NEW USES FOR OLD SMARTPHONES

Interactive Qualifying Project Completed in Partial Fulfillment
of the Bachelor of Science Degree at

Worcester Polytechnic Institute, Worcester, MA

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Apr 30, 2015

Abstract

Smartphones play an important role in our daily life. It is often the case, however, that they are replaced before they have been used to the full extent of their capacities. We investigate the feasibility of collecting old yet still very powerful smartphones and the potential societal impact of implementing some strategies for utilizing them in the fields of medicine, education and environmental observation. In particular, we investigate the use of smartphones as medical aids for Alzheimer's patients, managing a cardiac rehabilitation regiment and helping stroke victims learn to walk again. We consider smartphones as a means of improving education at various age levels in low income communities by way of the various apps available as well as by general access to the internet. We also examine the possibility of using smartphones to perform the tasks of monitoring air quality, monitoring structural health, detecting natural disasters, and preventing poaching. In our conclusions, we describe the expected impact of the many schemes and comment on which ideas we anticipate to be the most effective.

Authorship

Kewen Gu

Kewen is primarily responsible for the section regarding Alzheimer's and stroke victims, for the section on educational impact on elementary age children, the sections on smartphones in air quality monitoring and disaster prevention, as well as the analysis of the survey results and compiling the data in table 7.

Michael Smith

Michael is primarily responsible for the section regarding cardiac rehabilitation, the sections on high school and adult age educational applications, the sections on structure monitoring and poachers, as well as for compiling the data in tables 1-5.

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Executive summary

The primary purpose of this IQP project is to investigate how smartphones might be recycled from the community and used for purposes that could have a positive societal impact. It is not the purpose of this work to develop any such scheme in detail, but rather to serve as a discussion on a variety of ideas that show promise. We ultimately provide recommendations on how to effectively reuse old smartphones.

The first goal of this project is to determine the availability of smartphones in the United States. A number of issues are addressed. Firstly, given that smartphones have now been on the market for almost ten years and that the expected life of many of these phones is at least five years, does there exist a large number of working smartphones in the United States which are not being used? To answer this, we examine quarterly reports from various cell phone providers to get an idea of how many smartphones are likely in the country. This information is coupled with census statistics on the number of adults in the United States as well as data on how often statistically a customer replaces their old phone with a new one to estimate how many "old" smartphones may be in the country. To answer this question, we conduct a survey in which people are asked whether they own old phones and whether they would be willing to donate these for purposes that are intended to have a positive impact on society. They are also asked if a financial incentive would motivate them to donate old phones. This information is used to prescribe how phones might be collected and the likely expense this would incur.

With this data, various schemes to reuse old smartphones can be investigated. For each possible scheme, we address two questions. Firstly, what impact it might have, and secondly, for how much such a scheme may be expected to cost to implement.

The first category of applications is in medicine. We investigate the possibility of using old smartphones to aid in patients with Alzheimer's disease at various stages of the condition. For instance, apps have been developed to track someone who has Alzheimer's disease and has become prone to wandering long distances unaccompanied by anyone. With apps like this and others, we consider how, particularly in the case of low income individuals, donated smartphones might assist in the treatment of patients. Similarly, we investigate possible use for patients who have suffered a cardiac related issue and must undergo rehabilitation. This type of rehab can be expensive and the structure of it can be unappealing to many people. Recent research has considered a more informal program of rehabilitation that depends in part on the use of smartphone apps, study the impact of implementing this on a large scale. Finally we consider applications that support victims of stroke.

The second category we consider is education. We divide students into three age groups, elementary, high school and adult, and consider, as members of these demographics pursue education, how smartphones can help. The most useful development here is in the possibility of providing students in underprivileged communities with access to all the educational material available on the internet in broad and informal settings. For young children, we consider apps which have been developed to help young minds grow and consider how smartphones in classrooms can be a powerful educational tool. For high school age children, we consider the value of educational material on the internet and how to help students access it. For adult age people pursuing education, we investigate whether an approach using old smartphones could be beneficial.

The third category is various types of monitoring of the environment and infrastructure. We consider monitoring air quality, monitoring the structural health of buildings and bridges, identifying and managing natural disasters and catching poachers. In air quality, we envision pairing smartphones with devices used to detect the presence of various elements in the air. In structural health, we consider monitoring oscillations in buildings in three ways using smartphone technology. The phones utilize their basic technologies to determine when fractures and other defects may have occurred, as well as when extreme oscillations imply that a structure may be collapsing. In natural disaster monitoring, we investigate how systems of smartphones can be used to detect signs in nature of the occurrence of several natural disasters. In poacher monitoring, we devise a potential scheme for using smartphones to prevent poaching.

Finally we provide our recommendations and comment on the impact of each of our potential schemes, detailing how we expect each to play out. In particular, we conclude that a subset of approaches discussed in this project are expected to have a larger impact than others.

1 Introduction and Literature Review/Background

The role smartphones play in our society becomes ever more central as the technologies they utilize grow more varied and advanced. No longer simply cell phones, the current smartphone makes use of high tech video and audio recording, internet access, GPS service, multiple signal transmission and most importantly of all, access to the world of apps. Because of the advanced technology in a typical smartphone operating system (in this paper we consider iOS and Android), smartphones can now perform a wonderfully diverse array of tasks that make them some of the most useful tools in modern society. Furthermore, the fact that newer smartphones pour in to society at increasing rates implies the existence of a large number of working smartphones that no longer serve any function, which has induced researchers to consider how society might take advantage of these useful devices in new and different ways. The goal of this project is to investigate: 1) how many unused smartphones are available; 2) what are possible schemes to reuse them; 3) what is the cost associated with each scheme; and 4) what are the societal impacts of these schemes.

One can imagine a variety of hypothetical scenarios in which one or a collection of smartphones could be used to perform tasks related to surveillance, data collection, supervision, information diffusion and more. This is discussed in [1] from a number of perspectives, where such applications as forest fire prevention, home security, patient monitoring and education improvement are mentioned and reviewed. In the instance of fire protection, one scheme might be to set up an array of smartphones programmed to read gas density levels and humidity in the air in the forest and design them to warn when wild fires start or when conditions imply a strong likelihood of fire. Further investigation of this technique might include understanding exactly how the smartphones must be programmed and considering long term energy sources and protection from environmental affects for the smartphones. Beyond this, another question is how impactful a strategy like this might actually be. Likewise, other ideas mentioned in [1] are considered generically, or without much depth, while investigation of, in particular, the potential societal impact such strategies might actually have are not examined.

Two other examples in the literature of this kind of work are [2] and [3], where an in depth look at models for aid in cardiac rehabilitation [2] and stroke recovery [3] utilize smartphone apps in their designs. They also make use of a variety of other technologies and devices but achieve small, simple set-ups which open up the possible ways for people to get care related to these issues. Their strategies don't explicitly consider cost, however, which for their designs could be substantial. It is central to our paper to consider the financial drawbacks to any scheme of smartphone use, as we are interested in discussing positive societal impact foremost from a charitable perspective. The goal of this paper is to contribute to some degree in this area.

2 Methodology

We consider first, schemes for collecting a large number of old smartphones and the feasibility of implementing such schemes, and then examine three areas, medicine, education and environmental monitoring, where the reuse of smartphones might be beneficial by considering some specific applications and discussing their potential impact. Throughout our work, consideration is given to the effects on low income individuals and disadvantaged communities. In collecting the smartphones, the primary issues we discuss are: 1) how many smartphones might realistically be available and 2) how we might collect them. Contained in this issue is the question of whether an incentive for people might motivate a large number of phones being contributed, and whether depending on donations is also a worthwhile approach. In particular a survey is conducted aimed at resolving this issue. We furthermore consider some data collected from quarterly reports of various smartphone distributors and attempt to estimate the number of available smartphones in the United States. We compile these results and use them in the later sections.

In medicine, we examine the impact of implementing some techniques in the literature for aiding in Alzheimer's disease, cardiac rehabilitation and walking after a stroke. Smartphone use in aiding those with Alzheimer's disease has been discussed in [4], [5] and [6]. Apps have been developed particularly to aid the memory of patients with Alzheimer's, and techniques have been developed to aid those in the severe stages of Alzheimer's when situations like wandering become likely and problematic. We devise suggestions for large scale strategies that make use of these apps and comment on the potential benefits such strategies could have. Similarly, cardiac rehabilitation and walking after a stroke are other areas where technologies are utilized which perform tasks that can now be performed by smartphones. Ideas have been developed in [2] and [3] for how to benefit from the freedom that is gained by performing these tasks on portable devices. Furthermore, these ideas may have a beneficial financial impact as well. We investigate schemes here as well for implementing large scales strategies.

In education, we review data on accessibility to the internet for schools in low income communities and investigate how the donation of smartphones could remedy issues there. In particular, we discuss the growing availability of good educational material on the internet, how smartphones can aid students in accessing this material, and furthermore how educational apps can meaningfully contribute to public education. This is mentioned in [1] and related material is discussed in [7], [8], [9] and [10]. We partition this section into three parts, elementary age, high school age and adult age, and examine the possibilities for each.

The last area of investigation for us is environmental observation, which we mean broadly, taking four categories into consideration. First we consider air pollution and the utilization of smartphones as carbon dioxide detectors. Second, we consider monitoring the health of large scale structures like bridges and buildings with smartphones particularly as aids in detecting abnormal oscillatory frequencies within the structures. Third, we consider monitoring the environment to quickly detect disasters like earthquakes and forest fires. Fourth, we consider the possibility of using a system of smartphones in the wilderness to possibly aid in the detection of poachers.

Finally, we provide recommendations for the most meaningful ways of utilizing old smartphones and comment on how some of the techniques suggested are not expected to be of meaningful impact.

3 Results and Discussion/Analysis

3.1 Smartphone numbers and collection scheme

3.1.1 Smartphone in Circulation

In order to understand how smartphone reuse can impact society, it is important to understand how many smartphones there actually are, and how many are no longer in use or have been replaced by newer models. Table.1 reflects data collected by Statista* from the quarterly reports of various smartphone distributors and shows how many smartphones (in millions) by operating system had been sold by the end of 2013 [11].

OS	2009	2010	2011	2012	2013	Total
Android	6.80	67.22	220.67	451.62	758.72	1505.03
iOS	24.89	46.60	89.27	130.13	150.79	610.90
RIM	34.35	47.45	51.53	34.21	18.61	186.15
Symbian	80.88	111.58	88.41	28.51		309.38
Microsoft	15.03	12.38	8.76	16.94	30.84	83.95
Bada			9.51	15.78		25.29
Other	10.43	11.42	4.74	3.49	8.82	38.9

*as reported by Statista/various quarterly reports. Numbers are in millions of phones

Table.1 Global Smartphone Sales to 2013 (in millions)

The data in particular shows that roughly 1.5 billion android smartphones and 610 million iPhones have been sold in the world. To develop an estimate for the number of smartphones in the U.S. we rely also on Table.2 and Table.3 below, which show the number of smartphone units shipped to each part of the world in 2012 and 2013, to give an estimate of what portion of the world smartphone market the U.S. occupies. These tables show that the U.S. accounted for about 11 percent of all manufactured smartphones in 2012 and 2013. Using this estimate and Table.1, we determine Table.4, our estimate for the number of smartphones sold in the U.S. by 2013.

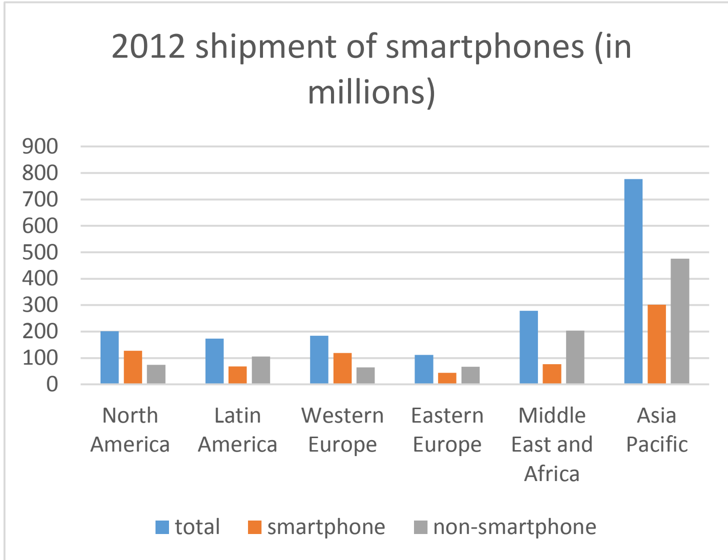


Table.2 2012 Shipment of Smartphones (in millions)

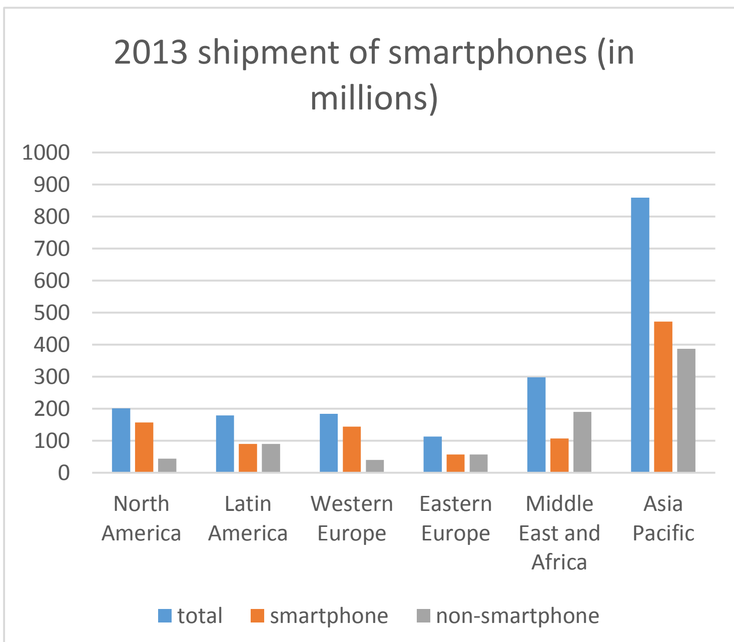


Table.3 2013 Shipment of Smartphones (in millions)

We rely on the first few entries in Table.4 to reach an estimated 250 million smartphones in the U.S. by 2013. According to a study done by Nielsen [12] in 2014, an estimated 65 percent of Americans own smartphones. The U.S. census bureau [13] estimates the total adult population of the U.S. to be about 247,614,000, which places Nielsen's estimate at 160,949,100 smartphones in use in the U.S. Having no data on the number of smartphones that have been irreparably damaged or stolen in the past few years, our tentative estimate for the number of smartphones in the U.S. which may be available for donation is between 50 and 100 million.

Operating Systems	U.S. sales by 2013
Android	165.55
iOS	67.20
RIM	20.48
Symbian	34.03
Microsoft	9.23
Bada	2.78
Other	4.28

Table.4 U.S. Smartphone Sales by 2013 (in millions)

Accuracy

Although much of the information used above comes from reliable sources, the estimations derived from them are clearly open to conjecture. In particular, data from tables 2 and 3 was used to estimate what portion of the global smartphone market the United States occupies. Although the two tables agree to a large degree, and so it might be expected that data from other years would also agree, there is a question as to how the global distribution of smartphone shipments to distributors relates to market participation, and furthermore how those shipments relate to the number of phones which were ever sold in a given country. We offer no insight into the possible correlations here. Deviation in this area could affect the estimations in Table.4. Furthermore, as was noted above, due to our lack of data regarding theft and destruction of smartphones, among other factors, the final estimation we make as to the number of available smartphones must also be viewed within a large confidence window.

However, assuming our estimation that the U.S. occupies 11% of the global market to be accurate to within 2%, we are left with a window of about ±30 million available phones, which is sufficiently accurate for our purposes. Our final results simply require that the number be on the order of 10 to 100 million. A deviation of 30 million smartphones is clearly large given that, in terms of the U.S., this corresponds to about 1/8 of the total adult population. We record for later reference Table.5 below.

Demographic	Population	Percent who own smart phones	Number who own smart phones
Total adult	247,614,000	0.58	143,616,120
Men	121,826,088	0.61	74,313,914
Women	125,787,912	0.57	71,699,109
White	223,553,000	0.53	118,483,090
African-American	38,929,000	0.59	22,968,110
Hispanic	50,478,000	0.61	30,791,580
18-29	64,728,000	0.83	53,724,240
30-49	83,742,000	0.74	61,969,080
50-64	58,781,000	0.49	28,802,690
65+	40,267,000	0.19	7,650,730
High school or less	100,428,000	0.44	44,188,320
Some college	46,484,000	0.67	31,144,280
College+	92,429,000	0.71	65,624,590
Less than $30,000/yr	114,015,000	0.47	53,587,050
30,000-49,999	45,288,000	0.53	24,002,640
50,000-74,999	29,612,000	0.61	18,063,320
75,000+	29,747,000	0.81	24,095,070
Urban	199,824,000	0.64	127,887,360
Rural	47,790,000	0.43	20,549,700

*population values from the U.S. Census Bureau [14], smartphone statistics from The Pew Research Center [15]

Table.5 Smartphone ownership in the U.S. by demographic

3.1.2 Collection Scheme

Although there might be as many as 100 million working smartphones in the United States which currently serve no purpose, it is no small task to somehow collect all of them and put them to use. To this end, we consider first the possibility of U.S. citizens freely donating their old phones and ask if this might result in a large number of collected phones, and then the potential improvement which might result from an incentive being offered.

To this end we conduct a survey. The information we hope to gather is simply an indication of whether a large scale collection of smartphones is a feasible goal. We want to know, would it be possible to collect old smartphones from people in some systematic way, and more specifically, would people be willing to donate their phones for such a cause? We also consider that a small incentive may motivate more people, and so we also want to know if people would be more interested in donating their old phones if such an incentive were offered. We constructed a three question survey aimed at answering these questions. We asked

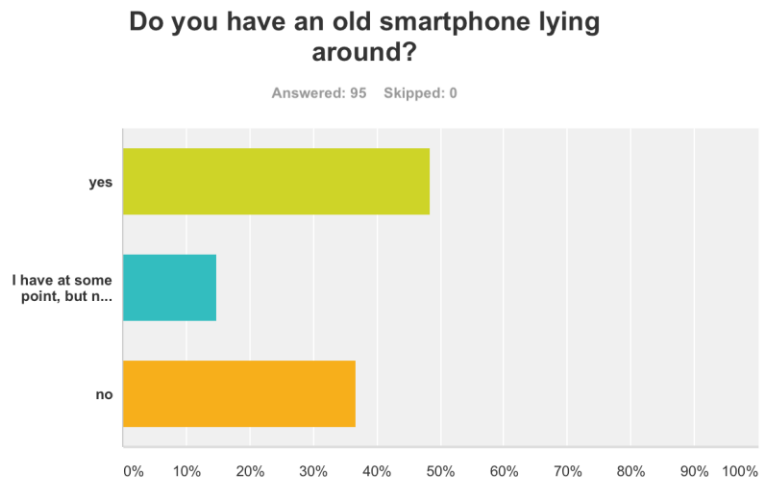
1. Do you have an old smartphone lying around?
   - Yes
   - I have at some point, but no longer
   - no
2. How willing would you be to donate such a smartphone for charitable purposes?
   - Not willing
   - Somewhat willing
   - Certainly willing
3. Which, if any, of these prices would you be willing to sell such a smartphone for? (select the smallest value)
   - $10.00
   - $20.00
   - $50.00
   - $80.00

From our data, we derive an idea of how to systematically collect a large number of smartphones.

Survey results and analysis

In our discussion of possible applications, we consider either that old smartphones are donated for on the basis of benefiting society, or that they are collected for a small fee. Therefore, in order to examine the possibility of gathering old smartphones in this way, we conduct a survey that provides insight into the likelihood that such schemes are feasible. The survey was conducted through www.surveymonkey.com and spread through social media, and it is expected that the responses represent a broad range of people in terms of age, gender, race and socioeconomic status. Hence the data obtained is expected to be reasonably unbiased, and we extrapolate the results to estimate a general response from the public to collection schemes.

The survey consists of three questions, the total number of recorded responses is 95. The first question asks "Do you have an old smartphone lying around?" The distribution of answers is shown in Table.6a:



Answer Choices	Responses	
yes	48.42%	46
I have at some point, but no longer	14.74%	14
no	36.84%	35
Total		95

Table.6a Question 1

It shows that 46 out of 95 individuals responded that they have old smartphones, which is about half of the total sampled population.

The second question asks "How willing would you be to donate such a smartphone for charitable purposes?" The results are shown in Table.6b:

How willing would you be to donate such a smartphone for charitable purposes?

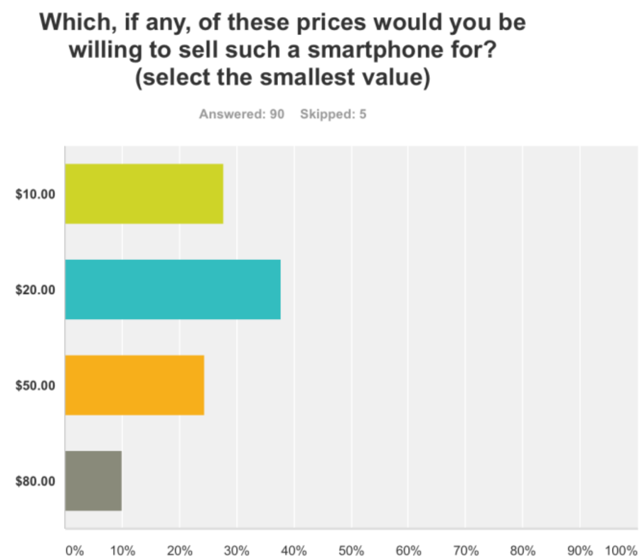
Answered: 94 Skipped: 1

	not willing	somewhat willing	certainly willing	Total	Weighted Average
Results	8.51% 8	36.17% 34	55.32% 52	94	2.47

Table.6b Question 2

86 out of 94 responses (1 skipped) express some willingness to donate their old smartphones for charitable purposes, while 52 indicate that they certainly would do this. Only 8 out of 94 state that they would be unwilling. Therefore, we estimate the percentage of owners of old smartphones who would be willing to donate old phones is around 55.32% (certainly willing) to 91.49% (somewhat willing plus certainly willing) of the sampled population of owners of old smartphones.

The third question asks "Which, if any, of these prices would you be willing to sell such a smartphone for?" The responses collected is shown in Table.6c:



Answer Choices	Responses	
$10.00	27.78%	25
$20.00	37.78%	34
$50.00	24.44%	22
$80.00	10.00%	9
Total		90

Table.6c Question 3

More than half of the total responses (59 out of 90) state a willingness to sell an old smartphone for a price less than or equal to 20 dollars. About 35% of the sample population would only sell for a price above or around 50 dollars, which, in some cases, is relatively high and unacceptable given that the intention of this collection scheme is partly to induce a low cost.

Although the sample population of this survey is small, it gives us an estimation of the percentage of the population who would be willing to donate old smartphones or sell them at a low price. The survey results suggest that at least half of the population are certainly willing to donate their old smartphones, and at least half of the population are willing to sell their old smartphones at a price around 20 dollars. Combining these estimates with the estimates for the total number of old smartphones among households provided above, we find that if half of the available phones can be collected, many of our applications for donated old smartphones are feasible.

3.2 Application in Medicine

3.2.1 Alzheimer's disease

Facts about Alzheimer's disease [4][16]

Alzheimer's disease (AD) is an irreversible brain disease in which patients slowly lose memory, thinking skills and the ability to complete even the simplest tasks. In most AD cases, symptoms first appear after age 65. In 2014, approximately 5.2 million American Citizens had AD. More than 500,000 elderly people die each year because of AD. It has become the 6th leading cause of death in the United States and the 5th leading cause of death for those aged above 65. Between 2000 and 2010, while deaths from major diseases like cancer decreased, deaths from AD increased by 68 percent.

In 2013, 15.5 million families provided 17.7 billion hours of unpaid care, valued at 220.2 billion dollars, to AD patients. In addition, due to the physical and emotional burden of caregiving, in 2013 AD caregivers were estimated to have spent 9.3 billion dollars in additional health care for themselves. AD is now the most expensive among all diseases in the nation. In 2014, the direct cost to the American society of caring for those with AD was estimated to be 214 billion dollars in total. Despite these staggering figures, AD is expected to cost an estimated 1.2 trillion dollars by 2050.

AD consists of three main stages: mild (or early-stage), moderate, and severe (or late-stage). Understanding the patient's behaviors during each stage can help caregiving and planning ahead. In the mild stage of AD, patients usually experience some memory loss and small changes in personality. Individuals may find it difficult to remember recent events or the names of family members; they may no longer be able to solve simple math problems or balance a checkbook. In addition, patients slowly lose the ability to plan and organize. In the moderate stage of AD, memory loss and confusion become more obvious. It is even more difficult for patients to organize, plan or follow instructions. They may also have trouble recognizing family members and friends. They may not know where they are or what day or year it is. They also may begin to wander, and therefore should not be left alone. By the final stage, patients lose the ability to communicate and begin to completely depend on others for their care. They may not be able to walk or sit up without help and they may not be able to recognize family members at all.

People with AD can benefit from technologies or devices that can provide them with support. Since AD is not a curable disease, our approach focuses on maintaining the quality of life of AD patients to the extent possible. Therefore, we consider how people with mild or moderate AD can benefit from some devices which are intended to help them remember and organize, while caregivers can benefit from other devices which aid in monitoring and locating patients.

How mobile applications can help

The Alzheimer's Disease Society [17] describes several assistive technologies that facilitate memory, reduce risks and promote autonomy for AD patients. Here are a few of these tools:

- Calendar clocks
- Touch lamps
- Reminder message using personal voice prompts
- Locator devices
- Medication aids
- Remote indoor monitoring systems
- Tracking devices

Smartphones are an ideal platform from which to implement the technologies listed above. Compared to PCs and tablets, smartphones cost less and are easier to use. Smartphones are relatively straight-forward in learning to use, which, Especially for the elderly, many of whom may have trouble working with electronics, and AD patients, who are prone to forgetting, serves our purposes. Our approach is based on general standards recommended when dealing with people with AD. This includes:

- Using simple language when interacting with AD patients.
- Repeating instructions several times.
- Instructions should be broken into small steps and given one at a time.
- Allow AD patients ample of time to respond and react.
- All messages should be as short as possible.

One application we propose is to use an MP3 player, which every smartphone is equipped with, to help facilitate the memory of AD patients. Music therapy is thought to be important for AD patients since it has been shown that it can boost brain activities. It can shift mood, reduce stress and agitation, and stimulate more positive interactions. The music player on a smartphone can be used by patients while the song library can be managed through mobile apps by family members or caregivers who are familiar with the favorite music of the patient and know many songs which played a significant role in the patient's life. The mobile app can be synced with the music player so that when a patient has visitors, a family member can play "their song" to assist the patient in recognizing faces. Family members and caregivers can also program different songs to play during different times of the day. For example, playing relaxing music to fight from sundowning, which is a form of late-day confusion. Another example is playing a patient's favorite upbeat, sing-along songs during social gatherings. Another benefit is that the family of a patient can stay connected to them by viewing the statistics of their listening habits. Lastly, when a patient is alone, the device acts like a companion, providing eye-catching symbols inviting them to play music.

The GPS (Global Positioning System) equipped on most smartphones can be used to track the location of wandering AD patients, which is expected to reduce the risk of a patient getting lost and release the burden on caregivers of constantly monitoring the patient. Tell My Geo [5] is an android app that allows caregivers to schedule regular location updates. Patients with AD can also easily alter who their caregivers are using the app's large help button whenever they are disoriented or in need of assistance. The app also allows caregivers to store critical medical information and send it directly to health care providers in the event of an emergency. Tell My Geo requires two smartphones to administer and use; one for the caregiver to track the patient's location and the other for the patient for monitoring his or her location.

Rehabilitation of AD patients focuses on slowing down the rate of further progression of the disease and decline of their ability to engage with the surrounding environment. A mobile app with several modules, named ADcope [6], is developed on smartphone platforms to support this approach. The app and its modules are designed to help patients in many aspects of daily life. In addition, ADcope provides an option for reminding AD patients to use the app frequently.

ADcope consists of three modules. The first module, named memory wallet, allows the patient to take photos of familiar people, places and events. The patient is given a chance to tag the photos with phrases that reminds him or her of the subject of the photo. Photos of people can also be tagged with voice samples of the person in the photo. The patient can go back to the wallet as frequently as needed to be reminded of these people, places and events.

The second module is a calendar with reminders of any necessary daily activities and events. The events can refer to information in the memory wallet, such as photos, to help the patient recognize the person and place. The calendar also includes a reminder to review the memory wallet itself.

The third module utilizes NFC tags that can be placed on various surfaces, such as drawers and doors. As the person touches these tags with the smartphone, the smartphone displays a list of content within the drawer or room. This saves the person from having to open each one for inspection when looking for things. It also benefits the patient who no longer know how their things are arranged.

Smartphones can also be utilized by research institutes to advance AD research. Scientists at the University of Vienna have developed a mobile app called Power Sleep [17], which serves as an alarm clock. When a patient is about to sleep, the alarm on the app can be set, and the phone is then plugged in to charge. After the phone reaches an 80% charge, Power Sleep starts to process data. The phone downloads a file from the Matrix of Proteins (SIMAP) database which holds information about all known protein sequences. While the phone charges, the database decrypts protein sequences and sends that information back to researchers. Understanding how proteins are arranged is crucial in fighting AD. Thus, with a simple app installed on smartphones, patients can contribute to AD research while sleeping.

How to implement

Old smartphones with the desired apps and hardware installed can be purchased by or donated to hospitals and distributed to AD patients. Hospitals can assign smartphones to patients at different AD stages according to their needs. For example, moderate and severe stage AD patients may begin to wander, and so they can be given a smartphone with GPS equipped to track their locations. Also, people with low eyesight may benefit more from a smartphone with larger display. Similarly, patients with hearing losses may prefer to use a smartphone with louder built-in speakers. However, for patients in the late stage of AD, hospitals should set some kind of restrictions to prevent them from losing or damaging the phone. One way is to institute a fee for a second phone if the first is lost or damaged. In particular, if the patient has completely lost the ability to take care of their daily needs and operate the smartphone on their own, smartphones should be assigned to their caregivers instead of the patients themselves.

The cost mostly requires developing the mobile apps, while a small portion of it may be for distribution, repackaging, maintenance and so on. However, the profits to companies for developing these apps are difficult to calculate because of the limited marketing knowledge for such a product. If smartphones are donated by people or organizations to hospitals, the cost could be even lower, leaving only the purchase of the mobile apps rather than including the purchase of the smartphones themselves.

What is the impact

In the previous section, we discussed that the benefits of utilizing the mentioned applications for AD patients includes facilitating memory, reducing risks and promoting autonomy. Because AD is not curable, our approach focuses on how to improve the life quality of AD patients, no matter the stage they are in. For example, some apps can help patients remember the names of their family members or the names of familiar places and events. The implementation of those apps could make the lives of AD patients much easier. To some extent, the mobile apps can also slow down the progression of symptoms.

Patients with low income are the ones who are expected to benefit the most from these technologies and devices. Most of them do not own a smartphone, as can be seen in Table.7. We observe from Table.7 that only 47% of low-income citizens (household income less than $30,000/yr), and 19% of citizens aged 65 and above own a smartphone.

Characteristics	2013 (in thousands)				
	Total	Below Poverty			
		Number	90% C.I.3(±)	Percent	90% C.I.3(±)
Total People	312,965	45,318	1,014	14.5	0.3
Under age 18	73,625	14,659	455	19.9	0.6
Aged 18 to 64	194,833	26,429	648	13.6	0.3
Aged 65 and older	44,508	4,231	227	9.5	0.5

Table.7 Population of poverty and the total population in the US [18]

With the information given in Table.1 and Table.7, we are able to estimate the total population of people in poverty aged 65 or older who do not own a smartphone. Based on the US census data from 2010, there are 40,267,984 people aged 65 or older in total. Approximately 81% of those people do not owned a smartphone, about 10.51% of those people are in poverty, and roughly around 12.42% of those people have AD. We therefor estimate that there are 426,000 people aged 65 and above who are in poverty, have AD and do not own a smartphone. In general, if the smartphone applications for AD patients are successfully implemented, at least 400 thousand people can be benefited.

The benefits of our approach also includes relieving the burden and stress on AD caregivers, as well as reducing the care costs. Applications such as location tracking can reduce the care time and cost significantly, because caregivers do not have to keep their eyes on patients at all times to prevent them from wandering. In addition, apps for reminding patients of daily events and activities can reduce repeated questions from the patients, which can be stressful for caregivers.

Hospital can benefit from these applications as well. If hospitals are willing to play the role of collecting and distributing smartphones to AD patients, they can develop better reputations. A good reputation is essential for a hospital to grow and to make progress in the future. This application can also reduce the frequency of patient visits to the hospital, which indirectly reduces the amount of health care needed.

With the rapid growth of the AD population and the increasing cost for care, the burden left on our society keeps growing too. As discussed in the previous section, AD will cost an estimated 1.2 trillion dollars by 2050. However, we hope by that time the advancement on technology can help AD patients and caregivers more substantially.

3.2.2 Cardiac Rehabilitation

There are a variety of medical conditions that qualify someone as a cardiac rehabilitation candidate. In particular, those who have recently suffered a heart attack or any of a number of heart related conditions including having undergone heart surgery or percutaneous coronary intervention procedures like angioplasty. The most well-known of these, a heart attack, is the result of lack of blood flow to the heart, causing damage to the heart muscle. Those who suffer from cardiovascular issues are at a greater risk of suffering from a heart attack, and poor lifestyle choices result in a pathological tendency toward having a heart attack. An immediate goal after a heart attack occurs is to preserve as much of the heart muscle as possible, but after the initial experience, and for those at increased risk, a long term technique for the prevention of a heart attack and for recovery after a heart attack is cardiac rehabilitation.

There are roughly 26 million people in the U.S. who are considered at a high risk of heart attack [19]. As with many conditions where high medical costs might play a factor in treatment plans, cardiac rehabilitation is often not taken advantage of for financial reasons.

<u>What is cardiac rehabilitation</u>

Cardiac rehabilitation is a generally supervised program of exercise intended to increase cardiac strength and prevent further problems in people who have suffered some kind of heart related issue, such as a heart attack. From [2], "Cardiac rehabilitation (CR) is widely recognized as playing a critical role in optimizing recovery in cardiac patients, with meta-analyses demonstrating reduced cardiac and all-cause mortality, fewer cardiovascular related events, less re-hospitalization and shorter length of stay. CR has also been shown to be a highly cost effective form of secondary prevention."

However, these programs are often not taken advantage of by patients for a number of reasons, one of which is related to travel [20]. In short, [2] investigates mitigating this by devising a scheme in which people can benefit from cardiac rehabilitation without having to leave their homes. Their program utilizes monitoring systems in smartphones which transmit data in real time to specialists who help patients in completing their rehab. The immediate benefit of this is that it provides a more flexible scheme for rehabilitation. In particular, if circumvents the need to travel, which is particularly beneficial to patients who don't own a car. It also simply means rehab can be completed without such a demand on a person's schedule, which is expected to have an impact on the number of patients who are willing to commit to a rehab regimen at all [21].

<u>How smartphones can help</u>

This is a prime area to consider the impact of using old smartphones for new purposes. As our primary goal is to improve cost-benefit comparisons in strategies for performing important tasks in societal settings, we consider first the cost of traditional cardiac rehabilitation. Such programs can cost from $2,000 to $10,000, depending on the approach, although schemes have been developed which can reduce the total cost to under $1,000 [22]. Much of this cost is associated with equipment for monitoring the patient's condition and progress. In [2], a collection of small sensors designed to assess various factors of a patient's condition are combined and linked via Bluetooth to a smartphone to perform this monitoring. The one expensive component to their setup is the heart monitor, which costs about $300, and can be managed by way of a free app available on Android and iOS. They also utilize a GPS system, but, as has already been discussed in this paper, these are considerably affordable on smartphones. A one-time fee for this kind of setup is clearly preferable when one considers that many people will be able to take advantage of the same equipment over time. Thus, fitting a hospital with a number of these units, particularly in low income areas, for no charge to patients can have a powerful impact on the potential for more people to benefit from cardiac rehabilitation. Below is an image of a readout of a person's condition during cardiac rehabilitation similar to what would be displayed on a smartphone.

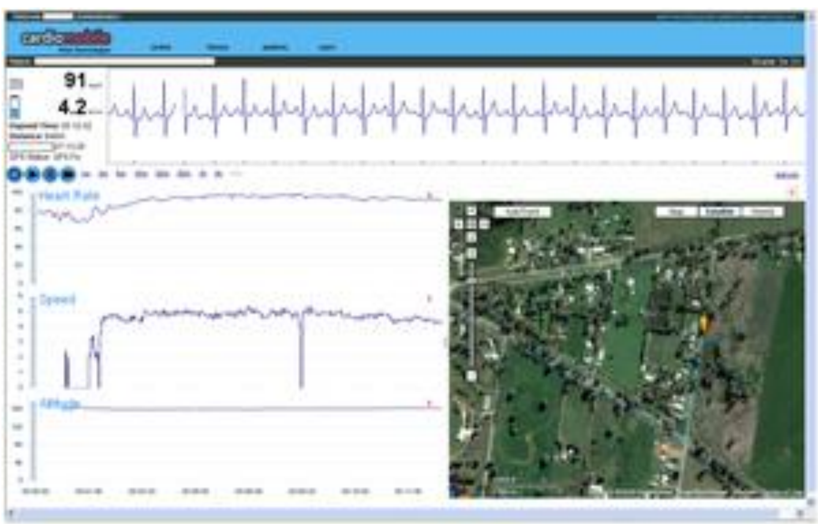


Figure.1 Example of readout of a smartphone setup for cardiac rehabilitation

<u>The strategy</u>

We envision patients committing to a program of daily exercise monitored through a smartphone by a specialist. As a part of the cost of the program, service to the phone must be paid for. If this is not absorbed as an aspect of the hospital's finances, then this fee would contribute to the cost to the patient or their insurance provider. The primary phase of cardiac rehab is expected to last only a few months [23], which puts a per-patient cost of roughly $100 for service throughout this time. There is of course also the cost for hiring the specialist, which is a necessary fee for any rehabilitation program. This means the primary financial impact that our strategy is expected to have is in the monitoring equipment, which in this setting is significantly cheaper than standard counterparts in a hospital [2], [21]. A program utilizing this idea can reduce the cost to patients if an initial fee is absorbed by the hospital to pay for the equipment, which is feasible in a low income area in which there is an impetus in the greater community to provide support.

From [24], "In many states, there is a wide gulf in access to and quality of care between those with below-average income and the rest of society." It is recognized in [24] that health care in low income areas is significantly poorer than that provided in more affluent communities, and that mitigating this is the responsibility of the public. The strategy we put forth is one example of a simple means of affecting this positively. Once a budget is determined for hospitals to provide free or reduced cost care to low income communities, enacting this plan through a portion of that budget would require exactly purchasing the necessary equipment and offering the opportunity of taking advantage of a rehabilitation program to qualified patients.

Cost

To construct an explicit cost for implementing a plan like this, we devise a cost per 10,000 adults within the population of expected patients for a given hospital. According to the Centers for Disease Control and Prevention [19], 11.3% of noninstitutionalized adults are diagnosed with a heart disease. Assuming that this number is not largely affected by such demographics as socioeconomic status, this means that for every 10,000 adults who fall under the care of a hospital in a low income area, about 1,100 experience heart related issues. Fitting a hospital then with 1,000 units per 10,000 people, and expecting each unit to cost under $500, this puts a one-time fee of $500,000 dollars per 10,000 people, or about $50 per adult in terms of a cost relative to the size of the community. Once a hospital is fitted with these units, the cost to the patient or insurance provider would be the monthly service of the phone and the specialist fee, which is expected [2] to be a strong improvement from the costs associated with the existing schemes.

3.2.3 Stroke

What is a stroke [25]

A stroke, also known as a cerebrovascular accident (CVA), cerebrovascular insult (CVI), or brain attack, occurs when the flow of blood to the brain is suddenly interrupted or when a blood vessel in the brain bursts. Brain cells die when they cannot receive enough oxygen and nutrients from the blood or there is sudden bleeding into or around the brain. Symptoms may include an inability to move or feel on one side of the body, problems understanding or speaking and a feeling like the world is spinning, among others. There are two main types of stroke: ischemic, due to blockage of blood vessels and hemorrhagic, due to bleeding into or around the brain. The main risk factor for a stroke is high blood pressure. Others include obesity, diabetes, high blood cholesterol, smoking and atrial fibrillation. The effects of a stroke can be permanent. Long term complications may include pneumonia or loss of bladder control.

"Generally, there are three treatment stages for stroke: prevention, therapy immediately after stroke, and post-stroke rehabilitation. Therapies to prevent a first or recurrent stroke are based on treating an individual's underlying risk factor for stroke, such as high blood pressure, diabetes and atrial fibrillation. Acute stroke therapies try to stop a stroke while it is happening by quickly dissolving the blood clot causing an ischemic stroke or by stopping the bleeding of a hemorrhagic stroke. Post-stroke rehabilitation helps individuals overcome disabilities that result from stroke damages. Medication or drug therapy is most common treatment for stroke. The most popular classes of drug used to prevent or treat stroke are antithrombotics (antiplatelet agents and anticoagulants) and thrombolytics" [25].

Strokes are the leading cause of death in the United States, killing nearly 130,000 Americans each year, which is equivalent to 1 in every 20 deaths. Strokes kill someone in the US about once every four minutes. Every year, more than 795,000 people in the United States have a stroke, and about 610,000 of these are first attacks and 185,000 are recurrent attacks. Strokes costs the United States an estimated 34 billion dollars annually, including the cost of health care services, medications and lost productivity. [26]

How mobile apps can help

Mobile apps are now widely used by health care professionals for evaluation and management. There are also apps that can be utilized by patients for maintaining medication compliance or management of risk factors for stroke prevention.

i-Stroke is a mobile system developed by researchers in Japan [27]. It is a free app and is already available in the Apple Store. The system comprises a transmitting server and a receiving smartphone, and has the following functions:

- Stroke call function for informing participating medical staff involved in all aspects of patient management of an expected admission.
- Time-bar function for monitoring patients' management course.
- Image view function for viewing images, including admission CT, digital subtraction angiography, 3-dimential bone reconstruction, real-time monitoring of procedure and postoperative images.
- Tick-box functions for input/displaying data, such as consciousness level and neurological findings.
- Real-time video streaming of microsurgical and diagnostic images from diagnostic and operating rooms.

- Tweeting to fellow specialists for exchanging opinion on the spot.
- Inter-hospital exchange of images and other information, allowing consultations for patients at other hospitals.

With i-Stroke installed on smartphones, information can be sent from a fixed workstation whenever there is a mobile signal. In addition to delivering images, when initiated before admission, the i-Stroke system alerts the relevant hospital staff on the patient's arrival condition and time, allowing the identification of patient-specific preparation. The real-time viewing of surgical and other procedures by senior experts outside the hospital allows the assessment of treatment progress and provides guidance, contributing to treatment safety and risk management. The Tweet function permits adding comments instantly about clinical images and other related data. i-Stroke is therefore a novel system that enables simultaneous communication among several members and results in significant time saving on decision making. Treatment instructions and other orders can be sent with a single touch.

Regaining the ability to walk after a stroke is a major rehabilitation goal. Rehabilitation strategies that are task oriented and intensive can drive cortical reorganization and increase activity levels in people after a stroke. Researchers at Clarkson University invented a wearable device for use with such rehabilitation strategies [28]. The device is based on the combination of a smartphone and in-shoe sensors. These shoe-based sensors will be able to monitor lower extremity activity, different postures and mobility tasks of an individual in his or her home or community. The information gathered by the shoe based sensor can provide feedback to the patient and therapist on real world mobility and affected lower extremity activity. Such information can also be incorporated into the Constrain Induced Movement Therapy (CIMT) program as part of the adherence enhancing behavioral strategies.

The system is composed of three major hardware components: the left shoe, the right shoe, and the smartphone. The left and right shoes are designed to use the identical software and hardware due to the symmetry of their operation and interaction. The sensor modules on each shoe consist of a microcontroller which is responsible for sampling of the pressure and acceleration sensors, a Bluetooth communication module and an on-board accelerometer. The shoe sensor hardware is attached to the back of the shoe and connected to the pressure sensor equipped with flexible insole that is underneath the shoe's original insole. The smartphone allows for synchronized monitoring and data collection from of a pair of shoes. Human interaction with the system is facilitated through the smartphone software. The software incorporates visual displays of the pressure sensors and accelerometers, which represents the data being logged in real-time.

Cost

If we assume that the smartphones used for these applications are all old smartphone donated to hospitals, the cost on smartphones will be negligible. However, designing and developing the mobile apps require a lot of time, money and human resources. And mobile systems like the wearable device we discussed above, require additional hardware peripherals, which cost a lot to design, build and test. In order to compensate the cost for developing both software and hardware, developers can charge a reasonable price on the product they make. While hospitals can order some of the products, whether they are apps, hardware or others, and then configure those products with the old smartphones being donated to the hospital. An advantage of this is that the device is relatively cheaper, and hospital can charge a small amount of money to rent or sell it to the patients. If the device is rented to the patient, it can be reused by other patients after being returned to the hospital. In this case, the cost to implement these applications can be reduced to minimum.

Impact

The mobile apps can help stroke patients in various ways, including preventing stroke by monitoring the risk factors, such as high blood pressure and diabetes, and regaining the ability to walk after a stroke.

Hospitals can also benefit from mobile systems like i-Stroke, which makes the treatment and management toward stroke patients more efficient, enhancing the communications both in and outside of hospitals, and saves time for treating patients after a stroke.

These applications reduce the risk of a stroke occurring. Meanwhile, they reduce the burden on health care providers as well as the cost spent by the nation on stroke.

3.3 Application in Education

In this section, we examine the possible impact on society caused by the reuse of old smartphones within the context of education. The idea is to understand the effects of not having access to the internet on children in underprivileged communities and to understand how providing these children with smartphones in the classroom, and potentially outside of it as well, can positively change this. These children could access data resources on the internet, possibly for doing research or to read material the school doesn't have in paper form. They could log in to educational programs such as, depending on the age level, MyMathLab.com [29] or funbrain.com [30]. Furthermore, with right planning, these smartphones could provide a new, streamlined way of providing homework assignments to children. This can not only improve the nature of the assignments the students are being given, but also provide the students with a more versatile homework experience, one that doesn't require sitting at a desk with a pencil and paper. We investigate three scenarios. First, we consider the impact of this kind of aid for elementary school children, second, high school children, and third we consider the potential impact on adults.

3.3.1 Elementary Age

Smartphones can be used in various ways in a regular classroom setting. In this section, we discuss possible uses of smartphones by students in elementary school and middle school in a classroom setting. With the proper modules and apps installed, most smartphones can be used by students to access dictionaries, record lectures, take notes as well as note photos, browse online resources, play online lecture videos, take in-class quizzes, check emails or school announcements, receive homework assignments, and more. Particularly for students at young ages, applications should be presented in a fun, user-friendly and easy-to-understand manner.

There are already a number of mobile learning apps on the market to be used by students and teachers in elementary schools and middle schools. An app called 'iTooch Elementary School' [31] is an integrated online learning environment mainly for exercise. It provides a collection of more than 18,000 exercises in mathematics, language arts and sciences for 3rd, 4th and 5th grade students. Below are two screenshots of iTooch.

Figure.2 iTooch sample images

It features chapters with lessons, examples and figures, and questions with clues, explanations and images. In addition, it has a built-in calculator and blackboard for students to write and calculate directly on the screen without having to leave the app. It also has a "badges and achievements" feature, which stimulates the user to progress further in the application. The app has three versions which are designed for students in 3rd, 4th and 5th grades respectively. Each version costs $9.99 (without taxes) from the app store, while ten titles can be tested for free before purchasing. However, websites like khanacademy.org also have their own mobile apps, and some of them are free of charge, which are also excellent learning environments for students in elementary schools and middle schools.

Smartphones are able to enhance learning outcomes and promote fun and interactive learning experiences for students. Researchers at Stanford University introduced a mobile interface called the Stanford Mobile Inquiry-based Learning Environment (SMILE) [32], which was designed to promote student-created questions in an engaging way in the elementary classroom. With SMILE, students use a mobile application to create questions, which are then solved and rated by peers. The entire process is controlled and monitored by a teacher with an activity management application on the teacher's PC. SMILE consists of two components: a mobile-based application for students called Junction Quiz and an activity management application for the weather called the Junction Quiz Controller. The entire process of creating and solving questions are managed through the Junction Quiz Controller by the teacher. Upon opening the Junction Quiz application, students are required to log in using their usernames and passwords. After all the students are logged in, the teacher can activate the "Make you Question" button on students' devices. Once activated, students proceed to create their questions. When all students finish writing their problems and those problems are sent to the server, the teachers activates the "Solve Questions" button. Students then solve the questions and rate each on a five-point scale from 1 (poor) to 5 (excellent) based on some predetermined criteria. Then, once all students have completed this, the "See Results" button can be activated by the teacher. At this point, students are able to view a summary of their results and the correctness of their answers. They can also view detailed information about individual questions including how many students answered each correctly and average ratings. Preliminary findings from the pilot study indicate that students were very satisfied with SMILE. Through open-ended questions, students specified that they most enjoyed the opportunity to create their own questions and share them with peers. Students also reported that they viewed SMILE as a valuable way to review class materials.

Smartphones enable more personalized learning for students. In particular, Students can learn from a broader range of topics and with less restrictive time and location requirements. Teachers can make customized study plans, assignments, and quizzes for the students to practice and complete on their own devices. MagicBox is a mobile learning platform from Magic Software [33], which introduces effective differentiation in instructional strategies, promotes collaboration and communication and supports self-paced, personalized learning. It supports anytime, anywhere learning both in its online and offline mode. This removes the constant dependency on the Internet and allows students to learn at their own pace without the time limitation which prevails in a classroom. It provides multi-format resources that can be housed in products ranging from e-books, activities, games, assessments, etc. It also features personalized teaching wherein teachers can work out customized lesson plans and assign them to individual students, thereby providing teaching which focuses on individual strengths. In addition, it enables monitoring of learning outcomes by teachers in the class/outside the class. The strong analytics measures the students' performance and helps the teacher focus on important aspects when back in class. MagicBox records every interaction that a student has within the platform. Teachers can easily look at reports for the entire class and find out which students have spent how much time on assigned work.

Cost

In order to using use smartphones in the classroom, students either bring their own devices, or schools provide the students with the desired devices and tools. According to a newly released study from Pearson [34], only 22% of elementary school students and 49% of middle school students in the US own smartphones. Similar to smartphone applications in medicine, old smartphones play an essential role for implementing these mobile applications inside the classroom, especially those smartphones donated by people, communities and organizations. In particular, parents with low income may not be willing to purchase a new smartphone for their child, so donated phones would play a crucial role particularly in low income communities. In this case, the cost for purchasing smartphones could be reduced to minimal.

Most smartphones have a built-in calculator, notepad, calendar, camera, voice recorder, and so on. These components are capable of fulfilling students' needs to some extent. Furthermore, there are tons of free educational apps for students and teachers to use. There are also many apps, which charge only a small amount of money, that provide better services and experience for users. As long as the smartphone functions properly, the smartphone itself as well as the mobile apps installed in it can be transferred and reused by other students after the current student graduates from the school. Thus, if we ignore the cost of the smartphones, the cost, which schools and parents should consider, is the cost of the hardware sets and mobile apps of the smartphones.

Impact

The idea of implementing smartphone applications in the classroom is revolutionary, with benefits discussed in the above section like speeding up the learning process, enhancing learning outcomes, promoting efficiency and enabling personalized learning. However, problems exists for such applications. On the one hand students have to learn when the use of smartphone helps them with their learning; on the other hand students also have to learn how to deal with the possible distractions and the potential of addiction of such devices. There are two ways schools or teachers can do to prevent any possible distraction and addiction that smartphones can lead to. One is a 'hard' way, which schools control and manage the use of smartphone on campus, and implement their rules strictly. For example, schools would regulate the functionalities of the smartphones being used with some modules disabled. And the smartphones may be restricted to be used inside the classroom without having students bring them home or outside specific location. In opposite, another way is a 'soft' one, that schools and teacher guide the student to utilize the smartphone wisely. Schools may let the students to bring the devices home and using them after school. However, teachers should collaborate with parents to monitoring the usage of the smartphone by the student, fostering good learning habits, and lead the student to a right place when the student shows misbehaviors. Some key points should be noted during the implementation of these applications. In order to prevent jealousy among students, schools should make sure students in the same level (grades) get almost the exactly same devices, with the same feature and functions, when dispatching smartphones to them. And schools can distribute the smartphones according to the individual needs at some points. For example, students with poor eyesight can be given a 'special' smartphone with a larger screen that the smartphones other students have. This allows a high autonomy when implementing these smartphone applications at school.

The integration of smartphones and mobile technologies into the normal classroom lectures would be challenging for the teachers. However, most apps provide services for teachers and instructors to use during class, such as the SMILE mobile platform we discussed in the previous section. And there're so many options that can be chosen from by the teacher to implement on their lectures. The only thing teachers must do is to spend time preparing for each class they are going to teach.

3.3.2 High School Age

According to [7] and the U.S. department of education, although nearly all schools have internet access, the average number of computers in a U.S. classroom is only about 3.5. Meanwhile, in 2010 the average student to teacher ratio across the U.S. was 16.0 [35]. This means that the possibility for a personalized learning experience in which each student is able to move at a pace which suits him or her cannot be achieved if it is to utilize these computers - there are simply too many students. However, with the versatility of today's smartphones it is not hard to see how they can help. While there are some obvious benefits to working on a desktop, many of the actual tasks that a student performs on a computer can in principle be performed on a smartphone. More importantly, smartphones can access apps provided by many leading educational websites. These apps can often be of great use in learning.

Dynamic study modules

For instance, Pearson, the developers of MyMathLab.com, are the inventors of Dynamic Study Modules. According to Pearson, these modules, which are implemented on MyMathLab.com, are "Based on brain science research, Dynamic Study Modules customize the learning experience for each student to maximize study efficiency and improve long-term retention of material" [29]. A study done at Fayetteville University on a college algebra course [8], showed that 70 percent of students who utilized MyMathLab passed the course, against 49 percent when they did not use MyMathLab. Pearson has now also developed the MyLab & Mastering Dynamic Study Modules mobile app, which gives the subscriber access to these modules on their smartphone. This means that a classroom where each student has access to a smartphone could be a simple way of providing children in all communities with access to this proven means of education. Pearson provides its modules in a variety of subjects including art, history, math, English, biology, chemistry and world languages, among many others [29]. In particular, it is well suited to have a beneficial impact on many aspects of a student's education. Below is an example of a math problem presented in MyMathLab.

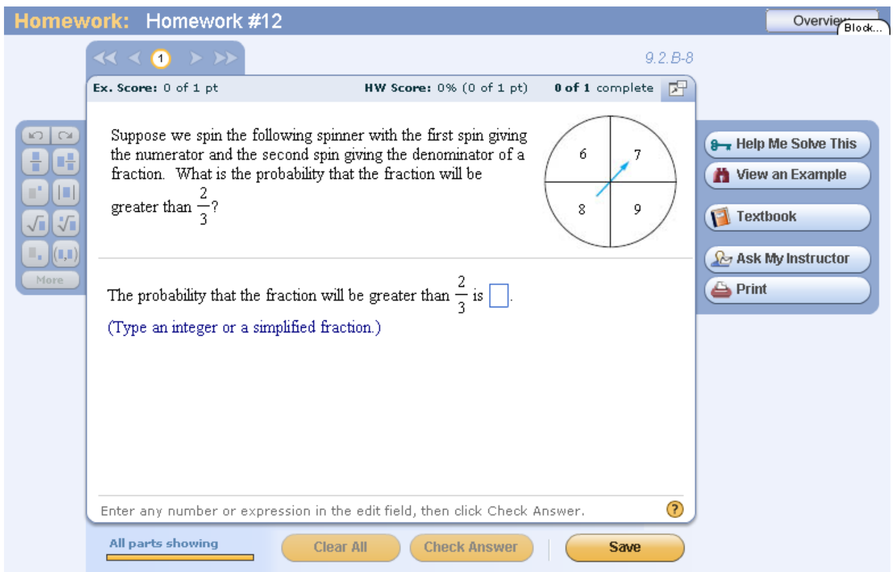


Figure.3 Mymathlab screenshot

Khan Academy

Another resource for educational material is Khan Academy. Khan Academy offers practice exercises, instructional videos, and a personalized learning dashboard that empower learners to study at their own pace in and outside of the classroom [10]. Khan Academy offers learning resources in math, science, economics and finance, and arts and humanities, among others. One of the most important aspects of Khan Academy is that all of its resources are free to anyone. It has achieved widespread acclaim and is supported by such organizations as Google and the Bill and Melinda Gates Foundation [36].

Khan Academy has also developed an app for its website, and it allows its users to download videos so that they can be watched offline. This is a tremendous resource when we consider what can be gained in allowing students to take smartphones out of the classroom. Videos can be downloaded in school which can be viewed anywhere, without a data connection. Free educational videos like these can be given as homework assignments that students can watch when they have time. We see how strong an impact this could have when we consider that nearly twenty million children in the United States do not have computers in their homes [7], and thus otherwise may have no way of accessing these videos on a daily basis.

There are also many interactive apps which do not require a Wi-Fi connection that can be downloaded on smartphones and which have tremendous educational value. Besides dictionaries, world maps, almanacs and encyclopedias, there are many more complex educational apps as well. An excellent example is Star Chart [37], an app which is available on iOS and Android, which provides a full, interactive planetarium in the phone.

How Does This Improve Education?

Especially at high school age, people are very vulnerable to how are they are viewed by others, and this can have negative effects in the classroom. "When social comparison has been made salient, students have focused on their ability, and these self-perceptions have mediated performance and affective reactions to success and failure" [9]. This means that while certain students may respond positively to the experience of being judged by others, on many it can be detrimental, even when it is as simple as being asked to respond to a question in the classroom setting. Of course, most humans are personally aware of this phenomenon, and it takes no study to affirm that being asked to accomplish a goal while being viewed by one's peers can be daunting. Furthermore, all teachers struggle with the task of "leaving no student behind" and providing a good educational experience to everyone. This is the most important aspect of what smartphones in the classroom offer, an interactive educational experience in a supervised setting where students can learn at a personalized pace.

With the two apps above and whichever others might be chosen by a given school, we envision students having individual access to a wealth of educational resources that they can utilize at a pace that suits them. Particularly, if the students can take the smartphones home with downloaded material, this should broaden the ways in which students can meaningfully spend their time. Furthermore, below we develop further comments regarding students in impoverished communities, and it is there that we expect these schemes to have the most impact. Where before, students may have had no access whatsoever to internet resources in their homes, they can now have a reliable device which every day is equipped with the resources that the students need to learn in any environment. Given that it is widely recognized, for instance in [38], that the socioeconomic imbalance between richer and poorer communities greatly influences the differences in their educational standards, the impact of such a simple stratagem could be great.

Cost

To implement this type of smartphone program in schools, the primary issues are in modifying the phones to prevent access to non-educational material on the web, installing the various apps that the students would have access to and paying for the Wi-Fi connection provided on school grounds.

There are roughly 15 million high school students in the U.S. [35]. This means, following our estimate on the number of available smartphones for donation given above, that it would be modest to assume we could provide a smartphone to every student in a United States high school, which is a far more ambitious endeavor than would be required, given that our aim is targeted primarily at disadvantaged communities. To that end, we note that 14.5% of Americans live below the poverty line, according to the U.S. Census Bureau [13], and we derive a rough estimate of about 2,175,000 (14.5% of 15 million) high school students who live in disadvantaged communities.

Restricting access on a smartphone is very simple. The phones typically come with the ability to prevent app purchasing, and there are a variety of free apps which can be used to restrict which apps can and cannot be accessed, as well as whether or not internet access is available and to which websites. We expect that this will not contribute significantly to the cost associated with this application.

Depending on how many apps the student is to have access to, this aspect of smartphone use in the classroom could be the most expensive. Nonetheless, assuming an educational objective is determined which anticipates utilizing ten apps per smartphone, and acknowledging that the average price of an app by provider in 2014 did not exceed $0.50 [39], this puts an estimate of just about one million dollars as a one-time expense for the purchase of apps into smartphones for every student in a high school in an impoverished community. According the U.S. Department of Education [35], the 2014 fiscal budget for the Department was over 80 billion, and most of the proposals being implemented required hundreds of millions of dollars. This comparatively puts this aspect of our smartphone plan at almost negligible financially.

Lastly, as mentioned above, nearly every school in the U.S. already has internet access, which means that internet access would not be a new contribution, meaning that it would not contribute to our cost.

3.3.3 Adult Age

Many adults actively pursue an education of some form or another, and in particular roughly 5 million college students were over the age of thirty in 2010 [40]. The following is taken from [40]:

"Many middle aged Americans have been the victim of the recession, layoffs, and corporate downsizing. Many have turned to taking college courses as a way to learn new skills, have a career change, or get an advanced degree. Some see it as a way to reinvent themselves.

According to the American Council on Education, studies have shown that adults go back to school for intellectual stimulation, socializing with others and the community, and enhancing their skills. A 2000 AARP study revealed that 90 percent of adult learners identified the goals of keeping up with current events, personal growth, and learning something new as the main reasons why they pursued higher education as older adults."

However, many adults also experience concerns about the idea. From [41],

"The following concerns are voiced by many working professionals reluctant to return to school:

Many working professionals are concerned about the cost of returning to college, the time commitment involved, and attending classes with younger students. Many adults considering a return to college are concerned that their employers will be unimpressed with their new degrees or certifications."

The case is that adults also want to develop themselves further, particularly if they begin to find an interest in changing careers. It can also be fun for them just to broaden their horizons in ways that make life more fulfilling. One way of realizing this goal is to enroll in college, often part time or in an online setting. If an adult is doing this, however, and paying their own way, it is unlikely in our opinion that old smartphones will serve them in a large scale way that is actually meaningful; most of them are likely to have a smartphone of their own. Furthermore, even in impoverished settings, public libraries and other public access places often offer access to the internet and other educational resources. By and large then, it is somewhat difficult in our opinion to devise a meaningful scheme of contributing to adult education with old smartphones short of just giving smartphones to those individuals who don't already have one.

If one were to consider techniques for the use of apps in smartphones which could further adult education, it is clear we think that adults who do have smartphones would certainly not benefit from a strategy we devise, in that they would not need smartphones from us, and adults who do not have smartphones have many other means of accessing the internet at large. One might also consider public access to smartphones, perhaps in a public library setting, but again, the general access to computers that most U.S. libraries offer supersedes the value of some approach like this. We conclude then that this is not a meaningful avenue for the investigation of new uses for old smartphones.

3.4 Application in Environmental Monitoring

Another interesting area of investigation in the use of recycled smartphones is environmental surveillance. This is also been mentioned in [1]. Here we consider four possible applications: air monitoring, structure monitoring, environmental disaster (i.e. earthquake, wildfire, etc.) anticipation, and lastly, the possibility of detecting poachers in the wilderness.

3.4.1 Air Quality Monitoring

Air pollution is a major concern in modern cities and developing countries. There are six common air pollutants according to the US EPA [42], including particulate matters, ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead. These pollutants are known to affect human health, cause respiratory illnesses and even cancers. The environmental problems caused by air pollution, such as acid rain and the depletion of the ozone layer, are getting more and more severe each year.

Many people spend most of their time indoors, whether they are at home, at school, in the office or inside their cars. Therefore, indoor air quality can have a significant impact on human health. Some air sensing devices which employ smartphones and air sensing hardware are developed for the purpose of monitoring indoor air quality. MAQS (Mobile Air Quality Sensing) [43] is a mobile sensing system designed by researchers in the University of Colorado Boulder for personalized indoor air quality monitoring. The MAQS client interface can run on most smartphones. When properly configured on the user's smartphone, it utilize the phone's accelerometer readings to detect room entering and departure events. Once it determines that its user has entered the room, the room localization function collects Wi-Fi signals from nearby access points and uses the subsequences of Wi-Fi signals (spatial information) and the user's mobility pattern (temporal information) to determine the current room. Then it uses zone-based proximity detection to select a subset of sensing device(s) in that room (may just be carried by the user) for collaborative indoor air quality monitoring. And the concentrations of CO2, VOCs (volatile organic compounds), and other pollutants are collected and transmitted to the server. They are stored in databases and combined with room information for air exchange rate estimation and personalized indoor air quality analysis. MAQS stops sensing after detecting room departure and restarts when another room is entered. Below is a sample of air quality readout from a mobile app.

Figure.4 Smartphone displaying air quality readout

The outdoor air pollution is mainly monitored by the networks of static monitoring stations, located all over the country. Data coming from those stations is reliable and accurate, but the spatial resolution of the publicized pollution maps are limited due to the extensive cost of acquiring and operating such stations. Because of this, some initiatives that pursue the public gathering of reliable data have gained popularity in the last few years. GasMobile [44] is a portable measurement system that was introduced by a group of researchers from ETH Zurich, Switzerland. The system is based on off-the-shelf components for measuring accurate air pollution data and are suited to be used by people with little or no knowledge of electronics. It connects a small-sized, low-cost gas sensor to a smartphone running the Android OS through the smartphone's USB port. However, in order to use the hardware, smartphones should have the software interface installed. When properly configured and calibrated, the mobile app collects raw reading from the sensing hardware and calculates the air pollutant concentration. It then transmits the data collected to the server, and the server generates the pollution map according to the data sent by the public. The use of GasMobile to measure ozone concentration is discussed in [44]. But extending GasMobile to support other sensors is straight-forward and only requires minor modification in two software components, as long as the sensor provides serial communication through USB. Since air monitoring requires external hardware and interface, the cost for this kind of application is relatively high. The price of gas sensors ranges from a few dollars to hundreds of dollars. Most commonly used gas sensors for monitoring CO and ozone cost less than 10 dollars. Sensors for monitoring CO2 cost around 30 dollars. However, sensors for measuring other atmospheric pollutants are costly and require more complex technologies. For personal uses, people with substantial knowledge of mobile devices and electronics are able to configure the indoor monitoring system using the gas sensors and smartphones. Others can also purchase products such as the MAQS, discussed previously, which is expensive but provides a reliable performance. For the participatory air quality monitoring application, the cost for the hardware is even higher because there are a variety of pollutants in the air, and different pollutants require different sensors which make the hardware large and expensive.

If the population involved in the monitoring is large enough, one approach to reduce the cost is to divide the public into groups. For example, one group can only measure sulfur oxides, and another group can only measure nitrogen oxides. In this case, the cost on the sensors and hardware is reduced to minimal, and the device becomes smaller and more user-friendly. Indoor air quality monitoring devices provide benefits to people by securing their sense of life and health. Especially for people working in factories, power plants and construction sites, when the concentrates of pollutant gases and particulate matters are very high, air monitoring devices can alarm workers to take action to prevent further exposure to harmful air, which may cause health issues later on. Furthermore, for those households with low income or which do not have any gas alarm installed inside the house, indoor air monitoring devices can serve as gas (CO) alarms as well. The device can notify the user when air quality is not satisfactory, raising living quality, lifting the mood, increasing productivity and preventing life and health crises. The participatory air monitoring provides more spatial resolution pollution maps complementary to the ones published by the static stations. However, there must be some non-profit organizations that gather the public and provide them with the required equipment to implement this air monitoring method. Otherwise, this idea would be difficult to implement, as the cost of the equipment is high and many people are not willing to do this voluntarily. Ultimately, the participatory air monitoring would be expensive and require a responsible organization to implement this, whether it is the government or an NGO. In addition, reduction on human health problems caused by air pollution releases the burden on health care providers and the government.

3.4.2 Structure Monitoring

Another application is the monitoring of large structures, intended to prevent their collapse or other decomposition. In the case of buildings, bridges and other Infrastructure, this is referred to as Structural Health Monitoring, or SHM. FROM [36], "it is important to note that there are stages of increasing difficulty that require the knowledge of previous stages, namely:

1) Detecting the existence of the damage on the infrastructure
2) Locating the damage
3) Identifying the types of damage
4) Quantifying the severity of the damage

It is necessary to employ signal processing and statistical classification to convert sensor data on the infrastructural health status into damage info for assessment." In particular, it has been recognized that the structural health of the United States' bridges is an engineering issue of pressing importance. For instance, the I-35W Bridge in Minneapolis, Minnesota collapsed in 2007, killing 13 people. Between 1989 and 2000, over 134 bridges in the United States partially or totally collapsed [45]. In light of such events, a plethora of ideas have been researched and developed to revolutionize techniques of structural health monitoring. In particular, old techniques relied heavily on visual inspection and this resulted in variation in determining which data indicated structural damage [45]. Another deficiency in older techniques was the need for costly installation of systems for structural health monitoring, often involving complex wiring networks which were expensive to install. This and other aspects placed a heavy demand on industry to produce more cost effective models. Newer techniques rely on signal processors, wireless networks, and cyber infrastructure tools [45].

The stages mentioned above are monitored by systems which utilize various modes of sensing, including signal processors, and demand that the devices involved can differentiate between data indicating the natural, expected state of the structure (which in itself can vary under environmental conditions), and data indicating that some kind of damage has occurred. While we expect that all of the four issues mentioned above can be detected by software implemented by a smartphone, or that smartphones can play a central role in a device which performs those tasks, it is clear from the literature that there most likely would be no important impact from the use of smartphones, as technologies developed specifically for the task of structural health monitoring are not only designed specifically for the task and capable of exactly those thing which a smartphone would perform instead, but they are already cost effective enough, that the implementation of poorer quality in the smartphones would be meaningful enough to counteract the benefit in cost.

One primary variable which is measured in SHM is mechanical oscillation, which is present in many structures, including buildings and bridges [46]. In [46], techniques for the measurement of mechanical oscillations with the use of smartphones is investigated. They detail how three components of a smartphone, the microphone and speaker, the accelerometer, and the GPS receiver, each can play a role in mechanical oscillation reading. The approaches are each very simple. With the microphone and speaker, the idea is to send out a sound wave with the speaker and have the microphone pick up the reflected signal. The smartphone reads the data it receives in this fashion to determine how the structure is oscillating. Below is a picture demonstrating how smartphones might be set up throughout a bridge's structure.

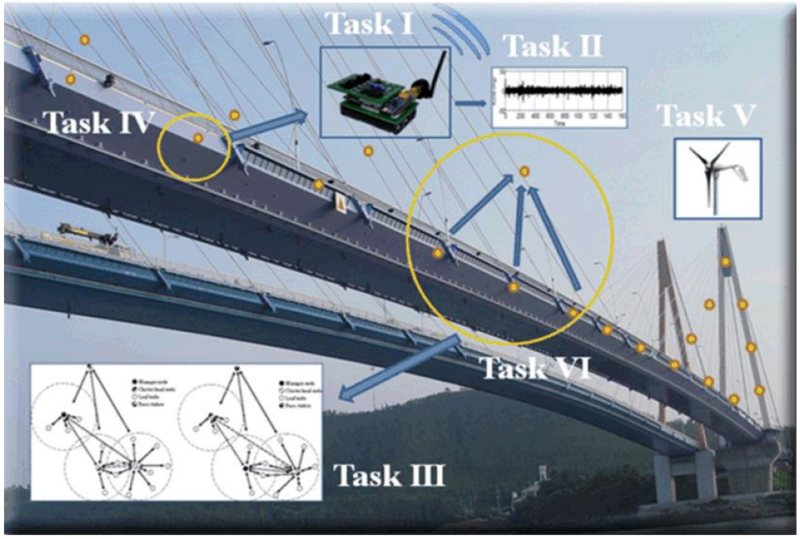


Figure.5 Example of positioning of bridge monitoring devices

An accelerometer is a small device inside of a smartphone which measures acceleration about three axes, which for standard purposes plays a role in orienting the phone with respect to gravity or serving as an input in smartphone gaming [46]. It is a direct application of this device's main purpose to attach it to a structure and program it to interpret accelerations in the structures movements to determine oscillatory behavior. Frequency can be obtained within the smartphone by calculations using standard Fourier Transform techniques.

The authors of [46] determine that, while GPS could be used to determine real time position of a structure, the poorness of the accuracy involved and the time lag in position determination each were too great for this aspect of a smartphone to contribute meaningfully to structural health monitoring. Their data shows that, even while a smartphone is completely stationary, its position as a function of time according to its internal GPS can exhibit an oscillatory pattern, which is certainly unacceptable if such a technique were going to work.

The end result in [46] is that, for a number of reasons, it is not yet feasible to use smartphones in this way. The microphone and speaker approach requires very little ambient noise, which is completely unlikely in any real world, particularly metropolitan, setting. The accelerometer approach places too much of a constraint on how the smartphone must be positioned, because even slight repositioning of the phone can result in incorrect data. These issues aside, they were able to correctly interpret mechanical oscillations, but this was in a controlled setting. We conclude once more that this is perhaps not the strongest area of investigation for the reuse of old smartphones.

3.4.3 Disaster Monitoring and Management

Smartphones and other mobile technologies are powerful, and can play significant roles before, during and after disasters such as floods, earthquakes, tornados and forest fires. Disasters can have a severe impact on local communication infrastructures. Therefore, enhancing communication during post-disaster relief operations is a top priority. In contrast to the vulnerable, fixed-network infrastructure, battery-powered, wireless, personal mobile communication devices (smartphones, PDAs) can be of great use during such events. Researchers at the B.P. Poddar Institute of Management & Technology, India designed a smartphone/PDAs based peer-to-peer communication system [47], assuming the absence of network infrastructure, to facilitate the communication and coordination of disaster relief operations. The major focus of their study is to come up with a framework for post-disaster resource requirement analysis, resource allocation and distribution, which involves on-going determination of what resource are needed, what resources are present, what resources need to be acquired and how long it will take for them to arrive. Using peer-to-peer communication, the entire network eventually turns into a dynamic, virtual star topology with a static central control station as the root node and static shelter points as end nodes. The connectivity between the root node and each of the end nodes is achieved using mobile devices (smartphones, PDAs) as message ferries. At the same time, mobile devices also exchange information among one another in a "peer to peer" mode, thus integrating the field information intelligently and autonomously using auto-configurable peer-to-peer communication. The simulation results of this study show that even if the entirety of coordinated operations is centralized and monitored far away from an affected area, the operation yields positive results about the overall resources present in that area.

Most natural disasters are easy to predict but impossible to prevent. Therefore, the goal in handling such disasters is often to take action once the disaster is beginning to happen, rather than to attempt to prevent the disaster from happening at all. Modern meteorology provides possibilities for monitoring and predicting floods, earthquakes, tornados, etc., while smartphones provide tools for predicting potential forest fires by analyzing accumulated information about forest structure from the ground and human perspective. There is an idea introduced by researchers in Canada [48] that gathers volunteers, mainly residents in or near target forests, to collect data about the forest's conditions, such as forest fuel loading, water reservoir and humidity. Volunteers are provided with a smartphone and asked to record data into it on a daily basis. The data is transmitted to servers monitored by researchers for analysis. When the forest fuel loading and the dryness of the forest reaches a certain point, and there is likely a forest fire happening in that area, surrounding residents will be asked to take shelter to prevent loss of human life. If necessary, local wildlife reserves and plantations will also be evacuated in order to preserve the local ecological system. If the forest fire does not eventually develop and forest conditions return to normal, people will be asked to go back to their homes and keep collecting the data. In order to predict a forest fire, much information, specialized analyzing methods, and intense human resources are required.

However, the benefits of this kind of operation are limited.

The smartphone applications used in disaster monitoring require state or organizational funds. However, the cost for these kinds of smartphone sets are low due to their minimal functional requirements. Therefore, even the oldest smartphones can be used to implement these applications once they have basic wireless functionality. The main portion of the total cost is in developing a mobile platform/system for these applications, such as the peer-to-peer communication system discussed above. Nonetheless, the system developed might promote more efficient communication and coordination during a disaster, which may ultimately save a state money.

The implementation of smartphones in disasters is positive and beneficial. It can not only coordinate relief operations, making them more efficient, enhance communication, and allocate and distribute resources quickly, but it can also reduce costs, and more importantly save time when rescuing victims, thus potentially saving more lives. The experience gained when using this kind of device during a disaster could help researchers and developers to design more reliable and user-friendly platforms based on real-time situations. In the near future, mobile devices could become indispensable when conducting post-disaster operations.

3.4.4 Poachers Monitoring

Poaching is the illegal killing of wildlife, often motivated by large profit incentives for animal parts that cannot be purchased legally. According to the Humane Society of the United States, "Poaching is a deadly crime against wildlife. Wildlife officials say that legal hunters kill tens of millions of animals every year. For each of those animals, another is killed illegally, perhaps on closed land or out of season, leaving orphaned young to starve. Few poachers are caught or punished." [49]. This is still a major problem in many parts of the world, including the United States. Alaska contains the largest population of grizzly bears in the world and bear gall bladders are used in Chinese herbal remedies, making them highly desirable, while it is illegal for most people to kill bears in the U.S. [49]. One of the most difficult issues in dealing with poachers is that they conduct their activities deep in the wilderness, over huge expanses of land, and it is near impossible to monitor effectively such large areas at all times. It is therefore the case that park rangers and state troopers advise hikers and campers to be alert for signs of poaching, as making the community involved contributes to the possibility of catching poachers [49]. It is nonetheless still very difficult, and most poachers are never caught.

We propose a scheme where smartphones are used to recognize the sound of a gunshot in the wilderness. After this, the smartphones will begin collecting visual and audio data with the aim of aiding officials in later finding or identifying poachers. They may catch footage of poachers nearby, or, with the aid of GPS, they may be able to make educated determinations as to the location of the gunshot, as well as listen for further gunshots to aid in this process of tracking the movements of poachers.

To position a smartphone in the wilderness for a long period of time, it is necessary to consider how it will maintain battery charge. There are a number of compact, environmentally friendly ways of steadily generating enough energy to keep a smartphone charged. We feel that an ideal scheme could require more research, but we mention some approaches to such research here. As we envision the phones being positioned high up in trees, two plans might be to have a small solar panel or wind turbine positioned along with the phone in an optimal spot where the energy gathering device is able to garner a good amount of energy. In the case of solar panels, positioning would be very important because the solar panel could not be below the tree canopy at all, or it would be nearly useless. A wind turbine could be within the canopy, but it still must be able to catch a strong current of wind. It would also be important to consider how these devices blend into the surround environment for a number of reasons. Not only it is important to avoid sight in the case of poachers, but it is also desirable when technology is implemented in the wilderness to infringe as little as possible on the natural ecosystem.

Assuming an energy source has been decided upon and the phones are placed in the environment, they would have to constantly record sound and utilize a program which detects the sound of a gunshot. Assuming a number of smartphones are positioned over some stretch of land and that they exchange information with each other and the necessary local officials, they would then begin to use GPS tracking to coordinate the location of the gunshot and begin analyzing the path of the wielder of the gun if more shots are heard. This information would be transmitted in real time to authorities to aid in the pursuit of the poachers.

This is expected to be very cheap and effective when compared to other means of catching poachers. Even today, means of stopping poachers consists of warning signs, eye witnesses and expensive wilderness cameras [49]. The warning signs and eye witnesses are obviously both fair strategies as well as potentially ineffective ones. Wilderness cameras are expensive. Furthermore, they rely on actually catching sight of someone whereas the smartphone approach would track by sight and/or sound, which may be beneficial for reasons that the cameras cannot match. The only price is in the programming and installation of the phones, (plus their price, which may or may not play a role given a specific scenario and whether a means of collecting phones for free has been devised) which is expected to be significantly less than wilderness cameras, which can cost as much as $100 each or more [50].

4 Conclusions and Recommendations

In this IQP project, we evaluated and discussed the potential uses for old smartphones in medicine, education, and environmental monitoring. We introduced approaches to reduce the cost of these applications, such as gathering old smartphones by way of public donation and distributing them to people for charitable purposes. In particular, we demonstrated the significance of these applications for people with low incomes who don't own smartphones. Moreover, we discussed the impact of each application on society and assessed its feasibility.

Medical applications that focus on improving the treatment of certain diseases seem worthwhile and are highly recommended, especially for the incurable disease of Alzheimer's. The benefits of utilizing smartphones in medicine include improving the effectiveness of treatment plans, promoting the efficiency of hospital operations, reducing the time and cost spent by healthcare providers, and so on. To some extent, smartphones can save lives and reduce national spending on health care. Additionally, smartphones can significantly help patients from low-income households, and improve their quality of living.

K-12 schools are also seem to be good places to implement mobile applications, though some already have laptops or desktops installed in their classrooms. The advantage of employing mobile devices in classrooms over PCs is that they allow more flexibility for students and are easy to use and control. Also, the cost of developing such applications as those we suggested is relatively cheap compared to comparable applications on computers. With the help of smartphones in and outside of classrooms, students are provided with different learning platforms and more flexibility, which assists them in learning in a more flexible environment. We found, however, that smartphones are not necessarily useful in education schemes centered on adults, for a number of reasons described in our study.

Air monitoring and disaster monitoring are two feasible smartphone applications as well. Both indoor and outdoor air quality monitoring devices are in demand in modern society, and the combination of smartphones with some sensing peripherals is a good platform for monitoring the air. Although the measured data from such devices has been shown to be raw and limited, the performance is still satisfactory for a typical household's daily needs. The disaster management applications are for conducting post-disaster operations, which help save time when rescuing and relieving victims during and after disasters occur. Applications for monitoring poachers are also feasible, but demand fewer smartphones than other applications, which makes them less impactful. The application we described for monitoring structures is also not suitable for a number of reasons related to complicated tasks which smartphones are not designed to perform. Smartphones can undoubtedly be used to monitor structures, but they may not be the most efficient and reliable tools to do this.

Many applications we have discussed in this paper are highly applicable in the real world, and there are already many researchers working on these applications now. We encourage individuals, institutes, and companies to devote themselves to developing applications on old smartphone platforms.

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