Sensors and Mobile Phones: Evolution and State-of-the-Art

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ABSTRACT: Sensors can be found virtually in all fields of applications for automatic real-world data acquisition for using in plethora of decision making processes. Recent advancements have turned mobile phones from simple communication devices into complete computing devices, leveraging novel systems and services. Most of the systems have used sensors for automatic data acquisition and have gained high levels of successes. Due to the increasing use of sensors in mobile phones, today's mobile phones come with a number of sensors while experiencing the integration of new sensors in the near future. Sensors and mobile phones integration can be attributed to plenty of reasons including easy usage, cost reductions, and high productivity etc. This paper gives a comprehensive overview of sensors integration in mobile phones, sensors classification, identifies a number of available and emerging sensors in mobile phones, and outlines a number of limitations and recommendations for the research communities to address.

Keywords: Sensors, Smartphones, Context Awareness, Wireless Sensor Network, Human Computer Interaction, Smart Applications

INTRODUCTION

The advancements in science and technology have enabled computers to visualize a plethora of physical phenomena through numerical simulation which would not be possible to observe through empirical means otherwise. This trend of advancements has been prolonged increasingly to the semiconductor technology by build exponentially low-cost, high-power, and multi-functional mechanical devices called sensor nodes which would be small in size and communicate in a short distance. A sensor is an electrical transducer which takes physical property as input, translates and generates a functionality related output in the form of electrical or optical signals to be read by an observer or by a device. There are a number of sensors, applicable for different functionalities e.g. to measure humidity, pressure level, speed, motion, temperature, light, and distance etc, and can be used in land, air, space, and sea etc (Alesheikh *et al.*, 2010){Alesheikh, #2}. In the recent years, there has been a tremendous increase in the number of products, appliances, and services from a broad range of fields using sensors. Recent developments in the sensors' issues such as size, processing requirements, power consumption, and cost effective production have enabled sensors for integration in products and appliances (Schmidt and Laerhoven, 2001).

Sensors classification schemes can range from very simple to complex. One way of classification is to consider all of their relevant properties, such as stimulus, specification, physical phenomenon, material, conversion mechanisms, and application fields etc. A sensor, by definition, converts energy form one form to another. Therefore, another way of categorizing sensors could be according to the energy they detect and convert such as chemical, ionizing radiation, acoustic, electromagnetic, mechanical, thermal, and optical etc. Several features are needed to be considered while choosing a sensor including accuracy, environmental condition, range, calibration, resolution, cost, and repeatability. In a broad sense, sensors can be classified as:

Analog and Digital Sensors: **A**nalog sensor measures continuous quantities such as voltage, current, gas pressure, temperature, humidity, light, position, force, magnetic field, and vibration etc. and produces continuous values in the range from 0 to 5 volts e.g. Cadmium Sulfide cells, whereas, digital sensors produce discrete signals at output, whose values have a specific range and increases in steps producing a stair case representation when plotted on graph chart e.g. infrared detectors in Robotics etc. Digital sensors are more complicated than Analog sensors, because input is analog and output is digital. Therefore, Analog-to-Digital converter (ADC) is required to be an integral part of a digital sensor.

Embedded and External Sensors: Embedded sensors are integral parts of devices and can be accessed using pre-defined interfaces e.g. accelerometer in iPhone etc, whereas, external sensors are not integral part of devices rather they exist in the environment and devices are required to find them out and communicate with them using standard wireless protocols and communication channels e.g. Bluetooth etc. (Grauballe *et al.*, 2008).

Variety of external sensors is larger than embedded sensors and is expected to grow more in the future.
Proprioceptive and Exteroceptive Sensors: Proprioceptive sensors determine/measure physical properties related to the internal conditions of devices/systems, whereas, exteroceptive sensors obtain information from the environment outside of the device. Exteroceptive sensors can be divided into contact and non-contact sensors. Contact sensors contains the same modalities as used in proprioception and non-contact sensors contains modalities which could be used for measuring physical properties at a distance such as direction, size, intensity, and range etc.
Passive and Active Sensors: Passive sensors measures the energy generated in the environment outside the device. Passive sensors does not need power supply or battery and gain their power from the electromagnetic waves radiated by the requesting devices e.g. RFID etc, whereas, active sensors emit energy into the environment and then measure the reaction generated e.g. LiDAR etc (Grauballe *et al.*, 2008). Active sensors need power supply or battery to operate.

Sensors could be deployed all over a physical space to sense physical phenomena closely, and communicate this information with other nodes. Individual sensor nodes might by limited in processing power , storage capacity, and communication bandwidth but when used in aggregation with other sensor nodes could have substantial processing capability to measure a given physical phenomena in greater detail (Culler *et al.*, 2004). To fully exploit the sensing capabilities of sensors, they would have to be deployed densely in an environment and co-ordinate with each forming a sensor network. A Wireless Sensor Network (WSN) is a collection of wireless sensor nodes organized in a cooperative network, distributed densely inside phenomena or close to it to sense a physical phenomena, and co-ordinate with each other to accomplish a definite task (Culler *et al*., 2004). Position of sensor nodes in a WSN need not to be pre-determined making their deployment in inaccessible terrains possible. Additionally, sensor nodes can work cooperatively, and process their sensed information locally using their on-board processing capability and transmit only the required data to the nodes responsible for fusion (Akyildiz *et al*., 2002). Despite of being beneficial, WSN poses a number of interesting challenges (Ganesan *et al.*, 2004 and Culler *et al.*, 2004) including energy constraints, scalability and reliability issues, manually deployment and maintenance, collision problems due to dynamic topology, and broadcast communication technology etc.

The ubiquitous nature of mobile phones or smartphones has made them as an integral part of our lives, many people finding it impossible to envision a world without the possibility of making quick voice calls, text messaging, and mobile Internet access from wherever they might be or more specifically within the area covered by their mobile operator (Vochin, 2009). In the present world, it becomes difficult to imagine a person without a mobile phone. According to Ofcom's first quarter 2012 (Q1 2012) reports that at least 92% of adults in UK own a mobile phone. Furthermore, 81.6 million mobile users, making over a quarter of all telephone calls in UK, and 200 SMSs and MMSs are send by each person per month with more than 150 billion text message sent in 2011 (Ofcom, 2012).

Modern mobile phones have sophisticated computing platforms with an increasing number of sensing capabilities such as detecting user location, measuring ambient light, sensing device orientation, recording high-quality audio, sensing geomagnetic, and velocity etc. Today's smartphones are accompanied by a number of specialized sensors, where sensors are capable for recording reading/obtaining, categorizing analyzing, and transmitting different types of data. Thus, make mobile phones as more flexible and broadly available sensing methods. Users can use them to create, take care, protect, control, and publish the data (Center, 2008 and Kansal *et al.*, 2007). The combination of mobile phones and sensors can be achieved in two ways (Leichtenstern *et al.*, 2005): (1) embedded sensors are provided as integral parts of mobile phones or placed somewhere above the screen which would be accessed using mobile phone's APIs, making a mobile phone a sensor itself, and (2). external sensors will be connected and provide information to mobile phones through some sort of wireless networking technologies e.g. Bluetooth etc for processing and analyzing. Highlighting the benefits of sensors in mobile phones, it is believed that future mobile phones will be embedded and surrounded by a number of different sensors with different tasks and different data processing architectures (Grauballe *et al.*, 2008).

Organizations usually have to build wireless sensors networks in an area about which they want to collect data, which becomes difficult even sometimes impossible, and requires high cost etc. Sensors enabled mobile phones can provide several significant advantages over traditional unattended wireless sensor nodes or networks [1] including solves power management problems, decreases sensor nodes manufacturing cost, coverage of hard to deploy areas, human users' assistances etc. This paper is aimed to provide comprehensive knowledge about sensors, mobile phones, sensors currently available in mobile phones and future emergences, possible applications of sensors in mobile phones, and a number of challenges and recommendations in a concise format to be beneficial for the researchers in finding solutions to the existing problems and for the new researchers to understand the phenomenon for finding new research dimensions and developing fruitful applications.

MOTIVATIONAL SCENARIOS

Mobile phones subscribers at present have passed four billion marks (Center, 2008). The technological advancements and the majestic integration of sensors in mobile phones has increased mobile phones importance in humans' lives and converted its role from a simple communication device into a Pandora Box. A number of services has been investigated by the research community, organizations, and academia, who exploits the sensing capabilities of mobile phones and capture a vast amount of information regarding the environment or the people, which could be used productively in solving people's real-world problems in different domains. A number of motivational scenarios can be established describing mobile phones and sensors.

Mobile phones, by definition, do not have knowledge about a user's context. Understating and identifying a user's context .i.e. context awareness will provide novel alternatives for the interaction between the users, their mobile phones, the services, and the surrounding world. A mobile phone could recognize the context of a user using sensors and change its behavior accordingly or initiate a service automatically. For example, a mobile phone might either not accept any call or switch off entirely in situations when a user is in bathroom or in meeting etc.

A farmer normally browses national weather agencies websites or watches television to get weather information that might be of potential danger for his seeds, which is a difficult and laborious task and can sometime result in destructive situations upon not accessing the important information in real-time. Mobile phones having embedded sensors or capable to communicate with external sensors can directly obtain weather information e.g. temperature, humidity, and wind force etc. and an automatic notifications application can throw an automatic text message to formers, informing them about potential dangers in advance.

Having no prior information about traffic condition e.g. congestion or accident etc and road condition e.g. road bumps etc can waste a lot time and might often result in late arrivals to homes, schools, or offices. A sensor enabled mobile phone can accurately capture these kinds of conditions and share them with other peoples in the area using some networking technology (e.g. Bluetooth, GSM network, Internet, WiFi networks etc) to help them in finding alternative and time saving paths to their destinations.

Hiking in a mountainous region can be catastrophic because as the elevation increases, the temperature drops pretty quickly resulting in quick changes in weather. People usually keep their GPS turned off to conserve battery life and might be caught in a bad situation because of not recording the tracks. Having real-time knowledge of altitude value and turning GPS on and off accordingly can be preemptive to a bad situation. An application using altimeter sensor can trigger an alarm reminding the altitude level upon reaching a threshold elevation value and might turn on the GPS upon reaching a threshold elevation value, saving battery power considerably while recording tracks relatively accurately.

Our main contributions of this paper are:

The key contribution is the tracking and analysis of the on hand knowledge about mobile phones, sensors, and their integration, and organizing them in a unique chronological order to be helpful for the researchers to find relevant knowledge in a single platform.

A comprehensive list of motivational scenarios is described for helping researchers in understanding the importance of mobile phones and sensors integration for the developing of useful applications and systems in the future.

The on hand knowledge is organized and presented in a way to boost up interest of new researchers in the area and provide them necessary initial knowledge to understand and add contribution to the area.

The novel contribution is the illustration of all of the possible internal and external sensors to the mobile phones as well as the sensors that can be emerged in the future.

A number of technological and non-technological gray areas in state-of-the-art technology are identified as well as a number of recommendations are outlined to help interested researchers in diagnosing novel research topics and ultimately enriching the domain.

MOBILE PHONES SYSTEMS

The ways of communication have been entered into new avenues with the advent of new technologies. In early history, pigeons were utilized as methods of communication. With the introduction of postal system, peoples started sending written messages. With the passage of time, telephone systems were emerged followed by the era of wireless communication, giving rise to the existence of mobile phone technology. Today's mobile phone is a complete computer having the same communication and technological capabilities. The very first services offered by mobile phones were mobility and voice but today they have powerful hardware architecture and software support particularly operating system. Mobile phones manufacturers realized that they can extend phone's features by integrating other technologies to it. Today's mobile phones are equipped with plenty of capabilities such as Internet access, download file textual/audio/video etc, playing games, and have a wide array of sensors, high resolution color display, support for different standards of wireless networking, mp3 players, advance processing power, and large memory for a number of applications etc (Grauballe *et al.*, 2008 and Leichtenstern *et al.*, 2005). In the recent years, the role of mobile phone is shifted from a verbal communication tool to a multimedia tool, adopting the name of "mobile device" instead of a phone at all. Recent mobile phones are replacing our other gadgets e.g. video camera, and voice recorder etc and mostly used for web surfing, email checking, photos snapping, and updating social networking status etc than placing calls actually.

In the beginning, mobile phones were not so common because they were expensive and communication costs were pretty high for people. But in the past few years, their costs have been decreased considerably and today's mobile phones are inexpensive, human friendly, highly portable, and equipped with latest features of high potential. Mobile phones are now first choice gadget for people belonging to different demographics. Every person want to be equipped with this magical gadget while having their own reasons and want to replace their old ones with the latest handsets providing the latest features. Since the introduction of mobile phones, different manufacturing companies are coming up into the market with new models to lure the users. Each vendor is providing their products with latest technologies and features to enlarge their customer numbers and eventually their market share.

Mobile Phones Classifications: Mobile phones industry is the fastest growing industry in the history of mankind, but is also the most fragmented industry, with numerous different types of mobile phones that all offer their own types of uses. The simplest way to differentiate between different types of mobile phones is by their features. Relying on this method the following two are the main types of mobile phones:

Low-end Mobile Phones: These type of mobile phones ranges from simple hardware based mobile phones providing limited features of making voice calls, text messaging, and contact management to the mobile phones having proprietary operating system and offers exciting features including medium-size screen, basic HTML browser, a decent camera, a music player, and applications as well as games support. Native applications might not be publically available but installed application can be developed at runtime using Java ME.

High-end Mobile Phones/Smartphones: Smartphones let you make phone calls as well as provide the services provided by the Personal Digital Assistance (PDAs) or computers such as to send and receive emails, edit office documents, and play games etc. A smartphone, by definition, would have a sophisticated multitasking operating system e.g. iOS, and Android etc, high profile web accessibility, having full featured desktop web browser (e.g. Safari etc), a full featured music player and video player, display photos, a wide array of sensors, 3G/4G and Wireless LAN (WiFi) connections, and TV out etc. A smartphone should be able to download and install applications, and may have virtual or physical QWERTY standard keyboard.

State-of-the-Art Mobile phones Technology: Mobile phones are now sophisticated computing platforms. The incredible increase in the computational power of mobile phones processors, improvements in the storage, considerable advancements in the operating system, and availability of fast mobile broadband have made mobile phones as the ideal candidate for mobile computing devices which could execute sophisticated and even scientific applications as well as store and process a large amount of data (Wong, 2010)(Center, 2008). The continued miniaturization in computing technology has allowed mobile phones to incorporate several of the features of the laptop personal computer, and personal digital assistance (PDA). These technological advancements have enabled mobile phones to fully support sophisticated applications while providing their basic functionalities.

Powerful Processors: State-of- the-art mobile phones have proven to be powerful computing platforms. It was believed that mobile phones processor will not beyond 1 GHZ due to power problems (Barton *et al.*, 2006) but Quelcomm among others have released dual-core snapdragon processor (which supports a pair of scorpion core at 1.5 GHZ) by the end of 2010 (Center, 2008). Mobile phones processors available in the market today are powerful enough to be used in low-end laptop or notebook. For example, Qualcomm's 1GHz Snapdragon (already used in HTC's HD2, Google Nexus One, and Sony Ericsson Xperia X10) is powerful enough to display a 12-inches screen at the resolution of up to 1,440 x 900 pixels. Today's smartphones runs with much smart and powerful processors which can execute sophisticated computing applications such as iPhone 4 uses 1 GHz ARM Contex-A8 processor, Power VR SGX535 GPU, and Apple A4 chipset, Samsung Galaxy S2 uses Dual-core 1.2 GHz ARM Cortex-A9 processor, Mail-400MP GPU, and Orion chipset, HTC Sensation uses dual-core Snapdragon 1.2 GHz processor. Quad core technology has been recently introduced in the mobile phones. It is believed that with the passage of time more and more improvements will be witnessed in the mobile phones processor technology.

Large Storage: Today's smart phones can provide internal data-storage capacities of 4 to 32 GB to store multitude of contents as compared to the 32 to 512 MB provided a few years ago (Wong, 2010)(Center, 2008). The continued advancements and miniaturization in storage technologies (e.g. flash memory, and small form-factor disks etc) enables future smartphones to have even larger storage capacities. The currently available storage in smartphone is rich enough to store multimedia contents, and raw or met data such as iPhone and Samsung Galaxy S2 comes with choices of internal storage either 16 GB or 32 GB but Galaxy S2 have MicroSD support as compared to iPhone, HTC Sensation comes with 1 GB of internal storage but can be expanded with MicroSD. In addition to storage, today's smartphones runs with enough RAM to provide room for large and complex application such as iPhone have 512 MB, Samsung Galaxy S2 have 1 GB, and HTC Sensation have 768 MB of RAM. Smart phones with terabyte storage capacity at consumer costs would be available within a decade (Barton *et al.*, 2006).

Operating System and Libraries: A mobile operating system (also called Mobile OS) uses the features of PC operating systems in combination with additional features of cellular, touch screen, WiFi, voice recorder, speech recognition, GPS mobile navigation, and Personal Digital Assistance etc. Today's smart phones have been provided with strong and powerful operating systems (e.g. Google's Android, Window's Windows Phone 7, Blackberry's RIM, and iPhone iOS etc) very much similar to computers. In the very similar way, smartphone operating systems can be either open-source or proprietary such as Android is open-source pioneered by Google but now proceeded by Open Headset Alliance (OHA) and iOS is proprietary used by Apple devices only (i.e. iPhone, and iPad etc). These operating systems have a wide range of libraries and APIs providing maximum flexibility, easiness, and freedom for developing applications for a wide variety of functionalities such as access to the internal sensors, making voice calls, Internet/Web connectivity, drawing maps, and playing multimedia etc (Wong, 2010).

Advanced User Interface: Today's smart phones provides easier and advanced user interface, supporting multi-touch technology to remember more than one touch simultaneously (Wong, 2010)(Center, 2008). For example, to zoom in on a picture, a user touches the screen with his two fingers and then spread them apart. Many smartphone now uses larger display with very high resolution such as Samsung Galaxy S2 and HTC Sensation have the same 4.3 inches touchscreen, displaying 960x540 resolutions and iPhone has 3.5 inches touchscreen, displaying 960x640 resolutions.

SENSORS AND MOBILE PHONES

Sensors are grown as the vital sources of data on the web, convincing organizations to investigate the novel methods of building wireless sensor networks, and capturing, processing, analyzing, and using sensors generated data. Understanding the advantages of mobile phones sensors over unattended wireless sensors and miniaturization in sensors technologies have paved the ways of integrating sensors in mobile phones either directly or through wireless networking technologies (e.g. Bluetooth etc). Using sensors in mobile phones will turn mobile phones into sensing nodes. Using mobile phones as sensors have several practical advantages as compared to traditional wireless sensor networks (Kansal *et al.*, 2007).

Mobile phones are always accompanied by users, therefore, solves the problems of power management, and network formation and maintenance. Much of the maintenance burden can be alleviated from the operator or network administrator because end-user always shows keen interest in maintaining their mobile phones such as hardware repair, installing/un-installing software, and maintaining data management with servers etc.

Nodes in a wireless sensor network needs to be manufactured and relatively have high prices, thus increasing overall cost of network implementation. Using mobile phones as sensors instead obviously would have high economy of scale as manufactured in large quantities and will help in surpassing the overall cost in millions.

Instead of being confined to a particular geographic area or instrument, mobile phones will provide advantage of significant geographic coverage. Mobile phones can provide coverage to a geographical area where static sensors are hard to deploy.

Mobile phones will provide coverage where it is needed the most and provide a close intact to the measuring phenomenon to get accurate observations.

Human users' assistances to mobile phones can be used to improve application's functionalities such as camera can be pointed appropriately by users to take picture of an object to be sensed.

Peer production systems, where large systems are build by several contributors' efforts to develop and share small components such as Wikipedia, Linux, and Web 2.0 application etc, can build useful sensing applications by leveraging the small amount of sensory data captured and shared by individual mobile phones users. For example, the utility of a collaboratively developed dataset will grow significantly and will become useful for a number of activities.

Mobile Phones Sensors: Sensors in mobile phone can be categorized into physical sensors and virtual sensors (Zander and Schandl, 2010). Physical sensors are hardware-based sensors embedded directly into mobile phone devices and derive their data directly by measuring particular environmental characteristics (e.g. accelerometer, gyroscope, and proximity etc are physical sensors). Virtual sensors also called synthetic sensors are software-based sensor deriving their data from several hardware-based sensors (e.g. in Android platform linear acceleration, and gravity sensors are virtual sensors). In this section, physical sensors are discussed which are either embedded or externally connected using wireless protocols with mobile phones and the sensors expected in the future mobile phones. Table - 1 illustrates the categorization of physical sensors using their behavioral characteristics and the categorization schemes discussed in Section 1.

Embedded/Internal Mobile Phone Sensors: Most of the today's smartphones are open and programmable and come with a number of embedded sensors. The number and types of sensors in mobile phones varies depending on the underlying mobile phones platforms and usability. Understanding the potentialities of sensors and increasing miniaturizations in technologies will enable the integration of more advanced sensors in the future mobile phones. Some of the state-of-the-art embedded mobile phones sensors are:

Proximity Sensor: Proximity sensor releases electromagnetic or electrostatic field or a beam of electromagnetic radiation (e.g. infrared) and looks for changes in the field or return signal and detects any nearby object presence without any physical contact. Proximity sensor's target refers to the object being sensed by the proximity sensors and different proximity sensors demands different targets. In smartphones, proximity sensor senses that how close a phone's screen is to a user's body while brining the phone near to his/her ear. Proximity sensor will automatically turn off and lock the screen not only to save battery power but also to protect against any unwanted input by accidentally touching the screen by a user's ear or check/face. As soon as, mobile phone is taken away from the ear, it will be automatically restored to its previous state (Asad-Uj-Jaman, 2011).

Ambient Light Sensor: This sensor measures light of the surrounding and adjust brightness of mobile phone accordingly to optimize screen visibility. If light of the surrounding is high, brightness of the mobile phone screen will be decreased otherwise increased. Adjusting of display brightness will not only optimize visibility but will also save battery power in smartphones (Asad-Uj-Jaman, 2011).

Accelerometer Sensor: Accelerometer sensor is used as user interface controller: changing the screen display by sensing the orientation of the device based on the way the device is being held by a user (Asad-Uj-Jaman, 2011). This sensor measures the acceleration of smart phone in three different axes: X, Y and Z (Asad-Uj-Jaman, 2011). Smartphones commonly uses 3-axis accelerometer to detect orientation of the phone and adjusts the screen display accordingly, providing convenience to the users to easily switch between portrait and landscape view. Similarly, camera also uses accelerometer to determine whether to take picture in portrait or landscape modes. Unlike Apple's iPad, Apple's iPhone does not rotate the screen when the device is turned upside-down. Apple's iPhone 4 also uses gyroscope sensor in conjunction with accelerometer to efficiently percept how the device is moved (Asad-Uj-Jaman, 2011). Accelerometers can be used extensively in a number of mobile phones sensing systems including users' activities recognitions, traffic and road monitoring, and automatic traffic accident detection etc.

Moisture Sensor: Moisture sensor is used to determine cause of smartphone damage: whether device has been damaged due to water or not. Apple's employees use status of this sensor to decide whether the device deserves for a warranty repair or replacement. Apple's iPhone has faced criticism due to their moisture sensor placement. It is believed that this sensor can be affected due to steam in the bathroom, owner's sweat during exercising, and some other light environment moisture.

Digital Compass Sensor: This sensor is a magnetometer, used to recognize the North and defines direction for users. Modern smartphones do not use magnets, because magnetic interference can degrade cellular capabilities significantly through dropping signal strength. Apple's iPhone 4 uses AKM AK8975 chip which is a small sensor and it determines the orientation and directions relative to the Earth's atmosphere using the Hall Effect (Asad-Uj-Jaman, 2011).

Barometer Pressure Sensor: A barometer is a low voltage, low power, and high resolution pressure sensor used as a scientific gadget by meteorologists for measuring atmospheric pressure. Barometer measures the exerted atmospheric pressure which

Table - 1: Classification of sensors frequently used in mobile phones sensing systems.

General Classification (Category)	Sensor Type	Embedded (Em) or External (Ex)	Proprioceptive (PC) or Exteroceptive (EC)	Active (A) or Passive (P)
Tactile Sensors	Proximity Sensor	*Em/Ex*	*EC*	*P/A*
Acceleration Sensors	Accelerometer Sensor	*Em*	*PC*	*P*
	Gyroscope Sensor	*Em*	*PC*	*P*
Thermal Sensors	Temperature Sensors	*Ex*	*EC*	*P/A*
Image Sensors	CMOS Camera Sensors	*Em*	*EC*	*P/A*
Light Sensors	Ambient Light Sensor	*Em/Ex*	*EC*	*A*
	Back-Illuminated Sensor	*Em*	*EC*	*A*
Water Sensors	Moisture Sensor	*Em*	*EC*	*P*
	Humidity Sensor	*Ex*	*EC*	*P*
Location Sensors	Digital Compass Sensor	*Em*	*EC*	*P*
	GPS sensor	*Em*	*EC*	*A*
Height Sensors	Altimeter Sensor	---	*EC*	*P*
	Barometer Sensor	*Em*	*EC*	*P*
Medical Sensors	Heart Rate Monitor Sensor	---	*EC*	*P*
	Biosensor	---	*EC*	*P*
Acoustic Sensors	Microphone Sensor	*Em*	*EC*	*P*
Radio Sensors	RFID	---	*EC*	*A*
	Bluetooth	*Em*	*EC*	*A*

can be used positively for weather forecasting and altitude estimation (Levi, 2011). Barometer performs pressure measurements in hectopascals or millibars (where 1000 millibars = 1 bar and 1 bar = 1 Newton). In practice, barometer is not used for weather purposes rather used to help GPS. In companion with barometer, GPS would work faster and more accurate because barometer would calculate one of the 3 main values (i.e. longitude, latitude, and altitude) to facilitate the work of GPS and make it faster.

Gyroscope Sensor: Gyroscope sensor is a movement sensor pretty much like accelerometer used in modern smartphones. It uses principles of angular momentum for measuring and maintaining the position and orientation of devices (Asad-Uj-Jaman, 2011). It concentrates on calculating and measuring rotation axis. Gyroscope when combined with accelerometer will allow devices to measure motion along six axes: left, right, up, down, forward, and backward, along with roll, pitch and yaw rotations and will provide more accurate motion measuring capabilities to the devices (Asad-Uj-Jaman, 2011). Apple's iPhone 4 is the pioneer using built-in gyroscope and uses MEMS (Micro-Electro-Mechanical-Systems) developed gyroscope (Asad-Uj-Jaman, 2011).

GPS (Global Positioning System) Sensor: GPS is a navigation tracking system where GPS receivers get information sent by the GPS satellites and calculates a user's exact location using triangulation. In smartphones, GPS applications can be programmed with a map in the background and displaying routes to the users where they have been or want to go (Asad-Uj-Jaman, 2011). Apple's iPhone 4 uses A-GPS (Assisted GPS uses intermediary server to gain access to the nearest satellite in case direct connectivity with satellite is not possible) as well as digital compass, whereas, Apple's iPhone 4S in addition to GPS also provides support for GLONASS global positioning system (Asad-Uj-Jaman, 2011).

Back-Illuminated (BI) Sensor: Back-Illuminated (BI) sensor also called as BackSide-Illumniated (BSI) sensor is digital image sensor which improves low-light performance and increases the amount of light during image capturing and makes more prominent image elements. HTC's EVO 4G and Apple's iPhone 4 uses BI sensor from Omni Vision Technologies in addition to their cameras (Asad-Uj-Jaman, 2011).

CMOS Camera/Image Sensor: A CMOS image sensor uses MOS (Metal Oxide Semiconductor) transistors to convert an optical image into electrical signals. This sensor forms an image by using unit pixel, where each pixel is a semiconductor which creates current signals by transforming incident light photons and the size of signal produced is relative to the amount of incident light photons. It is well suited for tiny cameras (commonly used in PDAs and mobile phones) because they can build all of the required camera logic and control circuits onto the same silicon wafer dice. As compared to CCD sensor, this sensor has same sensitivity (normally in the range of 6 to 15 lux) but is 10-100 times faster, low priced, and consumes more power. Initially used in less expensive devices but now they are excellent for use in professional cameras due to their improvement in quality. Although cameras are cheap but their processing power and storage requirements are still very much high (Schmidt and Laerhoven, 2001). iPhone 4 uses 5 megapixel camera at the back accompanied by back-illuminated sensor (for capturing pictures at low light conditions) as well as LED flash (for video recording at 720p resolution) and a second camera on the front for capturing VGA pictures and video recording.

Microphones Sensor: A microphone sensor is an electromechanical device that detects air pressure as vibration and creates an electrical signal that is proportional to the vibration. Microphones can provide very interesting information with minimal processing such as noise level, types of input (noise, music, and speaking etc), and base frequency (Schmidt and Laerhoven, 2001). In smartphones, microphone sensors can be for recording voice (i.e. human, or traffic etc) for using in valuable applications.

Bluetooth Sensor: Bluetooth sensor is a short range low-power radio communication device, designed primarily to connect personal consumer gadgets and peripherals available in proximity in a wireless network with a data rate of less than 1Mbps. Bluetooth is attractive because of its small size and low cost while using the same technologies, with little modifications, as used by WiFi, and wireless USB. Unlike infrared sensor, Bluetooth uses broadcast technology, not requiring connected devices to be in line-of-sight position. Bluetooth accomplishes its objective by integrating inexpensive, tiny, and short-range RF transceivers into the available electronic gadgets and operates in the globally available ISM radio band, centered at 2.4 GHz, providing data rate of up to 721 Kbps using three voice channels. Either point-to-point or multipoint (up to 7 units) connections can be made among devices with distance ranging from 10 m to 100 m subjected to power. Bluetooth uses frequency-hopping spread spectrum, changing frequencies arbitrarily up to maximum 1600 times/second, to avoid any radio interference among the units within a single proximity. To establish a connection, "inquiry" and "inquiry scan" principles are used. Scanning devices listens to devices currently inquiring on known frequencies. Upon receiving an inquiry, the scanning device responds to the inquiring devices with information needed to identify and render the type of the device who has recognized the signal. By selecting the scanning device on inquiring device kicks off the connection establishment process. Despite of using the same frequency band (i.e. 2.4 GHz), Bluetooth standard cannot be used as replacement to WiFi because of flow speed, short-range, and supporting fewer devices. In smartphones, Bluetooth sensor can be used for communication with other external computing devices which could be sensors or any other communication devices.

External Sensors: State-of-the-art mobile phones are provided with a limited number of embedded sensors. Apart from them, there is a lengthy list of sensors which can be connected and communicate with the mobile phones. If a sensor is available in a surrounding environment, which have short-range communication technology (e.g. Bluetooth, and WiFi etc), it can be connected directly with mobile phones. Several of these sensors are used by plethora of mobile phones sensing applications. For example, using of wireless ECG sensor in health monitoring systems, and CO (Carbon Monoxide) sensors and NOx (Nitrogen Oxide) sensors in environmental pollution monitoring systems etc. They can provide very valuable data to the mobile phones which can be used in a wide array of applications for meaningful functions. Some of the mostly widely used sensors in the lengthy list of external sensors are:

Temperature Sensor: Temperature sensors give information about the ambient temperature. This sensor uses solid state principles to determine the temperature instead of using mercury, bimetallic strips, or thermostors. The principle explores that the voltage across the diodes increases at an already determined rate as the temperature increases. There are two types of temperature sensors: contact sensors and non-contact sensors. Contact temperature sensors calculates the temperature of objects to which they are physically connected by assuming that there is not heat flow between the sensor and object (e.g. thermocouple sensor, and thermometer sensor etc). Non-contact temperature sensors receive thermal radiant power of the Infrared or Optical radiation from the surroundings (objects) (e.g. pyrometer sensor etc). Temperature sensors have found their applications in a variety of everyday products such as household ovens, refrigerators, and thermostats all depends on precise, quantitative measurements, maintenance and accurate control of temperature to function properly. They also have been used in a variety of engineering fields such as chemical engineering etc. They are cheap and provide information in some applications that are very helpful such as to detect body heat, or desert information etc (Schmidt and Laerhoven, 2001).

Humidity Sensor: Humidity sensor (also called hygrometer), measure the relative humidity (i.e. both air temperature and moisture) contents present in the environment/air. Relative humidity expressed in percentage, showing the ratio between the actual moisture in the air to the highest amount of moisture in the air at that temperature can hold. That is the warmer the temperature, the more moisture air can hold. Therefore, relative humidity changes with fluctuations in temperature. Humidity sensor uses capacitive measurement. Humidity sensors have achieved wide spread applications in industrial processing and environmental control (Chen and Lu, 2005). In homes, they can be used for people having illness affected by humidity such as low humidity can cause breathing problems as well as joint pain and high humidity can cause bacteria, fungus growth, and mold. Likewise in homes, they can be used in many domestic applications such as intelligent control of the living environment in building, intelligent control of laundry, and cooking control in microwave ovens etc (Chen and Lu, 2005). In museums, they can be used to protect valuable antiques and artworks, because they can be damaged or degraded by their constant exposure to too much moisture . In medical field, they can be used in respiratory equipments, incubators, sterilizers, biological products, and pharmaceutical processing (Chen and Lu, 2005). In agricultural, they can be used for plantation protection, green-house air-conditioning, cereal storage, and soil moisture monitoring etc (Chen and Lu, 2005). The most important specifications that should be kept in mind while selecting a humidity sensor are: accuracy, repeatability, interchangeability, long-term stability, ability to recover from condensation, resistance to chemical and physical contaminants, size, packaging, and cost effectiveness.

Emerging Mobile Phones Sensors: Next-generation of mobile phones is expected to integrate many new types of sophisticated sensors that will not only increase smartness of mobile phones but will also led to a number of modern application areas to provide valuable services. Introduction of extra sensors in mobile phones will strengthen the idea of finding sensor everywhere. In the coming few years, sensors would be found in each and every of a consumer's item such as shoes, socks, glasses and household fixture. They will provide services to the users, particularly adjusting environment affecting their health (Dolan, 2011). Future mobile phones could include altimeter in addition to GPS to accurately determine a user's elevation, heart monitor sensors to keep tabs on users' health, perspiration sensors to determine users' excitement level and even mood, some more microphones, and temperature as well as humidity sensors to efficiently determine users' locations and surroundings (Lee, 2011). Apple has filed several patents for different devices related to activity monitoring and measuring a user's body temperature level, oxygen level, heat flux, and heart rate, which could be easily embedded in iPhone to determine a user's mood etc (Dolan, 2011).

Integration of new sensors would also give raise to a number of applications areas. They could be used in game play to determine the excitement and emotion levels of users to adjust games while playing. They could be used to improve security and privacy of mobile phones (Lee, 2011)(Rauschmayer, 2011). After using a mobile phone for a short period of time, software will automatically learn a user's pattern and will lock and unlock mobile phone accordingly (Kim, 2011)(Rauschmayer, 2011) . Some of the sensors expected in the future mobile phones include:

Altimeter Sensor: Barometric Altimeter sensor, is a mechanical device designed to measure altitude above Mean Sea Level (MSL) using the idea of change in the atmospheric pressure (Manikandan *et al.*, 2011). It works on how the pressure and temperature changes with altitude (Manikandan *et al.*, 2011). It considers altitude in inverse proportionality to pressure and temperature. The standard atmosphere at sea level is 15^{o} C or 59^{o} F of temperature and 29.92 inches of mercury (inHg) (Manikandan *et al.*, 2011). With each 1000 ft of elevation, there is a decrease of 1 (inHg) in pressure and 2^{o} C in temperature. Altimeters can be of different types: Pressure Altimeter, Sonic Altimeter, and Radar Altimeter. Sonic altimeter is considered more reliable and accurate among them. To measure the distance between object and the surface, it uses sounds like a bat, which on return can be converted into feet. Although, GPS can also record altitude values but the height recorded by GPS is 10% greater than the actual altitude value. Therefore, making GPS not suitable for using in critical applications such as pilot navigation systems etc. Due to the fact of sun's unequal heating of the earth's surface and the real atmosphere will not be probably according to the standard atmosphere, there are still questions related to the accuracy of altimeter's altitude measurements. But, using in conjunction with other services such as map, digital compass, and GPS, these sensors can provide valuable services to passengers in an aircraft, skydivers, and mountain climbers etc. In smartphones, altimeter sensor be used to detect a user's elevation such as letting users know on which floor of a building they are or users can more precisely determine their location to their friends on a location based service etc (Lee, 2011).

Heart Rate Monitor Sensor: Heart rate monitor allows users to monitor their heart rate in real time or record their heart rate for later use. Heart rate monitors are of two basic kinds: strap heart rate monitor and wrist heart rate monitor. A strap heart rate monitor consists of two elements: a chest strap transmitter and a wrist receiver or mobile phone. Chest strap transmitter goes around the chest, receives impulses from the heart, and transmits this information to mobile phone or wrist watch in the form of a simple radio pulse or a unique coded signal to prevent one user's receiver from using signals from other nearby transmitters. Wrist watch or mobile phone receives the transmission, processes this data and displays the information to you. It is observed that proper attachment can provide pretty accurate results. But strap is usually tight, uncomfortable, and if does not attached properly, the results can be inaccurate. Writs heart rate monitors measure a person's heart rate without requiring a strap. Writs monitors uses wrist watches mounted with a sensor or two. A person is required to just put his one or two fingers on the sensor buttons for a few seconds, the sensors will read his heart beat and display the reading on the watch. Although wrist monitors are more popular due to their comfort and ease of use but they have downside as well. They can be used 'on demand' basis and cannot give heart rate constantly. As compared to chest strap monitors, they are less reliable and can result in no reading or wild reading if cold fingers are used. Wrist monitors can also include advanced features such as calculating calories expenditure. These monitors can calculate how many calories a person should use during his workout by inputting some basic information.

Biosensor: A biosensor can detect, record, and transmit physiological data using electrical signals. Without using the biological system directly, they can determine the concentration of substances and other parameters of biological interest. A biosensor has two components: a bioreceptor (a biomolecule that recognizes the target analyte) and a transducer (which converts the recognition event into a measurable signal) and these two components are integrated into one single sensor, which enables that without using reagents one can measure the target analyte. They can provide valuable context information in different applications like sports and medical while measuring skin resistance, and blood pressure etc (Schmidt and Laerhoven, 2001).

RFID Sensor: RFID is the abbreviation of Radio-Frequency Identification, an automatic identification method that works by storing and retrieving data (up to 2,000 bytes or less) remotely using devices called RFID tags or transponders. An RFID tag is basically an object capable of storing and processing information as well as modulating and demodulating of radio frequency signals. RFID tag also contains an antenna for receiving and transmitting of singles. RFID tags can be incorporated in a variety of systems including products, persons, and animals for the purpose of identification using radio waves. The scanning antenna radiates radio-frequency in short range for the purpose to communicate with RDIF tags. When an RFID tag comes in the range of scanning antenna, it wake-up and transmit the stored information stored on its microchip to be picked by the scanning antenna. RFID tags can be either passive or active. Passive RFID tags do not require their power source, get their energy from the signals radiated by scanning antenna, and can remain for a very long period of time may be decades. Active RFID tags have their own power sources but can remain for a short period of time (maximum 10 years or less). Smart phones can be used as an alternative for reading information contained in barcodes using apps available for iPhone and Android such as Red Laser on iPhone and Shop Savvy on Android. Instead of barcodes being cheaper, RFID tags are more flexible and functional than barcodes. Looking into the greater potential of RFID, iPhone registered a patent for touch screen RFID reader and it was expected that RFID would be provided as a feature in iPhone 4G. Near Field Communication (standard for using RFID in smart phones) specifies three possible use cases for smart phones: as an RFID tag, as RFID reader, and P2P (peer-to-peer) communication between two NFC capable phones. Mobile phones as RFID tag can be used for payment device (like credit cards), identity card, security device, keys for a car or house and many more. Mobile phones as RFID reader can be used for interaction with other RFID-enabled devices existing in the real world.

Sensors Applications in Mobile Phones: The marvelous expansion of sensor technology in mobile phones is increasing with each day and more exciting new ones are expected to be exposed in the near future. By connecting sensory devices to mobile phones, we can track the dynamic information about environmental impacts (e.g. noise level, air pollution level, humidity, and temperature etc), and understands patterns of objects movements (e.g. peoples' activities, and traffic and road conditions etc), and model them in fruitful ways (e.g. developing maps to render tracked information or sharing users' contextual information with online social communities etc). To exploit and leverage the enhanced sensing capabilities of mobile phones, researchers and developers are concentrating on introducing new advance, fruitful, and powerful mobile phones applications for a number of application areas including healthcare monitoring, road and transportation monitoring, security monitoring, commerce, environmental pollution monitoring, social networking, people's motivation and persuasion, and physical activities monitoring etc. These applications will extensively help peoples in solving their daily life problems and will ease quick data gathering in an urgent situation such as during a disaster-relief operation (i.e. earthquake, flood, or outbreak of a disease etc) personnel (e.g. sociologist, engineers, and doctors etc) can use their phones to sense, monitor, and visualize real world phenomena to realize public-health threats, and environmental hazards etc. The applications of sensors in mobile phones are summarized in Table - 2.

MOBILE PHONES CHALLENGES AND POSSIBLE SOLUTIONS

Mobile phones being the most versatile device of the day have the capabilities to do much more than just making and receiving phone calls. Although, the use of sensors in mobile phones can be advantageous in developing novel mobile sensing applications to help people in solving their plenty of real world problems. Despite of offering a vast number of benefits in the different walks of life, using mobile phones as mobile sensing devices suffer from a number of technological challenges. The continuous sensing may create extra load on the processor, require high storage for storing tones of data produced, require operational support from the operating system, and require easy navigation to produce qualitative results to the users. To make mobile phones as complete replacement of today's sensor devices and gain peoples' trust and confidence, these challenges needs to be addressed to enable mobile phones to provide prompt support for continuous sensing while not being jeopardized.

Decrease in Volume and Weight: The mobile phones systems are portable, if they are small and less weighty, so that carrier should not be bothered. With advancements in technology taking place in mobile phones, tremendous decrease in volume and weight has been witnessed confirming their comfortable use. More decrease in volume and weight is possible with the replacement of the current technology. Replacing traditional packaging technology (SMD) with advanced packaging technology (i.e. CSP, and flip-chip) would reduce footprint area to almost 10% and volume to less than 10% (Neuvo, 1996).

Removal of Discrete Passive Devices: Today's mobile phones contain a large number of discrete passive devices such as 80% of the devices at the RF section are discrete passive devices. Removal of these discrete passive devices will not only reduce size but will increase reliability as well. Using MCM-technologies (MCM-D or C) can reduce the amount of discrete passive devices up to 80% by the end of the decade (Neuvo, 1996).

Increasing Performance: To increase the computational power of mobile phones, the mobile processor's clock rate has been increased considerably but raising the problem of overheating. This overheating can cause mobile phones to either degrade their performance or explode (in the worst case). On the other hand, peoples are demanding their mobile phones to increase their performance to function like their personal computers. To increase mobile phone's capabilities and performance, cloud services can be used where a clone of the phone will live. At time of need, a mobile phone may enter into sleep state after offloading its current state and processor-intensive tasks to its clone in the cloud using available higher-speed Internet connection. The mobile phone gets out of the sleeping state and continues its task execution after receiving the state and task results from its clone in the cloud. The cloud will fasten the operations execution process while keeping the whole process of execution transparent to the users giving them a look and feel that their mobile phones are executing tasks much faster (Chun and Maniatis, 2010)(Chun and Maniatis, 2009).

Power Consumption: The power consumption of a mobile phone is directly proportional to the amount of computations it performs. Due to small size and providing room for chipboard, processor, screen, and antenna etc., mobile phones cannot provide enough space for large batteries to store large amount of charge. A number of methods including designing intelligent power-control systems and energy-efficient chipsets are commonly practiced to cope with power consumption problem. But the most interesting solution is the wireless power harvesting (ambient electromagnetic radiations emitted by the cellular network towers, and WiFi transmitters etc will be translated into electrical energy), which will continuously recharge the phone's battery so that it should not run out quickly (Neuvo, 1996). Despite of smartness, it might take several years

.**Table - 2: Applications of sensors in mobile phone systems.**

No	Sensors Categories	Sensors	Possible Applications 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 Biosensor	Measuring a user's physiological data such as heart beat rate, and pulse rate etc. for using in health care systems.
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.

to get success because of the lack of required power in the ambient electromagnetic radiations (minimum 50 milliwatts power is required to charge a turned off phone).
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Cost Considerations: A technology can only be beneficial if it is widely available and heavily used. Advancements in technology such as increasing processing power, increasing storage, enhancing chips used, adding additional features i.e. sensors, or slots etc. normally determines the price of mobile phones. But, a novel mobile application may require new technology i.e. a chip, or an antenna etc. to be placed inside a phone. This can increase mobile phones' costs as well otherwise will lead to restricting the application's popularity.

Security and Privacy Issues: Peoples' are particularly worry about security and privacy of data which they have entered into their mobile phones or captured automatically by their phones using their inherent features i.e. using sensors etc and would never want them to be revealed to any unwanted person or system (Lane *et al.*, 2010). Preserving peoples' data security and privacy should be the primary importance while designing mobile phones sensing systems. State-of –the-art mobile phones have a number of gray areas which can be exploited to destroy peoples' data security and privacy in a number of ways.

Mobile phones systems feature to support and run malicious third-party applications becomes vulnerable sometimes, if these applications got successful in finding pin holes in the systems and exploiting them, causing the phones to malfunction or lose users' data entirely.

An unauthorized person can breach the security and penetrate into a distributed network of mobile phones and can create catastrophic situations. A number of hacking and virus attacks have been reported on smartphones in the past several years.

An attacker once became successful in violating security measures can not only disturb mobile phones' functionalities but can also misuse the existing data. For example, a user's phonebook data, calendar data, or preferences data can be forwarded to a remote server automatically without informing the user. Likewise, a user's legitimate data i.e. captured by sensors etc would be replaced with some false data compelling applications/peoples to make wrong decisions.

Mobile phones systems can capture and store a great deal of users' personal information e.g. location, speeches, images, birthday, and credit card number etc, which can be forwarded to some remote server for some useful functions e.g. social networking etc, using high-bandwidth Internet connections (e.g. 3G etc). Data during the transit can be captured by unauthorized persons and used illegally such as a user's authentication data can be replayed to a server after some time to get an illegal log in (i.e. replay attack), and data can be tempered to produce illegal effects i.e. integrity attack etc.

CONCLUSION AND RECOMMENDATIONS

Recent technological developments have enabled sensors to find their space in a variety of application areas for performing a wide array of functionalities. A number of ways (i.e. wireless sensors networks etc. are investigated by the researcher since several years to effectively utilize sensors but each suffers from plethora of problems. Mobile phone technology has gone through a number of architectural, technological, and communicational changes since several decades to get into the one fits in our pockets and provides functionalities to the users much like our personal computers. The development process is continued and today's mobile phones are provided with highly sophisticated operating systems, processing power, and communicational technologies, converting them into smartphones. In this paper, we presented a detailed overview of the importance of sensors in mobile phones, outline number of sensors which can be integrated in mobile phones, and highlighted a number of technological and non-technological challenges requiring immediate attention to turn mobile phones into complete sensing platforms. Smartphones are provided with a range of sensors, which can be used for capturing numerous types of information that can be used fruitfully in different applications including health monitoring, home monitoring, and social networking etc. The application of sensor technology in smartphones is increasing geometrically and new incredible sensors are expected to be included in smartphones in the future. This rapid growth of sensor in smartphones will give raise to the new application areas as well as development of new applications and services.

Today's smartphones provides an excellent platform for sensors integration but with increase and multitude natures of the data to be sensed, more advancements in smartphones' processing power, storage, operating systems, and security as well as privacy perspectives are still needed. Apart from these challenges, a number of research recommendations are highlighted as follows:

More Embedded Physical Sensors: A number of mobile phones sensing applications have been researched by the academia, researchers, and organization in the past several years addressing particular application domains. Most of these application are heavily using external sensors i.e. ECG sensors in mobile phones health monitoring systems etc, thus restricting their ubiquity. Therefore, high valued external sensors are sharply needed to be embedded into mobile phones as early as possible.

Virtual Sensors: A way to introduce new and to increase the sensing capabilities of mobile phones is the creation of new virtual sensors instead of physical sensors. Virtual sensors will not only open new avenues of sensing capabilities but will also help in reducing size of the mobile phones significantly.

General Purpose Sensors: Instead of overburdening mobile phones with multitude of special purpose sensors, software driven general purpose sensors are needed to be investigated which could be used in different environments differently with the power of software.

Applications Development: Although the development frequency of application using mobile phones sensing capability is pretty high, but more and novel applications are needed to be explored utilizing mobile phones sensing capabilities in useful and productive ways.

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