3D Modeling for Mobile Augmented Reality in Unprepared Environment

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Abstract The emergence of powerful mobile smartphones, with embedded components (camera, GPS, accelerometers, digital compass), triggered a lot of interest in the mobile augmented reality (AR) community and new AR applications relying on these devices are beginning to reach the general public. In order to achieve a rich augmentation in terms of immersion and interactions, these mobile AR applications generally require a 3D model of the real environment to provide accurate positioning or to manage occlusions. However, the availability of these 3D models based on real spatial data is limited, restraining the capacity of these applications to be used anywhere, anytime. To overcome such limits, we developed a framework dedicated to the fast and easy production of 3D models. The proposed solution has been designed for the specific context of mobile augmented reality applications in unprepared environment and tested on iPhone.

1 Introduction

For some years, smartphones made a breakthrough in the telecom market. According to the information technology research and advisory company Gartner, Inc. "Smartphones continued to represent the fastest-growing segment of the mobile-devices market" (Gartner, Inc.). These mobile devices are powerful, small and involve several positioning, orientation and optical components: Global Positioning System (GPS) receiver, digital compass, accelerometers and camera. These components, in addition to the smartphone mobility, make this device a valuable platform for the development of unique and innovative activities or location-based services such as mobile augmented reality applications.

Augmented reality (AR) is the enrichment of the reality with virtual elements. These synthetic objects are projected in a live video stream as if they were part of

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the reality. Recently, some mobile augmented reality applications based on smartphones have been released like Layar (http://www.layar.com) or Wikitude (http://www.mobilizy.com). These applications are world browsers that enable a user to visualize virtual layers of 2D–3D information superimposed to the camera video stream. A tourist in New York City can see annotations with names and information about the skyscrapers in the camera field of view for instance. One of mobile augmented reality advantages is to clearly link information with real object as seen by a person on the spot.

The principle on which these applications rely does not involve information about the user surroundings when rendering the digital graphics. As a result, occlusions are not managed. Thus, a whole 3D graphic element will be rendered even if part of it is occluded by a real building for instance. To manage occlusions, it is recommended to integrate information or knowledge about the environment. Having a 3D model of the environment where the augmentation takes place offers opportunities for richer interactions and higher levels of immersion. More specifically, 3D models about objects in the user field of view can be used to merge more accurately the computer-generated elements with the reality, providing the user with a better sense of presence of these elements in the real world. However, these 3D models of the environment are not always accessible, therefore limiting the capabilities to deploy realistic augmented reality solutions anywhere, anytime.

Mobile augmented reality is anticipated as the next social communication and information hub. Following the current trends of social networking and location-based applications, citizen can already be foreseen as the main users and contributors of such technology. The real-world information used for mobile AR will be user-generated, as applications like Wikitude or Yelp (http://www.yelp.com) are already demonstrating. Within this context, tools to create contents for mobile AR need to be simple and intuitive to enable the user to augment his environment with information that matters to him and to deploy such applications wherever he chooses to.

This paper will present a new citizen based 3D modeling solution to enable mobile AR applications anywhere, anytime. The context and principles related to mobile AR will be first presented. A brief review of current mobile AR work will be provided too. Then, the proposed 3D modeling approach will be described as well as the prototype implementing such an approach. Finally, results of tests conducted to assess the prototype performances will be provided and discussed before concluding.

2 Mobile Augmented Reality Operational Constraints

The concept of an augmented reality environment is often presented using the Reality-Virtuality continuum of Milgram et al. (1994) (cf. Fig. 1). Reality, namely what is directly perceived by a person or indirectly by a camera, stands at the left extremity of the continuum. A virtual environment, which is completely synthetic, stands at the right end of the continuum. Between both extremities are all the mixed reality environments, which merge computer generated graphics and real elements.

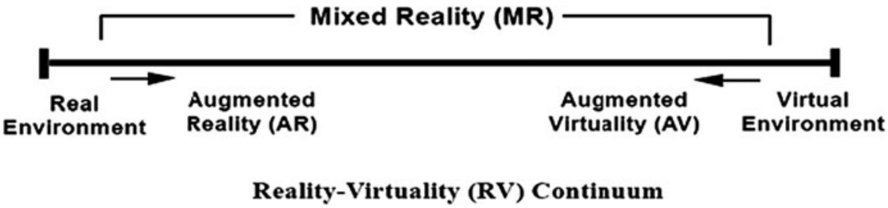

Fig. 1 Reality-virtuality continuum (Milgram et al. 1994)

Augmented reality, which is situated next to reality, is a real environment augmented by virtual elements. If the environment is predominantly synthetic with some real elements included, this context is related to augmented virtuality. Augmented reality approaches are relevant to many contexts, like, for instance, the maintenance of mechanical engine (Henderson et al. 2007), or teaching and learning 3D contents (Shelton et al. 2002). Augmented reality offers also an exceptional potential for gaming (Lindt et al. 2007).

An augmented reality application is said to be mobile if the user is his own avatar and his position in the synthetic world follows his displacements in the real environment (Broll et al. 2008). Those types of applications can display various levels of augmentation. Mobile applications with low augmentation (i.e. "weakly augmented") consist generally in displaying multimedia elements triggered by the physical proximity of the user to a virtual point of interest (POI). A POI is simply information, such as image, video or text, linked to a specific location at the surface of the Earth. Games described in Squire and Mingfong (2007) or Klopfer and Squire (2007) are good examples of such applications. Increasing the level of augmentation will increase the level of immersivity and interactivity of the application and, as a result, the capability to challenge the user interest. Applications with such level of augmentation are said to be "strongly augmented". Literature review shows that very few strongly augmented applications have been developed so far. Most of them used head mounted display, a laptop, a GPS receiver and an inertial system as their hardware configuration. However, these devices were rarely integrated and definitely not ergonomic, limiting their deployment and adoption by user community. With the emergence of lightweight and powerful smartphones equipped with GPS receiver, digital compass, camera and accelerometers, there are new opportunities to implement mobile AR applications using these platforms and to bring mobile AR outside the research community. Layar 3D application (Layar 2009) is already a good example. Having specified the various declensions of mixed and augmented reality, we will now address the requirements of strongly augmented solutions. They will be the focus in the following paragraphs and sections of the paper.

According to Azuma definition of augmented reality (Azuma et al. 1997), computer-generated graphics and reality should be perfectly co-registered in real time to provide the user with a strong augmentation of the reality. This requirement allows maintaining the user feeling of presence and immersion at all time. Good co-registration of virtual elements in the real world implies to precisely determine the user position and orientation and to tackle occlusion issues. These positioning and occlusion issues are generally resolved using 3D models of the environment (Schmalstieg et al. 2007; Ohlenburg et al. 2007). To correctly manage the occlusions, the 3D model of the real environment has to be first integrated in the same virtual world as the graphic elements. Then, during the rendering of the scene, the model of the real environment is drawn in a transparent manner so the background (i.e. the camera live video stream) could be shown in the foreground in lieu of the occluded parts of the 3D virtual graphic elements. To retrieve a more accurate position and orientation of the user, the 3D model can be projected in the current video frame according to the previous camera pose computation as proposed by Reitmayr and Drummond (2006). Using computer vision algorithms, the 3D model projection is compared to the model features in the current frame of the video stream. The detected differences will provide information about the camera movements. They will complement the pose and orientation measurements provided by the hardware components (i.e. digital compass, accelerometers, GPS receiver).

As it has been underlined above, a 3D model of the environment is required in order to build mobile AR applications with rich interactions and high immersivity. Various sources for 3D models currently exist. Virtual globes such as Google Earth or Bing Maps contain a handful of 3D models. However, it is not possible to retrieve them seamlessly depending on the user's location. Actually, the only way to access a single 3D model from Google Earth is to manually download it from the 3D warehouse website (http://www.sketchup.google.com/3dwarehouse/). Open 3D servers exist like OpenStreetMap-3D (Neubauer et al. 2009), but they offer limited coverage and they do not seem to have a strong community leverage. On the other hand, 2D data is more publicly accessible and the missing elevation data could be derived from other sources (in situ observations, building's altitude by adding the number of stories to the ground height). This data process still needs to be explored in the context of mobile augmented reality modeling. Taking into account that the availability for 3D models is currently limited, the constraint of having 3D models anywhere at anytime in mobile AR applications cannot be always satisfied. If a 3D model of the environment it is not available or cannot be retrieved, the environment is said to be unprepared for augmented reality. The proposed citizen based 3D modeling solution presented in this paper specifically addresses this context of unprepared environments allowing the user to capture on location the 3D model he needs. The next section describes the criteria such 3D modeling tool should fulfill to supply 3D models adapted to mobile AR application.

3 3D Modeling Solution Specifications for Unprepared Environment

The context of mobile AR in unprepared environment focus on augmented reality anywhere, anytime. As mentioned in the introduction, the general public is one of the main targets of such application. Therefore, it can be assumed that mobile AR applications in unprepared environment should rely on limited external devices beside the smartphone itself and should not require specific expertise in computer vision or 3D modeling from the user.

As underlined in the previous section, 3D model of the environment is necessary to achieve high immersivity and strong augmentation of the real world. How such 3D model can be made available to the user situated in an unprepared environment? In the current mobile AR context, the classical 1D-3D (i.e. surveying/geomatics) acquisition techniques and subsequent processing display strong constraints from a cost and time standpoint. For example, topographical survey and subsequent 3D modeling can require several work days before delivering the required 3D model. User cannot wait for days on site before being able to trigger his augmentation of the world. Terrestrial LiDAR (i.e. Light Detection and Ranging) offers high potential for fast data collection and large urban coverage. However, its cost is still expensive (approximately $150,000), which limits its availability. Even if mobile LiDAR data acquisition of large scale environment increases [e.g. NAVTEQ recently adopted this technology (NAVTEQ)], a lot of urban environments have not been scanned yet and mobile LiDAR survey remains very expensive (a survey generally costs tens of thousands dollars). As a result, these techniques are not considered adapted for mobile AR applications in an unprepared environment. Other techniques has been designed especially for mobile AR applications like the working planes (Piekarski 2004) or the combination of map coordinates and inertial sensor data (Kim et al. 2007). Even if these are successful tools, they are used with specialized and expensive equipment. Therefore there is a need for 3D modeling techniques dedicated to mobile AR applications in unprepared environment.

In this context it appears essential that the modeling process be low cost, fast, intuitive, ergonomic, and require neither survey equipment nor specific knowledge. Since the purpose of the 3D model is to contribute to the strong augmentation of the environment (i.e. precise positioning, occlusion management), it is important that the model displays relevant level of details and spatial precision. All the criteria aforementioned can be synthesized as the specifications the 3D modeling solution should fulfill to be relevant to mobile AR application in unprepared environment. Thus anywhere augmentation solution requires a 3D modeling solution:

- That is affordable
- That provides a 3D model of item in the environment as fast as possible
- That operates directly on the spot
- That does not require preliminary training and specialized expertise
- That could be implemented on integrated, ergonomic, lightweight on the shelf devices
- That provides precise and detailed 3D models suitable for a determined augmentation level

4 Fast and Easy 3D Modeling Approach for Smartphones

Relying on these specifications of the 3D modeling solution for augmented reality application in unprepared environment, we designed a fast, easy and generic approach to built 3D model using a smartphone. Smartphones provide valuable visualization and positioning functionalities based on their integrated components. The proposed 3D modeling approach focuses currently only on buildings since these elements are major landmarks of urban environments. In addition, as man-made structures, their regular shape eases the 3D modeling process.

The 3D modeling approach we designed consists of three main steps: (1) the retrieval of the 2D geographical coordinates of the buildings' corners at the ground level; (2) the computation of the altitude at the top corners of the building; (3) the 3D modeling process and the augmentation of the reality. Each of these steps is detailed hereafter.

The first step is carried out manually by the user. The 2D geographical coordinates of the buildings' corners at ground level (X_b, Y_b) are selected through a web based cartographic application. This application can rely on maps, airborne or satellite imagery. The only requirement is for the cartographic representation to display a spatial resolution relevant to the building corner precise visualization.

The second step is carried out using the camera, the GPS receiver and the accelerometers. In order to compute the altitude at the top corners of the building, the user must aim with his mobile device camera at each of the previously identified building's corners at roof level. The user can move around the building and choose the most suitable location to survey each corner. During each survey process, the GPS and accelerometers data are simultaneously recorded by the application. The elevation angle between the user and the roof corners is computed using the accelerometer data. Knowing the GPS position of the user (X_u, Y_u, Z_u) and the corner coordinates at ground level (X_b, Y_b), the distance (d) between the user and the surveyed corner can be computed. With this distance and the elevation angle (θ), the altitude difference (d_z) between the user and the roof corner can be easily computed using (1). In (2), the GPS elevation data of the mobile device (Z_u) is added to the altitude difference (d_z) previously computed in order to assess the altitude of the corner at roof level (Z_b) (cf. Fig. 2).

$$d_z = d \bullet \tan(\theta) \tag{1}$$

$$Z_b = Z_u + d_z \tag{2}$$

The third step focuses on the 3D modeling of the building and the augmentation of the reality including the occlusion management. Since the rendering engine cannot deal with longitude and latitude angular data, all the building's rooftop coordinates should be first transformed from a spherical geographic coordinate system to a planar coordinate system. Then, the 3D modeling of the building is carried out through a triangular meshing process relying on the 3D coordinates of the corner at ground and rooftop altitude. Since the altitudes of the corners at ground level are unknown, these values are set to 0. For now, such setting is admissible since it has no impact on the subsequent augmentation of the reality and occlusion management. In the future however, it might become a problem if texture has to be applied on the 3D model. The augmentation of the real world is performed through the superimposition of a 3D graphic element on top of the

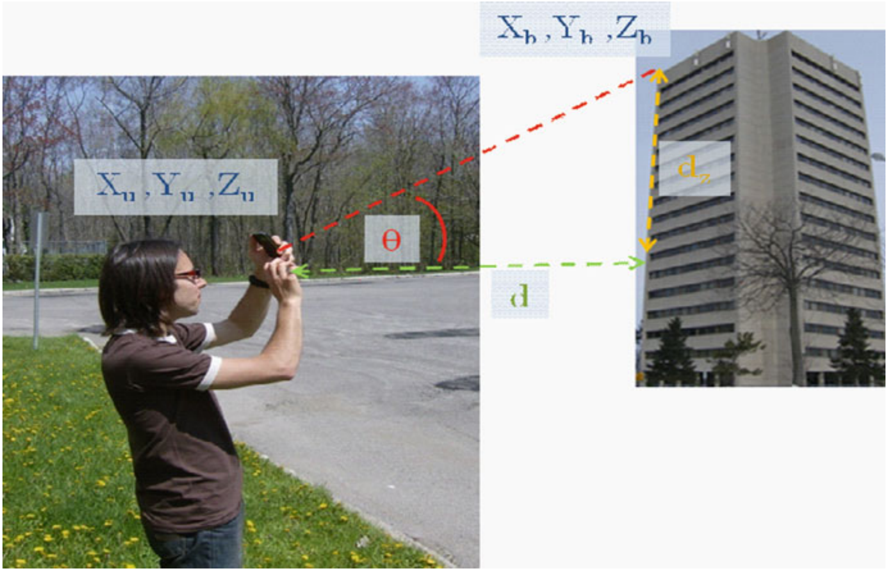

Fig. 2 3D coordinates calculation of a building's top corner

camera live video stream. The scene rendering takes into account the building 3D model location in relation to the 3D graphic element location and the user position and orientation. If the building is in the user field of view, the occlusion of the graphic element should be rendered accordingly. The 3D modeling of additional urban elements will be addressed in a near future.

The diagram below synthesizes all the steps of the proposed fast and easy 3D modeling approach (Fig. 3).

5 iModelAR Prototype

Relying on the approach described in the previous section, we developed a 3D modeling prototype we entitled iModelAR. iModelAR has been implemented on the iPhone 3G platform, taking full advantage of all its components (GPS, accelerometers and camera). The prototype has been programmed in the integrated development environment (IDE) XCode using Objective-C language. The three main steps of the fast and easy 3D modeling approach have been implemented as follows in iModelAR prototype:

- *Step 1*. The 2D geographical coordinates of the buildings' corners at the ground level are selected using a Google maps view centered at the user's location. In addition to placing markers at the corner location on the map, the user needs to

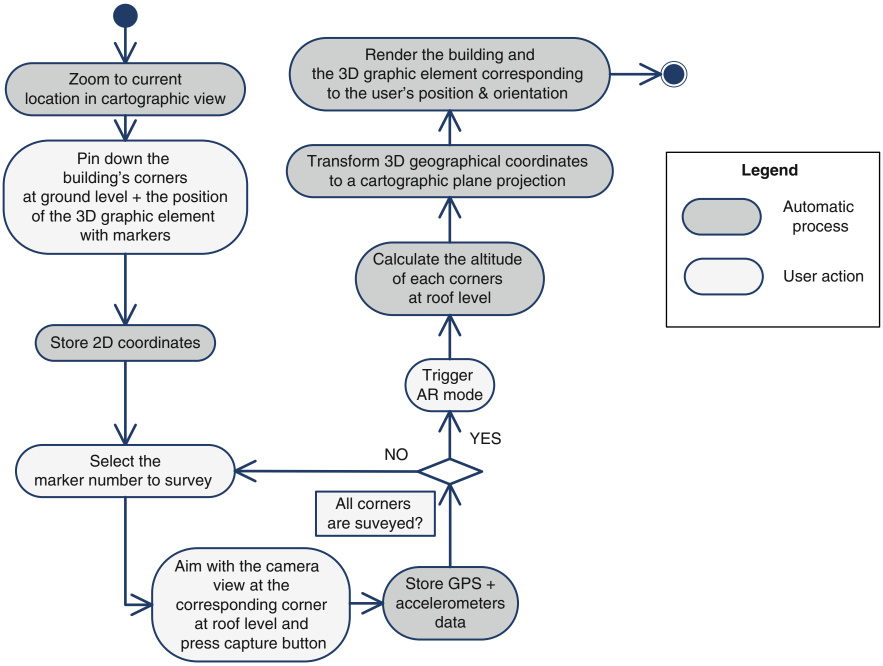

Fig. 3 Citizen-based generic 3D modeling approach for smartphones

mark the location of the 3D graphic element that will augment the real world later on. (cf. Fig. 4).

- *Step 2*. The user can rely on a red cross overlaid on the camera view to help him aim precisely at the previously identified building's corners at roof level (cf. Fig. 5). When surveying a building corner, iModelAR records series of accelerometers data. The more accelerometers data is recorded, the better the accuracy of the corner survey is but the longer it takes to complete this survey. Therefore, a trade-off is required between maximizing the total number of accelerometer records per corner and minimizing the survey time. According to our experiments, recording 250 accelerometers data seems to be the right trade-off. While accelerometer data are recorded, between five to seven GPS readings are recorded as well. These accelerometer and GPS data series are used to increase the redundancy of the orientation and position measurements. This will yield to more robust and representative position and orientation mean values. These values will be involved in the computation of the roof corner 3D coordinates as explained in the previous section. Once each corner has been surveyed, the user triggers the augmented reality view button.
- *Step 3*. The 3D coordinates of the rooftop corners are transformed from the geographical coordinates system of the GPS receiver (WGS84) to the Universal Transverse Mercator (UTM) coordinate systems relying on the WGS84 ellipsoid. The 3D triangular mesh of the building is computed in OpenGL ES

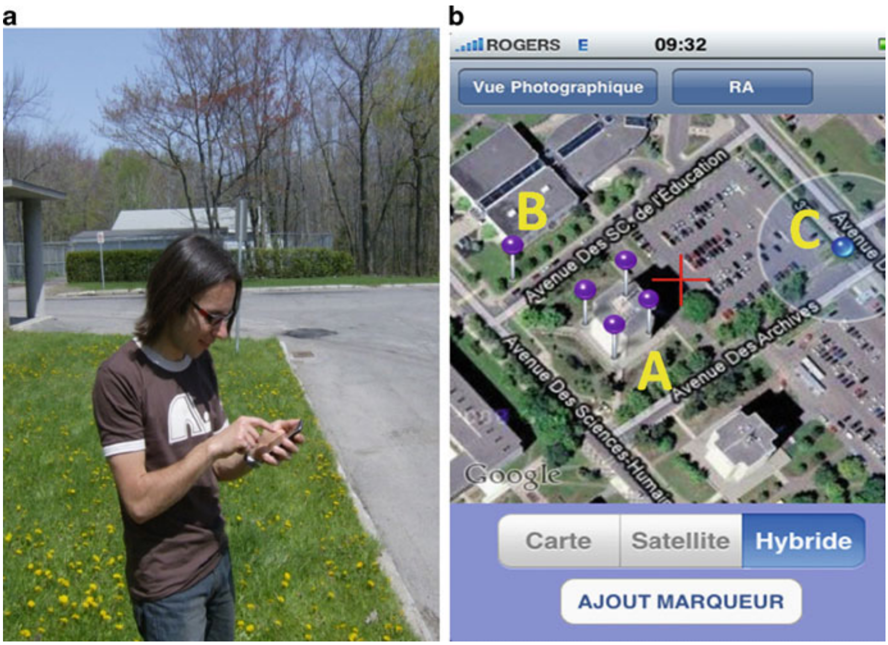

Fig. 4 (**a**) User at location, (**b**) Pinning down the building's corners in the cartographic view (A); select the position of the graphic 3D element (B); user's position (C)

Fig. 5 (**a**) User at location, surveying a building's corner, (**b**) Surveying interface of the photographic view

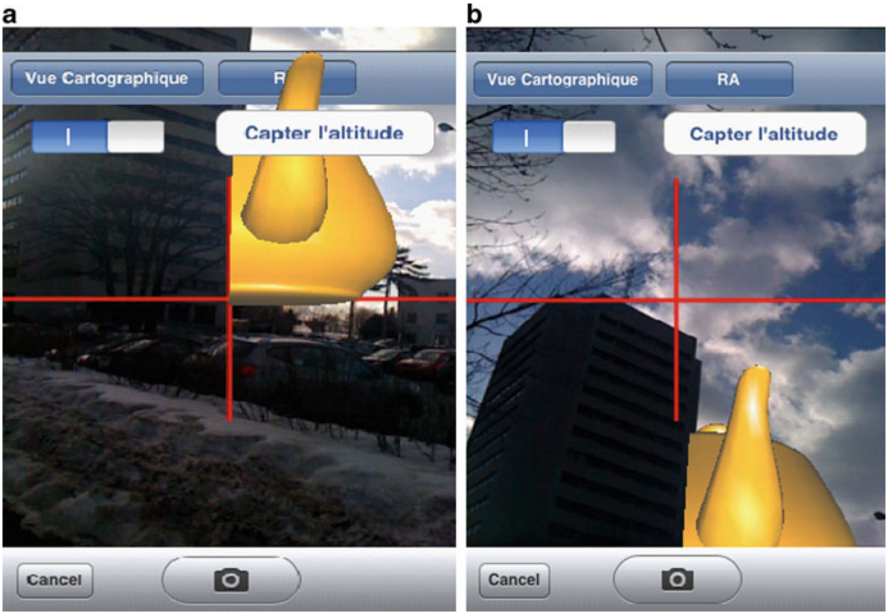

Fig. 6 (**a**, **b**) Rendering of the 3D graphic element according to the user's position and orientation while correctly managing occlusions

environment. Even though the main focus of this work was 3D modeling, an augmented reality view managing occlusions was developed to assess the relevance of the proposed approach and prototype towards anywhere augmentation. Only common lighting and color OpenGL ES functions have been used to achieve the rendering of the 3D graphic element (cf. Fig. 6).

5.1 iModelAR Performance Analysis

Within this section, the spatial precision and the fit for use of iModelAR will be presented. The impact of each of the components involved in the computation of the building's 3D coordinates at roof level on the resulting accuracy will be assessed. The fit for use subsection will consist of the comparison between the criteria previously enounced in Sect. 3 and the capabilities of the developed application.

Spatial Accuracy. Tests have been carried out according to the following testing protocol:

- Eight top corners on four different buildings with various heights have been surveyed using a total station. These measurements have been used as the ground truth
- The corners have been surveyed using iModelAR. This survey has been performed at the location of two geodesic points with known coordinates

Table 1 iModelAR accuracy analysis

Component	Ground truth	Mean difference	Standard Deviation
X_u, Y_u	Geodesic point	3.0 m	2.4 m
Z_u	Geodesic point	3.9 m	3.1 m
θ	Total station measurements	1.3°	0.9°
d	Total station measurements	2.3 m	1.6 m
d_z	Total station measurements	1.1 m	1.0 m
X_b, Y_b	Total station measurements	2.0 m	2.0 m
Z_b	Total station measurements	4.2 m	2.9 m

- Three series of observation of the eight corners have been performed at each of the two geodesic points location
- At the second geodesic point location, only six of the eight corners were visible

Being located on known 3D geodesic points, each position or orientation measures involved in the computation of the building corner 3D coordinates could be analyzed individually. Since the distance and the elevation difference between the geodesic points and all the corners were known precisely, the targeted measurements could be inferred. Table 1 sums up the mean difference in absolute value between the position and orientation measures recorded using iModelAR and those recorded using the total station.

Horizontal Accuracy. When addressing the horizontal accuracy of a building's corner, the main sources of error are related to the markers placement on the satellite image, the georeferencing precision and the highest zoom level available of the cartographic tiles of Google Maps. Sometimes, and because projective effects, it is tricky to approximate where the corner is at ground level if the building is tall (cf. Fig. 7) or has an extended cornice. Maximum errors up to 5 m have been assessed only for the Google Maps tile of our test zone on the Université Laval campus. Regarding the georeferencing of the satellite images of Google Maps, no metadata information was available about the accuracy of this georeferencing. Therefore an uncertainty remains about the inaccuracy value that should be attached to this error source. More testing should be done at various locations to assess its impact on the horizontal precision. Another point is the maximum zoom level available for a geographic zone. A high resolution Google Maps tile will enable an iModelAR user to achieve precise placements of markers at a building's corner. When combining the imprecision of the three aforementioned sources of errors, the mean difference between the coordinates in the (x, y) plane provided by iModelAR and those provided by the ground truth is about 2 m.

Vertical Accuracy. Three components are needed to compute the altitude of a building's roof corner with iModelAR: (1) the distance between the user and the corner that is surveyed [calculated based on their horizontal positions (x, y)]; (2) the elevation angle of the mobile device during the survey; (3) the altitude of the mobile device during the survey.

Let's focus at first on the precision of the distance between the user and the corner to survey. Two components are used to calculate this distance: the user

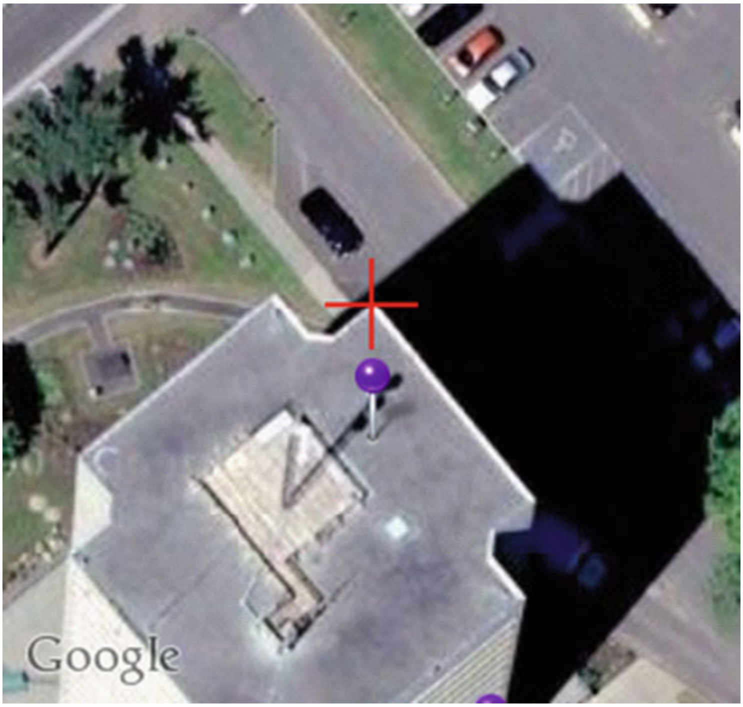

Fig. 7 Marker at ground level corresponding to the roof where the red cross is

position during the survey and the 2D coordinates of the marker. The horizontal position (x, y) of the user is retrieve using the iPhone embedded GPS receiver. Five to seven GPS positions are averaged each time a corner coordinate is surveyed in order to have redundancy in the data set. A mean error of about 3 m has been computed for the GPS measurement. The horizontal precision of the corner is about 2 m (cf. Horizontal Precision section). When taking into account these two accuracy values, the resulting precision for the distance was ranging between 2 and 3 m.

The elevation angle is calculated based on the accelerometer data recorded during each corner survey. 250 accelerometer measures are recorded and filtered to limit the effects of the user's quick movements. By comparing the elevation angles measured using iModelAR to the total station measurements, a mean difference of only 1.3° has been computed.

When combining the elevation angle with the distance, the mean error between the building's roof altitude as provided by iModelAR and the altitude surveyed with the total station is about 1 m. However, the iPhone's altitude from the GPS receiver should also be involved in iModelAR computation (i.e. its altitude should be added to the building's altitude computed by the prototype) in order to get the correct Z coordinate of the building's roof corners. In the context of this study, the iPhone's

Table 2 List of performances of iModelAR

Criteria	iModel AR performance
3D modeling speed (4 corners building)	<3 min
Ease of use	43 taps (4 corners)
Cost	CAN $699 (iPhone 3Gs), (CAN $199 with a communication plan)
On the fly?	Yes
With off the shelf material?	Yes
Required knowledge in 3D modeling	None
The 3D model produced can be used to augment the reality?	Yes
Occlusion management?	Yes

GPS provides altitude measures with 4 m imprecision (cf. Table 1) and this is the main source of error in the building's altitude computation using iModelAR.

The redundancy of 3D coordinates for the same corner can be increased and therefore the precision of the survey can be improved by aiming at the same corner more than one time. Modeling the building with flat roof helps improving the resulting precision since the mean value of all the building's top corners is used.

Fit for Use. Table 2 synthesizes the performances of iModelAR from a fit for use standpoint. In other words, the relevance of the prototype has been assessed in the context of mobile AR in unprepared environment.

From our experience of showcasing iModelAR, modeling a four corners building takes about 3 min for a user with no experience. 43 taps are necessary to achieve the modeling. However the sequence consisting of aiming at the roof for each marker is repetitive and no long taps sequence needs to be memorized. iModelAR runs on an iPhone 3G which actually costs about CAN $700 and drops to CAN $199 with a communication plan. With only this off the shelf material, iModelAR can model a building directly on the field, without the post-processing usually needed with common geomatics techniques.

Guiding instructions are providing to the user at each step of the 3D modeling process. No specific expertise is required to complete the task. The prototype relies on usual tools available on the Web (i.e. Google Maps) and on the smartphone functions. Therefore it should be fairly easy for the general public to use such solution. The prototype has been already showcased at various conferences and workshops. Comments from the attendance have been very positive. User tests should be conducted in a near future to confirm these preliminary feedbacks.

User adoption of iModelAR solution will rely, in part, on the AR view quality. In terms of augmentation performance, the augmented view is refreshed at a speed of about 30 frames/second. The 3D model of a four corners building consists of 8 triangles and 2,779 triangles are used to model the 3D graphic element (i.e. the famous Utah teapot). Therefore the rendering task is not too computationally expensive for the model device. If the user tilts the iPhone and moves in his environment, the augmentation follows accordingly at a fluid pace. Since the iPhone 3G does not have a digital compass, the yaw angle is not taken in account.

This problem can be resolved easily by using the iPhone 3Gs which includes a digital compass. A good calibration of the iPhone's camera will be necessary to supply the right field of view parameters to the OpenGL ES rendering function so that the 3D graphics would be perfectly aligned with the camera view. Actually, this causes the 3D graphic elements to seem nearer then they really are.

In the current version of the prototype, we can only model one building at once, but no extensive programming efforts would be needed to enable the software to model more than one at the time.

Therefore, in the light of the performance tests we conducted, iModelAR fulfills the specifications of a relevant 3D model solution (cf. 3D modeling solutions specifications for unprepared environment) in terms of costs, speed and ease of use.

6 Conclusions and Future Work

In this paper, a novel 3D modeling solution, iModelAR, dedicated to mobile augmented reality in unprepared environment has been proposed. Although iModelAR accuracy does not reach the precision performances of common surveying techniques based, for instance, on total station or LiDAR device, this application displays several other advantages relevant to mobile AR:

- It is rapid (<3 min)
- No post-processing is required (3D modeling + AR on the spot)
- It is simple
- It is low-cost (any recent Smartphone)
- No 3D modeling knowledge is required

Future works will be dedicated to precisely assessing the level of augmentation that can be achieved when using the 3D models provided by iModelAR. The next developments will also focus on the modeling of several buildings at a time and improving the realism of the augmentation. Some efforts will also be invested in devising a solution to bypass the GPS error and to be able to tackle building with complex shapes.

On the long term, solution like iModelAR can help develop an AR 2.0 user community where sharing your 3D models and augmenting your reality anywhere will be possible.

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References

Azuma, R.: A Survey of Augmented Reality. In: Presence: Teleoperators and Virtual Environments, 355–385 (1997)

Broll, W., Lindt, I., Herbst, I., Ohlenburg, J., Breun, A.-K., Wetzel, R.: Toward next-Gen mobile AR games. IEEE Computer Graphics and Applications; 28(4), 40–48 (2008)

Gartner, Inc.: Gartner Says Grey-Market Sales and Destocking Drive Worldwide Mobile Phone Sales to 309 Million Units. In: Gartner. (Accessed November 12, 2009) Available at: http://www.gartner.com/it/page.jsp?id=1224645

Henderson, S., Feiner, S.: Augmented Reality for Maintenance and Repair (ARMAR). Technical Report AFRL-RH-WP-TR-2007-0112, United States Air Force Research Lab (2007)

Kim, S., DiVerdi, S., Chang, J., Kang, T., Iltis, R., Höllerer, T.: Implicit 3D Modeling and Tracking for Anywhere Augmentation. In: Proceedings of the 2007 ACM symposium on Virtual reality software and technology, Newport Beach, California, pp.19–28 (2007)

Klopfer, E., Squire, K.: Environmental detectives – the development of an augmented reality platform for environmental simulations. Educational Technology Research and Development, Springer; 56(2), 203–228 (2007)

Lindt, I., Ohlenburg, J., Pankoke-Babatz, U., Ghellal, S.: A report on the crossmedia game epidemic menace. Computers in Entertainment (CIE), ACM; 5(1), Article 8 (January 2007), p. 8

Milgram, P., Takemura, H., Utsumi, A., Kishino, F.: Augmented reality: a class of displays on the reality-virtuality continuum. Telemanipulator and Telepresence Technologies. Proc. SPIE; 2351, 282–292 (1994)

NAVTEQ: NAVTEQ Launches Advanced Mapping Collection Technology. In: NAVTEQ. (Accessed January 6, 2010) Available at: http://corporate.navteq.com/webapps/NewsUserServlet?action=NewsDetail&newsId=836&lang=en&englishonly=true

Neubauer, N., Over, M., Schilling, A., Zipf, A.: Virtual Cities 2.0: generating web-based 3D city models and landscapes based on free and user generated data (OpenStreetMap). In: GeoViz2009, Hamburg (2009)

Ohlenburg, J., Lindth, I., Pankoke-Babatz, U.: Report about the crossmedia game epidemic menace. Computers in Entertainment (CIE), ACM; 5(1), 8 (2007)

Piekarski, W.: Interactive 3d modelling in outdoor augmented reality worlds. Research Thesis for the Degree of Doctor of Philosophy, The University of South Australia (2004)

Reitmayr, G., Drummond, T.: Going out: robust tracking for outdoor augmented reality. In: Proceedings of the 5th IEEE and ACM International Symposium on Mixed and Augmented Reality, Santa Barbara, CA, pp. 109–118 (2006)

Schmalstieg, D., Gerhard, S., Wagner, D., Barakonyi, I., Reitmayr, G., Newman, J., Ledermann, F.: Managing complex augmented reality models. IEEE Computer Graphics and Applications; 272(1716), 32–41 (2007)

Shelton, B., Hedley, N.: Using Augmented Reality for Teaching Earth-Sun Relationships to Undergraduate Geography Students. In: The First IEEE International Augmented Reality Toolkit Workshop, Darmstadt, Germany (2002)

sprxmobile: Layar 3D. In: Layar. (Accessed September 22, 2009) Available at: http://layar.com/3d/

Squire, K., Mingfong, J.: Mad city mystery: Developing scientific argumentation skills with a place-based augmented reality game on handheld computers. Journal of Science Education and Technology (Springer); 16(1), 5–29 (2007)