GNSS based Adaptive Monitoring for the Assistance of Persons with Orientation Difficulties

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Abstract: Severe problems with out-of-home mobility are common under persons with cognitive impairment. Technical solutions such as geo-fencing systems, based on GNSS position monitoring, exist to mitigate wandering and getting lost of such patients. However, manually defined, fixed geo-zones effectively limit the freedom of the person and can lead to false alarms even during normal walking behaviour. This paper presents work in progress on a GNSS based position monitoring system that computes adaptive personalized safe zones from the user walking routine. The system implements semi-rigid zone borders allowing the user to explore new areas and automatically extend their personalized safe zones over time. Making use of routing services the system can generate temporary corridors for appointments outside of the users typical walking routine. While the technical implementation of the system is completed, it will be future work to evaluate the system's effect on users in a field trial and a clinical study.

1 INTRODUCTION

Wandering and getting lost is one of the most dramatic problems of persons with dementia and Alzheimer's disease (Yatawara, 2017). An example would be someone who takes what would normally be a routine walk and then suddenly is unable to find his or her way. Sixty percent of people with Alzheimer's disease will wander at some point during the progression of the disease, and half of those will become lost and separated from a caregiver or the responsible person (Butler, 1991). Sixty-one percent of wanderers not located within the first 24 hours are found deceased (Koester, 2008).

GPS tracking systems, often called "geo-fencing" systems, are already used to mitigate the problem by permanently monitoring the persons position and alarming a carer if the person deviates from a predefined geographic area (Milne, 2014). However, such systems are not adaptable because they rely on fixed predefined geographic zones, that need to be manually defined by the care person. This can result in frequent alarms, when a person is intentionally exploring new regions or is visiting a friend, outside the predefined "fence". Such situations are limiting

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the freedom of the person and may cause extra worry to the caregiver (Landau, 2012).

GPS-tracking has been used to analyse the mobility of persons with cognitive impairment (Shoval, 2008). Geo-fencing systems with an additional automatic calculation of the shortest distance of the user to the closest carer in a group of carers has been described (Pratama, 2020) and an extension of the geo-fencing concept to overcome the disadvantages of the rigid "fence" including tests with a few persons have been presented (Lin, 2018).

In this paper we report on a new concept developed in the framework of the EU AAL joint programme, project “FreeWalker” (freewalker-aal.eu), which tests and validates a monitoring and warning system based on GNSS tracking that addresses the specific deficiencies of older adults with dementia and frailty. The FreeWalker system monitors typical walking routes and thereby learns the habits of the user to automatically generate an adaptive safe-zone around the user's home. Furthermore, the system can generate temporary safe-corridors from calendar entries, to allow visiting places outside the typical walking routes. Note that, for simplicity, the cared-for person (or primary user in the AAL context) will be called the *user*, and the supervisor or caregiver (or secondary user in the AAL context) will be called the *carer*, throughout this paper.

FreeWalker will allow persons with cognitive impairment - or who feel otherwise insecure in the outside environment - an increased freedom and self-determined way of moving outside. It is aiming at giving carers piece of mind by supporting them in tightly monitoring the user with the FreeWalker "Care" App for mobile devices, when needed. But FreeWalker also empowers the user by allowing to make own decisions, by automatically reminding him or her on unusual situations via the FreeWalker "Go" App, even before an alarm is issued to the carer.

In contrast to previous work on personalized safe zones that has been evaluated on GPS-tracks of three individuals (Lin, 2018), this project plans a pilot operation with a total of approximately 100 users (users and carers) in the three countries Austria, Switzerland and The Netherlands, accompanied by a clinical study. This paper describes work in progress as the technical concept is finalized but a field study to evaluate if the system can improve the situation for user and carer, is still to be done.

The paper concentrates on the technical description of the logic engine software component of FreeWalker that dynamically computes the safe zones and corridors and is organised as follows: The following section gives an overview over the system components and the dynamic safe zone concept. Section 3 explains the technical implementation, the logic engines algorithms to compute safe zones and safe corridors, as well as executing the rules to issue information on the state of the primary user to the care person. Section 4 presents an outlook on the future study and is followed by a conclusion.

2 SYSTEM DESCRIPTION

2.1 Components

Figure 1 shows an overview over the system main UI components that the users and carers are working with. Four different components are integrated in the system, that are directly interfacing to the users.

Two FreeWalker mobile applications: The user app (named "FreeWalker GO") and carer app (named "FreeWalker Care") have been implemented for Android and iOS operating systems. The carer app allows an overview of the users associated with one carer, displaying their status as well as alarms and a map to locate the users position in case of an alarm (see Figure 4a and 4b).

The user app allows the user to actively send an alarm via activating an alarm button but is also used as a terminal to provide feedback to the user: Remind them if he/she might have lost his or her way or might have forgotten to go to a scheduled appointment. The user app also constantly monitors the user position via the smart phone GNSS receiver and sends it further onwards to the system backend components. For those users not capable of operating a smart phone and mobile applications a GPS "dongle" can be used alternatively. The GPS dongle can be worn as a necklace or as a watch and provides an alarm button, but automated system feedback to the user is not possible with this option. Both, user app and GPS dongle allow for a two-way voice communication between carer and user in an emergency/alarm situation.

Carers can view the user status and configure certain system parameters in the web portal. The web portal also allows to maintain the calendar of the user, alternatively the calendar can be maintained by the user via the user app. The portal also features a map view page.

It allows to define a first, initial safe zone (see next section) for a user by drawing with the mouse on a map and to review the system generated safe zone and temporary corridors to an appointment. The history of alarms and how they have been handled by the carers is also recorded and available through the portal.

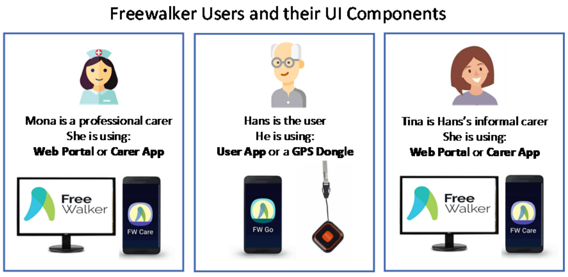

Figure 1: User roles and the system front-end components available to them.

2.2 Dynamic Safe Zone Concept

The strength of the system and its major difference compared to conventional "geo-fencing" approaches comes from an automatic, periodic update of the user's personal safe zone computed from the real-time monitoring of the user's daily walking routines. Figure 4b shows an example of a real life computed safe zone in a screenshot of the carer app. The system automatically produces two types of zones for each user, depicted in the map as green and orange polygons. The dynamic safe zone (or *green zone* as it will be referred to in this paper) represents the observed walking routines of the user over time. The second exploration zone (or *orange zone*) surrounds the green zone at a configurable distance (see Figure 4c). While the user can leave the green zone for an adjustable duration without triggering an alarm (30 minutes have been defined in the co-design process), leaving the orange zone (see Figure 4e) will initiate an immediate alarm to the carer.

Note that one of the major differences of FreeWalker from existing geo-fencing solutions is the orange zone in which the user can explore without triggering an alarm, but still his or her position is closely monitored by the system (see Figure 4d).

This approach combines the safety of a strict geo-fencing system with the flexibility to explore the outside of a fixed zone and thereby extending the green zone in consecutive walks. A moderate extension is possible, while a sudden and large change in walking habits indicates a potential wandering or disorientation situation of the user.

During the exploration period the user gains confidence in a certain area. This will empower the user to independently walk outside and at the same time protect him or her from getting lost. The green and orange zone shapes are periodically re-computed from the walking tracks of the previous day every 24 hours.

To mitigate the risk that the user is lost inside the orange zone, e.g. walking in circles, the system additionally monitors the time spent inside the orange zone and raises an alarm to the carer after an adjustable duration. To further empower the user towards independency and self-responsibility, the system is able to automatically ask the user via the user app if he/she feels lost or otherwise unsafe before the alarm is raised. Only if the user does not respond after a further timeout, or actively asks for help, the alarm is raised. The technical implementation details of this logic are explained in the next section 3 of the paper.

2.3 Safe Corridors

In addition to the periodically updated green zones the system offers temporary safe corridors computed from the appointments scheduled in the user's online calendar. This allows the user to visit destinations outside the orange zone within a predefined time window without triggering an alarm. This corridor extends the green zone to the destination address and is valid only for a certain time interval on the day of the appointment. At the same time the system monitors the distance of the user to the destination address and notifies the carer on late arrival or if the user has arrived on time. Figure 4f shows a typical corridor in a screenshot of the carer app.

It must be pointed out however, that the system does not offer navigation functionality to the user, but solely monitors the progress to, and on-time arrival at the destination address.

2.4 User States

The status of the user is computed by the logic engine component, one of the system backends (see Figure 2), from user position, zones and timing and is communicated to the carer via the web portal and carer app, using so called user state icons. Different user states indicate clearly to the carer in what situation the user currently is. Table 1 gives an overview of the states related to the user position and the zone concept. There are more states defined, related to important system conditions such as "battery low", but as this paper focuses on the safe zone concept, these states are not discussed here.

Some of the states will be displayed to the carer for information only, other states will be accompanied by an alarm (e.g. "OutOfZone") that must then be handled by the carer and is further documented by the system. However, as this paper focuses on the presentation of the dynamic zone concept, the alarming and alarm handling logic of the system are not detailed further in this paper.

Table 1: List of states related to the user position and dynamic zone concept.

State Name	Icon	Description
`Close2Home`		The user is very near to his/her home address
`Outside`		The user is in the green zone, his/her usual walking habit
`ExploringZone`		The user is in the orange zone, exploring the surroundings
`OutOfZone`		The user is outside of the green and orange zone, potentially lost/wandering
`IsReminded`		The user is too long exploring in the orange zone, potentially lost/wandering and is reminded to return
`AppointmentInProgress`		A scheduled appointment is due and a safe corridor to the appointment is active.
`Close2Appointment`		The user is close to the due appointment destination
`LateForAppointment`		The appointment is due, but the user is far from the appointment destination

3 IMPLEMENTATION

In this section the system's approach of green and orange user-specific zones and states is explained. An overview of the complete process done in the logic engine backend from mapping the locations, finding contours and zones to the evaluation of rules is presented.

3.1 Location Mapping

Position data is received by the logic engine backend (see Figure 2) and converted to corresponding pixel-coordinates in a user-individual weighted map. Each weighted map pixel is connected to an area on earth in the WGS84 reference system while the centre is the position of a user's home location.

The following two points determined the choice of map parameters:

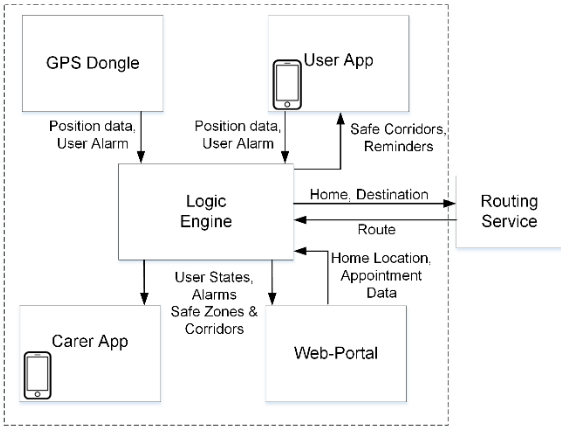

Figure 2: System architecture with the user and carer apps and web-portal front end and the logic engine backend and the interfaces.

(1) The size of a weighted map is proportional to the size of each pixel if the resolution stays constant. Bigger pixels result in more edge-shaped zones which is not consistent with the frontend-requirements.

(2) A higher resolution therefore results in higher server workload which led to processing time problems with a high number of system users.

For these two reasons, the size and resolution of a weighted map were set to $10x10km^2$ and 1000x1000 pixels.

To avoid trapezoid map shapes due to the curvature of earth, geolocations of the weighted map centre with values above 80° and below -80° latitude are not allowed. Each element of the weighted map can contain weights between 0.0 and 1.0. The lower the value the longer the walked route lies in the past (see Figure 3a). Due to a low transmission frequency in relation to the walking speed the pixels must be interpolated between the current and the last position to obtain a continuous line of weighted pixels. The walked routes have an adjustable width to achieve a zone size customized to common movement patterns. If on the one hand the width is chosen too small, it leads to narrow zone areas when walking back and forth on the same street which can easily activate an alarm by receiving a GNSS signal just below the filter threshold. On the other hand, a high value will make areas accessible the user should not go to. The value was set to two times the GNSS filter threshold of 30m plus 10m additional space which is a width of 70m.

To adapt to behaviour changes a linear decay algorithm is implemented to "forget" routes that have not been walked for a specified duration. All weights in a map are thereby reduced in proportion to time elapsed since the last entered location with a cap of 0.0 at the lower end (no negative weights are possible).

$$w_{i+1} = w_i - 0.5 * \frac{t_{delta}}{t_{decay}} \quad (1)$$

w_i is considered the weight before the decay is applied and w_{i+1} is the weight after the subtraction. The denominator in the fraction part t_{delta} is the time elapsed since the last entered location and the nominator t_{decay} is an adjustable value which specifies after what time period the starting weight of 1.0 is reduced by 0.5. For the planned study t_{decay} was set to 604.800s which corresponds to a duration of seven days. Consequently, routes older than 14 days will not be considered anymore in the zone creation process.

3.2 Zone Generation

In contrast to (Lin, 2018) the safe zone generation in this paper is based on the weighted map data described in section 3.1. To create a zone, state of the art segmentation and contour algorithms provided by the open source libraries OpenCV and SciPy are used. Figure 3a shows a heatmap visualization of a weighted map recorded over several days of test walks around the home location. The darker the colour of an area the longer the walked route lies in the past. Figure 3b shows the corresponding selected contour out of all contours found. The selected contour will then be transformed to a polygon with an average limit of 100 support points.

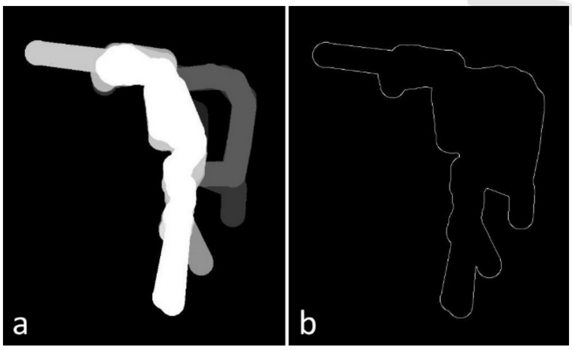

Figure 3: (a) Grey scale heatmap representation of the weighted map with walks, (b) Zone contour found in weighted map data.

Green Zone: Is the area limited by the locations entered in the map and always contains the home location. This zone indicates a save area where the user can move freely.

Orange Zone: An orange zone is created by applying a binary dilation algorithm on the data shown in Figure 3a, which then is used as the basis for a new contour search. The size can be changed per user and is specified in meters distance from the border of the previously processed green zone.

3.3 Corridor Generation

A corridor, or better described as temporary green corridor, is a zone for special appointments outside the 10x10km boundary depicted in section 3.1. The system creates these time-dependant green zones with a maximum map size of 30x30 km. This new type of zone is only available for the appointment duration plus estimated 90 minutes travel time before and after the event.

To create a corridor the caregiver needs to enter an appointment with a valid address, start time and end time into one of the available frontends. The appointment data is either pushed to the logic engine directly or queried from the portal every 24 hours for the appointments of the next day. The logic engine then computes this data by requesting up to three different routes from Google maps service with start address at the user's home location and end address at the appointment's location. These routes of geolocations are point-wise transformed to pixel coordinates and entered into an empty weighted map with a corridor specific width. Because all routes have the same starting and end point an enclosing polygon is therefore created and detected by the same contour-finding algorithms used in the zone creation procedure in section 3.2. Finally, the contour is down sampled and sent to the frontends.

3.4 Rule Engine

Interpretation of the current state of a user based on his/her position is done in a two-step process:

Step 1:

User specific properties are updated, triggered by each received geolocation. The properties are classified into three different subjects:

Zone-Properties: These values define the current state of a received location in regard to all colored zones available for this user.

Example: location is in green/orange/red zone (false/true), distance to home location (in meters)

Timestamps: The timestamps indicate when a zone was left and when a zone was entered.

Appointment-Properties: The appointment properties describe the current ongoing user-specific appointment task.

Example: the distance to the appointment (in meters), ongoing appointment (false/true).

Example: timestamp entered green zone (seconds), timestamp left orange zone (seconds).

Step 2:

Properties are interpreted by rules which directly define the status of a person. This is achieved by setting status-specific conditions for all relevant properties. All active rules are processed once per minute for every active user in the system, regardless if a location was received or not.

This provides up-to-date state information for all users. Table 2 shows an example rule for the user state "Close2Home". In the left column the code line and on the right the corresponding explanation is given. All conditions need to evaluate as *true* to send the defined user state to the system's frontends.

Table 2: Code lines of an example rule.

CODE	EXPLANATION
`time_now - last_loc_ts < 60`	Last received location timestamp must not be older than 60 minutes
`dist2home < 100`	The distance to home location needs to be less than 100m
`in_green == 1`	Last location needs to be inside a green zone
`in_orange == 1`	Last location needs to be inside an orange zone
`in_red == 0`	Last location must not be inside a red zone
`state_to_set: Close2Home`	State to set by this rule

4 FUTURE WORK

The FreeWalker system's technical components have been developed and tested by November 2020 and will be piloted in a field trial, accompanied by a clinical study.

4.1 Study Design

The study is designed as an open labelled, randomized, controlled, parallel study with a voluntary extension phase and will be conducted in three countries Austria, Switzerland and The Netherlands. The study will include both, users who live at home and users who are living in nursing homes with a focus on people with dementia. Study participants will be randomized in a 2:1 ratio into the intervention (FreeWalker, either Android Smartphone App or a GPS dongle) or control (GPS dongle with passive tracking only) arm using a pre-defined, country specific, block randomization list. Carers or contact persons of the users in the intervention group will be using the FreeWalker carer app based or the FreeWalker web portal.

Pre-screening of eligible candidates has started in fall 2020. The core study duration is set to 16 weeks, where the first study participants in Switzerland have started to use the system in December 2020. The voluntary extension is planned to terminate at latest end of June 2021.

After the pre-screening phase, to select eligible candidates, potential users will be evaluated for fulfilment of inclusion and exclusion criteria. After successful study inclusion, users will be randomized to the intervention or control arm of the study and users will be enrolled into the study. The enrolment phase of the study was expected to span two months but is currently behind schedule because of the outbreak of the Covid-19 virus. Carers and users will receive specific training in the operation of FreeWalker or the GPS dongle from the care organisations they are associated with.

After study enrolment the first study visit will be conducted during which demographic data, health-related data, etc. will be recorded and baseline outcome measurements will be assessed. Eight weeks into the core study phase a first follow up visit (second visit) will be performed and outcome measurements will be assessed for each user. After completion of the 16-weeks core study phase, a third study visit will be conducted, and outcome measurements will be assessed. If the user volunteers to participate in the study extension, he or she will receive FreeWalker regardless of the initial study assignment and additional training in the use of FreeWalker if needed. At the end of the extension phase, or if the user decides to terminate his or her participation in the extension phase a fourth, voluntary study visit will be conducted, and outcome measurements will be assessed a last time. At the end of the study, users are asked to return FreeWalker or the GPS tracker. No further follow-up visits are planned after the end of the study.

The primary outcome measurements of the study are whether FreeWalker increases independence and feeling of safety of the user and decreases worrying of the carer about the whereabouts and safety of the user. Outcome will be measured on a 5-point Likert Scale created specifically for this field trial and changes in the average sum will be assessed.

Figure 4: Example screenshots of the carer app in various situations of usage. (a) Dashboard overview of all users with current states and alarms, (b) map view showing the current active user states and the dynamic ‚green' safe zone and ‚orange' exploration zone. Typical display for different user states on the map: (c) User is close to his/her home, (d) user is in the ‚exploring' state, (e) user is out-of-zone alarm, (f) a safe corridor to an appointment extending beyond the exploration zone. Note that, for privacy reasons, the user position is only shown in case of an alarm and is visible here in (c)-(d) only in the test version of the carer app.

4.2 Ethics

Permanent tracking of a person poses an inherent risk of violating someone's privacy and thereby a fair balance between safety of the person with cognitive impairment and monitoring and disclosing his or her position need to be found (Landau, 2012).

The FreeWalker system will acknowledge this by providing the real-time position of the user to the carer only in case of an alarm. In all other situations the carer will be only informed on the general status of the user (e.g. the user is 'Outside'), without disclosing details unnecessary to understand the situation. Furthermore, the user, if still capable of operating a smart phone and using the user app, will be notified on a potentially abnormal situation in a first step by the system. Only after this step, the carer will be informed in a next step. It is expected that this will result in an increased freedom and self-determined way of moving outside.

Study participants assigned to the control group will naturally face a disadvantage to those assigned to the intervention group. To allow all study subjects to use FreeWalker we will offer a voluntary extension phase starting after the core study phase during which all study subjects are eligible to be switched over into the intervention group regardless of their initial group assignment. The study design has been approved by the ethical commissions of all three test countries.

5 CONCLUSIONS

We have presented work in progress on an adaptive, dynamic geo-fencing solution to improve the safety of persons with dementia and frailty in the outside environment. The "FreeWalker" system is capable of computing personalized safe zones by monitoring the typical daily walking behaviour of the user with a GNSS dongle or smart phone app, to mitigate wandering and getting lost. Temporary safe corridors to appointment destinations are automatically computed from the online calendar of the user.

The system computes the personalized safe zones using a weighted map of the users walking trajectories from GNSS data and periodically updates the safe zone every 24 hours. Safe corridors are generated from queries to the Google map API composed of three alternative walking routes from the user's home to an appointment destination. The corridors are activated during the time of the appointment only and the progress of the user to the destination is monitored and abnormal situations are detected.

In addition, the user will be notified on a potentially abnormal situation in a first step by the system via the smart-phone app. Only after this step, if the user does not respond or actively ask for help, the carer will be alarmed in the next step. It is expected that this concept will lead to an increased freedom and self-determined way of moving outside compared to existing "fixed zone" geo-fencing systems.

After the completion of the technical development in fall 2020, future work is to perform a clinical study on the beneficial effects of the system on its users. The study is planned with approximately 100 participants in Austria, Switzerland and The Netherlands, started in December 2020 and is planned to be completed in June 2021, to analyse the difference in outdoor movement behaviour of persons with and without the system.

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