A Survey of Mobile Phones Context-Awareness Using Sensing Computing Research

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A SURVEY OF MOBILE PHONES CONTEXT-AWARENESS USING SENSING COMPUTING RESEARCH

Shaukat Ali*, Shah Khusro*, Laiq Hasan**, Asif Ali Khan**

ABSTRACT

Recent technological advancements have not only emerged mobile phones as the key computing and communication platforms for performing individual's daily activities but have turned them into global sensing devices as well. Mobile phones sensing is a novel mobile phones context-aware computing paradigm enabling mobile phones to discover and capture peoples' contextual information, paving the way for the development of cutting-edge context-aware applications. Mobile phone sensing is old wine in a new bottle, having its roots extended from context-aware mobile computing. Mobile phones sensing capabilities can be exploited for developing context-aware applications to answer a number of real-world problems belonging to different sectors including automatic road condition detection and traffic monitoring, social networking, environmental pollution monitoring, and healthcare monitoring etc. This paper presents a comprehensive survey of research efforts contributed by researchers, organizations, and academia emphasizing on using mobile phones sensing capabilities for developing effective context-aware applications. The readily available knowledge is organized and classified effectively to give insight knowledge about the phenomena. We believe that this paper will serve as a compact platform for researchers and learners to shine their understandings and address the open issues and challenges which exist or can emerge in this novel paradigm. A number of research dimensions are also highlighted to help researchers in finding research topics.

KEYWORDS: *Context, Context-awareness, Mobile Phone Sensing, Context-aware Computing, Security and Privacy*

INTRODUCTION

Mobile phones (mobile phones and smartphones are used interchangeably in this paper) were originally designed with the sole purpose of voice-based communication, but today's mobile phones have been proven as the complete computing platform having the same computing and communication capabilities as other state-of-the-art computing platforms (e.g., PCs, laptops, and iPADs etc). In addition to technological advancements (e.g., processing power, memory, and user interface etc.) and highly sophisticated programmable multitasking operating systems (e.g., Android, iOS, and Windows Mobile etc.) support, mobile phones have been incorporated with a rich set of highly sophisticated and powerful general purpose and special purpose sensors. Special purpose sensors includes acceleration/orientation sensors (i.e. accelerometer and gyroscope), direction sensors (i.e. digital compass), location sensors (i.e. GPS), proximity sensors, and ambient light sensors etc., whereas, general purpose sensors includes sound sensors (i.e. microphone), and image sensors (i.e. camera) etc[1]. New exciting areas of research including data capturing, data mining, data inferencing and modeling etc have been opened by mobile phones due to their small tiny size, ample processing power, data communication capabilities and ubiquitous application in today's modern world[2].

Context-acquisition and context-awareness are the core technologies emerged in the ubiquitous computing paradigm and have attracted the extensive attention of both industry and academia. Context acquisition is aimed to understand users through extracting information related to users' position, time, physical properties (e.g., temperature, and heart beat etc.), and general parameters (e.g., specific device carried by a user etc.). The term "user context" defines the situation of a user by using its location, activity, environment, and preferences etc[3]. Devices capable of understanding users' contexts fit into the vast framework of context-awareness. Context-awareness refers to the ability of a system to automatically adopt itself according to users' environments and requirements by providing appropriate information and services without requiring their active interaction[4]. Thus, context-awareness offers numerous advantages and possibilities for new applications.

To extract context, sensors are needed to be embedded into peoples' lives. Mobile phones equipped with sensors can be used effectively for context acquisition

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as they would not need any extra cost. They are ubiquitous and have a number of advantages over unattended stationary wireless sensor networks: They are:

a. Sensing hardware deployment and providing it with power and network would have been already taken care by the users

b. Mobile phones can provide coverage in areas where static sensors are difficult to deploy and main

c. Applications' functionalities can be enhanced using human assistance to mobile phones (.e.g., focusing camera at a target object to be sensed etc[5].

Apart from them, mobile phones with embedded sensors have potential advantages including: mobile phones are carried by a large percentage of the population in most of the countries, data collection using mobile phones are energy efficient as compared to sensor networks, and provide smart platform for context data manipulation (i.e., such as sensing, processing, storing, and transferring etc.) With the growing maturity of computing and communication capabilities, and using mobile phones sensors for context-awareness, developing cutting-edge real-world people-centric mobile phones sensing applications are gaining high speed adaptation in a variety of sectors such as healthcare monitoring[7-10], roads and transportation modes monitoring[11], security monitoring[12-14], environmental pollution monitoring[6,15], social networking[16-18], automatic traffic accident detection[19], people's motivation and persuasion [20] and physical activities monitoring[10, 21, 22] etc. Collectively, they have created a novel research field known as mobile phone sensing[23].

Wide spread adaptation of mobile phone sensing by the research community is characterized due to[23]:

a. The availability of small, tiny, lightweight, and cheap sensors that could be very easily embedded into mobile phones to derive users' experiences

b. Open and programmable nature of modern mobile phones can provide effective platform for developing new smart and disruptive sensing applications

c. Ability of mobile phones to communicate with online social networks (e.g., Facebook, Twitter, and MySpace etc.) for sharing users' activities data with social networking friends

d. The availability of app stores by the mobile phones vendors for helping developers in making their application available to a wide range of population around the globe

e. Enabling developers to offload large-scale sensors data to backend servers for analysis and performing other resources intensive tasks.

Mobile phones technological advancements have opened a new area of mobile phone context-awareness where mobile phones' sensing capabilities can be efficiently utilized to recognize a user's context such as who a user is, what a user is doing, where a user is, and with whom a user is staying etc. However, success of mobile phones context-aware systems largely depends on their ability to derive data from sensors which should describe a user's context accurately without requiring user's explicit intervention[24]. However, mobile phones context-awareness is in its infancy and suffers from a number of technological (i.e., software, and hardware etc.) and non-technological problems.

In this survey paper, a detailed overview of the mobile phones context-awareness using sensing is presented by summing up the existing literature from the different fields of mobile phones context-awareness using sensing. Our main contributions of this paper include:

- The prime contribution includes the study, organization, summarization, and presentation of the on hand research literature related to using mobile phones sensing capabilities for exploiting context acquisition as well as context awareness. The gathered knowledge is organized and presented in a unique chronological order to be helpful for the learners in finding relevant knowledge in a single platform.

- The existing mobile phones context-aware applications are classified and organized into different categories depending on the contexts and the problem areas they address.

- A number of technological and non-technological issues in state-of-the-art technology are identified as well as a list of recommendations is made, which could be helpful for researchers in finding new research dimensions.

The rest of the paper is organized as follows. Section 2 provides a brief overview of context-aware computing. Section 3 discusses mobile phones context-acquisition using sensing comprehensively. In section 4, we describe different ways of representing/utilizing the contextual information sensed by mobile phones. A number of problems/issues related to mobile phones context-awareness are briefly described in section 5. Finally in section 6, conclusions are drawn and elaborate a number of future challenges and recommendations.

CONTEXT-AWARE COMPUTING

Context-awareness can be described as having knowledge regarding users'/devices' states including situations, locations, and surroundings etc. Context-awareness term was first used with pervasive (ubiquitous) computing by Schilit et al.[25] and defined as an application changing its behavior according to its location, surrounding objects and people. Context-aware computing is concerned with computing devices capabilities to sense aspects of users'/devices' local environments, interpret, and respond to them accordingly. Abowd et al.[26] has related context-aware computing with the ability of a system to provide task related information or service to a user using information from his/her context. They classified context-aware computing into two categories of using context, and adapting to context. Using context is more general and refers to the capability of computing devices to provide maximum flexibility in real-time sensing and detecting, interpreting, and answering to variations in a user's as well as the device's local environments. Adapting to context is more specific and refers to that a context-aware application should be able to monitor environmental sensors, automatically provide information, and dynamically change his behavior based either on the context, or according to user predefined guidelines or according to a user's current interest or activity etc. which allow him to select from a range of physical or logical contexts.

Chen et al.[27] extended the definition of context-aware computing for mobile applications which can be equally applied to mobile phones applications with certain advancements due to inherent features of mobile phones. Mobile phones context-aware computing can be classified into active and passive context awareness. Active context awareness is where applications automatically adapt to discovered context and changes their behavior accordingly. Passive context awareness is where applications informs concerned users about a fresh or uploaded context or make the context persevere to be retrieved by users afterward. In mobile phones, applications can acquire context using sensors. To detect context built-in mobile phones sensor can be used as well as sensors have to be embedded into peoples' lives which should satisfy three requirements: easy to deploy, easy to use and non-intrusive[28].

A mobile phones context aware application normally consists of three components[29]

a. Set of sensors for capturing contextual information

b. Set of rules for governing behavior according to contextual information

c. Set of actuators for generating responses.

Mobile phones context-aware computing is found fruitful in a variety of application areas for performing a wide array of services and making the devices calm as possible through lowering unnecessary interactions of users with devices.

Despite of advancements in mobile phones technology, mobile phones are still limited in resources[23] (i.e., processing power, memory, battery power, bandwidth, storage, and sensing etc.). Therefore, context sensing using mobile phones sensors is still facing with great problems such as energy wastage, privacy and security and accurate context sensing. Furthermore, state-of-the-art mobile phones platforms are quite smarter for low-level sensors data but are experiencing difficulties organizing low-level sensory data into coherent and expressive representation of high-level context descriptions[3]. Therefore, we have to tradeoff accuracy for low resources consumption by developing procedures requiring minimum computations and sensors data. Similarly, for effective and faster development of mobile phones context-aware applications, commonly agreed frameworks are needed confirming to two major goals:

a. Applications should be easier to design, test prototypes, and should support speedy iterative development processes

b. End-users should be empowered to build their own applications easily[30]

MOBILE PHONES CONTEXT-ACQUISITION USING SENSING

Mobile phone sensing along with mapping applications have become very widespread due to the availability of affordable and portable sensing hardware in mobile phones. Several state-of-the-art research projects have leveraged mobile phones' communication, computational, and sensing etc. capabilities for capturing and manipulating environmental information. Modern mobile phones are accompanied with a number of embedded sensors, whereas, a few more sophisticated sensors are expected to be added in the next generations of mobile phones[1, 23]. Mobile phones can use these sensors for a number of sensing capabilities such as detecting user location, measuring ambient light, sensing device orientation, recording high-quality audio and sensing geomagnetic and velocity etc[1]. These sensors collectively turn a mobile phone into a more flexible and broadly available sensing method. Users can use them to create, take care, protect, control, and publish data[5]. The combination of mobile phones and sensors can be achieved in two ways:

a. Embedded sensors are provided as integral parts of mobile phones and mobile phones APIs are used to access them making a mobile phone as a sensor itself

b. External sensors will be connected and provide information to mobile phones through some wireless networking technologies (e.g., Bluetooth etc.) for processing and analyzing by the mobile phones.

In the future, it is believed that mobile phones will be surrounded by a number of different external sensors with different tasks and their architectures might also be changed that is instead of simply forwarding the sensed data, it will be processed by the future generations of sensors before sending them to the mobile phones[1]. Table 1 summarizes the sensors (i.e., internal/external) available in state-of-the-art mobile phones and their possible applications in context-aware systems belonging to the different fields of human lives. However, mobile phone context-awareness using sensing is still in its early age and needs common/standardized methods for data collection and sharing to be developed[23].

A. Mobile Phones Low-Level Context Sensing

At present, a number of applications have been devised by the research communities, academia, and organizations demonstrating the mobile phones capabilities of capturing a plethora of low-level contextual information which could be used explicitly and collectively for generating productive results such as helping obese people in controlling their weights and helping drivers in determining road and traffic conditions etc. Sensors integrated in mobile phones are rich enough for capturing people's low-level contextual information. Summarizing the available literature, they are classified under the following headings.

1. Location Context:

Since location is an important element of a context, therefore, most of the context-aware application especially location-aware applications need reliable location-tracking system. Personal Navigation Systems (PNSs) are context-aware which uses positioning capability and navigation functions for providing location information to users using mobile devices[3].

Global Positioning System (GPS) is the common method for calculating locations information. GPS was originally developed for military use but in 1980 it was made available for public use. A GPS receiver captures information from GPS satellites and calculates a user's exact location using triangulation. With reduction of GPS signal degradation by US Government improved, GPS accuracy is improved to 10 to 20 meters (10 times more accurate than before)[27]. However, despite of improvements, GPS information are unreliable due to some inherent problems. Therefore, researchers have employed alternative methods for accurate location information estimations.

TABLE 1: Mobile phones sensors and applications areas

No.	Sensors Categories	Sensors	Application Areas
1	Tactile Sensors	Proximity Sensor	Detecting nearby objects in different systems such as in blind people guidance systems to help them during their walking etc.
2	Acceleration Sensors	Accelerometer Sensor	Measuring/capturing movements, angles, inclination, and acceleration information of users while conducting a multitude of physical activities, old people health care systems, automatic traffic accident detection systems, and games etc.
		Gyroscope Sensor	
3	Thermal Sensors	Temperature Sensors	Temperature data of an external environment (e.g. heat produced by traffic in an urban environment and environmental pollution monitoring systems etc.), body heat data of a user (e.g., during motional activities such as jogging, and walking in health care systems etc.), and heat data of mobile phone's internal environment (e.g., mobile phone security and protection systems etc.)
4	Image Sensors	CMOS Camera Sensors	Taking pictures of users and surrounding environment which could be used meaningfully in a number of systems such as recognizing user surrounding environment and location systems, users' authentication systems, and recognizing user's inclination systems etc.
5	Light Sensors	Ambient Light Sensor	Measuring light intensity data of surrounding environment to be used in environmental pollution monitoring systems, picture capturing systems, and weather forecasting systems etc.
		Back-Illuminated Sensor	
6	Water Sensors	Moisture Sensor	Measuring humidity or moisture level data of mobile phone external surrounding environment and mobile phone internal environment to be used in systems such as weather forecasting systems, and mobile phone fault/crash detection system etc.
		Humidity Sensor	
7	Location/Direction Sensors	Digital Compass Sensor	Measuring a mobile phone's or a user's location and direction data for using in several systems such as tourists helping systems in a new city, and soldiers helping systems in battle field or combat etc.
		GPS sensor	
8	Height Sensors	Altimeter Sensor	Measuring a user's or mobile phone's height data with respect to earth and can be used in health care systems, air traffic systems, pilot navigation systems etc.
9	Medical Sensors	Heart Rate Monitor Sensor	Measuring a user's physiological data such as heart beat rate, and pulse rate etc. for using in health care systems.
		Biosensor	
10	Voice Sensors	Microphone Sensor	Measuring/capturing voice levels either produced by different object in mobile phone's external environment or by the user for using in systems such as voice identification system, environmental pollution monitoring system, automatic traffic accident detection system, and spying helping systems etc.
11	Time Sensors	Clock Sensor	Providing and attaching time data with other contextual information captured by other sensor such as picture/video captured by CMOS Camera sensor (image sensor) to make them more meaningful for precise consumption in different applications.

• Location Estimation using GPS: Most of the mobile phones context-aware applications (i.e., MetroSense[31], DBpedia Mobile[32, 33] and WreckWatch[19] etc.) have used a user's location as the basic indicator of context. GPS can be an obvious choice of applications for outdoor positioning systems such as traffic monitoring or mobility tracking etc. However, recent investigations have shown some of the trade-offs when using GPS such as GPS's poor indoor quality, poor accuracy in dense urban area and high energy consumption[34]. GPS signal is not likely to work indoors due to a number of reasons such as low signal strength to penetrate through walls/ buildings and multi-path reflection (although reflection in some cases can allow reading inside a building but multi-path reflection makes this reading unreliable or causes fluctuations) etc. [27]. GPS energy usage is varying depending on a number of parameters, especially on the number of available satellites and atmospheric conditions[23]. Two mobile phones might be slightly physically separated from each other, yet they might be put into different contexts by the GPS. Due to these problems, it was realized to develop alternative location estimation methods which should provide fine-grained spatial information at a very high speed and should be robust, cheap, unobtrusive, and scalable.

• Location Estimation using Networking Technologies: Place lab[35] uses radio beacons such as GSM phone cell tower, IEEE 802.11 access points (APs) and Bluetooth already available in the environment instead of GPS to localize devices (e.g., mobile phone etc). Although enhancements in coverage and energy is heartening but accuracy is not given the prime importance. Coverage and accuracy depends on the types and number of beacons available in a device range and is supposed to work better in urban areas than rural areas. Experimental results have shown that with sufficient density, accuracy of IEEE 802.11 beacons exclusively can be about 15-20 meters whereas accuracy of GSM beacons exclusively can be about 100-200 meters.

• Location Estimation using GPS and other Sensors: Querying a web service using only GPS/WiFi/GSM can result in putting a user in a completely different context. AAMPL[34] assumes that augmenting GPS with some other components such as external/internal sensors, WiFi, or GSM etc. can help in fine-grained localization. Mobile phone's approximate physical localization should be coupled with context-aware logical localization. GPS is unified with Accelerometer, where GPS provides approximate localization and accelerometer readings can be effectively used in putting users into appropriate logical localization. Experiments have shown that this idea can work and can result in fine-grained physical localization where GPS (or WiFi/GSM) errors are hidden/controlled by accelerometer data about context. It was believed that test results can be improved by integrating more sensors.

2. Time Context:

Time contextual information, definitely, is not hard to capture but can be easily obtained from built-in clock of a mobile phone. Although there are different variants of time information such as week's day, month's day, year's month, and year's season etc. but mostly time of day is used in applications. Various mobile phones context-aware applications have combined time information with other context information such as time-stamping location information etc. to make them more meaningful. IYOUIT[16], mobile client uses mobile phone camera to capture photos, proactively adds other contextual information (especially time) to the photos and publish them directly on Flicker for online sharing with others. WreckWatch[19] uses time information to more accurately predict a traffic accident automatically as well as its intensity and severity. Furthermore, WreckWatch combines time information with other context information to help emergency persons in taking an appropriate action. SenSay[36] uses electronic calendar information of a user's mobile phone to determine a user's current state and modifies his/her phone's behaviour accordingly.

3. Voice Context:

Voice information has been exploited by researchers for numerous purposes such as detecting noise pollution and localization etc. Most of the researchers have used cheap and built-in mobile phones microphone for capturing noise information from an environment. Noise information can be helpful in inferring traffic condition or crowdness at public place, which eventually can be provided to other applications such as restaurant locator or picnic spot locator etc.[37]. MobGeoSen[6] has used mobile phone sensors (i.e., microphone and camera), which are connected with external devices through Bluetooth and annotations can be added interactively by users to scan their local environments for measuring the pollution levels as well as temperature conditions etc. Nericell[11] uses sensing components of mobile phones including microphone, accelerometer, GPS, and GSM radio to detect road and traffic conditions such as bumps, potholes, honking, and breaking in an energy efficient manner. Voice information recorded by built-in microphone provides rich noise information for honk-detection algorithm to estimate current traffic condition. Capturing noise pollution information unobtrusively and ubiquitously using built-in mobile phones microphone along with several challenges have been studied in[38]. Using microphone, mobile phone performance has been increased for engineers and musicians interested in recording audio in[39]. A recording system for Mobile STK Symbian mobile devices has been created demonstrating on using a mobile phone's microphone for music applications as well as synthesizing other information from voice information. SenSay[36] uses microphone along with other sensors to recognize a user's context and sets his mobile phone state accordingly.

4. Nearby Objects Context:

If a system could localize an individual or an object, it would be rather easy to figure out whom or what occurs in an individual's or object's proximity (i.e., restaurant, coffee shop, disco club etc.) by simply querying a location database or using datasets from Linked Open Data. DBpedia Mobile[32, 33] uses a number of dataset including DBpedia, GeoName, Flicker, YAGO, Revyu, GIA Factbook, FOAF, US Census and EuroStat to explore a number of information about resources locating in a user's physical vicinity through providing links to users to other resources in the Semantic Web. In MobiSem system, a context after identification is proactively, selectively, and transparently replicates relevant RDF triples about resources or object from global data sources (i.e., datasets etc.) to mobile phone's local RDF triple store which could be needed by users or application very soon.

5. Orientation Context:

Orientation of a mobile phone can be measured quite easily. Mobile phones comes with built-in accelerometer and gyroscope which senses orientation of device based on the way the device is being held by a user and adjusts the screen display accordingly, providing convenience to user to easily switch between portrait and landscape view. Accelerometer can also be used by a camera application to determine whether to take picture in portrait or landscape modes. Accelerometer can measure acceleration of a mobile phone in three axes: X, Y, and Z axis but when combined with gyroscope, it can measure motion along six axes providing pretty much rich orientation experience to the users. . Furthermore, orientation can be used as an input modality for soft-keyboard based smartphones[40]. Despite of simply changing mobile phone's display according to orientation, orientation information captured from accelerometer and gyroscope is used by researchers for a number of useful tasks. WreckWatch[19] uses accelerometer in the context of automatic traffic accident detection scenario. Activity recognition is another prominent application of mobile phone sensing. Several researchers have simulated orientation (using accelerometer) to recognize physical activities of users according to their current context. Researchers have used motion gestures (through accelerometer and gyroscope) either in two-dimensions or in three-dimensions for a number of input tasks including: navigating maps, games playing and images visualization[41], navigating through widgets on mobile devices[42], controlling cursor[43], inputting text[44], performing some task (e.g., answering a call etc.)[40] and verifying a user's identity[45]. Users are also provided with the freedom of defining their own gestures set for a number of actions (i.e., answering call, ignoring call, voice searching, and acting on selection etc.) and navigations (i.e., home screen, next, previous, pan, and zoom etc.).

6. Other Low-Level Contexts:

Sensors designed for special purposes could be used in conjunction with mobile phones sensors to sense other types of low-level contexts (e.g., temperature, humidity, and light etc.) and to provide a suitable comprehension of a user's physical context. N-SMARTS[46] uses mobile phones temperature sensor with CO and NOx sensors to measure temperature and humidity form an environment to determine air pollution in a region. Sameera Poduri et al.[47] have used mobile phones camera, magnetometer, and other sensors to determine visibility (light condition) in an environment. SenSay[36] uses light sensor to determine context (i.e., indoor/outdoor etc.) to adjust a mobile phones profile accordingly. HTC EVO 4G and Apple's iPhone 4 adjusts their screen brightness with respect to their surroundings by using ambient light sensor and Back-Illuminated sensor to increase amount of light during an image capturing to make image's element more prominent. EyePhone[48] uses human eye movements to select and execute an applications using mobile phone's camera sensor. Researchers of WreckWatch[19] project have developed a multi-sensor prototype which uses sensors to sense more about context of a traffic accident to provide a comprehensive accident profile and conveys efficient situational awareness to the first responder that he/she should comprehend the condition of vehicle and occupants.

B. Mobile Phone High-Level Contexts Sensing

Instead of simply collecting raw sensorial contextual information such as location, light, motion and noise level etc., researchers are interested in finding high-level contextual data including determining a user's current physical activity or events etc.[27]. A number of approaches could be used for determining high-level context. One approach could be the most basic of using machine vision technology, based on camera and image processing technologies. Another approach could be the use of user's electronic calendar directly to determining what he/she might suppose to do at what instant of time but users are not usually willing of filling entries about their activities into their calendar and follow their calendar schedule exactly. A third and most acceptable approach could be the use of Artificial Intelligence technologies in recognizing complex context by incorporating sensorial information from several simple low-level sensors. A new class of mobile phones' applications has been developed by both researchers and companies which could infer high-level events, activities, and context from low-level mobile phones sensors data. SenseNetworks (a US based company) has used GPS estimations from millions of mobile phones in a city for determining that what class of people are interested in what specific kind of bar or nightclub for example[23].

1. Physical Activities Context:

Activity recognition finds a prominent position within the broader framework of context awareness[49]. An activity is a person's task for a certain period of time and context is the result of a long-term activity[28]. In mobile phones sensing, activity recognition is a process where peoples' activities such as running, walking, talking, and sitting etc. are monitored and classified using mobile phones or specialized mobile devices fabricated on users' bodies or environments[23] (i.e., Mobile Sensing Platform (MSP) etc.). Such systems are called activity-aware systems. Systems that can recognize activities using sensors inspire novel user interfaces along with new applications in a number of fields including health care (e.g., fitness monitoring, eldercare support, and cognitive assistance etc.), smart environments, emergency response, surveillance and military missions. An activity-recognition system normally composed of three components[33]:

a. Sensing module which will continuously sense sensors and captures information relevant to activities.

b. Feature processing and selection which will process the raw sensors data and extract features (can be low-level content such as frequency and correlation coefficients etc. or high-level content such as number of people present etc.) useful to discriminate between activities.

c. Classification module which will use extracted features to determine an individual's current activity.

Activity recognition systems have gained attention of researchers because of the availability of low cost, robust and cheap accelerometer sensors embedded in devices like mobile phones etc. as well as many potential applications. An accelerometer sensor can estimate acceleration in three axes which is enough for easy measurement of velocity and displacement[49]. Accelerometers can be used for sensing motion, body position and postures. Accelerometers are actively used by a number of researchers for exploiting and recognizing a user context. Number of accelerometers used by state-of-the-art activity recognition systems varies where some uses mobile phones accelerometers and others uses several explicit accelerometers mounted on users' bodies who work in conjunction with mobile phones.

• Sensing Activities using External Accelerometer and Mobile Phones: Several researchers have assumed mobile devices as the ideal devices for solving the problem of recognizing and monitoring physical activities. But due to lack of technological advancements and sensorial capabilities, the earlier researchers did not consider the usage of incorporated sensors in the mobile phones. They used external sensors as data capturing devices and mobile phones as processing devices. Gyrobiro et al.[50] has created motional activities recognition system by using external magnetometer, accelerometer and gyroscope sensors in conjunction with mobile phone for monitoring and recording six activities (i.e., typing, resting, running, walking, gesticulating, and cycling) which spans for a longer period of time. The sensors were integrated in a wristwatch like Motion-Band and a mobile phone was employed to continuously collect motional activities data from Motion-Band sensors for performing aggregation, processing and transmission of sensory data to desktop computer for executing, learning and recognition processes. Information are stored on mobile phones for later retrieval with the fact that archiving current physical activity can be advantageous as search key for retrieving stored events. Ravi et al.[49] employed one tri-axial accelerometer connected with HP iPAQ (running with Microsoft Windows and carried by subjects) wirelessly over Bluetooth for recognizing activities: standing, walking, running, climbing up stairs, climbing down stairs, sit-ups, vacuuming and brushing teeth. A number of base-classifiers were used and it was found that meta-level classifier can produce better performance than base-level classifiers for activities recognition.

- Sensing Activities using Mobile Phone's Accelerometer: Several researchers have investigated the possibilities and feasibilities of using sensors enabled commercial portable mobile phones only for monitoring users' physical activities. Such systems are advantageous over accelerometer based systems because of being unobtrusive and not requiring any extra component for information aggregation and exact realization. CenseMe[18] is a phone centric sensing application which uses off-the-shelve sensors enabled mobile phones to spontaneously capture peoples' presence sensing (physical activities) and using social network portal (i.e. Facebook etc.) to share their presence with their social networks. CenseMe has used accelerometer and gyroscope for activity sensing and perform tasks such as deducing primitives from raw sensors data, presenting users' presence on mobile phones directly and uploading deduced primitives to backend servers without any external support. CenseMe found difficult to distinguish between sitting and standing activities and classifiers could effectively suffer from high frequency of false positives. Yang[51] used mobile phones built-in tri-axial accelerometer to recognize physical activities. Orientation independent features from vertical, horizontal and magnitude components about six daily life activities involving usual body movement and range of intensity levels such as standing, sitting, walking, running, bicycling and driving were extracted from acceleration. A number of classifiers were evaluated and compared; it was found that Decision Tree classifiers can result in high activity recognition with reasonable computational complexity. Furthermore, vertical and horizontal features showed good performance as compared to magnitude features. It dictated that a user's physical activities diary could be constructed using activity recognition model as well.

2. Health Context:

Mobile phones context aware computing is often used for ambulatory monitoring and remote-assisted rehabilitation. Most of mobile health monitoring systems focuses on pre-symptomatic testing and alerts peoples before any devastating situation take place. Jin et al.[52] and Chen et al.[53] have proposed mobile phones based ECG systems which can continuously monitor and record ECG information in real-time, automatically for identifying irregular CVD conditions, generating individualized cardio health summary report in plain language and classifying abnormal CVD conditions on spatial and temporal basis. HealthAware[54] is an obesity prevention application which counts the intensity of users' physical activities at real time and persuades them that how much physical activities are needed to reduce their obesity and remain healthy. SPA[55] treat chronic illness by continuously monitoring peoples' body, behaviour and environment during their daily lives using a number of external and mobile phones' internal sensors and in case of any risk, notify people to take appropriate actions.

3. Environmental Pollution Context:

Environmental pollution can be either of the air, water, soil, noise and light types. Mobile phones provide the potential for environmental monitoring for determining and monitoring the pollution level and leverages novel services. MobGeoSen[6] determines the noise pollution levels in an environment by using mobile phones' internal sensors in conjunction with external wireless sensors for information aggregation. To make the visualization of data in spatial or temporal visualization tool, the system allows users to interactively annotate data at the time of its collection which will be stored along data in visualization log file. NoiseTube[56] turns GPS-equipped mobile phone into noise sensor by collecting information from different sensors (e.g., microphone, GPS, time) and enables users carrying them to determine, locate, provide qualitative input and share their geo-localized measurements as well as personal annotation for the monitoring of urban noise pollution and the production of a collective noise map.

4. Road and Traffic Context:

Orchestrating the sensing and communication capabilities of mobile phones can help in developing powerful systems for monitoring road and traffic conditions which could be helpful to wide range of users such as an application annotating a map could be used by drivers in deciding driving conditions that would reduce stress by keeping away from the chaotic roads and intersections. Mobile phones based traffic monitoring approach is classically ideal for developing countries as it eliminates the need of existence of expensive, specialized and complex traffic monitoring infrastructures. Nericell[11] exploits the rich sensing and communication capabilities of mobile phones to detect quality of road (i.e. potholes, and bumps etc.), traffic conditions (i.e. breakings etc.) and noisiness of traffic (i.e. honking etc.). VTrack[57] calculates the routes from the imprecise data obtained from the sensors of mobile phones and helps users by providing them routes in a way to minimize travel time.

5. Commerce (Purchase) Context:

Prices of the homogenous products may vary across the different vendors even in the same vicinity and is called price dispersion in economics. Mobile phones applications are developed to provide on-the-fly price comparison to the consumers using the mobile phones sensors while relying on the online shared prices information collected and provided by the humans. MobiShop[58] leverages the sensing and communication capabilities of mobile phones to share consumer pricing information. The system provides a distributed system platform for collecting, processing and delivering of consumer products information to potential buyers from local retailer shops over their mobile phones. In addition, it might also work as an effective indirect cheapest medium for advertising retailer shops.

6. Online Social Networks Context:

With the proliferation of smartphones and increasing success to develop applications capable of accessing social network information have enabled applications to know about users' preferences, social groups, contacts and positions. Several mobile sensing applications have been developed sharing users' contextual information and experiences with friends using social networks. CenceMe[18] infers high level of states or "facts" regarding a person, which collectively determines the presence of a person (such as running, in a party, or conversion etc.) using off-the-shelf sensors enabled mobile phones and shares the obtained information using social networking portals such as Facebook, Twitter, and MySpace etc. Highlight MoVi[59] is mobile phone based video highlight system harnessing mobile phones in a social context to automatically create video highlights of social occasion collaboratively, positive to answer questions like "what happened at the party?" and this collaborative video recording can have applications in numerous fields including journalism, travel blogging, distributed surveillance and emergency response. Friendlee[60] uses ambient awareness by analysing the users' call (i.e. frequency, and duration) and messaging etc. history information to infer their intimate social networks automatically depicting a rich picture of the users' social lives. The system share a significant amount of a user's contextual information depicting his location at different granularities (i.e. street address, city, country etc.), his phone status (i.e. on/off/available/ringer/silent/vibrate) and status message, local time and weather etc. with their intimate social network and can track down a user's preferred services and businesses which he frequently use (e.g., favourite dentist, restaurant, coffee shop and health insurance etc.) and use them as recommendation to his social network.

7. Fall Context:

Unintentional falls are common occurrences of bring fatal and nonfatal injuries in people especially older people all around the world. The most probable injuries associated with falls can range from small fracture to death which could result in excessive medical costs. iFall[61] is a mobile phone based fall detection system which runs inconspicuously in the background and listens to the accelerometer to detect a fall. If a fall is detected, user is notified to restore the original position within a short period of time otherwise SMS is sent to every contact in the iFall emergency list asking them to take some necessary actions. PreFallD[62] is another mobile phone based fall detection system which runs in the background to detect fall using the accelerometer data. If a fall is detected, alarm is triggered and timer is started by the daemon service requiring a user to stop the alarm manually before a time period expires, otherwise the application will automatically and iteratively initiate voice calls and text messages up to five contacts which would be already defined by the user in his emergency contact list as per his/her priorities.

8. Human-Phone Context:

The term Human-Phone Interaction (HPI) is a renewed form of Human-Computer Interaction (HCI) whose objective is developing new techniques as well as technologies to facilitate the interaction of peoples with their mobile phones. However, HPI is more complex than HCI because of working in varying conditions due to mobility. EyePhone[48] captures eye movements and actions using the phone's front-facing camera to drive applications/functions and trigger actions on the phone. The system tracks the eye and infers its position as a user view a particular application on the mobile phone display and emulates eye blink as mouse click to activate application under view. SenSay[36] (Sensing and Saying) extracts context information and changes phone's behaviour to adapt to the dynamically changing environment and physiological states. The basic operations SenSay perform are: ringer control (off/low/medium/high), vibration control (on/off), sending SMS to caller, making call suggestions and providing access to electronic calendar.

Mobile Phones Contextual Information Modeling

Contextual information can be expressed and modeled in different ways due to their varied nature and properties[27]. State-of-the-art mobile phones context-aware systems models, organizes and represents contextual information in their own way due to decentralization. Sharing contextual information among applications or receiving context change notification by an application belonging to one system from an application belonging to another system is either impossible or not straight forward due to their different behaviors or architectures. Centralizing mobile phones context-aware applications would be rather troublesome and might have some other disadvantages such as slowing down the frequency of application development etc. Therefore, Semantic Web technologies are required to be used for building a common understanding of the contextual data captured and generated by diverse applications. In this section, we give an overview of how contextual information can be expressed by a number of mobile phones context-aware systems.

A. Mapping Location Model

Current mobile phones use geometric model (representing location using coordinates) due to their use of GPS for localization. Google Map is freely available to be accessed using APIs. An application after determining a location from GPS can easily plot information over map hired from Google Map. Such a kind of applications can be helpful in a number of ways such as guiding a tourist in exploring a new city etc. DBpedia Mobile[32,33] exactly pinpoints a user's current position and displays information (using different icons according to resource type and text) about resources (hotels, restaurants, clubs, underpasses and cinemas etc.) located in a user's physical vicinity over map. WreckWatch[19,63] maps the traffic accident location along with the path followed by the vehicle to not only help the emergency responders to locate the accident location but the other motorists as well to re-route themselves around the accident point to reduce congestion. IYOUIT[16] keeps track of a user's locations and triggers small alerts upon appearances of friends in the places over map showing approximated location along with some other additional information using his buddy map feature. mSpace Mobile application[64] makes location-based information access related to a user chosen topic of interest while he/she is on the move. mSpace Mobile has a composite interface and provides information to users queries such as "indicate me restaurant and cinemas" over a map. TravelWatch application of i-Zone platform[35] automatically identifies users modality choices, frequent routes, visited places, mobility footprints using GPS, accelerometer and electronic compass sensors and render them on map for users. MobGeoSen[6] has developed a tool to record GPS data from receiver and noise data from mobile phones' sound sensors throughout a journey into a time-stamped KML (Keyhole Markup Language) file for using with Google Earth. Upon opening KML file, Google Earth displays the track along with associated noise levels, annotations and photos. Topiary is a rapid prototyping tool for designing location-enhanced application, developed by UC Berkeley[65]. Topiary prototype can run over a mobile phone and uses Place Lab[35] technique instead of GPS for rendering position of objects on map. NoiseTube[56] uses GPS and other information captured through sensors or provided by users to create noise map indicating the noise pollution information about a region sensed.

B. Social Networking Model

Methods for communication and socialization have been changed significantly because of improvement in the Information Technology. Web based Social Networks uses web technologies for connecting peoples and organizations in a network. To fulfill the vision of online social networks, the services including instant messaging, podcasting and vodcasting, wikis, weblogs, slide sharing tools and picture as well as video sharing etc. which were bloomed using Internet are extensively used by a special bread of web sites called social networking sites. Social networking sites have been extensively integrated by millions of users around the world in their daily practices for numerous purposes such as contents sharing.

Several mobile sensing platforms/applications have investigated the sharing of users' contextual information with friends belonging to their social networks. IYOUIT[16] is a context-aware mobile digital lifestyle which captures photos, sounds as well as other contextual elements with standard mobile phones and facilitates instant (posting a single data item) or aggregated sharing of users personal experiences within online social networking communities using Web 2.0 services (e.g., Flicker and Twitter etc.) and with people defined through relationships by users among themselves (e.g., husband, wife, friend, and colleagues etc.). CenseMe project[18] is investigating ways to automatically infer users' daily physical activities and events (called sensing presence) using mobile phones and share their presence with colleagues and family members etc. through online social networking portals (i.e., Facebook, Twitter, and MySpace etc.). Friendlee[60] develops a user's social network by using information from the mobile phones and share a large amount of a user's contextual information and recommendations between social networks inmates.

Mobile Phones Context Awareness Issues

Mobile phones context-awareness, obviously, can provide elegant and economic solutions to many of the real world problems due to some of its inherent characteristics as compared to other context-aware systems. A context-aware system tends to be fruitful if it is practical and capable of accurately recognizing contexts which are performed routinely by different individual in different manners under different environmental conditions. But a robust recognition system is difficult to engineer due to certain number of constraints such as sensors should be lightweight and unobtrusive, intelligent machine learning algorithms should be developed which should require null or less human supervision and privacy issues should be properly dealt.

A. Context-Aware Applications Programming

It was believed that mobile phones would have better improvements in their computational capabilities in terms of processing power and memory etc., but the major problem which would be faced by developers in building mobile sensing applications is the lack of mobile phones' programmability[18]. Despite of introduction of advanced mobile phones operating systems, still only a handful of mobile phones are programmable providing much improved interfaces for accessing low-level sensors to developers such as android and iOS etc., but still they are not suitable for developing computationally costly common data processing components due to mobile phones' resources limitations constraints such as signal processing routines and inference routines etc.[23]. A reason of this programmer's freedom limitation could be that third party applications might jeopardize mobile phones and disrupt performing their regular/primary operations which is handling phone calls[18]. Further, to protect mobile phones from malicious attacks, mobile phones manufacturers' use rights management systems to control access to important components including the APIs for accessing the multimedia features, GPS, file system and communication via GPRS or WiFi etc.[18]. Although most of the mobile phones available in the market are open and programmable offering Software Development Kits (SDKs), APIs and several software development tools to the third-party developers but a number of challenges still remains in the development of sensor-based applications including mixed API and operating system support for accessing low-level sensors, fine-grained sensor control and watchdog timers required for developing real-time applications[23].

B. Context Polling Rate Adjustment

Context-aware applications require to be instantly notified about any change in the context. Continuous sensing would promote real-time applications but their resources demanding nature may jeopardize mobile phones and disrupt their primary operations (e.g. voice calls management, web browsing, and text etc.). Furthermore, applications would be interrupted at any time to confirm phone's regular operation which would require applications to have elegant exceptions handling and recovery features. Anyhow, a context has to be monitored (through polling etc.) regularly to send feedback (upon any change in the context) to some context service which would act accordingly. A similar context would have different properties depending on the context an object involved such as location of a person in motion will change after every second while location of a printer might not change for a year. Therefore, context polling rate is required to be customizable for different contexts either by the user or by the application at the startup time[27]. Polling rate, if chosen optimally either explicitly or implicitly will help in greatly reducing system's burden.

C. Efficient Energy Consumption Methods

In addition to generating extra burden, conitnous sensing a context can also result in draining our battery quickly. Sensors can consume a significant amount of energy while sensing, however, the energy consumption rate is variable for the sensors (e.g., GPS and Bluetooth are more power hungry as compared to accelerometer etc.). Furthermore, to effectively recognaize a context, algorithms (i.e. complex signal processing, inference and machine learning etc.) are required for real-time processing and categorization of sensors data which adds into the energy consumption rates. Similarly, a large amount of power is consumed during uploading data from mobile phones to a central location using GPRS especially when the mobile phone is away from the cell base tower. Experiments conducted over Nokia N95 have shown that a mobile phone running only with CenceMe application reduced phone's battery lifetime to just six hours which is far below than the ideal lifetime[18]. Mobile phones do not provide APIs to control power hungry sensors and to apply efficient duty-cycle strategies. Therefore, designing energy-efficient algorithms which would not only control sensor's power consumption but also enable applications to offer good fidelity and user experiences needs considerable attention from the research community. However, certain methods such as triggered sensing[11], split level classification[18], frame admission control[45] and information uploading delay[6, 18] are introduced by various researchers but still they need significant improvements to be practical.

D. Resolving Context Problems

In certain circumstances, a mobile phone may not be able to anticipate a situation accurately from the sensors data collected due to a number of problems, collectively called "context problems"[23]. Most of these problems are raised due to actions of the users as mobile phones are normally used in the manners which are impossible to be anticipated before occurrences. These problems may include: mobile phone may not be properly oriented towards an event (e.g., phone is usually kept in the pocket etc.), mobile phone may not get ample period of time to measure an event (e.g., a user may be traveling quickly in a car etc.), users' actions may disrupt or interfere other sensing activity (e.g., using accelerometer to recognize physical activity etc.) etc. Researchers have proposed solutions to these issues leveraging the co-located mobile phones such as sharing mobile phone's sensors with others to efficiently capture data about a situation or context and using "super-sampling" which means data about a situation or context is collectively used to eliminate aggregate noise from the reading[23]. Most of these issues are open and needs considerable attention from the research community.

E. Security and Privacy Issues

Respecting a user's privacy and security should probably be the most basic duty of a mobile phones context-aware system[23]. While mobile sensing enables creation of multiplicity of new applications but it can also be reason for seriously jeopardizing user privacy[66]. Key challenges associated with mobile phones context-aware systems security are: ensuring accuracy of captured information and identities (users and devices etc.) and establishing secure/secret communication[27]. Emerging mobile phones context awareness requires ensuring the secure capturing, storage and transmission of users' contextual information. Mobile phones custodians will worry about that their personal/context information might be leaked from both the data samples collected and the methodology used for samples collection[7] as well as during transmission to a remote server for processing[67].

People-centric context-aware applications poses serious privacy and security risks: privacy is breached due to unrestricted dissemination of users' sensors data, integrity can be compromised if other people might control the data originated from the sensors or if data consumer do not trust on the accuracy or timeliness of data, confidentiality can be effected due to transmission of data from sensor nodes to some gateway nodes using unsecured channels. However, context-aware applications will remain useful if availability of infrastructure is ensured[68]. People are considerably more worry about the mechanisms used for capturing sensors data and their usage, especially if the captured data is of sensitive nature such as user's location, potentially sensitive images, or speech etc. Although, methods are available which could be used for preserving privacy, confidentiality and integrity (e.g., cryptography etc.) but they are not practical for the state-of-the-art mobile phones platforms[23]. However, researchers have proposed different methods to preserve users' privacy and security such as trade-offs between user benefits and privacy intrusion[24], guaranteed privacy and both functionalities and efficiency[69], data perturbation[14], locally raw sensor data processing[8, 18, 67] etc. but they can lead to other problems such as generating exteral load on the system and high battery power consumption etc.

New privacy challenges can be posed by mobile phone sensing called second hand smoke problem[23] such as:

- How the privacy of people who are not custodians and would not be the primary sensing targets as well as the people who are custodians and would be the primary sensing targets can be protected from the accidental compromises of privacy by other people outfitted with sensors nearby[7,70]? For example, a traffic noise measuring application might sample microphone of another mobile phone if the custodian is standing at a busy city intersection.

- When peoples wearing sensors come closer to each other for collecting data from another party, how their mismatched privacy policies would be managed[23]?

MetroSense[31] project has attempted to solve these problems using the concept of anonymity and have applied k-anonymity rule. But applications of anonymity for protecting users/data privacy are considered as insufficient too by[12].

CONCLUSION AND CHALLENGES

Mobile phones context-awareness is old wine in a new bottle, exploiting the rich sensing capabilities of mobile phones for capturing contextual information for using in numerous applications in different fields of humans' lives. In this paper, we discussed state-of-the-art mobile phones context sensing and open issues as well as challenges which exists or could arise in the future of this novel paradigm. From the literature, it has been learned that mobile phones have potential for capturing, analyzing, processing, storing and disseminating contextual information paying the way for the development of cutting-edge real-world applications. Lack of infrastructure is not the primary obstacle in the path of mobile phones context-awareness using sensing as millions of users take care and carry their mobile phones along themselves. However, some of the technical challenges are the greatest barriers which are needed to be eliminated for maturing this novel paradigm. It has been found that mobile phones context sensing can be productively used in a number of fields such as environmental monitoring, healthcare monitoring, urban monitoring, traffic accident monitoring and social networking etc. of peoples' lives, which can be ultimately used to help society for bringing tremendous and productive improvements in their functionalities as a whole. It has been observed that using mobile phones sensing power to capture a complete set of low-level context for composing a high-level event, making use of the available context, discovering context accurately and efficient dissemination of contextual information are still in their infancy and needs further improvements. We believe that mobile phones context-awareness will become as prime consideration for the programmers to develop exciting applications for promoting the area of mobile phones ubiquitous computing.

Although numerous successes has been obtained by researcher in recognizing activities, predicting locations, identifying traffic accident, preserving privacy and identifying road and traffic conditions etc., which could encourage for the development of applications to bring benefits to business sectors and facilitate peoples' everyday lives. But still there are several challenges which are of potential importance and needs immediate attention from the research communities, organizations and academia. These challenges include:

- For mobile phones to effectively interpret and understand a user context and facilitate its decision making process, intelligence needed to be pushed over mobile phones. But how much intelligence should be pushed over mobile phone without jeopardizing mobile phones experiences (e.g. sending SMS, making calls, and web surfing etc.) or depleting battery?

- In addition to pushing intelligence, low energy usage and low resources usage mechanisms are needed to be developed for a number of tasks such as mechanisms for contexts inferencing, contexts classifications and machine learning. Similarly, additional efforts are needed to be performed for enabling mobile phones to accurately understanding activities and other contexts.

- A sensing application should be adoptable to customize its sensing scale. Therefore, how sensing applications should be empowered to extend their sensing scale from individual user to large community or even to the general population?

- Gaining people's trust is an important factor for the success of mobile phones based context-awareness. But people most often show concerns about their privacies. Therefore, how privacy of users' during information sharing, data mining and taking feedback should be protected?

- In spite of the recent technological advancements in mobile phones in terms of processing power, memory, storage, and display etc., they are yet not suitable for executing specialized learning algorithms and inferencing systems. Therefore, additional efforts are needed to be invested for the greater improvement of mobile phones hardware and software resources.

- In mobile phones, context-awareness is closely coupled with using sensors data. Sensors data, however, is not always in ideal form suitable for context-acquisition. Therefore, algorithms are needed to be developed for dealing with noisy sensor data.

- Using sensors more frequently for capturing and recognizing context will result into loss of battery power more frequently. Therefore, mechanisms are needed to be developed enabling mobile phones context-aware applications to deal with historical context data to derive new or existing contexts. Similarly, mechanisms using predictive methods of context acquisition are needed to be developed to help in predicting presence of contexts in the future.

- Successful sensing and inferencing process is always subject to ample time and resources which is available in ideal scenarios. Therefore, mechanisms are needed to be developed to deal with sensing and inferencing failure. Such mechanisms will assist the inaccurate data derived from sensing and inferencing to derive accurate contexts.

- Instead of using a single sensor, data from several sensors can help in accurate understanding of a user's context. Similarly, instead of using physical sensors only logical sensors should be used in collaboration to derive much more users' experiences. But the greater the number of sensors to be used results in the greater consumption of battery power which is scarce in handheld devices. Therefore, efforts are needed to be invested in finding highly smart sensors which should produce ample amount of data in short span of time while utilizing less battery power.

- Due to lack of standard models, researchers and developers usually creates mobile phones based context aware systems in their own ways. Thus creating heterogeneity, diversity, complexity and inconsistency in the domain. Therefore, shared conceptualization and standards should be specified for classifiers as well as other component that should be applicable for both small-scale and large scale experimentation and helps in the development operations.

• For declaring an application to be functional and reliable, it needs to be tested and evaluated extensively, which in turn needs an ample amount of testable data. Therefore, large-scale public datasets should be made available for evaluating advanced learning techniques, algorithms, applications and their performances.

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