front of the QR-code, holding the camera parallel to the surface that the QR-code is mounted.

TABLE III
QUESTIONNAIRE OF OUR PRELIMINARY SUBJECTIVE STUDY

Question 1	Easiness to get familiar with the Forthroid and use it
Question 2	Experience w.r.t. delay to obtain the information about the point of interest
Question 3	Usefulness of the application in general
Question 4	Easiness to successfully scan QR-codes

TABLE IV
PERCENTAGE OF USERS THAT PROVIDED A SPECIFIC SCORE IN EACH QUESTION

Question 1		Question 2	
Trivial	66.7%	Excellent	40%
Very Easy	33.3%	Very Good	33.3%
Satisfactory	0 %	Satisfactory	26.7%
Very Difficult	0%	Not Satisfactory	0%
Too Difficult	0%	Bad	0%
Question 3		Question 4	
		Trivial	26.7%
Very Useful	73.3%	Very Easy	40%
Useful	26.7 %	Satisfactory	33.3%
Not That Useful	0%	Very Difficult	0%
		Too Difficult	0%

- **Scenario B:** The user scans the QR-code holding the camera from different angles.
- **Scenario C:** The user holds the camera with arbitrary rotation. As a result the QR-code is rotated in the captured image. The user can stand either in front of the QR-code or at some random angle.

Each scenario was repeated three times. Figure 6 illustrates the error between the reported and the actual distance. The median error for scenario A is 1.3 cm, while for scenarios B and C is 2.6 cm. Moreover, the application can report a distance estimation at 94%, 84% and 87% of the cases for scenario A, B and C, respectively. The distance estimation procedure fails when the correspondences are not correctly identified, due to blurry images caused by accidental movement of the camera when taking a picture.

C. Battery consumption

Given the energy constraints of mobile devices, a developer should consider the efficient memory allocation and CPU usage. The battery consumption and the CPU usage of the Forthroid were evaluated. The following experiment was carried out: A user was holding the mobile device for some time during the preview period and then an information-aware QR-code was scanned. The battery consumption during the two periods was recorded using the PowerTutor application [15]. The experiment was repeated 90 times. In each run, the battery consumption due to the wireless interface, OLED display, and CPU was measured separately.

The median consumption of the wireless interface is 0.17 mW/ms during the query period (as shown in Figure 7). Since no wireless communication occurs during the preview period,

the wireless interface consumes no battery. The consumption due to CPU is much higher during the preview period compared to the query period, since during the preview period, the client device *continuously* tries to detect and decode a QR-code (which contributes to a great amount of CPU load). Note that fine level conclusions about the battery consumption cannot be easily drawn, since the consumption due to OLED operations depends on the specific content and color displayed on the screen [16]. We also observed that in a few cases the battery consumption due to OLED operations is significantly lower than the median value (as shown in Figure 7). In those cases, at the query period, the content changes from the specific image captured by the camera to an almost black screen, where the retrieved information is displayed. Moreover, camera previewing is still displayed with small intensity. Such cases occur when a user holds the mobile device in such a way that the content changes rapidly, while reading the retrieved information.

The CPU usage of the Android device during the preview and the query period was also measured. To measure the CPU usage we implemented a more lightweight version of the Linux top command. Top displays a listing of the most CPU intensive tasks of the system. We altered the top command, so as to measure the CPU usage on shorter intervals than the original top tool (top measures CPU load every 1 sec). During the preview period the total CPU usage was 89.6% of the CPU power, while the one caused exclusively by the Forthroid process was 67%. During the query period the total CPU usage was 49.6%. During this period, our system uses only 27.7% of the CPU, a percentage much lower than in the preview period.

D. Subjective study

We performed a preliminary user study to evaluate the user experience running the Forthroid application. The user study was carried out in the Telecommunications and Networks Laboratory at FORTH. We attached four information-aware QR-codes in various posters and one action-aware QR-code next to the printer for the printing service. At first, we briefly presented the functionality of the Forthroid to the 15 colleagues, mostly students of the Institute of Computer Science at FORTH, who agreed to participate in our user study. We then asked them to use the system for at least 10 minutes. At the end, each user answered a questionnaire and evaluated his/her experience using the system. The questionnaire is shown in Table III, while the scale/score for each question is shown in Table IV. Table IV shows the percentage of users that provided a specific score per question. Most of users found easy to use the Forthroid and scan QR-codes and tolerated the delay.

E. Discussion

We faced several challenges while developing the Forthroid on the Android platform related to the camera API, the screen, and GUI.

During the preview period, the screen of the mobile device displays the area viewed by the camera. The preview resolution may vary from 176x144 pixels to 1280x720 pixels. This resolution differs from the picture resolution, which is the resolution to which a picture is taken by the camera. Typical picture resolutions vary from 640x480 pixels to 2592x1952 pixels. The preview and picture resolutions depend on the specific model and brand of the device. The relatively low preview resolutions constraints the application. Camera calibration procedures require high resolution images in order to provide accurate results. We overcame this problem by capturing two pictures, one in the preview resolution for the process of QR-code decoding, and one in the picture resolution for the distance estimation. When a QR-code is detected, the application invokes the `takePicture()` method of the Camera API in order to capture a picture with the highest resolution available from the picture resolutions.

As in the case of most portable mobile devices, Android smart phones have relatively small screens. Inevitably, all mobile application developers come across the challenge to fit all the graphical content on such small screens. Moreover, the GUI should be user-friendly to be easily used without any special training. We attempted to keep the GUI simple and provide a Help button in the menu in order to guide users that are unfamiliar with technology or similar applications.

V. CONCLUSIONS AND FUTURE WORK

This work focused on the Forthroid, a location-based information retrieval system, and analyzed the delay, the distance estimation error, and the battery consumption of the system. The performance analysis indicates that the heavyweight image processing functions result in a significant increase of the total delay. Moreover, the network delay is also considerable due to the overhead induced in the network from transmitting large-sized images. On the contrary, the efficient hardware and software of the HTC Nexus One smart phone result in relatively small processing delays. A significant amount of the total CPU is “utilized” by the preview period. In contrast, the corresponding CPU load during the query period is smaller. However, during the query period the wireless interface and the OLED are the main sources of energy spendings.

We also performed a preliminary subjective study to evaluate the user experience. The study suggests that users can tolerate a 5.68 sec delay. Users characterized the Forthroid as a useful system, encouraging us to plan a larger-scale deployment. We plan to extend the Forthroid to support more services, e.g., enable the retrieved information to be sent via e-mail, posted it on a social networking page, or superimposed on Google Maps. Also, we will improve the scanning/decoding of QR-codes process by providing additional (visual or auditory) “messages/clues”, taking into consideration the feedback from the user study.

The integration of the Forthroid with Facebook and other social networking applications will enable users to enrich their

online social networking experience. The Forthroid technology will be integrated with the PhotoJournal to create various multimedia journals of the users’ visits [6]. Finally, the user study will be extended to a larger user population, for longer period of time, and in different set of premises, in order to have more conclusive results about the quality of user experience.

ACKNOWLEDGMENT

The authors would like to thank Manolis Surligas for his help during the implementation of the lightweight top command for the evaluation of the CPU usage. Thanks also goes to Google for their equipment grant with Androids smart phones (Google AndroidEDU programme).

REFERENCES

- [1] J. Rekimoto and Y. Ayatsuka, “Cybercode: designing augmented reality environments with visual tags,” in *Proceedings of DARE 2000 on Designing augmented reality environments*, Elsinore, Denmark, April 2000.
- [2] D. Lopez de Ipina, P. R. S. Mendona, and A. Hopper, “Trip: A low-cost vision-based location system for ubiquitous computing,” *Personal and Ubiquitous Computing*, pp. 206–219, May 2002.
- [3] P. Ljungstrand, J. Redström, and L. E. Holmquist, “Webstickers: using physical tokens to access, manage and share bookmarks to the web,” in *Proceedings of DARE 2000 on Designing augmented reality environments*, Elsinore, Denmark, 2000.
- [4] E. Rukzio, A. Schmidt, and H. Hussmann, “Physical posters as gateways to context-aware services for mobile devices,” *IEEE Workshop on Mobile Computing Systems and Applications*, pp. 10–19, December 2004.
- [5] M. Rohs and B. Gfeller, “Using camera-equipped mobile phones for interacting with real-world objects,” in *Advances in Pervasive Computing*, Linz/Vienna, Austria, April 2004.
- [6] N. Kotilainen and M. Papadopoulou, “You’ve got photos! the design and evaluation of a location-based media-sharing application,” in *4th International Mobile Multimedia Communications Conference (Mobimedia)*, Oulu, Finland, July 2008.
- [7] T. Kindberg, J. Barton, J. Morgan, G. Becker, D. Caswell, P. Debaty, G. Gopal, M. Frid, V. Krishnan, H. Morris, J. Schettino, B. Serra, and M. Spasojevic, “People, places, things: web presence for the real world,” *Mob. Netw. Appl.*, pp. 365–376, October 2002.
- [8] M. Maida, J. Y. Didier, F. Ababsa, and M. Mallem, “A performance study for camera pose estimation using visual marker based tracking,” *Machine Vision and Applications*, pp. 365–376, 2010.
- [9] R. Szeliski, *Computer Vision: Algorithms and Applications*. Springer-Verlag New York Inc, 2010.
- [10] D. A. Forsyth and J. Ponce, *Computer Vision: A Modern Approach*. Prentice Hall, 2002.
- [11] J. Heikkila and O. Silven, “A four-step camera calibration procedure with implicit image correction,” in *Proceedings of Computer Vision and Pattern Recognition*, San Juan, Puerto Rico, 1997.
- [12] J. Y. Bouguet, “Camera calibration toolbox for Matlab.” [Online]. Available: http://www.vision.caltech.edu/bouguetj/calib_doc/
- [13] C. Harris and M. Stephens, “A Combined Corner and Edge Detection,” in *Proceedings of The Fourth Alvey Vision Conference*, Manchester, 1988.
- [14] R. Hartley and A. Zisserman, *Multiple View Geometry in Computer Vision*. Cambridge University Press, 2003.
- [15] L. Zhang, B. Tiwana, Z. Qian, Z. Wang, R. P. Dick, Z. M. Mao, and L. Yang, “Accurate online power estimation and automatic battery behavior based power model generation for smartphones,” in *Proceedings of the eighth IEEE/ACM/IFIP international conference on Hardware/software codesign and system synthesis*, Scottsdale, AZ, USA, 2010.
- [16] M. Dong, Y.-S. K. Choi, and L. Zhong, “Power-saving color transformation of mobile graphical user interfaces on oled-based displays,” in *Proceedings of the 14th ACM/IEEE international symposium on Low power electronics and design*, San Francisco, CA, USA, 2009.