

Leveraging Augmented Reality Technology for Orientation and Mobility Apps for People with Visual Disabilities

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ABSTRACT

With the introduction of augmented reality technology to the iOS and Android platforms, mainstream smartphones now have the ability to determine their own motion in 3D space with high accuracy. Here, we present our work leveraging these new capabilities to create two smartphone apps for people with visual disabilities: (1) an app that provides automatic navigation guidance when backtracking along a route and (2) an app that leverages crowdsourcing to misplaced objects. Along with a discussion of the design of the apps themselves, we present a preliminary usability study that supports their utility. We conclude with a discussion of the promises and limitations of augmented reality smartphone technology to create assistive apps for people with visual disabilities.

ACM Classification Keywords

K.4.2. Assistive technology for persons with disabilities: Orientation and mobility tools for people who are blind or visually impaired

Author Keywords

visual disability; orientation and mobility; augmented reality; assistive technology; smartphone apps

INTRODUCTION

For people who are blind or visually-impaired (B/VI), improvements in orientation and mobility (O&M) have been shown to increase economic opportunity as well as psychological well-being. While only 30% of working-age Americans who are B/VI are employed [3, 26] (compared with 65% of the general population), individuals with better O&M skills have a higher likelihood of being employed [11, 10, 27, 33]. Similarly, while the link between visual-impairment and depression has been well-documented [35, 34, 21, 22], several studies have suggested that it is disability rather than blindness itself that is at the root of this linkage [34, 37]. For example, it was found that one's ability to perform daily-life tasks, such as shopping for basic necessities, was *more* predictive of overall life satisfaction than was degree of vision loss [37].

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Due to its high degree of importance, there is a long history of engineers creating assistive technology to empower people who are B/VI to perform O&M tasks more easily (see the *Background and Related Work* section). Here, we explore new technological developments and trends that have the potential to be utilized to create widely accessible assistive technology for O&M. The first enabling trend is the high rate of ownership of smartphones by people who are B/VI [32]. The availability of these devices has already had revolutionary impacts on accessibility (e.g., through GPS-based directions, OCR software). The second driver of this trend is the introduction of high accuracy 3D-tracking capabilities into mainstream smartphones. While the primary purpose of these modules, e.g., Apple's ARKit [24], Google's ARCore [30], is to enable augmented reality applications — whereby virtual and real world content are mingled, e.g., by overlaying images on a smartphone video feed — these modules can be repurposed to create very powerful assistive technology for O&M.

In this document we present our work on leveraging the augmented reality modules in modern smartphones to create assistive technologies to help users who are blind with everyday O&M tasks. In order to design maximally impactful technologies, we employ user-centered design principles throughout the research and development lifecycle, including working longitudinally with co-designers who are B/VI. Further, two of the study authors, who are visually impaired themselves, contributed to all aspects of the project and provided design guidance based on their personal experiences.

Our first app, *Clew*, enables users to backtrack along previously traveled routes. This app is designed to alleviate various pain points experienced by non-visual travelers (e.g., finding one's way independently after being led to a location by a sighted guide). The second app, *View Share*, utilizes crowdsourcing to enable a user to find objects and receive automated guidance to objects in cluttered environments. In the remainder of the paper we provide some relevant background and related work on O&M assistive technology, discuss some of the algorithms that underlie the AR technology of modern smartphones, discuss our two developed apps in detail, provide preliminary usability, and finally conclude with a discussion of future challenges and promising directions of smartphone-based AR technology for people who are B/VI.

BACKGROUND AND RELATED WORK

Engineers have long sought to use technology to improve the O&M capabilities of people who are B/VI. Most of the early

need a connection to orientation and mobility

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work in this area has focused on the usage of technology to help with obstacle detection and avoidance. For example, researchers have created obstacle-detecting versions of the long cane by instrumenting it with sensors such as lasers [5] and sonar [8]. These sorts of devices have not achieved high adoption in the B/VI community for a number of reasons, including their cost, lack of reliability, and limited new functionality over the white cane [36].

Recently, spurred, in part, by the high ownership rates of smartphones among people who are B/VI, the focus of this work has shifted from obstacle avoidance to problems such as navigation and spatial awareness. For instance, GPS-based navigation apps, such as BlindSquare [31] and Google Maps, allow users who are B/VI to navigate to destinations of interest and learn about nearby landmarks and businesses. The combination of location awareness, as provided by GPS, along with extensive databases of businesses, streets, and points of interest have allowed these apps to provide high-quality assistance to people who are B/VI.

While incredibly useful, GPS-based apps for O&M have a number of shortcomings. Most notably, GPSes in modern smartphones are only accurate to about 10m in ideal conditions (they are even worse in challenging environments such as cities) and GPS does not work in indoor environments. To circumvent these challenges, researchers are pursuing roughly two classes of approaches. The first is to utilize crowdsourcing, whereby people who are B/VI connect over the internet with a sighted person for on-demand assistance. Crowdsourcing has a successful track record in the area of assistive tech for the visually impaired, including the pioneering VizWiz project [6]), the free BeMyEyes app [23], and the subscription-based Aira system [9] (both BeMyEyes and Aira connect a user who is B/VI with a sighted volunteer through a video chat interface). The second class of approaches combine rudimentary (and somewhat inaccurate) motion estimation via inertial sensors (gyroscopes and accelerometers) along with special environmental infrastructure (e.g., Bluetooth-enabled location beacons or Wifi access points) that provide sporadic location cues to enable relatively accurate indoor positioning. For instance, [17, 16, 18] developed a system for navigating indoor environments using smartphone-detectable RFID tags. Dias and her collaborators utilized WiFi fingerprinting (calibrated using a highly-precise indoor mapping robot) and dead-reckoning (using the accelerometers and gyroscopes on a standard smartphone) for indoor navigation [13]. A similar system uses low-energy Bluetooth beacons instead of WiFi access points as landmarks [25, 1, 2]. A third approach utilizes a calibrated database containing images at known locations, which are then matched to camera images at run time [4].

AUGMENTED REALITY

Recently, both Apple and Google have released significant new capabilities that enable users to enjoy highly sophisticated augmented reality (AR) experiences on their smartphones. The key characteristic of AR-enabled apps is that virtual and real world content are seamlessly combined. The most common instantiation of this idea is to overlay virtual objects or characters on a smartphone's video feed. For instance, Figure 1



Figure 1. A virtual cat overlaid on a smartphone camera feed. The phone is able to accurately sense its movement in order to render the cat at the appropriate viewing angle and depth.

shows a virtual cat projected into a real world scene. As the user moves around in space, the phone senses the user's motion with high accuracy and will render the image of the cat at the appropriate distance and viewing angle, providing the illusion that the cat exists in the physical world.

These AR systems are made possible by spatial processing algorithms that are vastly more accurate than the simple inertial-based systems utilized in previous assistive O&M apps. The high accuracy of these systems has been driven by two key trends: the development of sophisticated algorithms for visual-inertial odometry (VIO) [29, 28, 7, 15] (which combine optical tracking using a smartphone's camera with inertial sensing for motion estimation) and the development of special purpose hardware that allows these highly computationally intensive algorithms to run on a user's smartphone with minimal heat generation and power consumption. The high-degree of motion estimation accuracy enabled by these systems, unlocks many new possible O&M apps for people who are B/VI, which we will described later.

Algorithms for Visual Inertial Odometry

In order to understand the potential of VIO for creating assistive O&M applications, it helps to understand a bit about how these algorithms function. A full explanation of VIO is beyond the scope of this document. For a more comprehensive treatment consult [19]. Approaches for VIO have been developed for both the stereo setting and the monocular (or single camera) setting. The monocular setting is directly applicable to most modern smartphones, which either only have one rear-facing camera or have a second camera that is unsuitable for use in a stereo pair. For the remainder of this section, we'll focus on the monocular case only.

VIO algorithms utilize sensor fusion to blend motion estimates generated by a camera and an IMU. An estimate of the motion of a camera can be made by tracking salient visual features (for instance, corners or other highly textured portions of the image) over the course of multiple frames. Utilizing the mathematics of perspective geometry, one can estimate the rotation and translation of the camera based on the global pattern of movement of these visual features [20]. Of particular interest

to the creation of assistive apps-based on this technology, the accuracy of these motion estimates is highly dependent on being able to track a large number of these visual features that ideally correspond to points at a range of distances from the camera and are distributed uniformly over the image. This dependency means that VIO is susceptible to inaccurate motion tracking when few visual features are able to be tracked frame-to-frame or when the visual features that are tracked represent are impoverished (e.g., all at the same depth or in the same region of the image). While some environments are simply more difficult for visual tracking, in some cases users may hold their phones in a suboptimal position (e.g., with the camera facing the ground). Assuming a suitable set of visual features is tracked, the motion estimates of the translation of the camera are only determined up to an arbitrary scale factor. This problem is known as scale indeterminacy. This indeterminacy arises due to the fact that the depths (perpendicular distance from the image plane) of the visual features are unknown [20]. For example, for any particular estimate of the translation of the camera, it is equally valid that the camera moved twice as far and the depths of the visual features were all twice as great.

The shortcomings of motion estimates from optical tracking, scale-indeterminacy and inaccurate performance in feature-poor environments, can be overcome (to some degree) by the fusion of inertial sensing data (gyroscopes and accelerometers). Gyroscopes, which provide accurate estimates of angular velocity over short timescales, can be used to refine the estimate of rotation generated by visual tracking and accelerometer data can be integrated to obtain an estimate of linear velocity to overcome the scale-indeterminacy problem. Since inertial sensors don't function optimally when subjected to extremely fast rotations or high accelerations, users need to hold their phones relatively stable to get the full benefits of VIO.

VIO in Mass-Market Smartphones

Both Apple and Google have released AR modules based on VIO. Unfortunately, the precise details of the algorithms employed by each platform are not publicly available, however, there are important high-level distinctions between these frameworks for application developers to keep in mind.

Google Tango

The first devices based on the Google Tango platform were released by Google's ATAP (Advanced Technology and Projects) division in late 2014. The Tango platform utilizes a wideangle (fisheye) camera equipped with a global shutter to enable maximally accurate visual-feature tracking. Further, the platform includes a PrimeSense depth-sensing camera. Two commercial products have been released based on the Google Tango platform: the Lenovo Phab2 Pro and the Asus Zenfone AR. While the tracking capabilities of Tango devices are superior to other platforms (discussed next), the reliance of the platform on special-purpose hardware has severely limited the adoption of the technology, leading Google to suspend the project in March of 2018 [12].

ARKit and ARCore

Apple's ARKit [24] and Google's ARCore [30], both released in 2017, provide AR-capabilities that do not require special

purpose cameras. Since these platforms utilize conventional cameras, the richness of visual features available for tracking is not as great as those available from the fisheye lenses of Tango-equipped smartphones. Based on our anecdotal observation, the narrower field-of-view results in less accurate tracking performance than the Tango. Further, since neither of these platforms have built-in depth sensing cameras, the availability of 3D information about the landmarks in the environment is limited to objects with special structure (e.g., horizontal and vertical planes). Despite their drawbacks, importantly these frameworks are capable of running on a wider share of phones than Google Tango. Further, given the high degree of preference for iOS devices among people who are B/VI [32], ARKit is the primary platform of interest for researchers seeking to develop assistive apps based on smartphone AR technology.

USER-CENTERED DESIGN PROCESS

Our lab has been working to develop O&M assistive technology for the last several years. We take a user-centered approach in which we deeply engage with people who are B/VI to understand their needs, wants, and values as well as any pain points and areas of opportunity that exist within their daily lives. As such, we've used a mixture of quantitative and qualitative methods to arrive at problem spaces along with ideas for assistive technologies to help with O&M.

Identified Areas of Opportunity

Based on background research on, interviews with, and observation of individuals who are B/VI, we identified several areas of opportunity for the development of assistive apps. The theme of high precision indoor navigation came up repeatedly during this phase of our design process. Further, the notion of being able to browse, e.g. in a grocery store or other public space, was often identified by our participants. Finally, users expressed a desire to more quickly build facility in navigating, independently, through unfamiliar environments.

Usability Factors of VIO Technology

Based on the identified areas of opportunity, along with the availability of VIO on modern smartphones, it was natural to investigate the suitability of these approaches. Since VIO is a sensor-fusion algorithm that relies, in part, on optical tracking, any assistive app based on VIO must require the user leave their smartphone's camera is unoccluded. In the designs explored in this paper, we assume that the user would hold the phone in one hand while holding their long cane in the other. In some cases the user may require handsfree operation of their smartphone. The development of handsfree methods for utilizing VIO is an area we are actively researching.

Participatory Design

Throughout the development of the apps described in this document, we utilized a participatory approach to design. This manifested itself in two specific ways. First, we worked with a college student who is blind during five, three-hour co-design sessions to both develop the basic concept and test various prototypes for our *Clew* app. Second, two of the authors of this paper are themselves visually impaired. In addition to their

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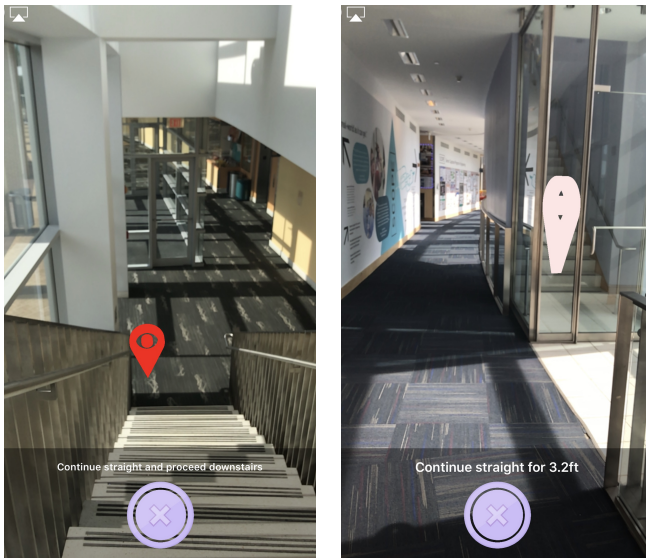


Figure 2. Two screenshots from our app “Clew.” Both images show the app in navigation mode where a user is using the app to retrace a route they have previously traveled. The text for the left image says “Continue straight and proceed downstairs” and the text on the right says “Continue straight for 3.2 feet.”

contributions to the design and implementation of the apps, their personal experiences helped guide the design process.

CLEW: AN APP FOR AUTOMATIC GUIDANCE ALONG PREVIOUSLY TRAVELLED ROUTES

1. Basic idea of the app
2. Co-design elements
3. Lack of suitability for guide dog travel
4. Path recording (including Douglas-Ramer-Peucker algorithm [14] (cool page for generating examples of the algorithm running <http://karthaus.nl/rdp/>))
5. Path following (including feedback mechanisms)
6. Pause feature
7. Usability test

VIEWSHARE: AN APP FOR OBJECT FINDING IN CHALLENGING ENVIRONMENTS

Todo: connect to idea of sense of space and building mental maps.

1. Basic idea of the app
2. Co-design elements
3. Overview of the 3D location mechanism
4. App for the searcher
 - (a) Speech interface
 - (b) Automatic snapshotting
 - (c) Guidance to object (3D versus 2D feedback)

5. App for the finder
 - (a) Description of general interface
 - (b) Special interface for triangulation
6. Usability test

DISCUSSION AND FUTURE WORK

1. Interpretation of the results
2. Future work for each of the apps
 - (a) New feature development
 - (b) Robust usability testing
3. Unresolved Issues
4. Promises of AR technology
5. Limitations of AR technology
 - (a) Accuracy
 - (b) Accessibility to voice over (minor problem, but worth mentioning)

CONCLUSION

We have presented two smartphone apps that each allow people who are B/VI to perform significant, new tasks with their smartphones. In contrast to the typical use cases of indoor navigation and image process where smartphones have provided significant value for users who are B/VI, our apps provide some of the first apps that can be used for navigation and object finding in arbitrary indoor environments. While the initial results of our usability test are promising, much more work is required to refine the developed apps to be maximally useful to the B/VI community.

Further, we have outlined several promising areas of opportunity for the development of new augmented reality-enabled apps to support people who are B/VI. We have also provided a discussion of the limitations of this technology. With a combination of the development of new algorithms, careful co-design with users who are B/VI, and the improvement of the underlying AR capabilities from smartphone vendors these limitations can hopefully be overcome to create impactful new assistive smartphone technology for people who are B/VI.

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Removed for anonymous review.

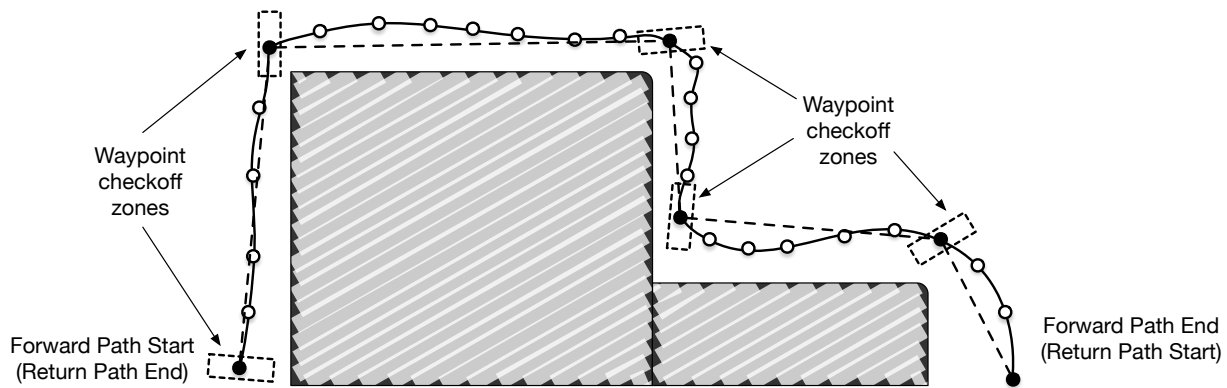


Figure 3. todo

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