Real-time Mobile-Cloud Computing for Context-Aware Blind Navigation

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Context-awareness is a critical aspect of safe navigation, especially for the blind and visually impaired in unfamiliar environments. Existing mobile devices for context-aware navigation fall short in many cases due to their dependence on specific infrastructure requirements as well as having limited access to resources that could provide a wealth of contextual clues. In this paper, we propose a Mobile-Cloud Computing approach for context-aware navigation by exploiting the computational power of resources made available by Cloud Computing providers as well as the wealth of location-specific resources available on the Internet. We propose an extensible system architecture that minimizes reliance on infrastructure, thus allowing for wide usability.

Keywords: Human-computer interaction, assistive technology, mobile-cloud computing, real-time, blind, context-awareness

1. INTRODUCTION

There are over 21.2 million visually impaired or blind people in the United States [Pleis et al.] and many more in the world. The 2009 survey by the U.S. Department of Labor [US Bureau of Statistics, 2010] shows that at all levels of education, persons with a disability were less than half as likely to be employed than were their counterparts with no disability and 75% of the blind population in the survey were not part of the labor force. The two biggest challenges for independent living of the blind and the visually impaired as stated in [Giudice et al.] are access to printed material and safe and efficient navigation. In order to navigate safely, blind people must learn how to detect obstructions, find curbs when outside and stairs when inside buildings, interpret traffic patterns, find bus stops and know their own location [Giudice et al.]. This implies being fully aware of the context of their living and working environment. Context-aware navigation for the blind is not only safely reaching a destination, but also being able to track personal items/objects of use (such as luggage on an airport carousel), and identify/interact with acquaintances on the way or at a social gathering.

Independent navigation is becoming a bigger challenge for the blind with the advances in technology, products of which such as hybrid cars (aka quiet cars), make it more difficult to rely on other senses, such as hearing, for safety [Emerson et al.]. Hence, while technology is improving the lives of the general public, it is a cause for people with disabilities to fall behind and even puts their lives at risk. Most navigation aids utilizing high technology have high price tags (a few thousand dollars), making them unaffordable. The difficulty of independent navigation in the increasingly complex urban world and the lack of affordable navigation technology cause isolation of the blind and visually impaired. Blind people, not being able to drive vehicles, are the ones in greatest need for accessible transportation services. However, as stated by Kwan et al. [2008], in many cities, people with disabilities are seldom seen using the street or public transportation due to insufficient accessibility. This situation has not changed significantly despite requirements of compliance with special accessibility rules in buildings and facilities vehicles (e.g. announcing major stops in public transportation vehicles) such as those stated in the Americans with Disabilities Act Accessibility Guidelines [US Access Board].

As reported by the World Health Organization, more than 82% of the visually impaired population in the world is age 50 or older [World Health Organization] and this population forms a

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group with a diverse range of abilities [Gregor et al.]. This diversity makes it difficult to develop a single navigation device usable by everyone. Devices requiring an involved training process are especially not appropriate for elderly people with decreasing learning capabilities.

In this paper, we propose a context-rich, open, accessible and extensible navigation system for the blind and visually impaired, bringing the quality of the navigation experience to higher standards. We propose the use of currently available infrastructure to develop an easy to use, portable, affordable device that provides extensibility to accommodate new services to help in high quality navigation as they become available. The rest of the paper is organized as follows: Section 2 discusses previous work in the area of mobile navigation aids; Section 3 describes the proposed Mobile-Cloud Computing based navigation system architecture; Section 4 elaborates on the proposed functionalities of the mobile context-aware navigation system; Section 5 mentions the privacy issues arising from the use of Cloud Computing in the proposed system along with possible solutions and Section 6 concludes with future work directions.

2. RELATED WORK

Research in assistive technologies resulted in different system proposals for the task of helping a visually-impaired or blind person navigate in indoor/outdoor environments. Research efforts in this field have mainly focused on three topics: outdoor navigation, indoor navigation and obstacle detection/avoidance.

After the introduction of the Global Positioning System (GPS) in the late 1980s, many systems based on the GPS to help visually impaired people navigate outside were proposed and some were commercially released. Among those systems are the LoadStone GPS (http://www.loadstone-gps.com), BrailleNote GPS and Trekker by Humanware (http://www.humanware.com), Wayfinder Access (http://www.wayfinderaccess.com), Mobile Geo by Code Factory and StreetTalk by Freedom Scientific (http://www.freedomscientific.com). The NOPPA [Virtanen et al.] system developed in Finland is another GPS based system used for outdoor navigation, including public transportation. The main problems with these GPS-only based systems is failure to provide guidance in cases where the GPS signal is lost, making them unusable indoors and at urban locations with tall buildings, as well as the high price for some despite limited context-awareness functionality.

Among the indoor navigation systems are Jerusalem College of Technology's system [Sonnenblick, 1998] based on local infrared beams informing the user of the names of specific places in a building and Talking Signs (www.talkingsigns.com) based on audio signals decoding names of indoor places. SWAN [Wilson et al.] by the Georgia Institute of Technology uses an audio-only interface to guide the listener along a path, while at the same time indicating the locations of other important features in the environment. Drishti [Ran et al.] is a system utilizing several technologies, including wearable computers and wireless networks, GPS, GIS, and voice recognition and synthesis, to guide blind users in both indoor and outdoor environments. The InfoGrid [Willis et al.] system, based on information loaded onto RFID tags installed at different locations inside a building, is yet another indoor navigation system proposal. More specialized context awareness systems for providing help in daily tasks also resulted from research in this field, such as Trinetra [Narasimhan, 2007] and ShopTalk [Nicholson et al.] for grocery shopping. The major problem with the previously proposed indoor navigation systems is their strict reliance on a particular infrastructure; for example, the InfoGrid system described above, will only be usable at places with special RFID tags installed. This hinders widespread applicability and adoption. Also, some of these systems require carriage of specialized equipment such as barcode readers, sacrificing portability, which is not desirable by the users.

Systems such as VOICE (www.seeingwithsound.com), Kay's Sonic Glasses (batforblind.co.nz) and Sonic Pathfinder (www.sonicpathfinder.org) use auditory feedback to create a three dimensional representation of the environment for the blind user and warn them about obstacles. There are also approaches such as MiniGuide (www.gdp-research.com.au/) using vibratory feedback to notify users of the distance to the closest obstacle. These systems have been really useful for part of the blind community, although their reliance on the correct interpretation of the provided feedback by the user makes them ineffective for some users, especially the elderly with slower learning curves compared to the young.

3. PROPOSED SYSTEM ARCHITECTURE

The basic Mobile-Cloud system architecture we propose for context-aware navigation consists of the main components seen in Figure 1. Visual context data is captured by camera modules integrated into sunglasses and fed to the mobile device through an appropriate interface (the strongest candidate for this interface is the Bluetooth technology due to proven effectiveness and prevalence, but experiments with different technologies should be performed to find the most appropriate in this context). A speech interface on the handheld device takes commands from the user and context-awareness guidance is achieved with local computation on the mobile device with an integrated compass and positioning module as well as computation in the Cloud. Context-relevant feedback is provided to the user via an auditory interface on the mobile device. Machine instances in the Cloud are reserved for running different context-awareness tasks, each of which acts as an integrator of context relevant data from the mobile device and various resources on the Web to provide accurate guidance.

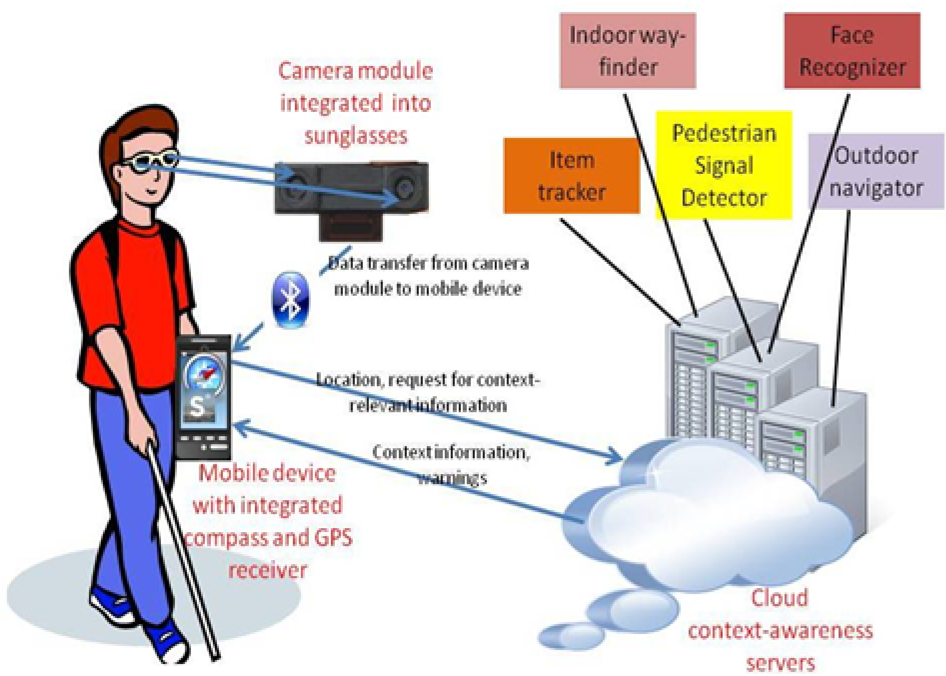

Figure 1: Broad view of the proposed system architecture.

The details pertaining to each of the main architecture components are as follows:

Positioning: Accurate determination of the exact location of users has been a major problem in the development of complete (both indoor and outdoor) navigation devices. Due to the unavailability of the Global Positioning System (GPS) signals at indoor environments and urban places with tall buildings, the navigation architecture we propose does not rely solely on GPS for positioning. Instead, the positioning module in the proposed system will leverage GPS, Wi-Fi access points and cell tower triangulation to provide the greatest accuracy in positioning.

The current strong candidate for the positioning module is that developed by Skyhook Wireless (www.skyhookwireless.com), whose core engine collects raw data from Wi-Fi access points, GPS satellites and cell towers with advanced hybrid positioning algorithms. Skyhook Wireless also provides Software Development Kits for major smartphone operating systems, allowing for easy integration into the proposed system architecture. Additionally, the system will utilize the compass integrated into the mobile device to determine the direction the user is facing and to correctly position the user at places like urban intersections.

Mobile Platform: Android is the mobile platform on which we have chosen to build context-awareness navigation functionality, due to its open architecture, support for multi-tasking and accessibility features. Android based devices come with integrated speech recognition and text-to-speech engines that will be of help for the development of an easy-to-use interface for the blind users.

Cloud Platform: We have started initial experiments in the Amazon Elastic Compute Cloud (http://aws.amazon.com/ec2/) due to its proven robustness. However, with the proliferation of Cloud Computing, new providers will continue to become available. Experiments with different providers should be performed to determine the most appropriate one for the purposes of this system in terms of efficiency, reliability and cost.

Camera Module: As opposed to using the native camera of the mobile device, the proposed system employs camera modules integrated into glasses to be worn by the user, considering the fact that the placement of the camera is of vital importance for collection of context-relevant data and an eye-level placement is the most natural. The best option for these modules will be the time-of-flight camera technology. Time-of-flight range cameras are a new technology of great use in real-time three-dimensional imaging. The technology has been utilized successfully in several fields including curb and ramp detection for safe parking [Gallo et al.], mobile service robots for collision free manipulation of particular classes of objects [Grundmann et al.], obstacle detection for autonomous ground vehicles [Bostelman et al.] and graffiti detection [Tombari et al.]. These cameras provide real-time depth information about pixels of a captured image, by emitting a modulated near-infrared light signal and computing the phase of the received reflected light signal [Ringbeck et al.]. As stated in [Hussmann et al.], time-of-flight range cameras offer numerous advantages over the stereo vision technique for detecting obstacles employed commonly by previous research in the field. These cameras also offer simpler and efficient processing compared to other range scanners such as [Sheh et al.], obviating the need to continuously scan the environment to construct three dimensional representations of objects. The camera modules and vision chips are made available by manufacturers at decreasing prices with the advances in the underlying technology (the next generation of time-of-flight cameras by PMDTechnologies have an estimated price of under $30), which is promising in terms of making a navigation device with integrated camera sensors affordable. Currently available time-of-flight cameras provide ranges of about 10 meters and high frame rates of about 100 frames/second making them even more attractive for various context-awareness tasks such as obstacle detection and face recognition. Use of the time-of-flight camera module will not only enable us to detect nearby obstacles, but also those at a distance, providing greater safety especially in the case of dynamic environments with fast moving objects that the user cannot easily recognize using senses other than vision (such as electric cars). Additionally, the depth information provided by the module will facilitate detection of elevation differences, making it possible to recognize important aspects of the environment including sidewalks and stairs in real-time.

4. SYSTEM FUNCTIONALITY

The following subsections elaborate on the functionalities the proposed system aims to provide for context-aware navigation of the blind.

4.1 Outdoor Navigation

Outdoor navigation is one of the most researched topics in assistive technologies for the blind and visually impaired. Although the main task of guiding a person from an origin to a destination is easily achieved with any device with a GPS receiver and navigation software, full context-awareness during navigation should ideally include other elements such as crossing guidance at urban intersections, detection of moving/stationary obstacles and identification of bus stops. Guidance should be unobtrusive, integrating all of these tasks in the main navigation task, without requiring the user to perform any special action. Among the challenges involved in this task are the accurate and real-time identification of specific classes of objects (such as pedestrian signals) and real-time integration of data from multiple resources to be presented to the user in a way without causing any confusion.

One problem to be solved as part of the outdoor navigation task is the integrated support for guidance for crossing at urban intersections. The ability to detect the status of pedestrian signals accurately is an important aspect of providing safe guidance during navigation. The inherent difficulty of the problem is the fast image processing required for locating and detecting the status of the signals in the immediate environment. As real-time image processing is demanding in terms of computational resources, mobile devices with limited resources fall short in achieving accurate and timely detection. An accurate pedestrian signal status detection service would benefit not only the blind and the visually-impaired, but also the color-blind as well as systems like autonomous ground vehicles and even careless drivers. This problem has been studied by many researchers including [Charette et al.], [Crandall et al.], [Ivachenko et al.], [Kim et al.], [Shioyama et al.] and [Uddin et al.]. The major shortcoming of some of the previously proposed approaches is their reliance on a low-portability computation device for the necessary image processing and yet others are lacking the universal design principle by limiting their training data to a specific set and draining the battery of the mobile device by running the detection algorithm on the device. These approaches also require the user to take a picture/do a video recording at the intersection, although the picture taken by a blind user may not be able to capture the pedestrian signal or crossing. On the other hand, although the approach proposed in [Bohonos et al.], not relying on image processing, is promising for accurate detection, it requires installation of special hardware at pedestrian signals. This limits its use to a very small area.

Our approach for development of a pedestrian signal detector uses an Android-based mobile phone and a crossing guidance algorithm running on a machine instance in the Amazon EC2 [Angin, "A Mobile-Cloud Approach"]. Crossing guidance is integrated into an outdoor navigation application, WalkyTalky, released by the Eyes-Free group at Google. The flow of actions in the proposed system as seen in Figure 2 is as follows:

(1) Android application captures the GPS signal and communicates with the Google Maps Server to detect the current location of the blind user.

(2) Once the application detects that the blind user is at an urban intersection, it triggers the native camera to take a picture (or multiple consecutive pictures) and sends the picture to the server running on the Amazon EC2 Cloud.

(3) The server does the image processing, applying the Pedestrian Signal Detection algorithm (described below) and returns the result as to whether it is safe for the user to cross.

In order to make the detection more accurate, we enabled the Compass function in the application. The purpose of using the Compass function is to obtain the heading direction of the blind user. Consider the case presented in Figure 3: A user may just go pass an intersection but not plan to cross it. With the heading direction information, the application can detect this case and not trigger the camera to avoid waste of resources.

The pedestrian signal detector of the developed system uses a cascade of boosted classifiers based on the AdaBoost algorithm [Freund et al.] that is popular for real-time object recognition tasks and haar-like features [Lienhart et al.] to detect the presence and status of pedestrian

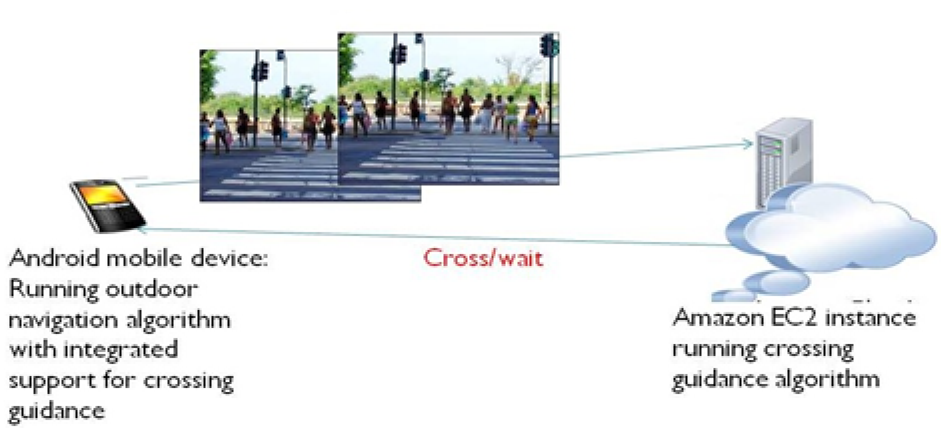

Figure 2: System architecture for pedestrian signal detector.

signals in a picture captured by the camera of the Android mobile phone. We are currently investigating the effectiveness of a multi-cue algorithm in providing accurate guidance to the user at intersections. As seen in figure 4, the presence of contextual clues, including other pedestrians crossing in the same direction, a zebra crossing and the status of traffic lights in the same direction provide additional information to make an accurate decision about whether or not the user should cross. With the help of Cloud Computing, we will be able to run all detection algorithms (those detecting the state of other contextual cues) in parallel to make a more informed and conservative decision at the crossing. Another important aspect we will take into consideration in development of the detection algorithm is the universal aspects of pedestrian signals. As signals in different countries and even different cities can be dramatically different from each other, it will be important to focus on the common features at the image processing stage, instead of training the detector with a dataset of signal images that may not be comprehensive.

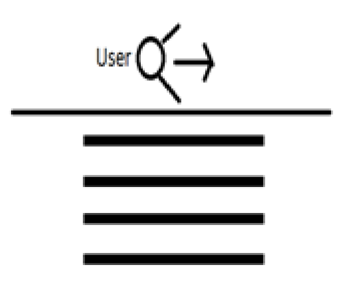

Figure 3: User at intersection.

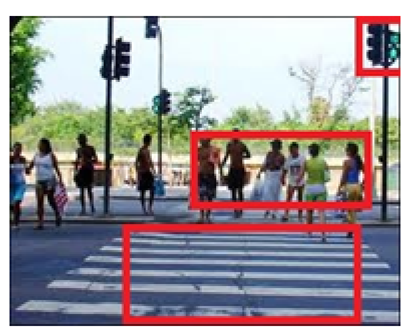

Figure 4: Cues to help provide accurate crossing guidance at an intersection (image from http://news.bbc.co.uk).

The two most important aspects of the pedestrian signal status detection problem are timeliness of response and accuracy. The real-time nature of the problem necessitates response times of less than 1 second, while high accuracy of detection should be achieved to ensure safety of the user. Experiments were performed to test the response time of the pedestrian signal detector application developed. Test data used in the experiments consists of pictures at outdoor locations at the Purdue University campus, which include scenes of different pedestrian signals. The application developed was installed on an Android mobile phone, connected to the Internet through a wireless network on campus. The sample task in the experiments involved processing five different resolution level versions of pictures. The average response times that were determined by the time period between capturing a frame and receiving the response from the server running at Amazon Elastic Compute Cloud about the pedestrian signal status, were measured for each frame resolution level as determined by a Java platform-specific measure. A resolution level of 0.75 stands for the original frame as captured by the camera, whereas the lower resolution levels represent compressed versions of the same set of frames, where image quality falls with decreasing resolution levels. The response times for different resolution levels are seen in figure 5 below. Response times for the original frames are around 660 milliseconds on average, which are acceptable levels for the real-time requirements of the problem. We also see that response time decreases further when lower-quality, compressed versions of the frames are sent to the remote server instead of the originals.

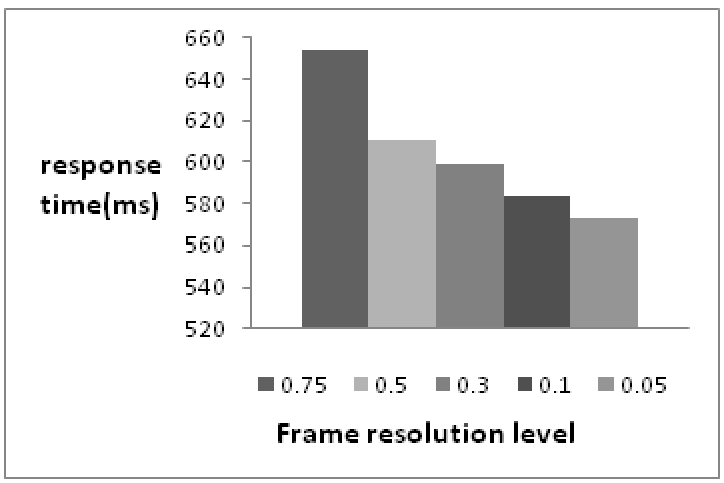

Figure 5: Response time experiment results.

4.2 Indoor Way-finding

Indoor navigation in unfamiliar environments is a difficult task even for people without visual impairments. Blindness makes this task harder with the added complexity of the presence of obstacles, stairs, doorways, etc. Accurate positioning is one of the main challenges faced by indoor navigation aids, while another major challenge is the absence of maps such as those available for streets. The absence of GPS signals indoors necessitates the use of some other positioning technology, the common one being Wi-Fi tracking. However, Wi-Fi has been shown to provide accuracy at most at the room level [Correa et al.], which is not sufficient for more refined tasks such as going to a specific seat in a specific room.

A Mobile-Cloud approach for indoor navigation has the advantage of being able to combine information from many resources to guide the user to find his/her way in an unfamiliar indoor environment. Whenever maps of the location in question are available online (The Micello company is already mapping important indoor locations worldwide), they can be used for guidance and in other cases image processing will help to detect people in the surroundings to ask for help or optical character recognition will help detect signs in the building leading to various places. Use of Cloud Computing also makes it possible to form a large online database of places visited by different users, such that after the first visit to that place, different features of the place can be logged in the database for use at subsequent visits to the same place.

Another problem named "way-back machine" by Curtis Chong, President of the Computer Science division of National Federation of the Blind, involves a blind person's finding his/her way back to a specific seat at a banquet without needing help from other people. With the requirement of no reliance on a particular infrastructure to achieve this task, the most feasible method will be to use information from the compass and accelerometer already integrated into most Smartphone devices in the market today.

4.3 Social Interaction

The blind and visually impaired people have limited opportunities for social interaction compared to those without visual impairments. Aiding social interaction for blind people has not received as much attention by assistive technology researchers as other topics, such as indoor/outdoor navigation, although it is a major component of context-awareness except for a few proposals including a system using a haptic belt to convey non-verbal communication cues during social interactions to individuals who are blind [McDaniel et al.]. Identifying familiar people in the immediate surroundings is a significant aspect of context-awareness and a system capable of this task is highly desirable by the blind, as it is expected to help with social interaction. Recognizing gestures makes communication even more effective.

Research in face detection mainly built on the state-of-the-art Viola-Jones algorithm [Viola et al.], has proven quite successful and is utilized by many real-world systems today, such as digital cameras and online social networks. The release of depth cameras (such as the time-of-flight range camera described in Section 3) is promising for further advances in the field of face recognition, as these cameras provide a three-dimensional pixel map of the face and make it easier to detect certain facial features with the extra information of pixel depth.

We believe robust person recognition can only be achieved with a combination of clues indicating the presence of a specific person in the immediate environment instead of solely relying on face recognition. One of those clues is the current location of a person as determined by the GPS and another one is the information that can be retrieved from online social networks that the person is a member of. This multi-cue approach to person recognition is made possible by using the combined resources of Mobile and Cloud Computing. Keeping track of the location of a person is a violation of privacy. However, applications such as Google Latitude (www.google.com/latitude), that allow tracking friends with their consent will prove very useful for the task of person recognition.

We propose a Mobile-Cloud based system for person recognition with a face recognition algorithm running in the Cloud and where an Android phone is used to capture an image of the environment and send it to the Cloud server for matching against a dataset of friends' pictures for a specific person. Higher performance is expected upon extension of the system to include location information retrieved using Google Latitude as well as data mining performed on the profiles in the user's social network to figure out patterns such as the frequent co-occurrence of specific people at the same location or information as to where a specific person currently is. User privacy will be preserved as only public profiles and limited profiles to which we have access authorization will be mined.

4.4 Object Recognition

Real-time and accurate classification of objects in highly complex scenes is an important problem, having been the recent focus of attention of the Machine Vision community due to its many application areas. A solution to this problem is particularly significant for the blind and visually impaired, as they have great difficulty reaching desired objects especially in unfamiliar environments. While boosting methods with the sliding window approach provide fast processing and accurate results for particular object categories, they cannot achieve the desired performance for other more involved categories of objects. Recent research in Computer Vision has shown that exploiting object context through relational dependencies between object categories leads to improved accuracy in object recognition. Integration of the pair-wise co-occurrence frequencies of object categories has proven effective to classify objects when the categories of their neighbors in the scene are known. While efforts in collective classification of objects in images have resulted in complex algorithms, the real-time nature of the problem requires the use of simpler algorithms with accurate results. Use of Cloud Computing is promising for a real-time solution to this problem, as the user will no longer be limited to the computational power of a mobile device for object classification in highly complex scenes and will be able to utilize the high processing power of the Cloud resources to obtain accurate results.

5. PRIVACY ISSUES

In today's world of growing security and privacy concerns, blind and visually impaired people are even more vulnerable than others. Dependence of the blind on people they do not know could cause problems if the people pretending to help them mislead them for their own benefit. Designing systems that increase independence of the blind and visually impaired is becoming increasingly important for protecting their privacy and security. While a Cloud-based architecture, as described above, is promising to provide an independent, thus more secure system for context-aware navigation of blind and visually impaired users, it introduces other concerns due to data submitted to the cloud for processing and/or storage. Below we list the main privacy challenges pertaining to the use of Cloud Computing in providing context-awareness to the blind.

Location Tracking: Location tracking is an essential component of any context-aware system, as the location of a user/device provides a wealth of clues about the immediate surroundings. Navigation devices operating today use the Global Positioning System (GPS) to get periodic location updates for route planning to the desired location as well as for rerouting in cases where their user fails to follow the given directions. Using a Web service to achieve a location-based task-such as finding the nearest location of a desired object category (e.g., the nearest pharmacy)-is a common need. When submitting their location information to the cloud, a blind user (and, in fact, any other user) could have security concerns that a malicious party could use this information to locate the user and harm or exploit the user for his/her own benefit. Therefore, any location data submitted to the cloud for a service invocation should not be linkable to the identity of the user of the service.

Social Network Information: Real-time recognition of the people among a blind user's contacts, as well as mediating communication with those contacts, would mainly rely on processing data in the Cloud, as the mobile device would be incapable of storing and quickly processing the data to suit the needs of this kind of application. Submitting information to the cloud about the contacts of the blind user however, gives rise to further privacy concerns, not only for the main user of the service, but also for many other people related to him/her. The data submitted could include pictures (of the people in the immediate environment of the user), phone number (which could be of use in cell-phone based tracking) and address (to deduce the likelihood of a person's being at a specific place at a specific time) of a contact, which are all part of personally identifiable information. The service invoked could even use more specific information mined from social networking websites such as Facebook, from the non-public profiles of the user's contacts that would then be at risk of being accessible to people without proper authorization. For example, for the task of recognizing people from their pictures stored on a blind user's mobile device, image processing would need to be performed in the Cloud on those pictures. In such a scenario, the user should have the option of only sharing the pictures anonymously, not allowing for the tracing of any links either to the actual identities of the contacts or to their relation to the user.

Remote Vision: The cloud-based navigation architecture described above makes it possible for outside authorized users to visually keep track of a blind user (upon his/her consent) to provide additional help in cases where human guidance is needed. This kind of task requires continuous recording of the surroundings of the user by a wearable/integrated camera and broadcasting of the recorded video in real-time on a dedicated Web site. It is vital that the recordings are only accessible by authorized users and the anonymity of the blind user is preserved, i.e. not linkable to the recordings, as these videos would reveal a lot about the places visited by the user as well as actions taken under different circumstances. The video captured could also be stored in the Cloud without the user's consent and exploited by people who have access to it. One solution to this problem is to send individual independent and encrypted video frames to the Cloud for broadcasting, none of which would be linkable to the blind user and can only be decrypted by the person providing guidance to the user.

Inferring Long-term Patterns: A major concern of a blind user of Web services is the long-term storage (without the user's consent) of data submitted to the Cloud. Stored data could be mined for user's long-term behavioral patterns, providing a wealth of information to malicious people. As an example, a blind user's route planning queries could be linked with his/her identity, allowing inference of the locations visited frequently by the user, possibly at regular times of the day.

The Mobile-Cloud navigation architecture we propose requires work on developing privacy preserving algorithms for communication with the Cloud to provide techniques for selective disclosure of information and anonymization, addressing the above stated issues. We have recently proposed an entity-centric approach for identity management in the cloud [Angin, "An Entity-Centric Approach"] that is based on: (1) active bundles-each including a payload of PII, privacy policies and a virtual machine that enforces the policies and uses a set of protection mechanisms to protect themselves; (2) anonymous identification to mediate interactions between the entity and cloud services using the entity's privacy policies. With this approach, the user gains control over the information shared with different parties and any data is destroyed if in the hands of an unreliable party. We will continue to experiment with the effectiveness of the proposed system in real-world scenarios including the context-aware navigation system we propose as the protection of the privacy of a blind user is of utmost importance.

6. CONCLUSION

In this paper, we proposed an open, extensible architecture to enable context-aware navigation for the blind and visually impaired. The proposed system is based on a collaboration model between everyday mobile devices, the wealth of location-specific information resources on the Web, and the computational resources made available by major Cloud Computing providers. Our architecture allows for richer context-awareness and high quality navigation guidance. We discussed major possible functionalities of the proposed system and showed promising results for real-time responses from the proposed architecture in the context of a pedestrian crossing guide.

Future work on the navigation system will involve efforts in many different aspects including robust obstacle detection and person recognition, integration of important context information into route planning such as dynamic/static obstacles information as well as infrastructure-independent indoor route planning.

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