33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Public Transportation Assistant for the Cognitively Impaired

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Abstract—**This project developed and evaluated the utility of a mobility assistant cognitive prosthetic that leverages the computing power and GPS location determination capabilities of smart phones to provide location-sensitive mobility assistance. New relatively inexpensive smart phones offer powerful computing and location sensing capabilities. A prototype cognitive prosthetic was developed to assist users in their use of transportation systems. User Interface design included remote caregiver programming features, and automated SMS status generation. Location specific memory cues are triggered by comparing current GPS coordinate location with expected route coordinates obtained from stored route databases based on the GTFS feeds from transit systems. Additional development focused on developing algorithms to identify potential user errors, such as wrong-bus. These reminders and instructions will allow cognitively disabled persons to utilize public transportation systems with greater confidence leading to greater mobility and independence.**

I. INTRODUCTION

The number of individuals suffering with cognitive disabilities in the United States is greater than 20 million [1]. As the population ages, the number of individuals with cognitive impairment is expected to grow rapidly [2]. The mobility and independence of these individuals is restricted due to their inability to drive a vehicle. Instead, public transportation systems represent the only viable option for independent living [3].

Existing systems aid cognitively impaired individuals through the use of schedule assistance with visual or verbal reminders. However, these systems are not able to provide reminders based on current location, nor are they capable of detecting usage mistakes common to transportation systems like wrong-bus or wrong- or missed-exit. Public transportation systems represent an important societal institution and are virtually the only means available for cognitively impaired individuals who are typically unable to operate automobiles.

Proficient use of public transportation systems allows these individuals to remain independent and to be integrated into their communities [4]. The system proposed here seeks to enable these individuals to utilize these complex systems with greater confidence, safety and effectiveness.

Transportation is the key element enabling independence for the disabled. Yet, the mobility of cognitively impaired individuals is restricted and their quality of life is impacted because few posses drivers licenses. Specialized transportation systems for the disabled often require reservations to be made ahead of time, and only cover limited regions. Private transportation options such as taxi services are suitable, but are cost prohibitive. Transportation was identified as a significant unmet need among the disabled, with higher levels among respondents under age 65 [5]. The negative consequences of this unmet need impact an individual's ability to maintain employment and keep important appointments, including medical and therapy.

For many individuals ubiquitous public transportation systems represent the only viable option for independent living [3]. However, mastery of complex public transportation systems presents a significant challenge for individuals with cognitive impairment: understanding complex transit schedules and vehicle identification within transportation hubs with many nearly identical vehicles is followed by the challenge of determining where and when to exit the vehicle; a task that requires planning aboard a conveyance on which stops must be requested within the precise locale and inside which the atmosphere may be busy and distracting. Transportation tasks are even more complex when establishing a new routine on routes without familiar milestones. Mistakes, such as wrong-route and wrong- or missed-exit pose a serious dilemma for the cognitively impaired. The early detection of route deviations can alert the disabled traveler and allow the consequences of the mistake to be reduced. Location and time based event notifications will increase the likelihood successful trip aboard a public conveyance.

II. METHODS

A. Design Overview

The objective of the transportation assistant prototype is to utilize the GPS capabilities of smart phones to provide location-based memory cues to individuals with cognitive disabilities to enable them to more effectively utilize public transportation systems.

Manuscript received March 26, 2011. This work was supported in part by the U.S. Department of Education under Grant H133S090055

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978-1-4244-4122-8/11/$26.00 ©2011 IEEE

Writing software for individuals with cognitive impairment and potentially other additional conditions represents a significant challenge. A principle goal of the project was to support the widest possible user base. To provide maximum accessibility it was determined that the user interface should offer considerable configurability, allowing the device to be tailored to the individual. The user requirements should also simplified as much as possible. The system design started with a consideration of the system requirements and the user interface elements. The following requirements were set for the prototype system:

- *The user should not have to manually start the software application; it should automatically run at boot-time.*
- *The system should be reasonably tolerant of reboots, allowing the phone to be restarted during a tracking session and resume tracking.*
- *The relevant navigational databases and data should be stored locally on the Smart-phone to prevent disruption due to temporary loss of connectivity.*
- *The system should allow trips to be planned ahead of time and stored locally on the phone.*
- *Caregivers should have the means to remotely program trips into the handset.*
- *The application should provide a mechanism for sending automatic text message feedback to caregivers in case of OFF-ROUTE or SUCCESS conditions.*
- *A simple interface should be created to allow the user to contact caregivers in case of difficulty or distress.*

B. Smartphone Platform

The objective of this research was to evaluate the feasibility of a prototype cognitive assistant device based on the Android smartphone platform. Smartphones offer a broad range of sensors, communication options and significant computing capabilities. When compared to dedicated hardware cognitive assistants, smartphones offer significant advantages.

The Android Dev Phone 2 manufactured by HTC and running the Android 1.6 OS, was selected for the prototype cognitive assistant platform. This phone features a modest MSM7200A, 528MHz processor with integrated Qualcomm gpsOne GPS/AGPS receiver with -160dbm tacking sensitivity, but no dedicated floating point unit.

C. User Interface Design

Based upon our UI goals a design of the application interface was created (see figure 1.) The system provides alerts to the user based on calendar entries containing trip information, and based on geo-location. In a typical trip the user is not required to manipulate the device – users provide input to the system by changes in their geo-location in response to alerts. Expected progress is tracked using algorithms developed described below.

Trips are scheduled ahead of time and stored in the user's calendar by their caregiver utilizing an internet based calendar application, or via caregiver configuration features on the mobile device. When a calendar event time is triggered, the software application wakes up and starts the tracking functions. This continues until either an OFF-ROUTE detection is determined or the BUS-EXIT alert is triggered. An alarm interface for the user was included in the prototype UI whereby the user can at anytime access it by vigorously shaking the phone. The user can then select (touch) the large red touch button (shown in figure 1) to trigger automatic SMS communication with the caregiver.

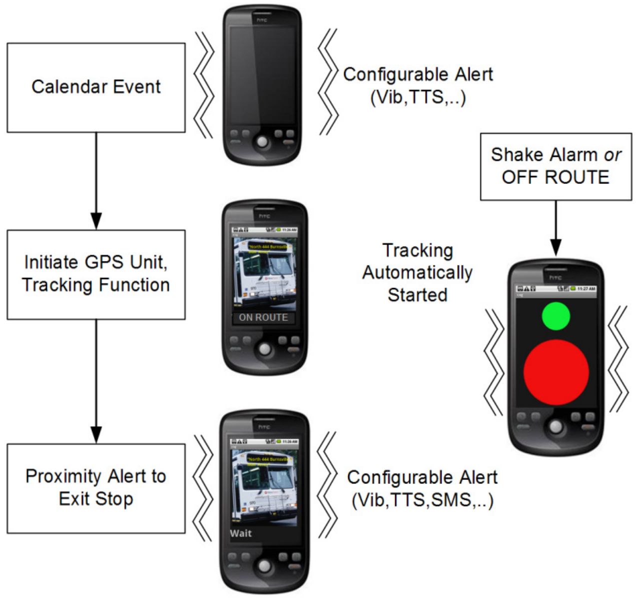
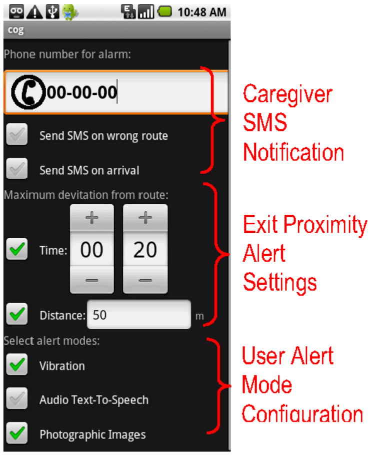


Fig. 1 UI design showing a typical trip and the emergency interface.

The Android OS enables developers to create services that will start automatically upon boot and enable processing of background events unobtrusively. A background event was programmed for service every two seconds. If no trip is currently being executed, the service remains in a wait state and continues to compare preprogrammed trip start date/times to the current system date/time.

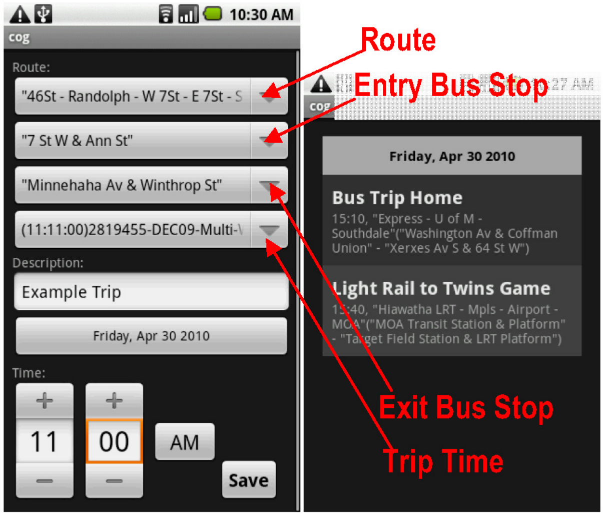
The prototype application supports caregiver configuration and trip programming. Access to configuration options may be restricted to prevent accidental modification. The caregiver interface is manually launched like a typical Android application. Figure 2 shows the application settings pane enabling caregivers to specify automated SMS status notifications, exit proximity settings and alert options. The calendar page enables the caregiver to review, edit, create and delete



Phone number for alarm:
00-00-00
☐ Send SMS on wrong route
☐ Send SMS on arrival
Maximum devitation from route:
☑ Time: 00 20
☑ Distance: 50 m
Select alert modes:
☑ Vibration
☐ Audio Text-To-Speech
☑ Photographic Images

Fig. 2 Caregiver configuration settings.

calendar entries. Figure 3 shows the calendar review pane on the right, and the calendar create/edit pane on the left. Pull down menus are automatically populated with the relevant stops and schedule entries for the selected route.



Route:

"46St - Randolph - W 7St - E 7St - S

"7 St W & Ann St"

"Minnehaha Av & Winthrop St"

(11:11:00)2819455-DEC09-Multi-\

Description:

Example Trip

Friday, Apr 30 2010

Time:

11 00

Friday, Apr 30 2010

Bus Trip Home

15:10, "Express - U of M - Southdale"("Washington Av & Coffman Union" - "Xerxes Av S & 64 St W")

Light Rail to Twins Game

15:40, "Hiawatha LRT - Mpls - Airport - MOA"("MOA Transit Station & Platform" - "Target Field Station & LRT Platform")

Fig 3 Calendar edit and calendar display panes.

A significant benefit of utilizing the Android calendar for trip schedules is that it contains a mechanism to synchronize the Smartphone calendar with an associated web-based Google Calendar account. This synchronization provides an automatic mechanism for remote management of the Smartphone's calendar. A prototype desktop application was created that successfully added trips to the Android device.

A final element of the UI is the emergency condition. A two-button pane offering one-touch communication with caregivers is activated upon detection of vigorous shaking via the embedded accelerometers. SMS communications including the users' current geo-location are relayed to the configured caregiver phone number.

D. General Transit Feed Specification

The prototype application featured an SQL navigation database containing the transit schedule and route data for the entire Minneapolis metropolitan region. The Minneapolis Metropolitan Council periodically publishes this information formatted according the General Transit Feed Specification (GTFS) [6]. Currently over 250 public transportation systems worldwide offer public access to their GTFS feeds. GTFS formatted data was directly translated to SQL tables for use by the prototype application. GTFS data in includes stop times and locations as well as detailed 'shape' data representing the expected bus route represented as a piecewise path consisting of latitude/longitude pairs. The typical segment lengths were between 10-50m.

At the initiation of tracking the calendar function generated SQL queries to obtain the shape data for the route together with a list of stop times and locations. The stop times were used to annotate the shape data with estimated times of arrival (ETAs), with points between stops receiving ETA estimates based on interpolation.

E. Exit Proximity Detection

Tracking and proximity detection are key features in the transportation assistant. Development began with location accuracy tests and measurements of GPS availability within vehicles in typical city driving. The gpsOne claims accuracies of < 10m, and this was confirmed. GPS availability was a greater concern. In approximately 60 hours of GPS data sampled at 1Hz temporary unavailability was common but typically very brief (<10s at >98%.)

Exit Proximity Determination was calculated based upon the Haversine distance between the current GPS reading and the lat/long of the exit stop. A programmable proximity distance threshold enables the alarm to be triggered at a configurable distance away from the goal. In the event of GPS unavailability a fallback alarm based purely on expected time of arrival is generated.

F. OFF-Route Detection

An algorithm to detect error conditions coming from potential user errors such as boarding the wrong bus was developed. At each GPS data acquisition time a simple search algorithm finds and measures the distance of closest approach to the piecewise GTFS shape trajectory and obtains an ETA for that point by interpolation from the times annotated to the bracketing shape points. These estimates of position and time error feed a running likelihood estimator of the ON-ROUTE probability. The on route likelihood is proportional to $e^{-\chi^2/2}$. Calculation of chi-squared is convenient to calculate and has the attractive feature that its numerical value normalized by the number of measurements should have the value of one for Gaussian distributed data. For N GPS data points the chi-squared function is given by,

$$\chi_N^2 = \frac{1}{N}\sum_{i=1}^{N}\left(\left[\frac{dx_{i,\min}}{\sigma_{GPS}}\right]^2 + \left[\frac{dt_i}{\sigma_{time}}\right]^2\right)$$

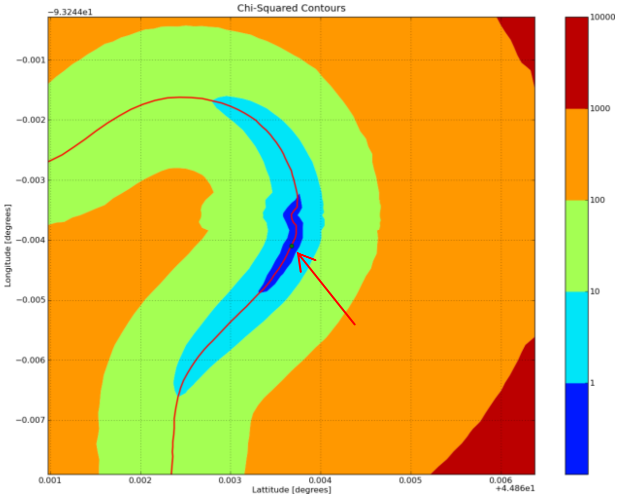


Fig 4 Contour plot showing chi-squared values for a 300m square region near the route marked in red. The chi-square values are calculated based on the expected bus space-time position marked by the arrow. The time error was reduced 3.6s here to better allow the time contours along the route to be visualized.

Where the spatial and temporal error estimates are weighted by the expected GPS position error and time errors of the transit schedule. In the prototype these were set to 10m and 10min respectively. The conversion of eq. 1 to a running calculation for the real-time calculation yields,

$$\chi_N^2 = \frac{1}{N}\left(\left[\frac{dx_{N,\min}}{\sigma_{GPS}}\right]^2 + \left[\frac{dt_N}{\sigma_{time}}\right]^2\right) + \frac{N-1}{N}\chi_{N-1}^2$$

In an off-route condition the errors rapidly accumulate and the chi-square value will increase, passing the OFF ROUTE threshold and generating alerts. Figure 4 shows the chi-square contours for a single GPS measurement. The threshold for evaluation was set at 1000, corresponding to a single position error of approximately 300m.

G. *Location Based Alert Testing*

The proximity alert was tested in a total of 41 trips. In all cases the boarding alert was generated and GPS tracking initiated. An exit alarm was generated in 100% of the test cases. The alarm threshold was set at 100m. The actual distance to the goal was measured and found to be 93m +/-12m, with the mean less than 100m due to the expected lag associated with the 0.5Hz tracker generating the alert after passing the threshold.

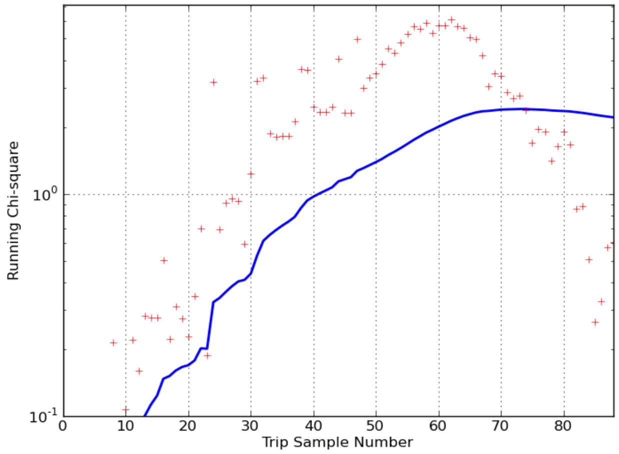


Fig 5 Running chi-square (blue) and individual chi-square values for a typical Metro Transit bus trip

To test the OFF-Route algorithm it was decided that the data sample should include a broad sampling of schedule errors, urban canyons and GPS outages. The Minneapolis Metropolitan Council to request access to their bus GPS data. Each bus in the system is instrumented with GPS units to transmit their current location to provide real-time schedule updates. The Metro Transit GIS Administrator generously provided a GPS dataset containing all the data collected in one calendar day. The dataset comprised 6127 distinct bus traces and 125 different bus routes. The chi-square values for every run were calculated (see figure 5) and the distribution of final chi-square values showed that 95% of the final chi-square values were less than 25. An OFF-ROUTE threshold of 1000 was selected. 34 routes failed this threshold due to corrupted time stamps (26), off-route points recorded after completion of scheduled route (3) or apparent mislabeling (5).

To test the OFF-ROUTE detection algorithm, tests were run with the entire Metro Transit dataset. For each trip we queried the transit database for a list of all potential false bus trips defined as busses departing from the same stop within a time window of 10min. The potential false trips and the true bus trip were each used to run the tracking algorithm with the GPS trace data. The resulting chi-squared results were then compared to determine how frequently the identified route had the lowest chi-square when compared to the candidate routes. In 96% of the routes the identified bus trip had the lowest chi-square value. The remaining 4% of cases included the trips with large chi-square values due to timestamp errors. In some cases the identified route was not among the trips departing from the bus stop within the time window. Apart from these artifacts in the Metro Transit dataset, the Off-Route detection algorithm showed significant success at identifying the correct route followed, among likely candidates.

TABLE I

Cumulative Frequency	*Chi-Squared*
0.99	526.28
0.95	24.60
0.90	8.99
0.85	5.57
0.80	4.12
0.75	3.25
0.70	2.65

Measured Relation between cumulative probability and final route chi-squared value

ACKNOWLEDGMENT

The authors would like to thank the Minneapolis Metropolitan Council for generously providing a large GPS dataset to assist with the development of the algorithms described above. The authors would also like to thank the Ability Building Center (ABC) in Rochester MN for providing helpful design feedback.

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