Landmark-Based Pedestrian Navigation from Collections of Geotagged Photos

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ABSTRACT
Mobile phones are an attractive platform for landmark-based pedestrian navigation systems. To be practical, such a system must be able to automatically generate lightweight directions that can be displayed on these mobile devices. We present a system that leverages an online collection of geotagged photographs to automatically generate navigational instructions. These are presented to the user as a sequence of images of landmarks augmented with directional instructions. Both the landmark selection and image augmentation are done automatically. We present a user study that indicates these generated directions are beneficial to users and suggest areas for future improvement.

Categories and Subject Descriptors
H.5.1 [**Multimedia Information Systems**]: Artificial, augmented, and virtual realities; H.5.2 [**User Interfaces**]: Evaluation/methodology; K.4.1 [**Social Issues**]: Assistive technologies

General Terms
Human Factors, Experimentation

Keywords
Location Applications, Assistive Technologies, User Studies, Visual Navigation, Mobile Applications

1. INTRODUCTION
Mobile phones have become a compelling platform for new location-based services. Their ubiquity, portability, good connectivity, the trend towards increased performance and inclusion of new sensors such as GPS and cameras make them an ideal target device. In particular, navigation is emerging as a critical application for the mobile phone industry. Our work extends a standard mobile navigation system with a pedestrian mode. It uses an existing user-contributed database of geotagged photographs to automatically generate navigational instructions using photographs of landmarks augmented with directional information.

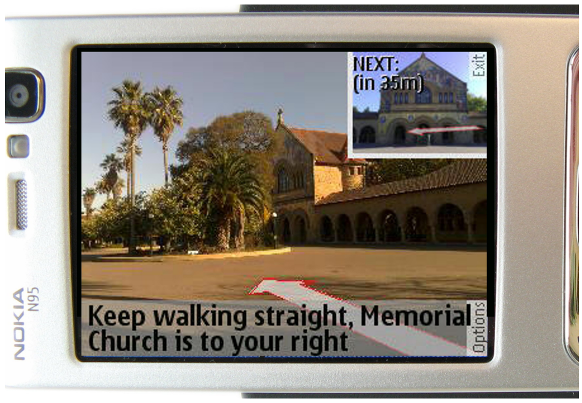

Figure 1: An example of a landmark-based navigation instruction. The image automatically chosen from a database of geocoded images, augmented with directional arrows corresponding to desired path, and corresponding text directions.

According to recent studies using mobile devices [1, 2, 3], landmark-based navigation instructions are easier to follow, shorten the navigation time, and reduce confusion by providing an instant visual feedback on the correctness of a navigation decision. Landmark-based navigation is particularly effective when the landmarks are clearly visible and the directions are properly embedded in the photographs, and when it is integrated with a standard map-based system.

A service that utilizes landmark-based navigation faces the problem of automatically creating and visualizing the instructions. It is generally accepted that approaches such as Google Maps Street View [4] are not well suited for mobile devices, since they are too intensive and frequently suffer from limited landmark visibility [5]. In this work, we explore the possibility of leveraging existing collections of geotagged photos acquired using mobile phones for automatically generating navigational instructions. We believe this is a promising new approach, since these databases are more targeted towards useful information and are inherently more scalable.

MUM'2008, December 3-5, 2008, Umeå, Sweden.

In this work, we build a prototype system that uses an adaptive online database of user contributed geotagged images to automatically generate navigation instructions as a set of photographs of landmarks augmented with directional information. Building the prototype revealed many shortcomings of the original design, such as suboptimal image selection and improper embedding of navigational instructions. We were able to correct many of these flaws by the end of the design cycle. An example of our resulting system is seen in Figure 1.

We also conducted a user study to qualitatively evaluate the generated navigation directions on a mobile phone client. This study can be used to inform the design of the direction generation system. The user study confirms prior findings showing that landmark-based navigation is a simple and effective method of navigation. They also show a clear path for further improvements for landmark-based navigation systems, some of which we have already addressed and others that we plan to address in the future.

1.1 Prior Work

Our system is motivated and shaped by prior work. Requirement studies and user surveys have shown that pedestrian navigation systems that make use of landmarks are more helpful than those that do not. Previous attempts at generating these types of pedestrian directions are too labor intensive or too costly, and we aim to have a solution that is automatic and lightweight. Certain methods of visualizing directions are also too costly: for example, full augmented reality systems are difficult to develop and run on today's mobile devices. We will discuss these limitations in the remainder of this section and show how our approach helps solve some of these problems.

A wealth of different studies have investigated the space of pedestrian navigation systems, and specifically the use of landmarks in these systems. May *et al.* [6] study information requirements for pedestrian navigation aids by surveying people about the directions they would use to describe a particular route. They conclude that landmarks are by far the most predominant navigation cues and that they should be used as the primary means of providing directions for pedestrians. Goodman *et al.* [7] show that landmarks are an effective navigation aid for mobile devices—they shorten the navigation time, reduce the risk of getting lost and help older people lower the mental and physical demand required to navigate. *Advance visibility* and *saliency* of landmarks have been studied and shown to be important measure in identifying suitable landmarks by Winter [8].

A wide variety of proposed landmark-based navigation systems exist. Many of these rely on data that is difficult or costly to obtain. For example, Miyazaki and Kamiya [9] develop a pedestrian navigation system for mobile phones using panoramic landscape images that were synthesized from 3D models of cities. This work assumes an existence of a detailed, photo-realistic 3D model of a city. An approach to identifying suitable landmarks and evaluating their usefulness for navigation has been addressed by Brenner and Elias [10, 11]. The visibility is determined through 3D reconstruction using laser scanning. The above mentioned approaches are both capital and labor intensive, hence not likely to succeed on a large scale. Our approach of using online collections of geotagged photos for automatically generating navigation instructions is much easier to achieve and is more scalable.

Other systems try to leverage the benefits of augmented reality (AR), however these systems often require special hardware. Nokia's MARA project by Kähäri and Murphy [12] demonstrates outdoor AR on a cell phone, but relies on an external GPS for localization and an inertial sensor to provide orientation. Reitmayr and Schmalstieg [13] build a mobile AR system for tourist navigation. It uses a notebook computer, GPS receiver, inertial sensor and camera mounted on a helmet worn by the user. Kolbe [3] uses a PDA to display video clips with augmented location information or to show image panoramas with virtual signpost overlays at the decision points, similar to Google Maps Street View [4]. The usefulness of AR for pedestrian navigation has been investigated by Walther-Franks [5]. AR was found to be very well suited for wayfinding as it puts instructions into the visual context of the user. However, the video see-through AR system was determined too costly for mobile devices and the use of incremented guidance with augmented photos was suggested instead.

Closest in spirit to ours is the work by Beeharee and Steed [1], who perform an exploratory study of building a guiding system for mobile devices based on collections of geotagged photos acquired using mobile phones. They build a prototype database of geotagged photos by manually entering the location and the viewing direction of each photo. The study found that with landmarks the users finished the route significantly faster than without them, and that they found the landmarks helpful and informative. Since the authors did not use any augmentation of images, the users found some of photographs that were not taken exactly along the navigation path confusing.

Unlike Beeharee and Steed who provide a method to augment maps with links to images, our system is built with images of landmarks at the core of the system. We also extend their work by showing that landmark-based navigation instructions can be generated automatically from an existing database of geotagged photos and that with proper image augmentation we can greatly increase the confidence of users and their understanding of the navigation instructions. These instructions are lightweight enough to be used on current mobile phones.

2. SYSTEM OVERVIEW

This section describes our landmark-based pedestrian navigation system that uses an online database of geotagged photos collected using mobile phones. We start by describing an adaptive database of geotagged images that was used to produce navigation instructions. We then describe the algorithm used for identifying images with the best advance visibility and saliency. Next we talk about the algorithm for augmenting images with navigation instructions that highlight the direction information and are properly embedded in the image. We finish this section by describing our mobile navigation client.

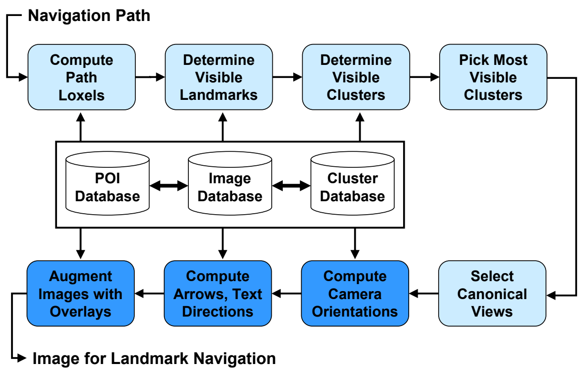

Figure 2: Block diagram for selecting navigation photographs and augmenting them with directions. The first five steps select photographs and the next three steps augment the photographs.

2.1 Database Organization of Geotagged Images

We are currently using a database of geotagged images from an existing outdoor augmented reality project [14]. It was populated by many users taking pictures with GPS-enabled camera phones over a period of time. Each image was tagged during capture with the GPS location and the names of landmarks selected from a list of nearby objects. The landmarks stored in the database also have an associated GPS location—a single point placed somewhere within the geometric extent of the landmark. We chose to use this data instead of data from Flickr or other sharing services because the image tagging found there is generally of poor quality. We are investigating techniques to filter and leverage Flickr data, but our database currently provides more functionality and better quality.

This type of dataset has a desirable property that the interesting landmarks will naturally have more pictures of them available. We can rank landmarks by popularity (the number of images of them), find most salient images of the landmark, and reason about the landmark visibility from different locations based on the existence of pictures. All these properties are important and helpful for generating high-quality landmark-based navigation instructions.

We organize images in our database into clusters representing unique views of a landmark. The clusters are computed from an image graph that represents relationships between pairs of images. The algorithm proposed in [15] is used to compute star shaped image clusters. Each cluster will consist of a *canonical view* at the center, which is a representative image for that cluster and all other images that are visually similar to it.

We rasterize the world into a grid with cells of size 30×30 meters. We call each cell of the georeferenced raster a *loxel*. Loxels are convenient for reasoning about proximity of objects and indexing in the database.

2.2 Photograph Selection and Augmentation

The next two sections describe the process of selecting navigation photographs and of augmenting them with direction information overlays. Figure 2 shows the block diagram for both.

2.2.1 *Selecting Photographs for Navigation*

This section explains the steps taken to convert from a given navigation path to a set of photographs representing landmark-based navigation instructions.

1. *Loxelize the path*, i.e., compute which loxels a user will visit by following the navigation path. These are shown in Figure 4 as colored squares along the navigation path.

2. Determine *visible landmarks* for each loxel along the path. This is done by finding which landmarks have their images inside a 3×3 kernel of loxels centered at a given loxel. This larger kernel is used to improve robustness.

3. Select the image clusters that are completely inside the current kernel.

4. Compute two ranks for the selected clusters. The first rank orders clusters based on how close the images in the cluster are to the navigation path (computed as the number of cluster images inside the central loxel). The second rank orders clusters based on how well the viewing direction is aligned with the navigation direction (computed as the dot product of these two directions).

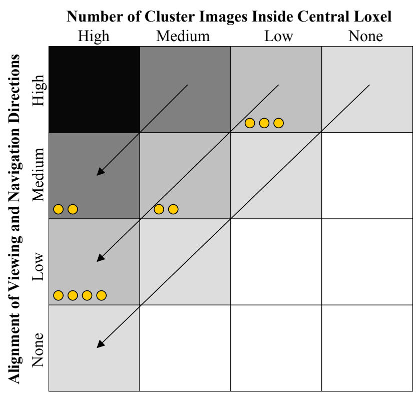

Figure 3: Ordering of clusters based on their alignment with navigation direction and closeness to the navigation path.

5. Discretize each rank into 4 value bins: high, medium, low, none. Create a 4×4 grid, where each cell corresponds to a unique combination of a pair of bins for the two ranks, as shown in Figure 3. Image clusters are distributed across the grid cells based on their pair of discretized rank values. These are shown as dots in the figure.

6. Traverse all bins, starting with the bin that has the largest number of images in the central loxel that are

Figure 4: A sample tour path and the loxels that the path intersects. White lines pointing from loxel to a landmark along the path indicate that this landmark is the best for navigation directions for that loxel. The loxel color changes whenever the previous loxel along the path uses a different landmark for navigation directions.

well aligned with the navigation instruction (black square in the top left corner) and continue towards the bin containing worst ranked images (white square in the bottom right corner). The ordering of the traversal is indicated in the figure by the diagonal arrows. The arrows start with bins that have the best alignment and go towards bins with most images close to the navigation path.

7. Stop after reaching the first non-empty bin. In the figure it would be the third cell visited. Pick the largest cluster from that bin. Use its canonical view as the landmark navigation image.

Figure 4 shows the best choice landmarks for each loxel as chosen by this algorithm. The white line in the figure indicates which landmark gets associated with each loxel. Note that the representative image chosen is not necessarily taken from inside the current loxel; since we choose images from the clusters that are within the 3×3 kernel around a loxel, occasionally we end up with an image that was taken from one of the neighboring loxels.

2.2.2 *Augmenting Photographs with Directions*

Prior work has demonstrated that arrows overlaid in the context of the image help greatly in a person understanding the direction [5, 13, 3, 16]. The image database and route information together contain enough information to determine the angle the arrow should indicate. The GPS coordinate of the image to be shown is known from the database, and the GPS coordinate of the landmark visible in that image is also

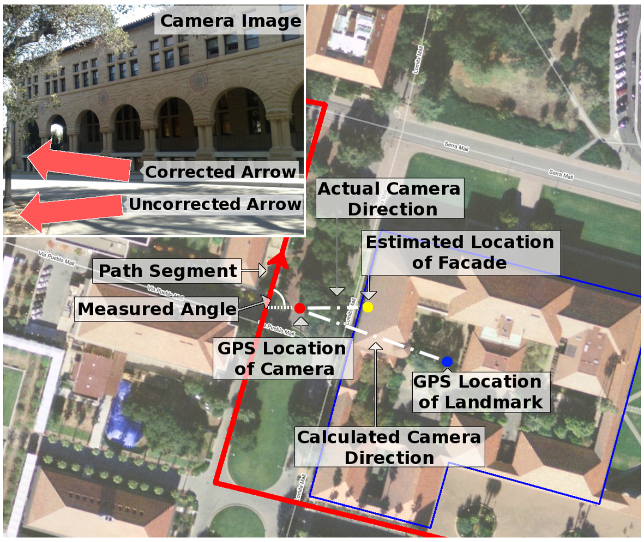

Figure 5: Example of calculating orientation of arrows for image augmentation. The angle between the current path segment and the camera direction defines the arrow placement in the context of the camera image. Compare the result indicating a path parallel to building using the corrected arrow (from the cluster location) to the uncorrected arrow (from the original GPS location) in the inset camera image.

in the database. These two locations are used to determine roughly which direction the camera is pointing. The angle between this vector and the current path segment defines the angle that the arrow should be placed at in the image.

This method of determining camera direction has difficulties with very large landmarks (for example, campus buildings), and we found it necessary to split the single GPS location of the building into multiple points, since the location of the portion of the facade seen in its photograph might be quite far away from the location for that landmark specified in the database. This can result in unnatural and confusing direction augmentations. To deal with this problem we geocode the location for the portion of the landmark shown in the image selected for navigation by localizing this point in a satellite image. It appears that this fairly coarse estimate of the shape of the landmark produces sufficiently good results. See Figure 5 for a diagram of how the arrow direction is calculated and how the correction is accomplished. This same relationship between the path and the landmark can also be used to generate basic text directions that reference the landmark.

In the section on future work we describe how we plan to further improve landmark shape and camera pose estimation in order to improve the computed navigation instructions.

2.3 Navigation Client

We built a client prototype for conducting user studies. The client supports two navigation modes, as shown in Figure 6. The *map-based mode* shows a top-down view of a satellite image for the area of interest. The navigation route and the current location of the user as seen by the GPS device are highlighted on the map. The map is centered on the current location and a trail of recent location history is also shown. The *landmark-based mode* shows an image of a landmark with navigational instructions augmented in the image. The next image landmark along the path is shown in the top right with an approximate distance, and the overlaid text is displayed for a few seconds (as in Figure 1) and then disappears so the full image can be seen. Although the client supports text directions, our user study focused on the use of images, and thus we did not use the text feature. The client program continually checks which loxel along the navigation path is closest to the current GPS location of the user and presents the photograph and directions chosen for that loxel by the algorithm we have described.

2.4 System Summary

With all the pieces of the system in place, landmarks can be chosen along the path, images can be selected and augmented with directional information. These directions are generated in about a second on a standard desktop computer. It is also worth noting that when there are no images available in an area, our system can fall back to producing text and map-based directions. Text directions can still include references to landmarks, which is expected to be an improvement over standard turn and distance descriptions. An example of some directions generated from our current system is shown in the section on future work.

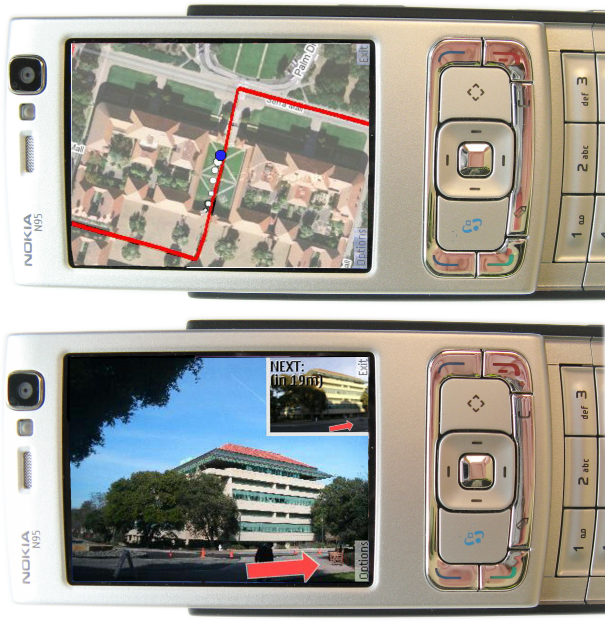

Figure 6: The navigation client from the user study tour. *Top:* **Map mode of the client, with the path marked as a red line and dots representing GPS location.** *Bottom:* **Visual landmark mode of the client, with the top right showing an image of the next landmark.**

3. USER EVALUATION STUDY

We have performed a qualitative study of the client application and directions generated by our system. This was to see how people reacted to the generated landmark directions and how this compared to a standard map-based system. The field study explores the usability of the generated directions and prototype client. Participants were instructed to follow the path shown in Figure 4. This study had a relatively high degree of realism, but was not designed to obtain statistically significant data. Instead, we aimed to confirm previous research on the topic of landmark-based navigation, obtain high level usability feedback on our system, and produce guidelines on how to proceed in the system's development. As mentioned earlier, the client version used in this study did not include text directions. We also decided not to support route recalculation, since it would not inform us about the basic usability of our generated directions, and would potentially make analyzing the results more difficult. We assumed that the user would stay roughly on the path, and in practice this was true.

We recruited 10 participants through an Internet ad calling for people unfamiliar with the Stanford University campus. Through this, participants who responded had existing knowledge and motivations similar to our target users. Participants ranged from ages 19 to 50 (average 32), with 4 men and 6 women. Upon meeting the researcher, they were read a brief introduction to the study, then filled out a background survey. They were then led a short distance away and given a brief tutorial to the application.

In this tutorial, participants were instructed to try out both the map-based and landmark-based modes of the application, but were encouraged to switch modes freely, using whichever they found most useful in the moment. They were also asked to behave as though they were alone during their navigating and to use the application to orient themselves if they got confused. During the navigation portion of the study, a researcher shadowed the participant, noting places where the participant seemed confused. When the participant completed the navigation (roughly 15 minutes), a follow-up semi-structured interview was conducted.

3.1 Application Study Results

All participants were successful in navigating to the end of the path, and none required serious intervention from the researcher during the navigation session. However, all participants showed signs of confusion at least once during the study.

Usage Patterns. Participants' usage of the two modes varied quite a bit: Participant 1 nearly exclusively used the landmark mode, while Participant 5 only used the landmark mode once. All of the other participants fell somewhere in between these two. Five participants described primarily using the map mode, but occasionally switching to the landmark mode. Two of them explicitly described their strategy as an "80/20" rule: they spent 80% of the time in the map mode, and 20% in landmark mode. When questioned further, they explained that they switched to the landmark mode at critical points in the path, primarily turns. They used the images as feedback on their navigation decisions, in this case, the direction to turn. In general, participants found the map mode easier to navigate with, because they could easily see when they were deviating from the path. Nearly all, however, confirmed that the landmark mode was useful to them and that they would prefer to use it again (provided there was an accompanying map mode) in the future.

Confusion While Navigating. Participants spoke of the images being confusing, primarily caused by uncertainty of the image's corresponding landmark. This uncertainty was caused by several factors: first, trees covered many of the landmarks along the path. In some cases, buildings were nearly entirely hidden by trees. Participants had trouble identifying the buildings through trees and had to instead rely on the map to guide them. Second, 9 out of the 10 participants said that the arrows were sometimes confusing. In one typical case, one participant said,

> "There was no depth to the arrow, so I didn't know what I was supposed to do." (Participant 2)

Other participants did not comment on the perspective of the arrows, but instead had trouble interpreting the meaning of the arrows. One participant summarized his problems,

> "I wasn't sure if I was supposed to walk along the sidewalks, or supposed to cross sometimes, or supposed to go into the buildings. [...] I wasn't sure whether the arrows were exactly lined up with where I was supposed to be going." (Participant 1)

Finally, six participants said that because the images shown were not taken from their current position, it was difficult to match the image on the screen with nearby buildings. This was exacerbated by the fact that the system sometimes chose landmarks that were to the side of participants, rather than directly ahead. This meant that the perspective shown in the image on the screen may only be visible when the landmark was directly to the side of the participant. This result confirmed the findings of [1] and reiterated the importance of a good image selection algorithm. We plan to continue improving our algorithms for detecting bad landmark images. We also plan to study when users decide that an image of a landmark is not helpful and should not be presented and plan to incorporate these findings into our system. These plans are discussed in more detail in the future work section.

Suggestions for Improvement. Participants had many suggestions on how to improve the quality of the navigation. Most were satisfied with the map mode, with a few suggestions that we will implement in the future. This section, however, will focus on the landmark mode, for which there were a large variety of suggestions. Several suggestions came up multiple times across participants.

First, as mentioned earlier, some participants found the arrow placement confusing. Because they lay flat on the screen, participants had trouble translating that 2D direction into a 3D one in the real world. Subsequently, we have addressed this by creating 3D arrows that appear to point into the scene. Participants also asked for more accurate arrow placement in general that indicated precisely where to walk.

Second, participants had several suggestions for how to improve the clarity of images. First, they preferred images that they could see without turning from their current path. Some suggested simply choosing better pictures, but others went a step further and suggested showing multiple pictures (with changing perspectives) for each landmark. With this change, each picture would be more closely aligned with what the user is seeing at that moment. Second, they requested images of landmarks that were clearly visible, rather than being hidden behind trees. For situations where there was no visible landmark nearby, they suggested showing a picture of the upcoming sidewalk or road as a confirmation of the current path.

Finally, eight participants requested explicit directions in the application, either via text on the screen or voice directions, like a car navigation system. Participants described this functionality as being useful when the pictures were ambiguous, or to alert them when they had moved off of the path. Participants commented that the verbal directions would be useful to both remind users of upcoming turns (e.g., "Turn right in 20 meters") and as reassurance of the correctness of the current path (e.g., "Continue straight on this path for 50 meters").

3.2 Summary

Overall, reactions to the application were positive. Eight out of ten participants said they would use an application like this one again if given a choice between it and a standard map navigation system. One participant claimed,

> "The pictures are almost a must for me." (Participant 8)

In addition, their comments confirmed previous research on this type of navigation. This feedback, along with that from our second user study, gives us a clear path to improve our system, which we discuss in the future work section.

4. FUTURE WORK

Based on the feedback from our user study and the insights gained during the current prototype development, we have lined up many improvements for future work. Some of these, such as more realistic 3D arrows (Figure 7) and text directions, have already been implemented. See Figure 8 for sections of the campus tour generated by our current system. In this section, we summarize the list of planned improvements and ways to realize them.

- **Improved 3D-Arrow Overlay**

  After our user study using simple 2-dimensional arrows, we developed 3-dimensional arrows to show perspective and aide understanding, as shown in Figure 7. Camera height and tilt are not calculated, but are simply estimates that look reasonable for most cases. Since we are not attempting to indicate specific items in the image, this accuracy is sufficient. We plan to calculate both camera pose and location of objects within the image in order to provide even more meaningful arrows.

Figure 7: Some examples of overlaid perspective arrows calculated by our system. Direction of the arrow is calculated as described in Figure 5. Relative arrow location, camera tilt and height are assumed values.

- **More Precise Landmark Shape Estimation**

  We plan to work on more precise landmark shape estimation using structure and motion estimation techniques, such as the ones used by Brown and Lowe for 3D reconstruction from unordered image collections [17] and in Photo Tourism [18]. The organization of images and features in our database simplifies this problem. Only the features that belong to the landmark are kept in the database, and the grouping of images into clusters gives us a good estimate of the shape complexity of a landmark, further simplifying the reconstruction problem.

- **Landmark Selection**

  We will continue to investigate how choices of landmarks influence success in navigation. We are also conducting ongoing user studies to evaluate what type of landmark-based directions are most easily understood. This information will be used to inform what types of landmarks should be chosen in what situations in order to improve the generated directions. Since some users followed an "80/20" rule using maps in straight areas and landmarks at turns, our system could focus landmark use around these important sections of the path. This variation in use may also lead to personally adaptive systems to provide individuals with directions tailored specifically to their tastes.

  We currently do not support adaptive route recalculation, but this information about pedestrian routes would allow the system to calculate a new route if a user got too far off course.

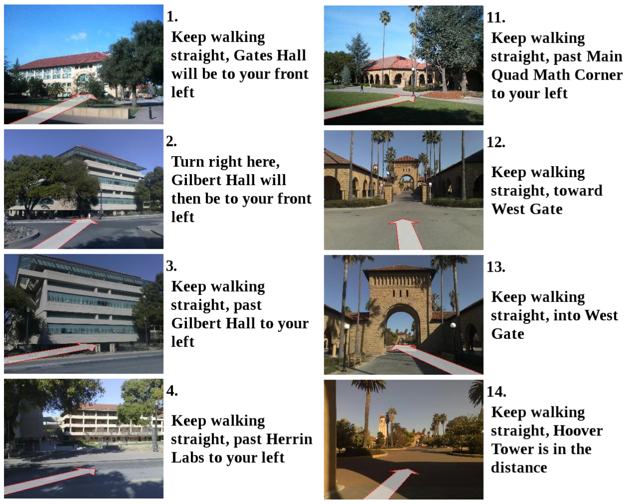

Figure 8: Example directions and images generated for portions of the Stanford campus tour.

5. CONCLUSION

We have presented the design and evaluation of a prototype system that can automatically generate landmark-based pedestrian navigation directions from existing collections of geotagged photos. Both the selection of navigation images and augmentation of those images with directional instructions are done completely automatically. We conducted a user study to help inform the design of the system and investigate the usability of landmarks in navigation. This study shows a clear path for further improvements for landmark-based navigation systems, some of which we have already addressed and others that we plan to address in the future.

In contrast to prior work, our approach is scalable, since it is automatic and depends on the growing accessibility of geotagged photos. Our approach also promises to become ubiquitous, since it targets the compelling new platform for location-based services: the mobile phone. We also envision a variety of extensions of the basic system being built in the future. These can range from a tour guide system designed to provide extra information along a walking tour to a personal, customizable navigation assistant that can teach people a route or remind them if they get off track.

6. REFERENCES

[1] Beeharee, A.K., Steed, A.: A Natural Wayfinding Exploiting Photos in Pedestrian Navigation Systems. In: MobileHCI '06: Proceedings of the 8th Conference on Human-Computer Interaction with Mobile Devices and Services, ACM Press (2006) 81–88

[2] Millonig, A., Schechtner, K.: Developing Landmark-Based Pedestrian-Navigation Systems. Intelligent Transportation Systems, IEEE Transactions on **8** (2007) 43–49

[3] Kolbe, T.H.: Augmented Videos and Panoramas for Pedestrian Navigation. In Gartner, G., ed.: Proceedings of the 2nd Symposium on Location Based Services and TeleCartography. (2004)

[4] Google: Google Maps Street View. http://maps.google.com/help/maps/streetview/index.html (2007)

[5] Walther-Franks, B.: Augmented Reality on Handhelds for Pedestrian Navigation. Master's thesis, University of Bremen (2007)

[6] May, A.J., Ross, T., Bayer, S.H., Tarkiainen, M.J.: Pedestrian Navigation Aids: Information Requirements and Design Implications. Personal Ubiquitous Computing **7** (2003) 331–338

[7] Goodman, J., Gray, P., Khammampad, K., Brewster, S.: Using Landmarks to Support Older People in Navigation. In Brewster, S., ed.: Proceedings of Mobile HCI 2004. Number 3160 in LNCS, Springer-Verlag (2004) 38–48

[8] Winter, S.: Route Adaptive Selection of Salient Features. In: Spatial Information Theory. Springer (2003) 349–361

[9] Miyazaki, Y., Kamiya, T.: Pedestrian Navigation System for Mobile Phones using Panoramic Landscape Images. In: SAINT '06: Proceedings of the International Symposium on Applications on Internet. (2006) 102–108

[10] Elias, B., Brenner, C.: Automatic Generation and Application of Landmarks in Navigation Data Sets. In Fisher, P., ed.: Developments in Spatial Data Handling. Springer (2004) 469–480

[11] Elias, B.: Pedestrian Navigation - Creating a Tailored Geodatabase for Routing. Positioning, Navigation and Communication, 2007. WPNC '07. 4th Workshop on (2007) 41–47

[12] Greene, K.: Hyperlinking Reality via Phones. MIT Technology Review (2006)

[13] Reitmayr, G., Schmalstieg, D.: Scalable Techniques for Collaborative Outdoor Augmented Reality. In: ISMAR '04: Proceedings of the Third IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR'04). (2004)

[14] Takacs, G., Chandrasekhar, V., Gelfand, N., Xiong, Y., Chen, W.C., Bismpigiannis, T., Grzeszczuk, R., Pulli, K., Girod, B.: Outdoors Augmented Reality on Mobile Phone using Loxel-Based Visual Feature Organization. ACM International Conference on Multimedia Information Retrieval (MIR'08) (2008)

[15] Simon, I., Snavely, N., Seitz, S.M.: Scene Summarization for Online Image Collections. In: Proc. of International Convference on Computer Vision (ICCV 2007), IEEE Computer Society (2007)

[16] Liu, A.L., Hile, H., Kautz, H., Borriello, G., Brown, P.A., Harniss, M., Johnson, K.: Indoor Wayfinding:: Developing a Functional Interface for Individuals with Cognitive Impairments. In: Assets '06: 8th ACM SIGACCESS Conference on Computers and Accessibility, ACM Press (2006) 95–102

[17] Brown, M., Lowe, D.: Unsupervised 3D Object Recognition and Reconstruction in Unordered Datasets. In: 5th International Conference on 3D Imaging and Modelling (3DIM05). (2005)

[18] Snavely, N., Seitz, S.M., Szeliski, R.: Photo Tourism: Exploring Photo Collections in 3D. In: SIGGRAPH Conference Proceedings, ACM Press (2006) 835–846