The Feasibility of Repurposing Recycled Cell Phones as Sensors in a Smart Campus Shuttle Monitoring System

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Abstract. Information updates on the current location of public buses and shuttles are necessary to everyday commuter life and plays a vital role in their efficiency. Some current approaches to providing this information involve installation of stand-alone GPS modules and others involve user-driven participatory sensing. In this paper, we present a low-cost approach to providing information on a vehicle's location by repurposing damaged mobile phones as sensors. This approach reduces the battery draining effect that users experience when using their personal cell phones to transmit the location of the vehicle (participatory sensing). Additionally, as small-island-developing states (SIDs), this concept reduces the need for the importation of new GPS devices by repurposing mobile devices that are already on island and will likely contribute to the landfill waste problem. We tested our repurposing approach with The University of the West Indies - Cave Hill Campus (UWICHC) student shuttle service in Barbados. Students access this system using any web-enabled device. The web application displays the shuttle`s location on a Google™ map that also shows the route and direction of the shuttle. A student survey indicated that they found the system useful and are willing to donate retired cell phones to such a project. This result demonstrates the sustainability of the mobile phone repurposing concept.

Keywords: Smart campus · Cell phone · Transportation · GPS · Repurpose cell phone · Recycled cell phone

1 Introduction

Most approaches to providing information and data on transportation systems to users involve the collection of data using new stand-alone GPS devices or user enabled participatory sensing. Mandal et al. [1] provide an example of the former with bus stop identification and visualization using GPS systems in the developing world. Their work requires the acquisition and installation of new hardware. It is, relevant since this was applied in a developing world scenario similar to the locale of UWICHC. Zhou et al. mention that their [2] participatory sensing method is less demanding and less energy

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intensive since they do not use GPS. Thiagarajan et al. confirm in their work [3] that GPS' effect on the user's mobile phone battery is high which causes them to turn off this feature to preserve their battery. However, other cell phone features used in the work by Zhou and colleagues can also reduce the lifetime of the user's mobile. These features include the microphone and audio analysis that require CPU power. Additionally, crowd-participated approaches introduce battery effects and reduction in battery life for multiple users as opposed to one [6]. Additionally, the importation of new devices such as stand-alone GPS devices can contribute in the long term to landfill issues that currently affect countries as explained in work by Musson et al. in [2].

Cell phones and other mobile electronic devices contain toxins such as arsenic, mercury and lead. If these harmful metals enter the water supply due to improper disposal methods, they can be harmful to humans [2]. Additionally, the brominated flame retardant found in newer cell phones and other devices can cause organ dysfunctions [3]. Our recycling approach - demonstrated in [4] - shows that we can implement the repurposing concept to use mobile phones that are already available, and in our case on the island, are damaged and no longer used by owners. Such out-of-service phones will likely end up in the landfill and cause problems. Hence, we use them to perform the task of GPS sensors and Bluetooth beacons rather than acquiring new hardware.

Previously [6] we explained that it is simple to replace a failed repurposed cell phone (RCP) sensor with another since the applications can run on any compatible device. Therefore, the failed repurposed mobile phone can be properly disposed of and another one can be repurposed. In this work, we repurpose a damaged cell phone as a sensor, in this case for its GPS, Bluetooth and Wi-Fi capabilities, to perform a task without human interaction. We then deployed a repurposed damaged mobile phone on the UWICHC shuttle independent of a user to collect and report GPS data on the location of the shuttle to help shuttle users to plan their time. We also show that acquiring retired cell phones on a university campus for such applications is sustainable.

2 System Requirements

To gather requirements and design a system that caters to students' needs, we asked a convenience sample of 78 students from UWICHC if a mobile application that indicates that the shuttle is entering the campus compound, or has already arrived, would assist them. Ninety-six percent (96%) of respondents answered in the affirmative. This confirmed the need for the application.

We also asked students if they preferred a voice indicator or a visual indicator to identify the shuttles' location when they are in class. Most - 69% - of respondents preferred visual indication rather than voice indicator for the shuttles' arrival at the shuttle stop. Additionally, Zhou et al. [5] stated that bus users indicated that they would like to be able to track the arrival time of the bus instantly on arrival at the stop. Hence, the visual indicator also needed to track arrival time instantly.

Based on the requirements identified by respondents to our survey we decided to investigate if a system that will visually display the location of the campus shuttle and its estimated arrival time using an RCP will assist students. Additionally, we realized that using RCPs for such systems must be sustainable.

3 Collection, Testing and Selection

Ward and Gittens [20] developed three models to identify suitable devices for building smart campus applications using cell phones. They considered the attributes outlined by Shye et al. [16] and Ahmad et al. [17]. The authors of the work in [16, 17] identified the following attributes: battery, input mechanism, data/power interface, mobile phone services, SIM card, antenna, microphone, speaker, and a CPU. Additionally, most smartphones carry an accelerometer and GPS capability.

After applying the models outlined in [20] we classified all donated cell phones into the following groups:

Group 0: Either these cell phones do not power on or they have touch response and USB port problems. They cannot be repurposed in their current state.
Group 1: Cell phones in this group do not respond to touch commands. However, they can still be repurposed because they can be controlled via USB.
Group 2: In this group, cell phones respond to touch but have no functioning USB ports. These can be repurposed since they are touch controlled but they cannot connect to a computer.
Group 3: These cell phones are preferred because they have passed all tests. They are easier to work with since the basic hardware works.

After classifying the devices into groups, we applied the features test introduced [20] to identify donated devices with GPS, GPRS and Bluetooth.

4 Case Study

In this section, we discuss the system design based on the primary system requirement elicited from students in the previously mentioned survey, that is, to provide a visual indicator that would instantly track the arrival of the shuttle.

4.1 System Design

In order to meet the visual indicator requirement, we assessed the hours of operation of the shuttle. The hours range from 7 am to 11 pm Monday to Friday. Our solution needed to be operational within these hours. However, we recall from the work of other researchers [2, 3] and from our own experience that the GPS capabilities that enable the necessary tracking are battery intensive and drain the cell phone battery. We mitigated battery depletion by installing a cell phone on the campus shuttle and in the first instance; the five (5) volt lighter socket in the vehicle powered the mobile phone directly. In the second instance, if there is no functioning lighter socket, an alternative installation method is used for the bus sensor.

In order to describe how the system operates we will describe the system components and their interaction to provide GPS real-time information and detection of the shuttle at the shuttle stops. We will then discuss the additional installation method of the bus sensor.

4.2 System Components

The system has six (6) components were two (2) are optional, these are (Table 1):

Table 1. Six core components of the RCPs configurations for tracking

Component name	Function
Reused cell sensors:	
Bus sensor (recycled cell phone)	A Group 3 cell phone was used as a GPS sensor and also to constantly emit a Bluetooth signal which would be detected by the shuttle stop sensor when in range - The smartphone used was a BLU Life Play 2™
Shuttle stop sensor	A Group 3 cell phone was used as Bluetooth sensor which scanned and detected Bluetooth signals when the bus sensor is in the range - Alcatel POP C3™ housed in PVC box [6] at the shuttle stop powered by fixed 110 v outlets
Other components:	
Database server	The database server runs the Ubuntu 14.04.3 LTS and MYSQL server as in [6, 7, 13]
Processing and display engine	As in [6–8, 13] we used Google JavaScript API 3 maps to display the location of the shuttle. The information was first processed using a set of PHP scripts that filtered the GPS and Bluetooth data. The location was shown on a Google map using Google JavaScript API 3 via a web page accessible by students
Raspberry pi zero (Optional)	Used with a battery pack in the absence of a functioning cigarette lighter to keep the mobile phone continuously charged.
Battery pack (Optional)	The 10000-mAh battery pack is used in the second configuration to power the Raspberry Pi that then powers the mobile phone when the shuttle or bus does not have a working lighter socket

4.3 System Core Component Interconnection

We will now discuss how the components of our system connect. The bus sensor performs two functions in the system. Its first function is to emit a continuous Bluetooth signal. Bohonos et al. [9] show that Bluetooth can be used as a beacon. They used a Bluetooth device as a beacon to assist the blind in crossing busy intersections. We used this approach and treated the shuttle sensor as the beacon. When the shuttle arrives, the shuttle stop sensor, which is constantly scanning for Bluetooth device signals senses the bus sensor emitting the Bluetooth signal and sends it to the database. The shuttle stop sensor collects the MAC address of the device and its RSSI value emitting Bluetooth devices. Ghose et al. [10] developed a system called BlueEye that detects distances between individuals in crowds using the Bluetooth on their mobile phones. We used this approach in our system to determine if the shuttle was at the shuttle stop. We stored the MAC address of the bus sensor in our database so we could verify the shuttle in the Bluetooth data.

The second function of the bus sensor collected GPS location data for the shuttle and transmitted it to the database. Similar work by Anderson et al. [11] developed an SMS and GPS system to provide information to users of a transportation system in a developing country. However, their work [11] required the bus operator to enter the route using a keypad. However, in our work no interaction with the driver is necessary. The PHP scripts analyze the Bluetooth data every minute to determine if the shuttle is in proximity to one of the on-campus shuttle stops. The PHP scripts also display the current position of the shuttle by querying the database for the latest update using database time stamps aligned with the GPS data.

Bus Sensor Installation. The cigarette lighter in the bus is the primary source of power for the bus sensor; however, there may be some cases were the cigarette lighter is not functional. An alternative installation method requires the use of two additional components. These components are a 10000 mAh battery bank and Raspberry Pi Zero. In this alternate installation method, a battery pack powers the RCP. However, we noted that when the mobile phone became fully charged, the power bank would switch itself off. When the mobile phone needed an additional charge, the power bank remained off and the mobile phone died. To address this issue, we attached a Raspberry Pi Zero to the power bank and then connected the mobile phone to the Raspberry Pi Zero. This method keeps the power bank on as the Raspberry pi Zero constantly uses 80 mA [12] to keep the power bank on and available when more power is needed by the mobile phone.

Cost Reduction Using RCPs. The cost of implementing our system is reduced by RCPs. When compared with the work done by Anderson et al. in [11] who dismissed the possibility of using a mobile smartphone as opposed to their US $200 self-designed device due to the possibility of theft. Even with the additional components required for the alternative installation method shown in Table 2, the cost is reduced.

Table 2. Cost of Bus and Shuttle sensor

Sensor name	Cost
Reused cell sensors:	
Bus sensor (recycled cell phone)	$ 0 (Donated)
Shuttle stop sensor	$ 0 (Donated)
Supporting components:	
USB cable 5v charger	$ 5 US
USB vehicle charger	$ 8 US
Raspberry Pi Zero (Optional)	$ 17 US
Battery Pack (Optional)	$ 21 US
Total:	**$ 51 US**

4.4 Deployment of RCPs

We outline how the cell phones selected in as in Sect. 3.3 were deployed and tested before and in operation. We outline the process of developing the bus sensor application and shuttle-stop-sensor application on the RCPs.

Bus Sensor Application: The (onboard) bus sensor application is a native Android application designed using Android studio and the Java programming language. The Android application was designed as an Android service. The service listened for location updates and as the GPS update occurred, the application would send the GPS data to the database for storage. This service also controlled the beacon emitted from the shuttle. The service checks every minute to ensure the Bluetooth on the bus sensor is enabled and it has Bluetooth discover set to be constantly on.

Shuttle Stop Sensor Application: Like the (onboard) bus sensor application, the shuttle stop sensor application is a native Android application designed using Android studio and the Java programming language. The android application was designed as an Android service however, unlike the bus sensor application, which uses 3G data to submit the GPS data to our database, the shuttle stop sensor uses Wi-Fi on the UWICHC as done in similar work by Ward et al. [6, 13] where we designed an application to monitor and report on Wi-Fi in areas. The shuttle stop application connects to the Wi-Fi then constantly scans for Bluetooth devices in the area and transmits them to the database.

Application Development and Testing: The bus sensor and shuttle stop application were installed on the cell phones and run for 24 h. This testing ensured correct functioning. Subsequently, the cell phones were ready to be deployed.

4.5 Hardware Implementation and Deployment

This section presents the deployment of the hardware in various environments.

Bus Sensor Hardware: Figure 1 shows the configuration of the bus sensor. The Raspberry Pi Zero keeps the battery pack on even if the mobile phone is fully charged. This is unlike customary operation. The Raspberry Pi will keep the battery pack on as it requires constant power. Therefore, when the mobile phone requires additional charge it would be available via the USB port on the Raspberry Pi.

Fig. 1. Showing the bus sensor configuration comprising a Raspberry Pi Zero, 16750 mAh power bank and BLUE LIFE PLAY 2 with a damaged screen

Shuttle Stop Sensor Hardware: The shuttle stop sensor hardware adopts the same hardware implementation method used in [6]. The RCP is placed in a PVC box which contains a 110v outlet which powered the RCP as shown in Fig. 2.

Fig. 2. Showing the installation of the bus stop sensor.

Information Delivery: We displayed the shuttle information to students on a Google Map similarly to [6, 7]. As shown in Fig. 3 the green blimp indicates the current location of the shuttle and the red circle is a radius of five meters from that point. The four red blimps behind the circle indicate the direction that the shuttle came from. This is the trail. The trail is ascertained by selecting the last four points the bus sensor reported. The trails indicate to students the direction the shuttle is traveling since the shuttle travels the same route to and from the campus. This eliminates confusion. The trail can also be used to indicate if the shuttle is stationary or moving, since all red blimps would be in the circle if the shuttle were stationary or moving very slowly. The web application also displays the last updated time and the current route of the shuttle. The current route is determined based on the Bluetooth data collected using the shuttle-stop sensors. We can identify which stop the shuttle left from and this would indicate its current route. The (onboard) bus sensor application, the shuttle-stop sensor application is a native Android application designed using Android studio and the Java programming language. The Android application was designed as an Android service however, unlike the bus sensor application that uses 3G data to submit the GPS data to our database. The shuttle stop sensor uses Wi-Fi on the UWICHC as done in similar work [6, 13] with an application to monitor and report on Wi-Fi availability and strength in outdoor areas. The shuttle stop application connects to the Wi-Fi then constantly scans for Bluetooth devices in the area and transmits them to the database.

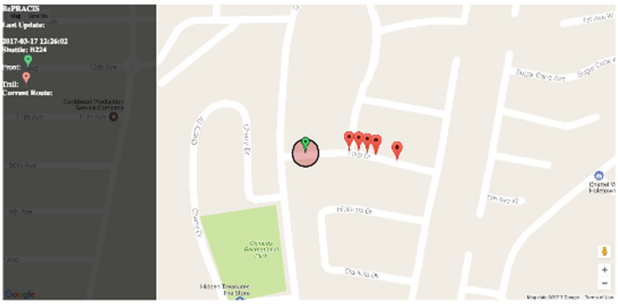

Fig. 3. Shows the students a visual application indicating the shuttles current location. (Color figure online)

5 Feasibility, Sustainability and Usefulness

In this section, we will discuss our findings from our survey of 175 randomly selected UWICHC students. We will examine the feasibility of the cell phone repurpose concept and its sustainability for building smart campus applications.

5.1 Feasibility

Our findings have shown 54% of respondents keep cell phones they do not use in their possession. Additionally, based on our responses 44% of the students indicated they retired their cell phone, not because of a fault or issue but because they simply wanted to upgrade. This coincides with what Geyer et al. [1] mentioned in their work that users mainly dispose of their cell phones just to get a newer version or model. As it relates to the repurposing of the cell phones this could be a good indication since these cell phones would more than likely still be in good working condition and capable of performing majority if not all of its capable task. In addition, our findings have shown 74% of students are willing to donate their old/retired cell phone to the repurposing research. This is also good for feasibility because the acquisition of these cell phones for repurposing would come at no additional cost where the cell phone could be repurposed to reduce cost in some systems. However, a few people not willing to donate their cell phones to research said they would however sell their cell phone. Although this is not favorable for feasibility it demonstrates that retired cell phones can be acquired, but there may be a cost. Our findings have also indicated 22% of students have retired their phones not because of a hardware issue but because the cell phone sticks and freezes. This shows that the cell phone still works and may be a candidate for RCP with some diagnosis.

5.2 Sustainability

The majority of persons indicated they would donate their current cell phone to research when upgrading. This is good for sustainably not only because of willingness to donate the cell phones for repurposing, but because over the collection period, no cost would be attached to the acquiring of the cell phones. Interestingly, the majority of the students who indicated that they no longer had their retired phone, indicated they gave it away. This can suggest the people who they gave it to also could possibly fall into the 73.7% who would donate or the 60.6% who would not donate but would sell. Additionally, 24.2% of who are no longer in possession of their cell phone threw it away. This may change with an option to donate.

5.3 Usefulness

We interviewed users who wished to share feedback. This totaled ten (10) users. The users boarded the shuttle from various locations they also boarded at random times. Students were pleased with the system as it allowed them to perform activities right until they needed to board the shuttle that helped them to use their time more efficiently. Some students indicated they would like to receive more information such as how long it would take the shuttle to get from its current location to where they are waiting. Additionally, some students stated they would like to be alerted when the shuttle is at one of the shuttle stops so they could make their way there. Overall we believe the user`s comments were supportive and indicated we have a working and value-added system for its users.

6 Related Work

In this work, we were able to develop a low-cost shuttle tracking system using the Ward et al. cell phone repurposing concept originally shown in [6] for detecting the Wi-Fi signal strength and download speeds in study areas. Ward et al. [13] also showed it was possible to use a mobile phone without user interaction by using mobile applications installed on the phone.

The primary advantages of using these approaches are the reduction of battery power consumption which mobile phone users experience by contributing to participatory sensing as used by Zhou et al. in their work [2]. Zhou et al. developed a bus prediction system using participatory sensing by relying on users to enter information and using nearby resources such as cell towers and resources found on the bus such as transit IC card readers and accelerometers to determine the location of the bus. In this work by Zhou et al. they reference GPS as heavily draining the phone battery as opposed to bus tracking using cell towers which they used in their work. However, Zhou et al. did not include the other attributes of the user's cell phone such as accelerometer and microphone as also affecting the user's battery life. In our work, battery degradation and energy use of the user's device does not have to be considered, since our system features a stand-alone device that removes battery drainage and the privacy concerns mentioned in Zhou et al.'s research [2]. This also noted in work by Thiagarajan et al. [3].

In work by Anderson et al. [11] they mentioned disadvantages due to the cost associated with replacing a new mobile phone when deployed in a bus when it was stolen. Consequently, they decided to develop their own device. However, the development of this new device to perform GPS tracking of the bus requires the acquisition of new components that will eventually add to the E-waste in landfill problem mentioned earlier. Our approach also addresses these concerns mentioned by Anderson et al. since by employing the repurposing concept these mobile phones have no cost as they were no longer needed and were therefore donated. Since they were damaged, they also become less attractive and less likely to be stolen. Calabrese et al. [18] in their work mentioned that the high cost of GPS device implementation across a fleet of vehicles is a deterrent. However, Calabrese et al. [18] failed to mention the concern would not only be the cost of acquiring these new devices but also the implication it has on the environment. When these brand new devices are replaced, they will contribute to the e-waste problem.

On the other hand, if the repurposing or recycling of devices concept is used as mentioned in a report by AT&T [19], it indicated a reduction of one million cell phones in the landfills which would equate to the removal of 1368 cars off the road. We also saw work by Biagioni et al. [14] were they have developed an easy tracker system using a cell phone placed on transit vehicles to track its location and path. However, in their work, it was not clear how they installed and powered the phone or if the cell phone battery lasted throughout the entire period of operation of the transit vehicle. This is a concern since users of the system need to know where the shuttle is in real time. Additionally, Bagioni does not mention if interaction with the cell phone. Required user interaction is prone to faults since the driver may forget to engage the system. Other approaches to repurposing cell phones were found in work by Katsumoto and Inakage [15] where they designed toys from damaged cell phones. This confirms that the repurposing concept is also applicable in other contexts.

7 Conclusion

We have shown in this work it is possible to apply the repurposing concept to provide a service which can be used to determine the location of the shuttle and if it is at a shuttle stop. Additionally, the system is capable of displaying the shuttles' locations on visually on a map. Additionally, this concept not only shows its benefits to users in information delivery but also its benefits in comparison to other methods that provide vehicle location services to users, such as the mitigation of battery power depletion encountered in participatory testing. Furthermore, benefits can be seen in its sustainability as it is easy to replace one RCP and the software is interoperable. Benefits can also be seen environmentally as RCP after they have failed and need to be disposed of can be done correctly removing some of the cell phones that would otherwise be disposed of incorrectly. We have therefore shown repurposing cell phones for use in vehicle location tracking are beneficial financially, environmentally, and it is sustainable.

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