REDLE: A Platform in the Cloud for Elderly Fall Detection and Push Response Tracking†

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ABSTRACT

Caring for a rapid and ever-increasing older population, providing social support and monitoring emotional wellness, is the most immediate and most urgent challenge prompted by the global aging of baby boomers. Elderly assisted systems do not only promote independent lifestyles, enhancing their quality of life, but also reduce stress and worry of families and friends. While being physically active is beneficial and much encouraged, it does increase the risk of falls. We developed an affordable fall detection and response tracking application on the cloud platform; mobile cloud computing is a major evolution with rising impact in information technology and enterprises. Our system, named REDLE, features push notifications for fall alerts and real-time maps for tracking and providing locations and phone numbers of nearby hospitals. Implemented on Android, it captures signals from an embedded tri-axial accelerometer and a global positioning system sensor. Coupled with an efficient threshold-based fall detection algorithm for instantaneous responses, REDLE achieved a near perfect fall detection rate and accurate tracking. Users enjoyed the smoothness of our interactive interface, and complimented on its ease of use and familiarity.

Keywords: Fall Detection, Response Tracking, Eldercare, Mobile Cloud Computing, Push Notification

1. INTRODUCTION

The demand for elderly care has never been more urgent than it is today. Baby boomers, those born between the years 1943 and 1960, are between the ages of 56 and 73 years in 2016, while baby busters, those in Generation X or Y, are approximately at working ages. Proportionately, the number of elderly dependents per working individual is strikingly increasing. Aging adults naturally require support both physically and mentally. They are funtional decline and frailty. Their health condition is declining; their vision is deteriorating; their walking is becoming imbalanced and unstable. Many are more vulnerable to unintentional falls, which are the leading causes of serious injuries, disabilities, or accidental deaths worldwide. Severity of outcomes ranges from broken bones, hip fractures, wrist, arm, and ankle fractures, or upper limb injuries, to head or traumatic brain injuries. According to the World Health Organization (WHO) report [2], supported by many epidemiological studies, 40% of fatal injury in older age is a result of a fall. Among the population at the age of 65 and older, falls account for more than half of injury-related hospitalization. An estimate of 28-35% of individuals in this age group experiences a fall each year. This number increases to 32-42% for senior populations who are 70 years of age and older.

Family members and relatives are faced with difficulties and challenges caring for their vulnerable elderly parents or relatives, providing them a safe environment. Some choose a residential care or a nursing home; others opt for an in-home care service. The majority, nevertheless, embrace a traditional family-based model. Living in a multi-generation household is a rewarding experience but it could be exhausting and full with challenges. Tremendous responsibilities are upon working-age persons to care for both youngsters and elder adults. When kids are at school, their grandparents are often alone at home or out running an errand. Staying active is encouraging and proves beneficial for the elderly; it comes however at a great concern for their safety. Accidents such as falls happen and when they unfortunately do, not only is medical attention often required but also a relative or a person in charge should be promptly informed.

Addressing the need for a self-monitoring device, we have developed an ubiquitous fall detection and response tracking application on a mobile phone, that is equipped with personal confidentiality and privacy protection. REDLE automatically alerts designated and authenticated caregivers in case of a fall. Setting ours apart from the others, we utilize a push notification, processed through a Platform as a Service in the cloud, preceded over a Short Message Service (SMS or text messaging). A cloud-push posts an alert on a caregiver's device regardless of an application a user is actively using or if the device is inactive or unused. Once alerted, it quickly returns the user to our ap-

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plication, which readily delivers the current location where the fall has taken place. In addition to the global positioning system (GPS) coordinates of the respective elderly person, REDLE promptly features an interactive map along with contact information of nearby hospitals, clinics, or healthcare institutes.

2. BACKGROUND AND RELATED WORK

Research on fall detection and monitoring on mobile devices has gained much attention and been continuously evolved following rapid advances in networking technologies and embedded sensors. Fall detection gadgets can be broadly grouped into three categories [3]; they are wearable, ambiance, and vision-based devices. Relying only on embedded sensors, wearable approaches are the most cost effective and the easiest to setup. Ambient devices effectively combine audio and video signals, triggering events based on vibration data. Vision techniques track users using surveillance cameras, employing complex artificial intelligence algorithms. Though achieving higher accuracy, camera based only provides assistive care in a limited, often pre-allocated, and usually indoor space.

Over the past couple of decades, mobile devices, especially tablets and smartphones have become one of the basic needs for almost everyone in every age group. Carrying one or multiple phones everyday everywhere we go is a norm rather than a luxury or a burden. A cellular phone is indispensable; it is always within reach, almost never out of sight, and often in ones' pocket or around the neck. An installation of a fall detection application on a smartphone is thenceforth without a doubt a natural choice. Android operating systems is selected since it currently holds over 80% of the market share in 2014-15 with Apple iOS at less than 15% [4]. Based on Linux kernel, an Android platform allows enthusiastic developers, from amateur to professional, to customarily reconfigure both its hardware and software. Commands and controls of various sensor components are programmable; they are easily accessible and generally adaptable.

Reviewing Android-based fall detection and monitoring systems [5], an accelerometer is a primary sensor being utilized. It has come quite a very long way from being externally mounted in old, obsolete, and discontinued Nokia phones with Symbian OS to a robust tri-axial accelerometer embedded in most modern smartphones; a typical coordinate system of the three axes is illustrated in Fig.1. Raw time-series signals captured are immediately processed on an ever increasing, yet still largely limited, computing power of mobile devices. Concerned with low computational requirements on limited resources of mobile devices as well as real-time responses, we have chosen to implement a simple but effective threshold-based fall detection algorithmic scheme applied to acceleration data. Other strategies that distinguish falls from other regular everyday activities employ pattern

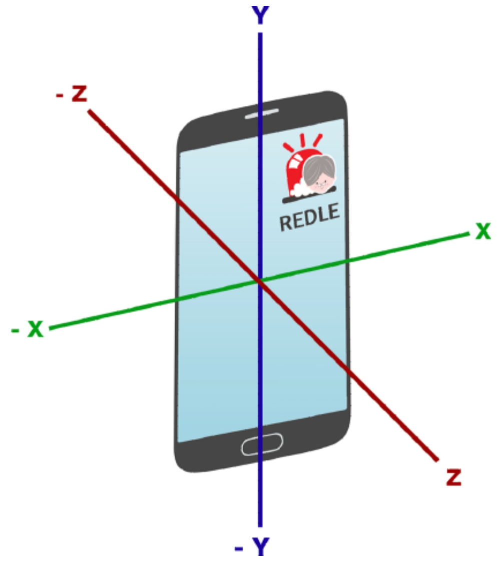


Fig.1: *The three axes associated with a tri-axial accelerometer sensor embedded in most smartphones.*

recognition methods or machine learning techniques [6]: multilayer perceptron, a feedforward neural network, a probabilistic naïve Bayes classifier, support vector machine (SVM), and decision tree (C4.5, an extension of Iterative Dichotomiser 3 or ID3). Developing of such an artificial intelligence (AI)-based detection system involves training and validating phases before conducting a test on real application data. A classifier is trained based on known, labeled samples (supervised learning) or unlabeled instances (unsupervised learning). Since training a classifier is commonly a complex time-consuming task, it hinders the feasibility of on-board smartphone processing.

Communication channels responsible for activating an alarm and sending out an alert when a fall is detected plays a crucial role in the effectiveness of the system. Physical gateways vastly limit the operative range of the applications mostly to indoor environment. Free coverage of cellular networks or wireless mobile telecommunications (3G or 4G) and Wireless Fidelity (Wi-Fi) has been extensively expanded in range; its signal quality has also been largely improved. This allows an application to operate while users are busily moving about. SMS text messaging has been dominated for alert notifications; examples include iFall [7] and Fade Fall Detector [8], among a few commercially available applications on Google Play. Putting much efforts into preventing false positive alarms, however, both iFall and Fade do not send an alert immediately after a positive indication of a fall is perceivably detected. Instead, they attempt to make contact with the user, a prompt in iFall and a verbal contact in Fade, and a fall is confirmed only after the user fails to respond in a limited time frame. Only then a text, containing the time and the GPS coordinates of the fall, is sent to selected individuals whom the user has earlier entered in the contact list.

Without remote monitoring, most fall detectors, iFall and Fade included, operate on the end-user side. The application is constantly active only on the one user (an elderly) whose falls are being monitored, and inactive on the other receiving end (a family member, a relative, or a close friend). REDLE takes a different approach, making the system two-sided and without the high-cost of setting up a remote site. Elderly persons and their caregivers are pre-paired. This avoids any delays due to a verification block when a fall happens and when every second counts (iFall attaches a password authentication with its alerts). Operating two-sided, REDLE lets a careperson query the current location of the elderly at any time, a particularly useful function especially when the elderly is traveling from one place to another for some appointments.

Distinguishing itself from existing applications and advancing a fall detection and notification system to the next level, our REDLE explores the emerging field of mobile cloud computing (MCC) [9, 10]. Clouds deliver seemingly unlimited computing resources over the internet. Access to shared storage and processing units is on demand, available from anywhere from any device connected to the internet. Application data as well as computing elements are stored and processed on either a private or a public cloud instead of a user's own device. Cloud computing solutions are generally grouped into multiple categories based on how much of the resources is disclosed to users and which level of management and functionality is provided to developers. Standing at one extreme, Software as a Service (SaaS) provides a complete package, targeted end-users. It is an application on demand with back-end services and font-end user interfaces. At the other extreme is Infrastructure as a Service (IaaS), which provides only the hardware. It offers storage, computing capabilities, and networking equipment. This is analogous to having a virtualized environment or a virtual server that developers must manage.

Closely related to SaaS is a Backend as a Service (BaaS), which is geared towards mobile applications, referred to as mobile-BaaS or mBaaS. BaaS offers plug-and-play services with the backends taken care of plus additional services such as user file management and report, email and push notifications, location services, and dashboards and social networking. Developers work with application program interfaces (APIs) generally provided in multiple languages to integrate selected elements into their own applications. Another category of cloud services is a Platform as a Service (PaaS) that provides a runtime development and deployment environment on which a customized application can be built. Users usually access PaaS hosted hardware and software via a web browser, getting a slice of cloud to develop, code, test, and deploy their applications. PaaS provides tools such as content distributed networks and load balancing, but developers must setup and built their own database.

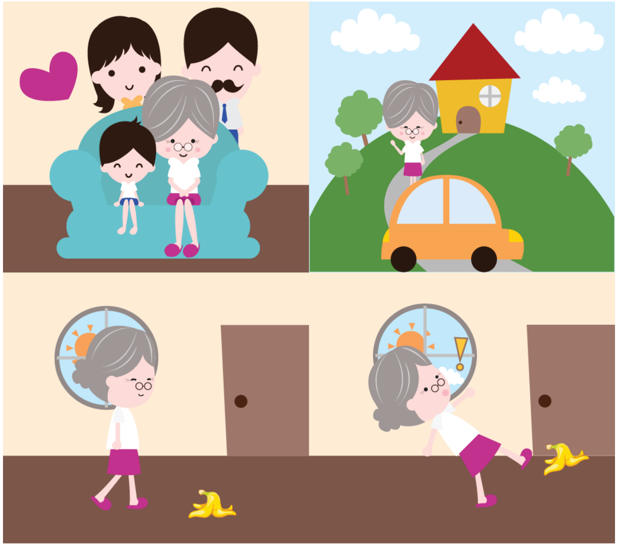


Fig.2: *A grandmother is at risk of accidental falls and it worries family and friends when she is alone.*

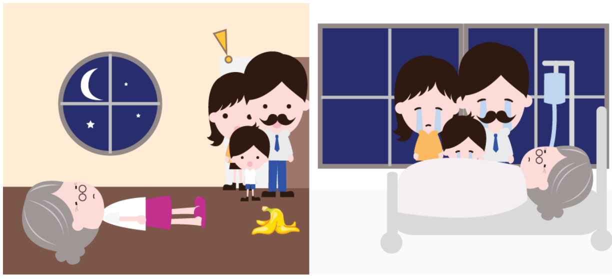


Fig.3: *Accidents happen. A grandmother slips and falls. Unabled to call for help, she lays helplessly for hours until a family arrives to find her later at night.*

These new frontiers of mobile cloud computing do offer great flexibility and excellent scalability at the minimal cost for a large number of application developers. At the core, one of the keys to our fall detection and response tracking application is the utilization of push notifications for alert messages. Flows of data, processes, implementations, and deployments of REDLE are in the cloud. Its first version effectively employed Parse [11], a notable mobile-backend-as-a-service acquired by Facebook in 2013. We have since migrated it to Heroku [12], a platform-as-a-service, following the expected retirement of Parse in 2017.

3. OVERVIEW OF REDLE

The motivation for REDLE is described in Fig.2. Advocating healthy family relationships and always keeping their bonds tight, the grandparents, the parents, and the grandchildren share a single multigeneration living household. Promoting independence of an elderly person, while everyone is busy working at an office or studying at a school, a grandmother stays home alone. She may occasionally go out to socialize with friends in the neighborhoods or to run an errand.

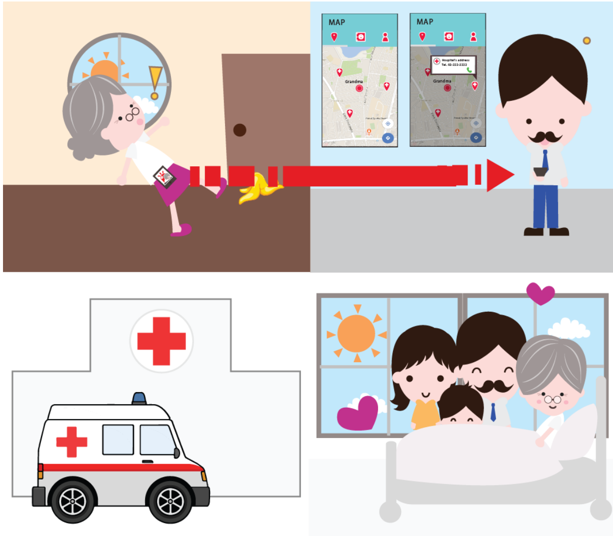


Fig.4: *REDLE alerts the family immediately after a grandmother falls. The father calls an ambulance, getting her much needed medical attentions. Informed family members promptly arrives at the hospital.*

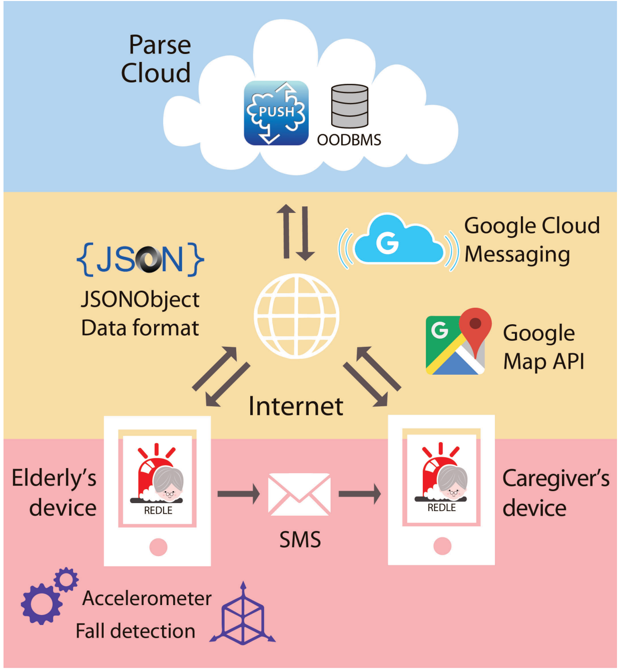


Fig.5: *The architectural platform of REDLE in three layers: mobile devices and sensors, application interfaces through the internet, and Parse Cloud.*

These activities come at a cost of accidental falls; time and again one single fall is all it takes in causing serious injuries, a forever life-changing incident. When it happens (Fig.3) a person is frequently unable to call for help. Laying on the floor, waiting helplessly until someone arrives home later in the evening or at night often leads to regrettably undesirable consequences. The injuries and associated symptoms usually progressively worsen the longer the delay of medical care.

Accidental falls, especially slipping and tripping, do worry everyone when a grandmother is relaxing at home or independently enjoying a stroll around town. Equipped with REDLE (Fig.4), nonetheless, ones can breath easier, knowing that she is being ubiquitously monitored and that they would immediately be notified if she falls. Family members together but individually register on our application. A grandmother logs in as an elderly user whose falls are to be monitored. Parents plus extended relatives and trusted friends log in and agree to join a circle of pre-designated caregivers. When our application detects a fall, it pushes a notification to relatives and friends. Along with a fall alert, it provides the location of the grandmother placed on an interactive map, addresses and contact phone numbers of nearby hospitals. A careperson can quickly call for help resulting in the grandmother receiving medical attention in no time with a comfort of having family members rush to be by her side.

4. REDLE ON PARSE IN THE CLOUD

Installable on any Android device, REDLE (Fig.5) utilizes the moblie-BaaS Parse Cloud [11]. The open source Parse Server provides data storage infrastructure, database functions, queries, and push notification services, all through a convenience of application-level hyper-text-transfer-protocol (HTTP) endpoints. Our application employs an object-oriented-database management system (OODBMS), where data is modeled as objects, supporting classes, subclasses, methods, interfaces, and inheritances. Parse objects are efficiently read and written via a lightweight JavaScript Object Notation (JSON) format. Specifically for our application, we implement five collections of stored objects. They are installation, storing the hardware model and the software version of a device, log-in sessions, user account including name, phone number, and password, the last known location of an elderly user, and a list of friend requests and responses.

Once users are registered and authenticated, their data file is stored in the cloud. Pairing of an elderly person with caregivers requires a successful exchange of push request-accept notifications. Such a request is processed automatically when an elderly person adds his or her desired caregiver. This arrangement needs to be setup only one time; still, profile preferences can be modified at any time and the contact list can be added, deleted, or edited as often as desired. A positive detection of a fall triggers flows of data and services through a Parse server, establishing necessary connections, sending and receiving alert messages and responses. Processed in parallel, the system instantly extracts and locates the geographic coordinates of the fall. It fetches the address, contact information, and phone number of local hospitals and nearby medical facilities. Integrated with Google Map API, REDLE effectively marks these locations all on one interactive map shown on a caregiver's screen.

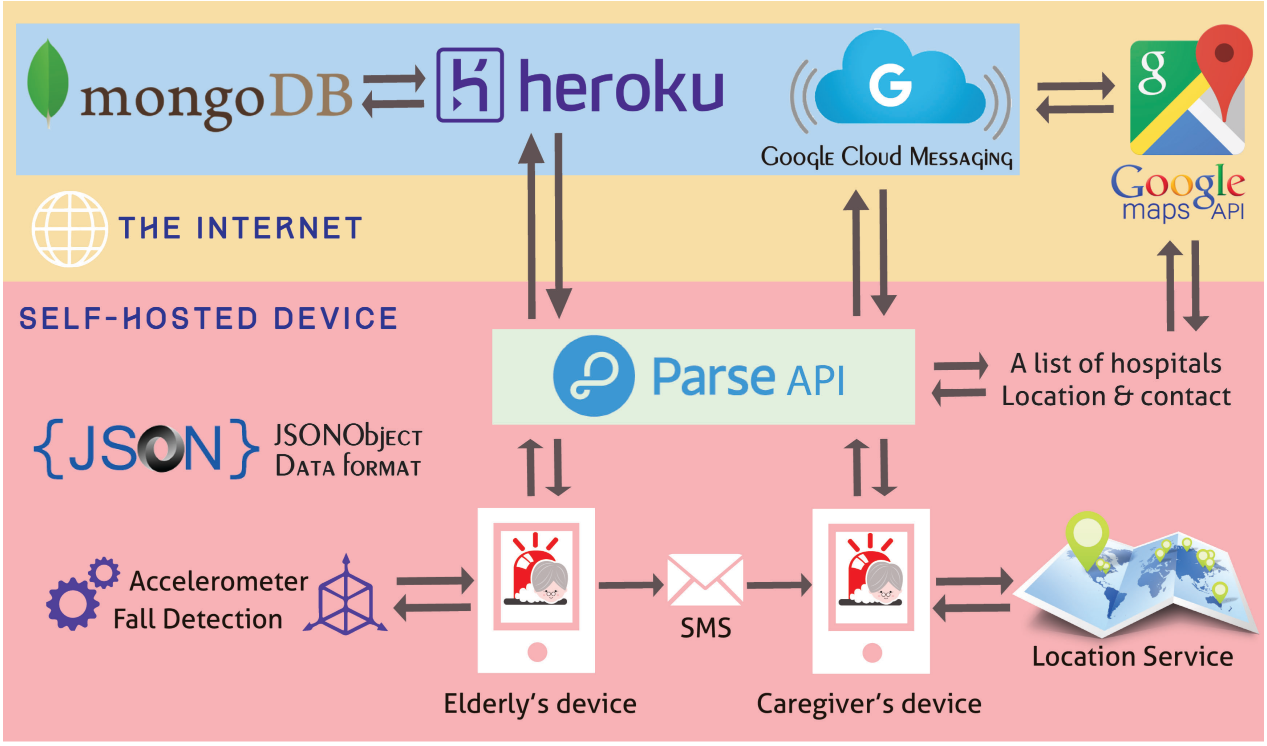


Fig.6: *The revised architecture of REDLE; it has since move from Parse to Heroku and MongoDB.*

5. REDLE ON HEROKU AND MONGODB

After a successful development on Parse, we have migrated our application to Heroku and MongoDB per Parse's recommendation as Parse hosted service is retiring in January 2017. Our revised design and architecture is diagrammed in Fig.6. Registered mobile devices, both the elderly and the caregiver side, interface with Parse API; Parse has since released its open source server, allowing developers to setup a self-hosted Parse server. Instead of a local machine, we deployed Parse server to Heroku. REDLE is then hosted by Heroku [12], a leading PaaS cloud solution.

Integrating with Heroku cloud services, our choice for database programming and management is the open-source MongoDB [13] for its speed and unprecedented scalability, adaptibility, and flexibility that is well-transparent to end users. MongoDB is not a relational database management system (RDBMS) where records are stored in tables with rows and columns. It is a cross-platform document-oriented, no-structured-query-language (NoSQL) database, where records are stored in collections. It employs a rich data model, allowing a mix of literally any type of data to be incorporated. Data is representing in JSON-like documents in a binary-encoded serialization format, called BSON. Instead of a join clause in traditional SQL for querying and retrieving data that requires combining columns of two or more related tables, MongoDB exercises a concept of embedded documents and linking. Furthermore, it features dynamic schemas. Records can be created without pre-defining a fixed schema; fields can be added, removed, or modified as needed.

6. FALL DETECTION ALGORITHM

To detect an occurrence of a fall, REDLE captures signals from a tri-axial accelerometer, embedded in most Android smartphones. An accelerometer senses acceleration forces, the rate of change of the velocity of a device. The amount of dynamic acceleration is an indication of the physical motion of a device: its vibration and how it is moving. Static or gravitational acceleration enables an analysis of the angle of a device with respect to earth: how much it is tilted. Interpreting these signals, we evaluate a velocity pattern of a fall from a measure of dynamic forces; we assess the body position of a person relative to the ground from the values and directions of static forces.

An acceleration is measured quantitatively in metre per second squared, m/s^2, reading at a sampling frequency between 50-200 Hertz [14]. The actual rate depends on the specific hardware model and the software drivers installed. A recommended resolution on a device for converting an analog voltage to a digital value (ADC) is 16-bits or at least 12-bits.

Time is vitally critical as we aim for a real-time fall detection alert and an instantaneous response tracking application. Thus, an approach that necessitates less computational complexity is preferred. This led us to a threshold-based fall detection methodology. Three parameters associated with falls are analyzed: impact, velocity, and posture. Bourke and colleagues [15, 16] demonstrated that algorithms that combine these three parameters could achieve 100% sensitivity and 100% specificity; their settings, particularly threshold values, are utilized in this work. We note the definition of sensitivity and specificity, where TP, TN, FP, and FN represent true positive, true negative, false positive, and false negative, respectively:

$$\text{sensitivity} = \frac{\text{TP}}{\text{TP} + \text{FN}} \qquad \text{specificity} = \frac{\text{TN}}{\text{TN} + \text{FP}}$$

Sensitivity or true positive rate measures an amount of recall, that is, the proportion of positive instances that are correctly identified. Specificity or true negative rate assess such proportion of negative instances.

Fall detection parameter: impact

Impact takes into account the four phases of a fall when a person inadvertently and oftentimes suddenly comes to rest on the ground. These are pre-fall, critical, post-fall, and recovery states. A pre-fall is when one becomes unstable but may or may not be falling. A critical stage normally spans a very short period of time; it is a rapid movement of a body down towards the ground. A post-fall is a relatively inactive stage; one is coming to rest, usually in a lying position. Last but not least, during an aftermath, a person instinctively attempts to recover, sitting up or standing up, either with or without help.

Analyzing the transition between these four different phases, the dynamic Root-Sum-of-Squares (RSS) of the three signals recorded from each of the three axes of the tri-axial accelerometer are calculated [15]. The rate of change in velocity over time is captured, both its dynamic and static components. More concretely, these signals are the acceleration in the x-axis (A_x), the acceleration in the y-axis (A_y), and that in the z-axis (A_z). The mathematical formula for the total sum vector, denoted SV, follows Kangas [17]:

$$SV = \sqrt{(A_x)^2 + (A_y)^2 + (A_z)^2}$$

The contour of SV is plotted against time for evaluation. An occurrence of a fall is positively detected when RSS drops below a lower-fall-threshold (LFT) and a short time later it peeks above an upper-fall-threshold (UFT) [18]. RSS equals $+1g$ at stationary where the acceleration due to gravity g is $9.8\, m/s^2$. The value of LFT is set at $+0.65g$ and UFT $+2.8g$.

Fall detection parameter: velocity

A velocity, more explicitly, vertical velocity is estimated through a numerical integration of the Root-Sum-of-Squares over the time period of a fall.

$$v_0 = \int_{t\ \text{start of a fall}}^{t\ \text{impact}} SV(\tau)\, \mathrm{d}\tau$$

A fall is detected when the measured vertical velocity v_0 is lower than $-0.7\, m/s$, following an empirical analysis on activities of daily living (ADLs) data by Bourke and colleagues [15, 19].

Fall detection parameter: posture

Posture is a measure of an angle between the reference vector of gravity, $\vec{g}_{REF}$, and that of the body segment, $\vec{g}_{SEG}$, which corresponds to the z-axis of a tri-axial accelerometer. Mathematically, this angle θ at time t is the dot product of the respective vectors:

$$\theta\,(t) = \cos^{-1}\left(\frac{\vec{g}_{SEG}\,(t) \bullet \vec{g}_{REF}}{|\vec{g}_{SEG}\,(t)| \cdot |\vec{g}_{REF}|}\right)\frac{180}{\pi} \quad \text{(degrees)}$$

According to Karantonis et al. [20], a measured angle $\theta(t)$ between zero and sixty degrees implies an upright position: while zero to 20 degrees is an indicative of a person standing, 20 to 60 degrees indicates sitting. An angle between 60 to 120 degrees suggests an individual is in lying position and that beyond 120 degrees signifies an inverted position. Correspondingly, our REDLE application detects a fall when the measured angle exceeds 60 degrees.

7. PUSH NOTIFICATION FOR FALL ALERT AND RESPONSE TRACKING

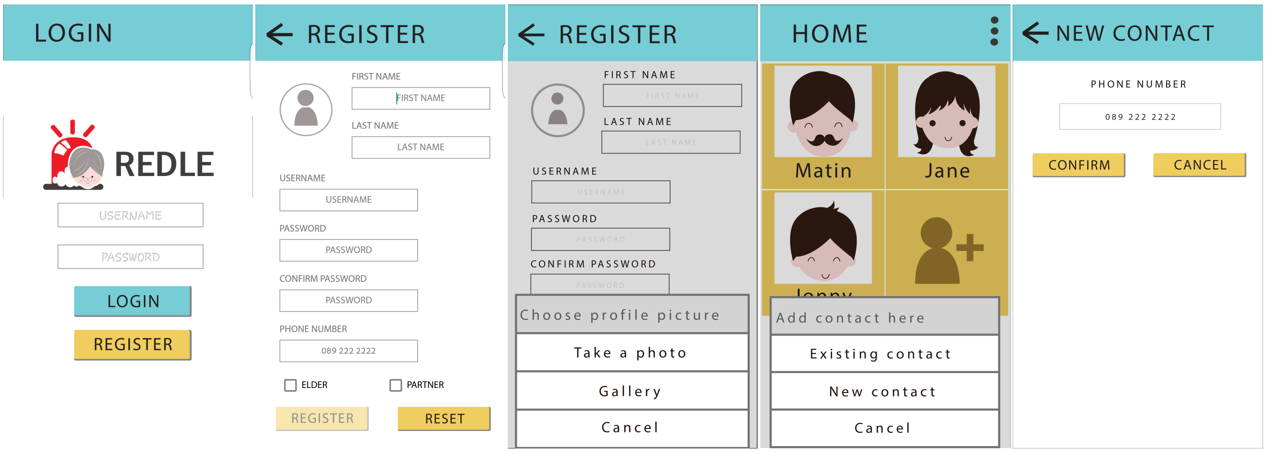
Immediately at the time a fall is detected, a push notification alert is automatically sent to every predesignated caregiver via an integrated Google Cloud Messaging (GCM). More specifically, through Parse API, using Parse Push Notification services, REDLE sets the GCM's sender ID and initiate push messages. In unfortunate circumstances, internet access may be unavailable. Instead of blocking, unabled to respond, our application is set to take an alternative route. It switches, sending a fall alert through a SMS.

The latitude and longitude geo-coordinates of the location of a fall incident are read from the embedded GPS sensor on an elderly's device. This information is then passed to a caregiver's device. Going beyond other existing applications that uses GPS signals only to provide the location of a fall, REDLE is effectively linked with Google Map APIs for maps, locations, and directions. The geo-location of a fall is used to further extract geo-information of nearby medical care centers, which is delivered directly to a careperson. Their locations are marked on a Google map, their phone numbers are shown in pops up.

Following a similar flow of data and services, REDLE includes an unparalleled real-time monitoring and tracking as another added feature. Being a two-ended application, at every instant of time, a careperson may request a map view indicating the current location of every elderly person in his or her care.

8. REDLE'S USER INTERFACE

Designing an interactive user interface for our application focuses on simplicity, user-friendliness, and ease of use. The platform of the system is built on advanced cloud computing, wireless network technologies, and embedded sensors. The front-end, notwith-



(a) Login (b) Registration (c) Profile picture (d) Home page (e) New contact

Fig.7: *Screenshots in elderly mode: login, registration, and pages for managing a contact list of caregivers.*

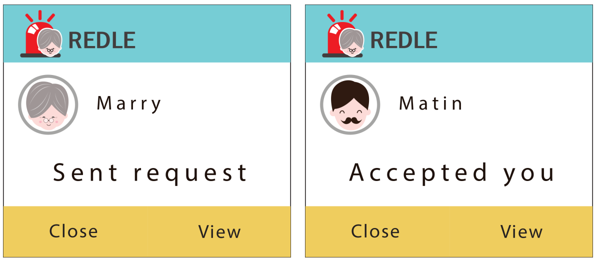


Fig.8: *REDLE's push notifications: (Left) a request to be notified of a fall is sent to a careperson's device and (Right) a response sent to an elderly's device notifying that a pairing has been successfully accepted.*

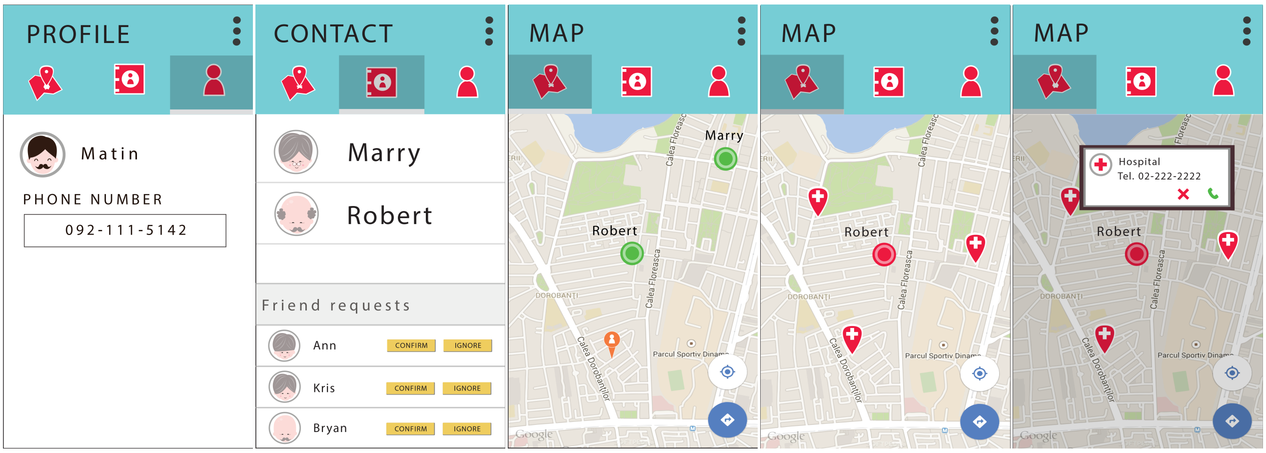
standing, must create user-experience suitable for aging baby boomers. Unlike Generation Z who are digital natives, growing up with electronics and the internet, they are digital immigrant; they are not born digitally aware. Older adults are very capable of operating mobile devices but they are not tech-savvy.

Existing applications such as iFall and Fade do not specifically target elderly users. They are intended for everyone who is at risk, individuals who are vulnerable to accidental falls. Their application user interface is therefore not designed particularly for elderly persons. Their fancy graphics and complicated functions may enhance the general look and feel, but it is not preferred by non-technical baby boomers.

In contrast, REDLE focuses on health and safely of aging individuals. The objective of our application is primarily for elderly adults to receive medical attentions as quickly as possible in all cases of unintentional falls especially in isolated environment. It is critically important to avoid much confusion during emergencies. Our interface design facilitates the urgency of medical care, ensuring that crucial elements: the geolocation of a fall, informative and interactive maps, and local hospital contacts, are quickly understandable and easily accessible, most preferably at a glance and at a fingertip. Another equally indispensable factor to the design of UI/UX (user interface and user experience) is setting up an account and keeping an application running. These must be minimal and straightforwardly natural. Communicating and interacting with REDLE should occur instinctively with a simple but elegant appearance, accessible menus, and handy commands and controls. Otherwise, many elderly people may feel fairly awkward, intimidated, or burdened, and deliberately decide to neither sign-up nor continue using the application altogether.

Examples of screenshots in elderly mode are presented in Fig.7. Keeping them simple but descriptive, these are relatively plain and uncluttered. Fig.7a is the homepage of our REDLE application. Users login with their existing account and first time users are required to register. Creating a new account (Fig.7b) is straightforward. The system asks for nothing more than necessary information: a name, a phone number, and a password. Fig.7c shows an optional profile picture, which can be added or modified at any time. Users choose a photo from a gallery or take a new one using an embedded camera. Having a picture makes it easier to identify from whom a notification comes; REDLE displays it along with every message as well as on a contact list. From the home screen (Fig.7d), adding carepersons is easy and uncomplicated. An elderly user can either select relatives and friends from his or her existing contact list or create a new one (Fig.7e) where only a phone number is needed.

When an elderly chooses or enters a caregiver, REDLE automatically sends a push request to a respective careperson's mobile device. Fig.8 depicts a notification alert a caregiver would receive. It precisely specifies an elderly relative or friend who has initiated the pairing. Once a caregiver views the request and confirms either to accept (or to reject), an elderly user is immediately informed through another accept (or reject) push message, which clearly indicates from



(a) Profile page (b) Contact list (c) GPS tracking (d) Fall location (e) Local hospitals

Fig.9: *REDLE's screenshots for caregivers, showing a profile page, a contact list, and different map features: a real-time querying and tracking, the location of a fall, and contact information of nearby medical services.*

whom the request is responded.

Fig.9 illustrates screenshots in caregiver mode. Login and registration are the same as those for elderly users. We exemplify a profile page (Fig.9a); that of an elderly mode resembles the same format. A contact page (Fig.9b) displays a list of pending requests on the bottom; each with an option either to confirm or to ignore. Confirmed requests are put onto the list at the top of the page. Once paired, by navigating to a map screen, a caregiver is able to pull the real-time location of one or more elderly persons in his or her care. Their locations are simultaneously marked on a map (Fig.9c) for easy tracking and clear visualization. This feature is particularly useful for checking if grandparents have arrived at their planned appointment or destination when they are out and about.

A series of events that REDLE spontaneously activates when a fall is detected is laid out in Fig.9d-e. A push alert mirrors those notifications shown in Fig.8. It is a message indicating that a fall has been detected along with the username and a profile picture of an elderly who has just fallen. Immediately after a caregiver responds, a map with the geo-location of a fall is displayed (Fig.9d). On the same map, a caregiver can view or browse for locations and phone numbers of hospitals, clinics, or healthcare facilities in the vicinity of the elderly person's fall location. At a fingertip, on a pop-up window detailing the contact information of a selected medical service (Fig.9e), a caregiver can conveniently tab or click on it and right away call for a much needed medical attention.

9. TESTING AND EVALUATION

A preliminary evaluation of REDLE aims towards functionality and efficacy of the application platform. We targeted reliability of MCC with push notification and interactive maps and robustness of the threshold-based fall detection algorithm. Our experiments were generally conducted in simulated environment involving only the authors of this work. The phone used is a Samsung Galaxy S6 Edge (SM-G925F) with Android 6.0.1 installed. Keeping the phone in a pocket, a common practice by most individuals, we imitated a number of fall positions frequently occurring in the elderly [21]. We tested nine positions: hard fall forward, hard fall backward, hard fall left, hard fall right, collapsing while standing, collapsing against the wall, slip, fall and holding on to a rail, and falling out of a bed.

- Hard fall forward, backward, to the left, or to the right. Walking unstably, many elderly persons trip when their feet collide. They miss a step and lose a balance. These falls are usually caused by physical hazards such as poor lighting or uneven surfaces; a person may stumble upon cluttered walkway.
- Collapse, happening unexpectedly, is typically due to existing medical conditions. Older patients may be standing freely or leaning against the wall when they suddenly become dizzy and possibly fainted.
- Slip then fall can be caused by wet, oily, or greasy floor, and inappropriate footwear (too loose or slippery shoes). Many come straight down, landed on their buttocks, resulting in painful hip injuries, sustaining a hip fracture or a dislocation hip joint.
- Involuntarily becoming shaky or wobbly, an elderly person is able to grab on to some physical structure for support such as a handrail or a bar, but cannot regain the balance and still ends-up falling.
- It is not uncommon for seniors to roll over and fall out of bed. A bad dream, anxiety or distress, struggling to get up, becoming disoriented, and misjudging the edge of a bed are prevalent reasons.

Each of the nine positions is repeated ten times for the total of ninety falls. Our application achieves a recall rate of 95.56%, detecting all but four hard falls (one with the right-side down and three backwards). Along with every fall that was detected, a real-time

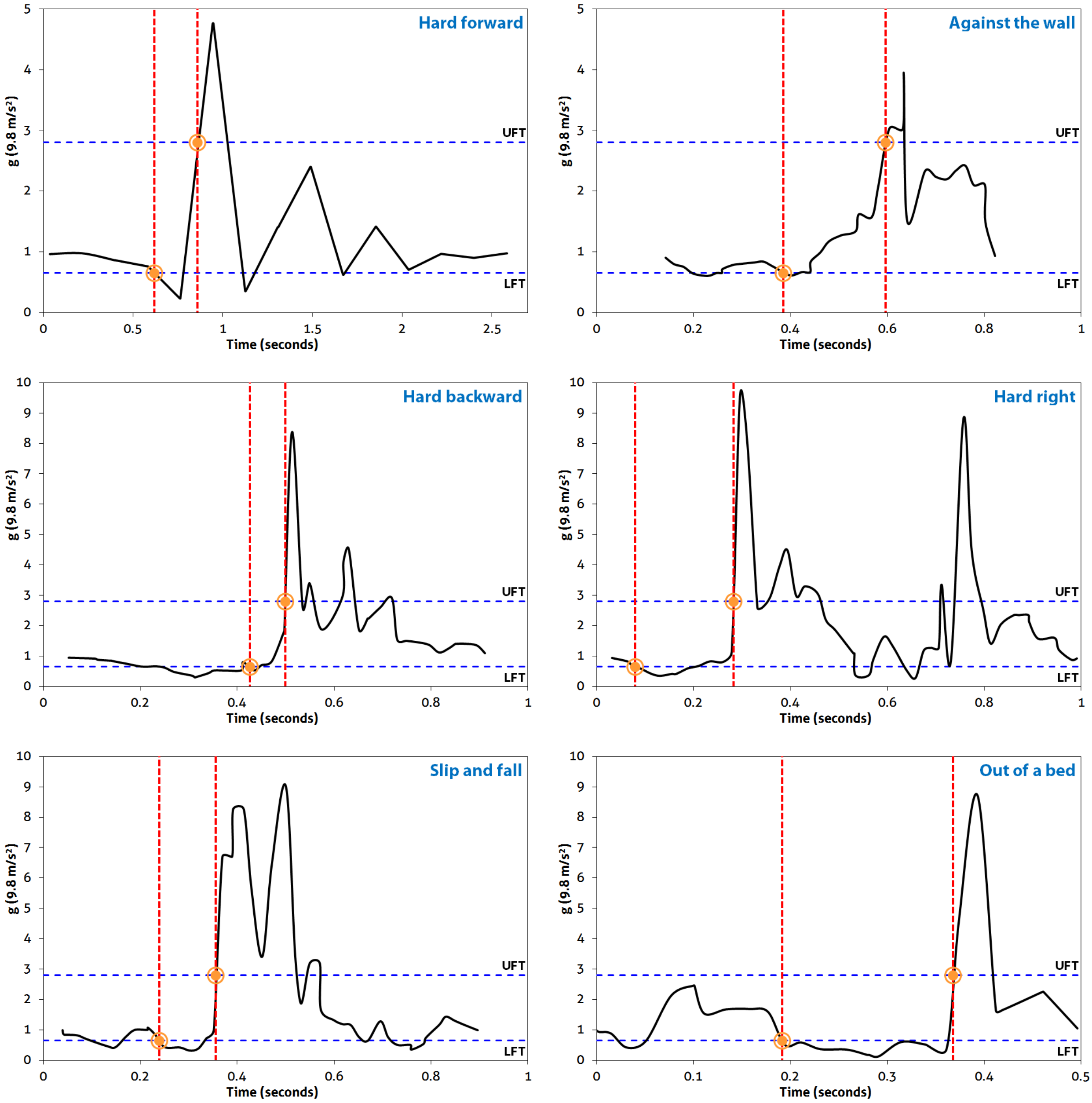


Fig.10: *Signal processing and analysis in REDLE for fall detection. Plotted are the total sum vector, SV. We showed six of the nine fall positions: hard forward, hard backward, hard right, against the wall collapse, slip, and fall out of a bed. The other three are similar: hard fall left is similar to hard fall right, standing collapse is similar to slip (both are relatively hard and sudden falls), and hold on a rail is similar to against the wall collapse (a person comes down relatively at slower speed with lesser force). Marked on every plot are the falling-edge time [15], from the last drop of the acceleration below LFT, until it peeks above UFT.*

push notification was successfully sent and received. GPS sensing and location mapping were manually assessed, thoroughly checked and verified; all of which were accurately reported and fully functioned.

Fig.10 details how REDLE analyzes the gravitational acceleration signals and detects a fall. Acceleration below $1g$ suggests an initial state of a critical phase; a person is accelerating downward, experiencing a free fall. Upon hitting the ground, one absorbs an upward force, instantaneously reversing the direction of the acceleration. During the course of an aftermath, it takes a small, but relatively longer, amount of time for an individual to come to rest. The stronger the impact, the higher the acceleration force surges and the longer the post-fall lasts. As reflected in the results, falling forward and against the wall exhibited lower impact, while falling to the side caused a more intense consequence and posed the longest post-fall period. Slip and fall was similar to falling hard to the side, but less vigorous. Last but not least, falling out of a bed is a rather unique scenario, its mild impact followed by a brief post-fall was preceded by an extended pre-fall, which echoed a rolling motion.

Empirically, REDLE has displayed its potential to withstand variations and noises in the signals, which were partially caused by a free vibration of a mobile phone kept in a pocket, compared to previous studies [15, 19] where sensors are wrapped tightly to the body. In our experiments, though we had a few false negative, we have not experienced any false positive.

In order to collect different opinions and user recommendations on both the technical components and the usability of our application, the developer team has entered REDLE into the eighteenth Thailand National Software Contest (NSC) 2016. At the poster presentation and live demonstration, our REDLE was tested, evaluated, and criticized not only by many expert committees but also a large number of audiences, ranging from high school participants to undergraduate students and university-level faculty members. Most commented positively on the interface; they like how easy it is to use and understand. While the look and feel of our application is uniquely simple but elegantly attractive, it maintains the familiarity of commonly available mobile applications. This particular feature makes navigating the application spontaneous and effortlessly painless; users waste no time figuring out how it works or what to do. An integration of a well-known Google map makes it very straightforward to find locations and to extract needed information.

10. CONCLUSION AND FUTURE WORK

A successful development of an Android-based fall detection and response tracking mobile application in the cloud has been well-received. Distant from existing fall detectors, our platform is cloud-based; alert messages are sent via push notifications. REDLE has demonstrated a very promising potential for a deployment of the system to extended communities and an extension onto wearable devices such as instrumented wristbands. The application effectively keeps an eye on elderly adults, enabling them to stay active at the comfort of home and boosting the benefits of strong family connections across generations.

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