HANDHELD LANDMINE AVOIDANCE SYSTEM

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Abstract

The recent miniaturization of GPS receivers has made it possible to design a mobile "personal safety" system to help individuals avoid mapped landmines left over from previous conflicts. The handheld system continually compares the bearer's GPS-reported position with a compressed map of mined danger areas, sounding an alarm on approach.

Two kinds of mobile devices are supported: a wearable wristwatch model for general alarm-only use, and a PDA model that also allows for recording and uploading of discovered mine locations. The mobile devices are integrated into a complete Internet-connected support system, with a central GIS landmine map repository and regional map distributors capable of updating mobile devices in their immediate locales. The data representations allow the mine maps to be stored in compressed form, and the algorithms for real-time proximity calculations are designed to minimize the computation, memory, and power requirements of the wearable mobile device, so as to reduce its cost, without sacrificing accuracy.

Keywords: *GIS, GPS, landmines, handheld computing.*

1. Introduction

In 2004, the theme of the Computer Society International Design Competition (see www.computer.org/csidc) was "Making the world a safer place." The University of Guelph fielded a team of four senior undergraduate students, with Dr. W. Gardner as faculty mentor. We created an application called "MineAlert," a landmine avoidance system, thus fulfilling the humanitarian objective of the competition. The team could not fully complete the prototype before the contest deadline, but work is continuing on the implementation. This paper describes the MineAlert system, as designed by the students.

1.1. Background

Parts of the world are afflicted with landmines left over from previous conflicts. In recent years, the campaign to eliminate the threat of unexploded landmines has intensified in effort. Governments around the world, as well as nongovernmental organizations, such as Mines Action Canada [4] and The International Committee of the Red Cross [3], have combined causes in an attempt to save the thousands of people that will be maimed or killed every year due to landmines [2]. Funding efforts have chiefly gone towards military demining, but most fatalities occur in village areas, where children and elders are unaware of regional landmine risks. Furthermore, explicit removal of landmines is tedious, dangerous, time-consuming, and costly. For these reasons, some residents will be forced to live among landmines for years to come. To help these people move about in greater safety, we designed a handheld or wearable product, MineAlert, equipped with a Global Positioning System (GPS) receiver, that alarms when its bearer is approaching a previously-mapped minefield. MineAlert enables individuals to navigate safely around mined regions, and also allows mines action agencies to record coordinates of newly found mines.

MineAlert does not *detect* mines, so it cannot offer protection against unmapped mines. Instead, it is targeted at the case where the presence of mines has been noted by some agency, but barriers or signage that would warn local inhabitants are missing, deteriorated, inadequate, or were never erected. Furthermore, MineAlert provides an aggressive audible warning, which should be a greater deterrent than passive signage, especially for children.

Indeed, according to Unicef, 30% to 40% of all mine victims are children under the age of fifteen. These children require new artificial limbs every six to twelve months. The ability of our system to provide an auditory warning will be extremely useful to this demographic because they will not easily be able to ignore the warning.

The MineAlert solution is achieved by deploying mobile systems storing compressed regional maps originating from the Geographic Information System (GIS) format, and integrating this data with real-time GPS data. The MineAlert system also performs as a map-updating tool for mines action relief workers. In this way, GPS data specifying the location of newly found landmines can be stored and used to update existing regional landmine maps.

1.2. System Overview

The MineAlert system is comprised of three components. These subsystems and their interconnections are illustrated in Figure 1.

The first component, termed the Map Transaction Unit

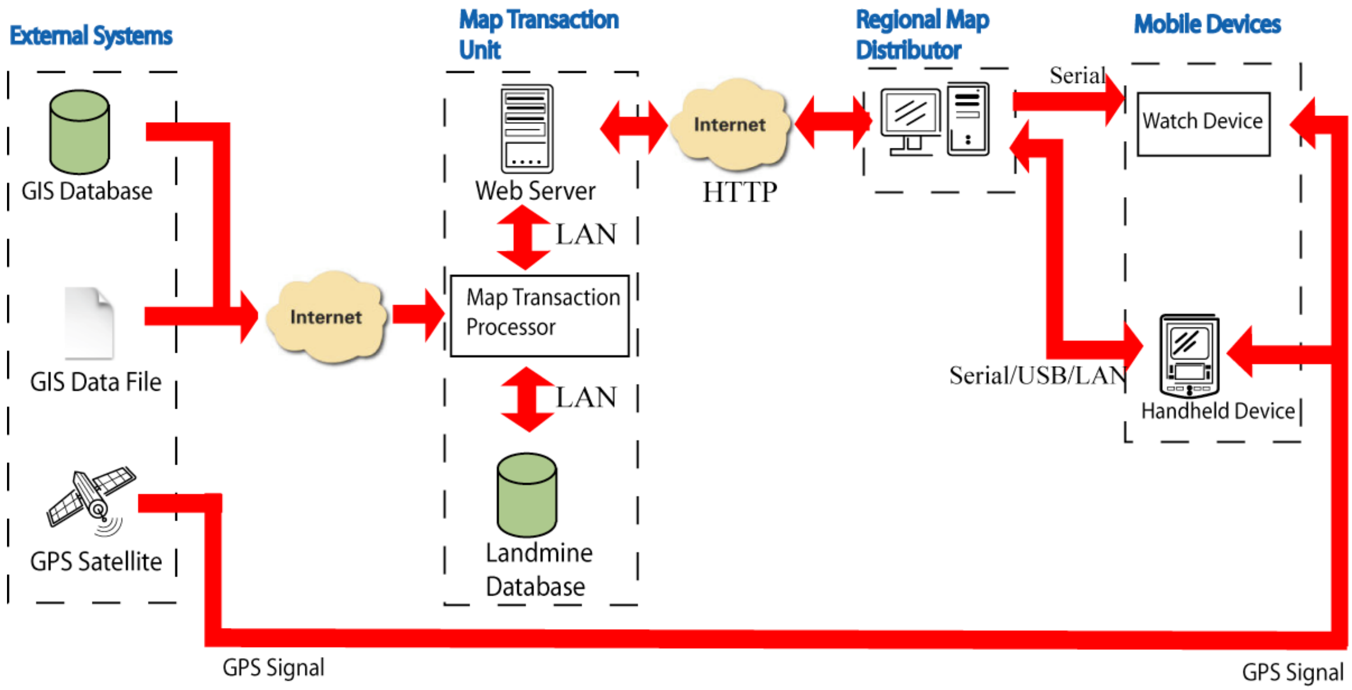

Fig. 1. MineAlert Component Subsystems

(MTU), accepts GIS data from external systems, extracts the landmine data, and then imports the landmine map into its landmine database. An MTU could be hosted by a national level agency or nongovernmental organization (NGO), for example.

The second component, the Regional Map Distributor (RMD), is a commodity personal computer located at an individual village or regional center. It is responsible for communicating with the MTU, and synchronizing the various mobile devices in its purview with the current local mine maps. These devices are brought and physically plugged in when synchronization is needed.

The third component of the MineAlert system is the collection of mobile devices, each fitted with a GPS receiver. The type of mobile device used is dependent on its application: A watch device would be worn by ordinary villagers. It is equipped with an audible signal that sounds when the wearer approaches a mined region. For users such as NGOs, interested in reporting new mines, a handheld PDA-type device allows the current GPS coordinates to be saved for later transmission to the MTU via the RMD. In addition to the audible signal, the handheld device's visual display allows the user to observe the exact location of mines on a geographical map.

2. System Description

The MineAlert system components form a three-tier distributed architecture. These components and their interactions are illustrated in the data flow diagram in Figure 2. The MineAlert system will be described in top-down fashion in the following sections.

2.1. Map Transaction Unit (MTU)

The Map Transaction Unit is itself a subsystem consisting of three components. The central component is the Map Transaction Processor. It is responsible for inputting GIS-formatted maps from external GIS Map resources, given a URL by the system administrator. Our research has shown that such external resources are often provided by governments and NGOs. GIS maps typically consist of multiple superimposed "layers," e.g., geographical features (rivers, mountains, etc.), political boundaries, habitations, and in this case, mine locations. The Map Transaction Processor extracts the landmine data layer and inserts it into the SQL-compliant Landmine Database, which is the second component of the MTU. The system is now prepared to accept map requests.

The final component of the MTU is the Web Server, which acts as the gateway for the other components of the MineAlert system. The Web Server receives landmine map data requests from the village-based RMD. This data is passed on to the Map Transaction Processor, which constructs an SQL command and retrieves the queried landmines from the Landmine Database; this process is known as regionalizing the data. The queried landmine map data file is returned to the Web Server for transmission to the requesting RMD. The Web Server also performs the function of receiving updated map data from RMDs, and passing this data to the Map Transaction Processor. The Map Transaction Processor then constructs an SQL command to insert the new landmine map data in the Landmine Database.

One function of the Map Transaction Processor is the extraction of the landmine data layer from the external GIS map.

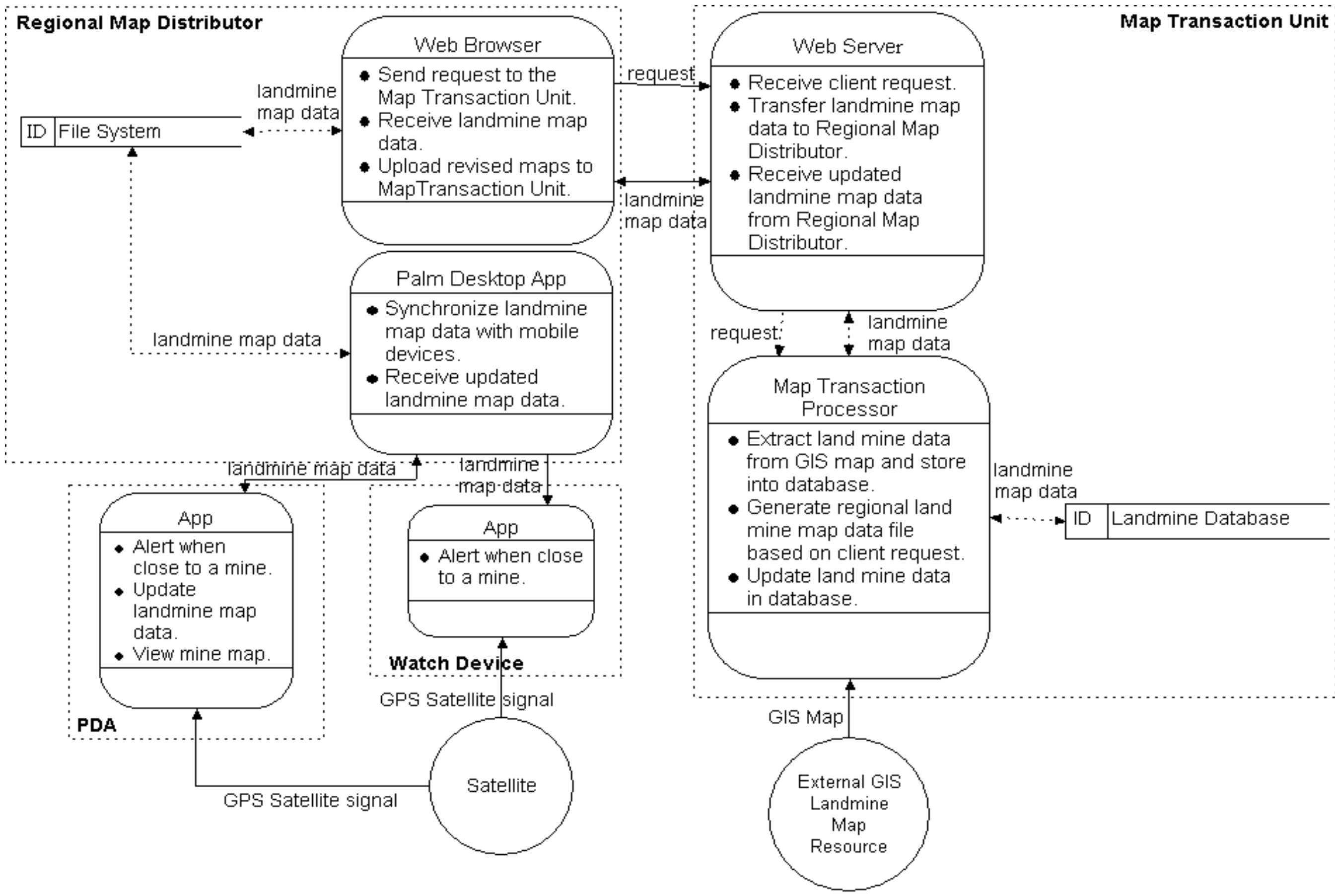

Fig. 2. Data Flow Diagram

Because the popular GIS format is proprietary to ESRI (Environmental Systems Research Institute), its integration with the Java standard is also proprietary. Thus, for our Java implementation of the MTU, we used the client-side Java solution of ESRI. This MapObjects-Java Edition [1] is a package of mapping components available as a Java class library; it facilitates interfacing with ESRI's proprietary GIS data formats. The Map Transaction Processor uses the MapObjects API to retrieve landmine points from GIS maps and to insert new mine locations in the Landmine Database. We used MySQL as the database management system.

The Web Server application was implemented with a Java servlet, running on a Tomcat web server. The Apache web server is integrated into the Tomcat Application Server package, negating the need for a separate product for that task. The Java servlet handles requests from the RMD web clients. The Map Transaction Processor is a group of Java objects residing on an RMI (remote method invocation) server. The Processor objects, which are called by the Java servlet, communicate with the MySQL database and perform all the map transactions. The results are passed back to the servlet, which in turn passes them to the client.

2.2. Regional Map Distributor (RMD)

The Regional Map Distributor represents the system located in the village or communal area. It is comprised of two components, a Web Browser, and the Palm Desktop Application. The Web Browser allows the machine administrator to request a specific circular regional map from the Map Transaction Unit. Following the instructions on the web page, the user will enter his/her location information as Latitude and Longitude. The user will then specify the maximum area that the map will cover, by the entering the radius in kilometres. Finally, the user must choose one of two map formats. Once the user clicks “SUBMIT”, his/her information will be sent to the Map Transaction Unit, and the Regional Map Data will be returned. The circular map is defined by a center point, given by a latitude and longitude, and by a radius in kilometres. This information is sent to the MTU. Once the MTU returns the regional landmine map to the Web Browser, it is saved to the RMD's local file system. The Web Browser also provides an interface through which the administrator can upload any new landmine data that is locally collected.

The second component of the RMD, the Palm Desktop Application, is used to interact with the mobile devices. Specifically, it is used to synchronize the landmine map data among the mobile devices. It is also used to transfer any new, updated landmine data from a handheld PDA device to the RMD.

The Regional Map Distributor runs a standard Microsoft Windows desktop operating system, upon which the Palm Desktop synchronization software is installed. Each time the Palm Desktop synchronizes, it makes a backup of all databases stored on the handheld device to a defined folder on the PC. It is this backup of the database as it exists on the Palm handheld that is chosen to be uploaded to the Map Transaction Processor by the Regional Map Distributor.

2.3. Mobile Devices

The mobile device, equipped with a GPS unit and carried or worn, can be implemented in various forms. All forms, however, share the ability to detect dangerous mined regions, since all devices store the regional landmine map data and continually compute their current position relative to mine locations. The user is made aware of danger by an audible signal. The wearable form will be a watch device. The current implementation of the mobile device is a Palm PDA. The PDA allows for a visual display of the nearby mine location, and allows the user to store the present GPS coordinates of a newly located landmine. The updated landmine data can be synchronized with the Regional Map Distributor using a serial port. In general, the PDA device is targeted to governmental and nongovernmental agencies associated with the mines action movement, while the watch platform is for public distribution.

The hardware implementation of the PDA MineAlert client is straightforward. In the case of our prototype, a GPS expansion device (Navman GPS m series [5]) was simply attached to the Palm Universal Connector and secured along the sled retention mechanism.

The PDA alerts users of danger using both auditory and visual methods. This ensures that the user is aware of the imminent danger and also provides accessibility to those impaired from using either one of the two alert methods.

The watch device as envisioned is a simple segmented LCD including a SiRFStar IIe chipset [6]. The segmented LCD displays a time signal corrected at regular intervals by the Navstar GPS satellites. While the manufacture of such a small GPS-based device may be uneconomical at present, the design team is confident that the continuing evolution of Moore's law will make large-quantity production of this device feasible in the near future.

The design of the watch device is effective due to the accepted usage of wrist watches. The auditory beeping sound allows the user to be warned even while clothing such as sleeves are covering it. The shrill beeps common to watches are very suitable for notifying users that they are approaching danger.

3. Algorithms and Data

The interesting design problems in the MineAlert system revolve around minimizing the computation, memory, and power requirements of the wearable mobile device, actually an embedded system, so as to reduce its cost, without sacrificing accuracy. The main issues to be addressed were the representation of mines as data and the algorithm to determine the user's proximity to dangerous areas.

In addition, decisions were needed on the margin of safety to build into the proximity calculation, taking into account the accuracy of the GPS location data and the consequences of inaccuracy. Data formats were worked out for downloading byte streams of map data into the mobile devices based on the representations that are described below.

3.1. Representation of Mine Maps

Two different concepts were used to represent mine maps in the two kinds of mobile devices, as illustrated in Figure 3. The Point Form concept uses Cartesian coordinates to represent each landmine. The distances between the user and every mine

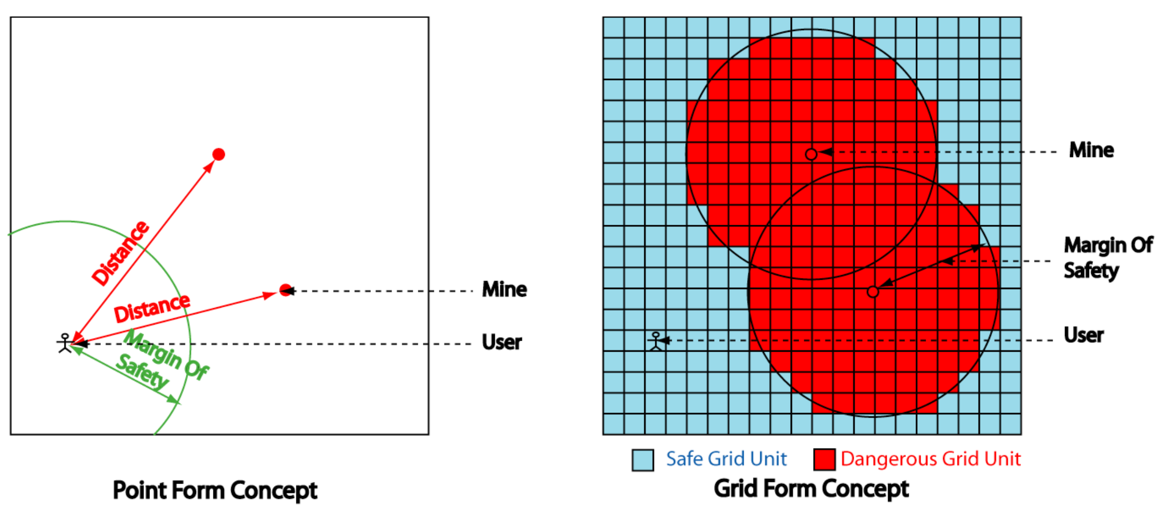

Fig. 3. Point Form and Grid Form Concept

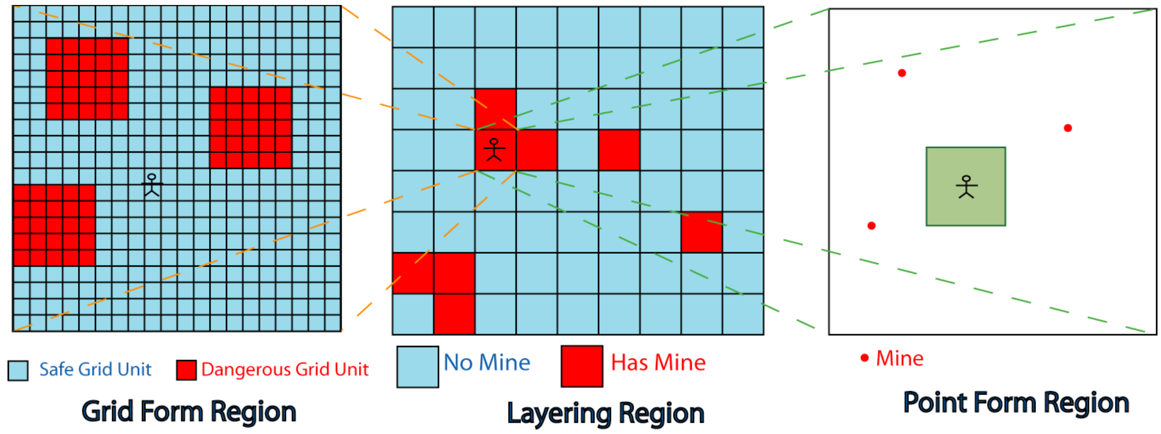

Fig. 4. Layering Illustration

in the map are calculated and compared to the Margin Of Safety to determine if the user is in danger. In contrast, the Grid Form concept precalculates a bit map of the terrain where each grid unit's one-bit flag indicates whether or not it is a dangerous area. It is then trivial to identify whether the user's position is on a flagged grid unit.

For the watch device, the time between battery changes must be maximized. Therefore, the amount of processing power consumed should be minimized. The Grid Form was used on this platform, since it, in effect, offloads the major calculations to the RMD.

But for handheld devices, the internal battery may be recharged or replaced more frequently. Handhelds typically contain processors that are much more powerful than smaller embedded devices. This increased availability of resources enables the Point Form to be used for the sake of its other advantages: ease of creating a visual display of the mines and the user's position, accurately calculating the distance between the user and any mine, and facilitating the user's reporting of new mines.

However, both of these data representations waste system resources: In Point Form, a calculation for the distance to each mine needs to be computed for every change of the user position. Most of the results of these calculations are wasted because most of those mines in practice will be far from the user. In Grid Form, bits are used in storage despite whether the region has mines or not. If an area does not have any mines at all, the memory space used for that area is wasted.

A good solution in both cases is to create a two-layer map. The top layer is a coarse grid with mined regions flagged. Each flagged region has a fine-grained layer subordinate to it, in either Grid Form or point Form. As shown in Figure 4, applying layering to the Grid Form data format saved about 7/8 of the memory and the Point Form data format saved about 7/8 of the computations, in return for the small overhead associated with the layered data structure.

3.2. Accuracy of Proximity Calculations

The GPS receivers used by MineAlert mobile devices comply with the NMEA 0183 2.01 standard, outputting the current position in latitude and longitude. Using the Point Form concept, the mobile device should calculate the distance in meters between itself and mines, also stored in lat/long. This involves repeatedly computing a Great Circle Distance Formula:

$$RadiusOfEarth \times \operatorname{acos}\left[\sin\left(lat_1 \times \frac{180}{\pi}\right)\sin\left(lat_2 \times \frac{180}{\pi}\right) + \cos\left(lat_1 \times \frac{180}{\pi}\right)\cos\left(lat_2 \times \frac{180}{\pi}\right)\cos\left((lon_2 - lon_1) \times \frac{180}{\pi}\right)\right]$$

Two problems arise: On the one hand, the formula is computationally demanding, and on the other hand, it relies on an average earth radius of 6378.7 km. While the error caused by the latter assumption is bearable in most applications, the mine proximity calculation cannot withstand the error introduced by this approximation.

Instead of the above formula, a modification was adopted, shown in Figure 5, which both simplifies the calculation and increases the accuracy. At the time when the regional map data is created on the Map Transaction Processor, the Margin of Safety, normally expressed in meters, is converted to fractional degrees of latitude and longitude appropriate for that spot on the earth, and appended to the map data file. In the field, the mobile device can quickly ascertain, without converting coordinate systems, whether both its latitudinal and longitudinal distance from a mine violate the margin, and if so, sound the alarm.

Using the Grid Form concept, the main issue is the choice of grid unit size. A very fine grid occupies more memory, while an overly coarse grid results in loss of positional accuracy. In the end, a grid unit size of 10 meters was chosen, since the maximum GPS error is about 10 meters, or one unit in grid terms.

The Margin of Safety was chosen as 20 meters, or one radial grid unit from a dangerous grid space. Together these parameters provide a minimum safety distance of 10 meters. When

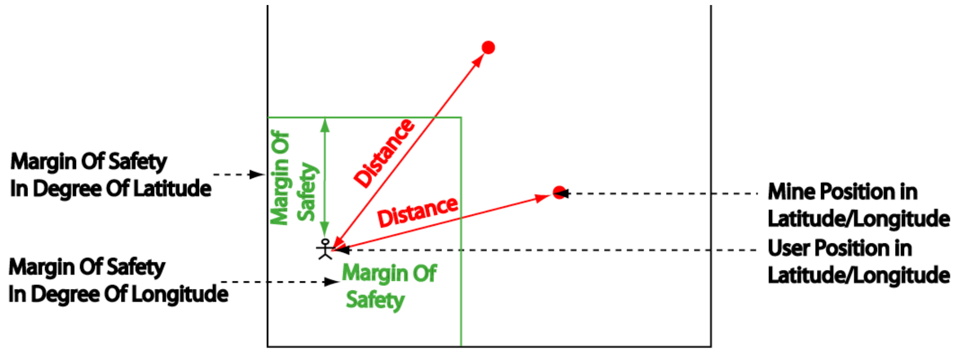

Fig. 5. Modified Algorithm for Point Form

alerts are activated at a reasonably small distance, users should be conscious that they are very close to landmines whenever the alarm sounds. Obviously, these parameters can be easily changed if desired.

Various worst-case scenarios were examined—e.g., mine in far grid corner with maximum GPS error—using both Point Form and Grid Form, to validate the calculations, the safety margin setting, and the grid size.

4. Summary and Conclusions

MineAlert is an innovative application of handheld (and wearable) computing. It is also capable of performing a valuable humanitarian service when deployed to war-scarred regions where minefields still exist in proximity to habitations. We envision that national governments and NGOs may wish, in addition to funding mine removal, to also fund the setting up of MineAlert systems, and especially the distribution of the mobile watch devices to populations at risk, in particular, children.

The current prototype includes a PDA mobile device running the algorithms described above, but the landmine map display capability is incomplete. The MTU and RMD components have been completed. The extraction and regionalization algorithms of the MTU have been implemented and tested thoroughly, while the user interface and synchronization functionality of the RMB have also been functionally implemented.

In terms of future work, it would be wise to perform human subject testing with different age groups and various cultures, to observe how people react to the audible alarm, and possibly adjust the safety margin.

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