In the Direction of a Sensor Mapping Platform Based on Cellular Phone Networks

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Abstract **-During the preliminary part of the project, already available or documented services and research projects were closely studied, and it was found that many services currently make available location finding applications for cellular phones. These programs and services can be integrated into a platform which will make available a map created by sensors attached to mobile devices. The platform will be designed to be compatible with many acquisition sensors. These maps will show the network of sensor data superimposed onto a map for simpler visualization. The pilot, to show the capabilities of such a platform, will involve a sound or decibel meter attached to a cellular device. The device will have loaded unto it the platform which will be able to analyze, store, and send the data collected from the meter. Benefits of such an application, further discussed in the paper, include city planning solutions, real estate assistance, and gunshot sensing.**

I. INTRODUCTION

Currently, we live in the Age of Information: nothing is worth more to companies than information. Companies such as Google and Facebook have made billions by gathering data from the internet. An example of such is Google's AdSense which infers the reader's interests by matching the content of the currently viewed web pages to relevant advertisement [21]. By focusing on key words of a web site, an email, or any other web document, Google is able to show the user banner advertisement which directly correlates to what he or she is interested in. Along the same lines, Facebook profits off of the information of its users by creating "a new advertising system that would let marketers target users with ads based on the massive amounts of information people reveal on the site about themselves. . ." [2]. i.e. When users enter in information, e.g. favorite books, current music, current events, Facebook takes it, and uses it as a survey. Companies who are interested can pay to see what users are currently interested in.

Both of these companies focus on information about online user data, but neither can gather useful data while the user is offline. If there is a way to analyze sensor data collected from users during their every day lives, the information could be valuable in many ways. One possible way would be to directly send the user advertisement based on his or her current conditions, e.g. sending information to the user about a nice, refreshing bottle of soda if the temperature in his or her proximity is uncomfortably high. Another opportunity for valuable data would be a better understanding of different areas, allowing for a better management of such areas; e.g. city officials could improve upon air quality more successfully by specific area if sensors were able map out pollution data.

There are many reasons why cellular phones would be excellent solutions for such an application. First, cellular phones are already widely used. A research firm called Informa did a recent study on the number of mobile phones worldwide and found "Worldwide mobile telephone subscriptions reached 3.3 billion -- equivalent to half the global population" [4]. Thus, cellular phones provide an already available platform in order to build up a large data collection network. Secondly, there is the benefit of cellular networks being wirelessly connected. This reduces the costs of creating more infrastructure, as well as allows for the data to be collected from constantly changing positions. A third benefit of a cellular phone based platform is their hardware capabilities and compact size. Any sensor not already on the device could be easily attached. Many phones already have mini-usb ports as well as MicroSD/Transflash flash memory slots. Any sensor can be easily modified to communicate through one of these available ports. Future designs could integrate the sensors within the device. Also, mobile phones have enough processing capacity in order to analyze the sensor data that it receives. No second controller would be necessary for the sole purpose of data processing, thus simplifying the requirements for such a platform. The last significant benefit of basing the solution of real-life data mining on cellular phones is their already available capability of relaying their location to a database. There are many services, which will be discussed later, that allow the user's location to be established by his or her cellular phone. This capability is extremely beneficial due to the fact that any sensor data collected from the user would be many times more valuable if its location data is collected alongside it. By having both together, anyone interested at looking at the sensor data would also be able to directly correlate the

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information with specific regions; e.g. a company can look at a map with the information superimposed, a "sensor map". If this platform is used to replace currently wired sensor networks, the benefits would include a significant increase of space saved, a decrease in maintenance costs, and an increase in the flexibility of the network due to upgradeability and mobility [16]. In industrial operations, this would save an estimated $200 for each foot of wire laid [15].

This report will first focus on the various possibilities available currently for location mapping with cellular phones. Then it will move to various sensors that could be implemented into such a cellular phone, including some work that has already been done in a similar field. Finally, the report will combine the findings into an outline of a future project that will become a platform for sensor mapping networks.

II. Location Tracking

A. FCC mandates on cellular phone location mapping

In 1999, the FCC put into effect the Wireless Communications and Public Safety Act (911 Act) nationwide. The 911 Act mainly focused on improving the safety of the general public by encouraging improvements on the infrastructure for emergency service communications. The relevant component of the 911 Act "requires wireless telephone carriers to provide 911 and E911 capability…wireless E911 will provide an accurate location for 911 calls from wireless phones" [4]. In other words, the FCC requires all carriers to be able to give the position of the cell phone in case of an emergency situation. This opens the door to projects, such as the one currently discussed, to use this infrastructure as well. In order to comply with the FCC, some mobile phone carriers, such as Verizon and Sprint, now require a global positioning system (GPS) chip in their phones. GPS works by getting signals directly from three or more of the twenty-four GPS satellites orbiting the skies. When direct line of sight to the satellites is not available, these phones are able to find the position of the cellular phone using a similar technique, except instead of using satellites, this method, called triangulation, uses cellular phone towers to find position. Because GPS requires extra hardware, other carriers have opted only use triangulation to fulfill the FCC mandate, e.g. Cingular.

Although this creates a huge opportunity for location mapping, the main problem of this data is that most companies are keeping the information proprietary. Nextel-Sprint is the one of the few exceptions that allows for outside services to use this information.

B. Companies are currently offering location mapping services

There are many companies which have already begun "piggybacking on this E911 location technology" [10].

These companies focus on various aspects which would benefit from location gathering, such as advertisement, real estate information, business location, friend finding, and asset tracking. Some companies who are using mobile phones, specifically, for tracking include Super Local, Loopt, Trisent, Smarter Agent, Socialight, and Verizon's VZ Navigator. Due to many similarities between the services offered by these companies, this paper will focus the discussion on Loopt and VZ Navigator.

Loopt. Loopt focuses mainly on using the location capabilities of a cellular phone as a personal networking device. If installed, Loopt allows the user to locate, with detailed maps, the whereabouts of their friends along with their current activities. Also, if a friend comes into close proximity to the user, he or she may opt for a message to appear. The user has full control of whether or not his or her location is exposed to their friends in order to eliminate any unwanted attention. Currently, Loopt is only compatible with Sprint and Sprint subsidiaries, i.e. Boost Mobile and Nextel [23].

VG Navigator. On the other hand, Verizon has centered its VG Navigator around giving a cellular phone GPS navigation capability, e.g. replacing the user's GPS navigation system with an integrated one inside of his or her phone. The VG Navigator service provides for its customers everything that a navigation system provides, i.e. looking for nearby places to visit (restaurants, hotels, offices, etc.), providing a route to those places, and even real time directions for while the user is driving. Verizon's service, paid monthly or daily, uses the GPS chip installed in many of its phones. If a strong GPS signal is not received, VG Navigator is able to switch to using cellular tower triangulation techniques to find position. VG Navigator is only available for use in Verizon phones [20].

These two services both combine the location finding capabilities of cellular phones with innovative applications. Both are good examples of how there are definitely markets opening for such applications.

C. My Location by Google

Recently, Google revealed that it has begun testing the use of cellular tower triangulation in order to provide GPS capabilities for mobile phones without GPS chips. According to Google, by pressing "0" on a mobile device with this system implemented, the device's location will show up on a Google map as a blue dot on the screen. This solves the difficulty of entering the starting address using the small keys provided on mobile devices. A benefit of using "My Location" for location tracking is that because it doesn't use GPS, it drains a lot less power from the battery when in use. Energy efficiency is particularly important on mobile devices in order for increased portability. Even so, Google's location service is not without its faults, being only able to locate the device within one-quarter to three miles of the user's true location due to using cellular phone triangulation and wifi nodes instead of GPS. Also, the service requires an already built database to find the location of the mobile device, and due to its early stages of development, there are still many areas where the service would not work due to an incomplete database. As the service becomes more widely used, the database will be able to fill in those preliminary holes. Google may eventually use this service to advertise to its users about nearby businesses, but currently, the mobile maps are advertisement free. My Location will be made available as an add-on to Google's mobile device operating system, Android. The benefits of using this open source operating system are many, but mainly, because all of the code for both Android and My Location are out in the open, there would be much more freedom when integrating sensor mapping with the service [5].

A major downside to the use of Google's mobile device operating system will be the smaller audience that this platform would appeal to. Because there is not even a product currently on the market which runs Android, there is no way to be certain that there will be enough users for this project to be successful. Upon further research, it was found that other operating systems can have similar capabilities as Google's My Location. The software which My Location uses is based upon Skyhook Wireless which has a software development kite available for Windows Vista, Windows XP, Windows Mobile, Windows CE, Symbian, Mac OS X and Linux. If using Android becomes an issue, it may be feasible to create a mapping function within the platform based on any of the previously mentioned operating systems, instead.

III. Possible Sensors For Mapping Application

A sensor is defined as any transducer that is able to transform an analog value into an electrical signal. [17] Ideally, the sensor mapping platform will allow for any sensor to be easily attached to and measured by a cellular phone, while also recording its location onto a virtual map. Possible applicable sensors include temperature, humidity, pressure, carbon monoxide, nitrogen monoxide. Mapping any of these aspects can be beneficial industrially and environmentally.

A. N-SMARTS: Networked Suite of Mobile Atmospheric Real-Time Sensors

The N-SMARTS system is currently being researched within the Electrical Engineering and Computer Science Department at the University of California, Berkeley. The researchers are currently working on two basic platforms which they hope create the network off of. One platform is a "personal data acquisition platform" which is a set of sensors that the user carries on his belt. The current design includes a Carbon Monoxide Sensor and Data Logger, a Nitrogen Dioxide sensor, a Sulfur Dioxide sensor, and a Carbon Monoxide sensor. In use, all of the sensors' data is processed, interpolated, and cleared of any miscalibrations on the phone and sent using a SMS to a central database. All of the data must be related to the users' current status, which needs to be added in manually. In order to better visualize the data acquired, the information is organized onto a contour plot comparing value and location. The second platform that the N-SMARTS team is constructing focuses on integrating the sensors into a smaller form factor which also allows for constant airflow. The main use for this second proposal would be for data collection on automotive transportation such as taxis, buses, or cars. With the combination of the data collected from both platforms, many environmental benefits will arise. With all this data on pollution, city officials or businesses can improve their own air contamination in more specific areas [9].

B. Current noise sensing applications

Noise Mapping, England. The Department for Environment, Food, and Rural Affairs (Defra) in England conducted a survey on the amount of noise throughout England. Defra was able to map out the entire city of London with its estimated noise level. The noise map has contours that show what areas are "hotspots" and what areas are quiet. This noise map does not actually measure the amount of noise within an area. Defra uses a computer program which needs the user to input a lot of data. First, it needs an accurate map of the location that needs to be mapped. The program depends on an algorithm that includes the effects of buildings on sound spreading. Also, depending on the material in that area, e.g. concrete, water, dirt, sound may be absorbed or reflected. Secondly, the sound mapping software needs each specific noise that the user wants to include in the map. The algorithms work when estimating how much sound there will be at a particular point by calculating the inference from each source of noise. In their initial project, Defra only included sources of noise from roads, railways, and airports. Though the project does not actually consist of any sensors, the end goal of the study is similar to that of this project. Defra was able to map out a certain dynamic factor and relate that factor with its position on a map [14].

Gun shot detection-SENTRI. Researchers at Safety Dynamics, in collaboration with Laboratory for Neural Dynamics at the University of Southern California, have been able to design and implement a system called Sensor Enabled Neural Threat Recognition and Identification (SENTRI) that is able to recognize and distinguish between gunshots and explosions. SENTRI is also able to send range and direction in order to locate the event. Currently, this data is connected to a camera which then takes a photo in attempt to capture the event. SENTRI uses a biologically based pattern detection system; the design attempts to duplicate how the human brain remembers and responds to events that have occurred. Because of this different style of detection, SENTRI is able to identify gunshots through intense background noises with speed and accuracy. The SENTRI system is currently in use in the Chicago Police Department and Tijuana Mexico. These units incorporate the SENTRI system into a network of surveillance cameras which are then able to listen for gunshots and provide audio and visual contact for law enforcements even before they reach the scene of the crime.

Currently these systems only detect small arms and assault rifle fire, but due to the variable design of the SENTRI system, a user could teach the system a whole library of acoustic events [6].

IV. Platform Design Goals

The purpose of this paper is to act as preliminary research for a future design project. By evaluating the strengths and weaknesses of each of the previously discussed topics, the project will be able to combine the advantages of each application in order to overcome their shortcomings.

A. Design Statement

As stated previously, the final goal of the project will be to create a software platform on cell phones that will enable users to connect the sensor of their choice to their phones and be able to view the collected data from a network of similar mobile devices with the same sensor. That being said, the pilot project will include a sound meter capable of sensing the amount of sound in its proximity, in decibels. It will be based on mobile devices running the Google Android OS. The sound measuring device will be the same microphone that is already in the device; the voice input microphone.

B. Contributions from current applications

There will be many benefits for using Google's mobile device operating system. First off, it already includes a location finding program. Because this program's source code is open, the second benefit of using My Location, programming the platform to include the location finding capabilities will have a lot more freedom. It would also be possible to discuss with the currently offered services, such as VZ Navigator or Loopt, to try to integrate a sensor with their service, but this could contribute to more difficulties. It has been decided to consider that direction in the future, once the platform's capabilities have been proven. The third benefit of using Google's My Location is that it can be used on all cellular phones. There are still many phones without GPS capabilities, so basing the platform on cellular triangulation the pilot study can open its doors to a larger range of testers. Also, because My Location doesn't use GPS, the battery of a device running the program will not greatly decrease. Many users would be unhappy with the platform if it was detrimental to the regular functions of their cellular phones.

The platform will be much more accurate than what Noise Mapping in London consists of currently. One of the main reasons why they do not base their measurements on real sound is cost [14]. On the other hand, the currently discussed measuring platform would be a very low cost alternative because it is based on a device that is already there. This gives the platform a large cost advantage over its competitors. Even with the obvious difference that Noise Mapping doesn't actually measure noise, the results of their study give a good example of what the platform's outputs will be.

The N-SMARTS system, by UC Berkeley students, is also very similar to the discussed pilot project, but instead of focusing on the sensing aspect, this paper's main discussion is the platform itself. Because the sensor focus of the N-SMARTS project, their designs concluded with a large, bulky system including a GPS unit, a Carbon Monoxide Sensor/Data logger, and a NO2, SO2, and/or O3 Sensor. All three are separate units attached to the user on their belt. This form factor on its own could be a huge deterring feature for users. Again, because of the future platform's basis on a device that the users already own, the implementation of the network will not have as many deterrents. Even so, because of the similarity of the basic ideas, the results of the N-SMARTS study are very valuable for the pilot study for this platform. One lesson that can be learned from the N-SMARTS project is the possibility of sensor calibration using the differences in measurement between two sensors in close proximity [9].

C. Applications

There are many applications for using various sensors with location, but for this pilot project, the focus will be on sound sensing. There are many benefits of having sound data collected along with its location. Below, some of the possible benefits are discussed. Other applications may arise as the pilot matures.

City Sound Pollution Improvements. One huge benefit will be the ability of city managers to review the data in order to discover what parts of their city have especially large amounts of noise pollution. If the data is open for the government to actively review, they can pinpoint areas with problems and try to find solutions. Once these solutions are implemented, because the network will constantly update, the managers can check the data to see if those areas have improved. If they have, or have not, the city can either continue what changes they have made or decide to go in a different direction. This information can give the city accurate and real time information about areas in question.

Significances within Real Estate. Another possible application could be centered towards any are interested in or working in real estate. Sound is a very important factor in purchasing real estate. With the information gathered from the sound gathering network, interested audiences, e.g. developers, real estate agents, or homebuyers, can view the sound levels of the properties of interest. The platform can be designed to show not only real time data, but also logs of previous data. In this way, an interested customer can check the network to see if the noise levels of their property of interest match their preferences. e.g. If a customer wanted to buy a house and had already seen it during the day and heard a reasonably low amount of noise, he could check if that level of noise was consistent with that which occurs at night. Doing so, he could know, if it so happens, that during the time he is asleep, his future neighbors create a lot of noise. This information could be invaluable to many people.

Gun Shot Detection. A third possible application for having a network created from sound and location data would be the ability to detect, locate, and report gunshots. Using the sound analyzing capabilities of the SENTRI system along with the mobility and location detecting capabilities of the pilot platform, it would be possible to identify gunshots. The basic plan of this idea would be that the processor of the cellular phone will be alerted when a loud noise, with a similar sound description as a gunshot, is recognized. Then, it would send a recording of the sound to the SENTRI system which would then analyze it to tell whether or not the sound was actually a gun shot. If it does identify a gunshot, SENTRI then calculates the estimated location of firing by the network of cellular phones nearby which also registered the noise. This application could serve to be very useful in areas where the SENTRI system has not been built. It could also be connected to the local authorities to notify any gunshots that occur.

D. Problems

As with any pilot study, there will be many problems that will arise. To account for all of the problems would be impossible, but the main ones should be noted. A large problem will be the fact that many people do not want to, and are suspicious of, being tracked. Because this platform will require their location to be registered, it must be noted that their specific identities will not. The platform will automatically delete the identifying aspects of the location and sensed data. In order to ensure to the user that their data is not being misused, the particular part of the code will be made public.

Another problem that may arise is the difference in sound levels of mobile devices depending on their placement. That is, cellular phones within one's pocket may sense a much lower level of noise compared to one in the open. Many tests must be run in order to discover the true effects of such sound isolation to see whether or not this effect is significant. If it is found to be a large problem, changes will need to be made, such as an external microphone.

The third possible problem will be the limitations of the devices' microphones. Because the microphones, in normal use, only need to transfer human voices effectively, there may be problems detecting or measuring audio that is outside the range of human voices. To solve this problem, the program may need to process the received signal to compensate for this range limitation. It is possible to "reverse filter" the signal to amplify the signal outside the normal dynamic range [11]. Of course, this method can never be better than using a higher end microphone, but it may be enough to measure the sound level effectively.

A fourth issue that may occur develops from the fundamental problems of wireless sensor networks. Cellular phones are wireless, so power consumption will be a very large factor in the design of the sensors. It would be very detrimental to the project if the battery consumption was greatly increased due to the attachment of a sensor. If this occurred, users would be deterred from attaching the sensors for longer periods of time. Also, the possibility of an unstable connection must be taken into consideration. As mentioned before, each node must be calibrated to output uniformly across the network [1]. Lastly, data transfer rate must be kept in mind. Though upload bandwidth is lower than download bandwidth, the platform may be limited by the total amount of download bandwidth. If the user wishes to view a real-time map of the sensor network may take a bit of time if using the 30kbps provided by GPRS (General Packet Radio Service), which is currently what most cellular devices use to transfer data. This translates to 2.2 seconds to transfer 10KB of data [18]. In order to overcome this issue, scalable vector graphics, as mentioned in Xiaoyong Su's paper [18], can be very valuable for rendering the maps. Another issue with data transfer is the current cost of data service on cellular devices. Though it is becoming more popular to have unlimited data on cell phones, thanks to multimedia cellular phones such as the iPhone, it is definitely not widespread.

Lastly, there are a lot of different parameters that each type of sensor will need as inputs. Some sensors will require more bandwidth due to a faster refresh rate, while others may need to measure at a finer grain [17]. This issue will need modifications of both the hardware and software of this mapping network.

V. Conclusion

The platform to attach sensors onto cellular phones can be a great data collection tool. Just from investigating one sensor, there were many applications that were made possible that would otherwise be very costly or unfeasible. The applications discussed could change the way their fields are currently run. The platform does not include limitations on which sensors may be made, only that any sensor could be connected into a cellular device to create a network of information. In this way, doors are opened for anyone to apprehend monumental changes in the world we live in. Significant work still remains to create the sensor mapping platform and develop the sensor capable of connecting to it.

References

[1] Culler, David, Deborah Estrin, and Mani Srivastava, Guest Editor's Introduction: Overview of Sensor Networks, ***Computer***, 2004

[2] McCollum, Jordan. Facebook Really Does Make Money, *Marketing Pilgrim*, 10 Dec. 2007, http://www.marketingpilgrim.com/2007/08/facebook-really-does-make-money.html

[3] Find and Buy Real Estate, *Smarter Agent*, 15 Dec. 2007, http://www.smarteragent.com

[4] Global Cellphone Penetration Reaches 50pc., *Reuters*, 09 Dec. 2007, http://investing.reuters.co.uk/news/articleinvesting.aspx?type=media&storyID=nL29172095

[5] Google Rolls Out Mobile Phone Locator, *Yahoo,* 10 Dec. 2007, http://news.yahoo.com/s/ap/20071128/ap_on_hi_te/google_mobile_maps;_ylt=AoUK.8BXdj0hMCoqZN_Zb536VbIF
[6] Gunshot Detection, *Safety Dynamics*, 11 Dec. 2007, http://www.safetydynamics.net/
[7] Home, Socialight, 10 Dec. 2007, http://socialight.com/
[8] Home, *Super Local Media*, 10 Dec. 2007, http://superlocalmedia.com/?page=blog
[9] Honicky, R. J. Automatic Calibration of Sensor-Phones Using Gaussian Processes. *Electrical Engineering and Computer Sciences, University of California at Berkeley. Berkeley: Department of Computer Science, UC Berkeley,* 2007.
[10] Is Your Cell Phone Exposing Where You are?, *CBS*, 10 Dec. 2007, http://www.cbsnews.com/stories/2007/05/01/scitech/pcanswer/main2746509.shtml
[11] McLane, Daniel. E-Mail interview, 3 Dec. 2007.
[12] Mobile Phone Location Technology, 10 Dec. 2007. *TRISENT*. http://www.trisent.com/
[13] N-SMARTS, *UC Berkeley*, 10 Dec. 2007, http://www.trisent.com/
[14] Noise Mapping England, *Defra*, 10 Dec. 2007, http://www.noisemapping.org
[15] Paul, L. G., Cutting the Cord, *Managing Automation Magazine,* Sept. 2004.
[16] Ramamurthy, Harish, Dhananjay Lal, B. S. Prabhu, and Rajit Gadh, ReWINS: A Distributed Multi-RF Sensor Control Network for Industrial Automation, *IEEE Wireless Telecommunication Symposium WTS, Pomona*, 2005.
[17] Ramamurthy, H., B. S. Prabhu, and R. Gadh, Reconfigurable Wireless Interface for Networking Sensors (ReWINS), *In Proceedings of IFIP TC6, 9th International Conference*, 2004.
[18] Su, Xiaoyong, B. S. Prabhu, Chi-Cheng Chu, and Rajit Gadh, *Scalable Vector Graphics (SVG) Based Multi-Level Graphics Representation for Engineering Rich-Content Exchange in Mobile Computing Environment*. *University of Los Angeles, California. 2005*, http://www.wireless.ucla.edu/techreports/UCLA-WINMEC-2005-201-SVG-EXCHANGE.pdf
[19] The National Emergency Network, *FCC*, 10 Dec. 2007, http://www.fcc.gov/pshs/911/Welcome.html
[20] VZ Navigator, *Verizon,* 10 Dec. 2007, http://www.verizonwireless.com/b2c/splash/turnbyturn.jsp
[21] Welcome to AdSense, *Google*, 10 Dec. 2007, https://www.google.com/adsense/login/en_US/?gsessionid=UBWKnnG8SLw
[22] What is Meetro?, *Meetro*, 10 Dec. 2007, http://www.meetro.com/
[23] Your Social Compass, *Loopt*, 10 Dec. 2007, https://www.loopt.com/loopt/sess/index.aspx