

In-home Localization for Home Care of Alzheimer's Disease Patients using Wireless Sensor Networks

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ABSTRACT

Continuing developments in Wireless Sensor Networks (WSNs) have introduced the prospect that tiny, battery-powered, wireless smart sensing devices (referred to here in a generic way as “motes”) can be discreetly embedded in objects such as shoes, furniture and home appliances. We argue that current mote networks can be a useful basis for provision of in-home services for elders, Alzheimer's disease patients, and others with disabling conditions. One important practical obstacle in designing mote networks and similar distributed WSNs is detecting the location of motes (and through them the locations of objects of interests such as patients) so that this location information can be utilized by applications used by the patients, their doctors, or others involved in their monitoring.

This paper introduces a proposed application system based on a sensor localization middleware called GDL that we demonstrate can provide a range of location-based services related to home care, from PDA-based reminders for a patient based on location triggers to location tracking information for care personnel. A key advantage of the proposed system is the use of the GDL localization middleware to avoid both additional hardware and configuration. We suggest that this is a necessary requirement for making it convenient to help develop pervasive devices for in-home WSNs for the care of the elderly, especially Alzheimer patients.

Categories and Subject Descriptors

C.2.1 [Computer- Communications Networks]: Network Protocols, Wireless Communications

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General Terms

Algorithms, Management, Measurement, Performance, Experimentation,

Keywords

Localization, Sensor networks, Mobile networks, In-home care

1. INTRODUCTION

As America's population ages, the needs of the elderly have come into increasing prominence. There is growing interest in solutions for the home care of elderly and Alzheimer's in particular. At the same time, continuing developments in Wireless Sensor Networks (WSNs) have introduced the prospect that tiny, battery-powered, wireless smart sensing devices (referred to here in a generic way as “motes”) can be discreetly embedded in objects such as shoes, furniture and home appliances. Such small, smart, mobile, networked motes can be a useful basis for provision of in-home services for elders, Alzheimer's disease patients, and others with disabling conditions.

We argue that current mote networks can be a useful and cost-effective basis for provision of in-home services for elders, Alzheimer's disease patients, and others with disabling conditions, provided that steps are taken to make their deployment and use as free as possible from difficult hardware and configuration requirements. We anticipate that WSNs for in-home services may involve different types of nodes, some with high computational power while others are quite limited; some static and others mobile or worn (see Figure 1). All these nodes will need to be location-aware to collaborate together effectively. Detecting the location of motes (and through them the locations of objects of interests such as patients) will allow this location information to be utilized by applications used by patients, their doctors, or others involved in their monitoring. In-home monitoring has the potential to be very helpful for Alzheimer's disease patients in particular, the number of whom is projected to triple to 14 million by 2050 as the elderly population continues to increase, according to a recent Alzheimer's Association report.

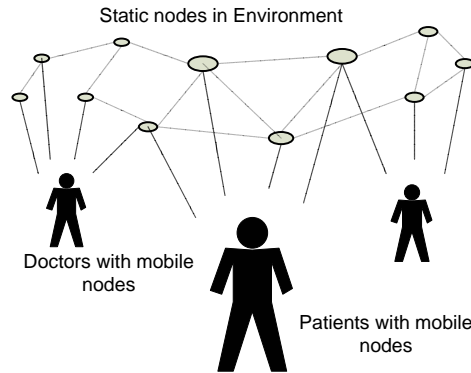


Figure 1. An example of WSNs for in-home care. There are static nodes embedded in the environment, and other mobile nodes are worn by patients or doctors or represent mobile medical devices.

While WSNs in such scenario are patient-centralized, in order to provide useful information, one important practical obstacle in designing mote networks and similar distributed WSNs is detecting the location of motes, or in other words, providing location-aware data. The most standard location technology, GPS (Global Positioning System), does not require prior configuration or specification of locations, but is unavailable in indoor environments. Approaches based on centralized localization, in which key nodes are configured with a priori location information, exist but require extensive setup. However, we explain how inexpensive solutions, such as a distributed localization middleware layer called GDL (Geographic Distributed Localization), can be used to provide help for collaboration in the above static/mobile WSNs services using standard sensor network systems without any additional hardware or configuration. By making use of the accelerometer sensors that are deployed in current standard mote-class sensors, GDL computes a moved distance for each node; if any moving nodes are detected, the GDL middleware layer triggers a mobile localization procedure based on MDS (Multidimensional Scaling) to recalculate and update a map of regional node locations. Unlike alternative configuration-free methods, GDL can provide location information for not only static nodes but also mobile nodes—an important consideration in the home care problem. GDL also improves on existing methods in other key ways. Results from extensive simulation in the Network Simulator (NS-2) show a significant improvement in the accuracy with which locations can be determined in WSNs with varying density and different number of nodes on irregular placements. GDL also has a low constant memory cost, and low communication cost per node.

One example scenario of such WSNs for home care of elders and Alzheimer's patients is that there are different nodes which have different sensors on them, are deployed in the home environment, and are collecting data from heterogeneous sensors such as temporary sensors and photosensitive sensors, which basically have a fixed but unspecified location, while other nodes are deployed by patients or articles' carried by patients to collect the data which are more directly related to the patients. There are potentially many nodes that can be deployed to collect different data for patients and make possible decisions or provide assistance. Obstacles between this concept and the reality of a deployment are (1) how can such data be used and shared, and (2)

how can we make such a data collaboration efficient? One important consideration for the latter obstacle is that in order to make collaboration on location-aware data that may be collected not only by static nodes but also by mobile nodes, we should make data fusion or aggregation location-aware for both static and mobile nodes.

GDL middleware provides for standard sensor network systems without any additional hardware or configuration. By making use of the accelerometer sensors that are deployed in current standard mote-class sensors, its algorithms compute a velocity vector for each node; if any moving nodes are detected, the GDL middleware layer triggers a mobile localization procedure based on MDS (Multidimensional Scaling) to recalculate and update a map of regional node locations. Unlike alternative configuration-free methods, GDL can provide location information for not only static nodes but also mobile nodes—an important consideration in the home care problem. GDL also improves on existing methods in other key ways. Results from extensive simulation in NS-2 show a significant improvement in the accuracy with which locations can be determined in WSNs with varying density and different number of nodes on irregular placements. GDL also has a low constant memory cost, and low communication cost per node.

The paper is organized as follows: Section 2 introduces the GDL middleware architecture briefly, Section 3 describes how higher-level applications can collaborate with GDL middleware, and a final section summarizes our argument for why WSNs can benefit Alzheimer's patients and the advantage of localization and device interoperation is needed to facilitate this application.

2. WSNs FOR IN-HOME CARE OF ALZHEIMER'S DISEASE PATIENTS

In this section, we discuss some WSN types, and present an argument for establishing a middleware layer for WSNs that are to be used for in-home care of Alzheimer's disease patients.

2.1 Wireless Sensor Nets (WSNs)

Recent advances in micro-electro-mechanical systems (MEMS) technology [1], wireless communications, and digital electronics have enabled the development of low-cost, low-power, multifunctional sensor nodes that are small in size and that can communicate over short distances. These tiny sensor nodes, which consist of sensing, data processing, and communicating components, and have enabled a new vision of sensor networks based on the collaborative effort of a large number of nodes.

Sensor networks have the potential to greatly impact many aspects of medical care. By outfitting patients with wireless, wearable vital sign sensors, collecting detailed real-time data on physiological status can be greatly simplified. However, there is a significant gap between existing sensor network systems and the needs of medical care. Most sensor networks are intended for simple sensor node deployments and the nodes transmit simple data without complex configuration at relatively low data rates, with a focus on data collection at a central base station. Such inflexibility in configuration or deployment may lead to higher overall costs than adaptive deployments in which only necessary nodes are used. More importantly, such WSNs may not fit the needs of an Alzheimer's disease patient—for example, a monitoring application may need EKG data from the patient at

one time, while at another time a temperature sensor node may be needed, so a flexible configuration is required.

2.2 From Medical Aid Robots to Mobile Wireless Sensor Nets

Robots, from companion assistants to motor-driven chairs, are proving useful for in-home care for Alzheimer's disease patients. They can improve the quality of healthcare for Alzheimer's disease patients by providing mobility or other healthcare supplies, or monitoring the environment to ensure it is clean and safe for patients. To enable more convenient development and combination of these systems, these mobile robots and other sensor network devices must be based on a robust, scalable, situation-aware and information-efficient sensor deployment architecture that provides for information sharing and fusion.

However, more attention may be needed to achieve this end. Focal issues include: improvement on efficiency of collaboration between different mobile robots and sensors to rapidly locate patients needing immediate attention; possibly including support for attending patients remotely, for example, besides data from temperature sensor nodes some additional EKG sensor nodes may be needed to make decision for possible treatment to a patient, while the collaboration between different kinds of nodes are necessary. To achieve the above, we argue that what is needed is a multipurpose, heterogeneous collaboration and support for flexible solutions for in-home healthcare.

2.3 WSNs for Home Care of Alzheimer's Disease Patients

With the analysis from Sections 2.1 and 2.2 above, we can see that some current WSNs and mobile robots may need more data-sharing, collaboration and location-aware services to provide better healthcare environments and to enhance quality of life for Alzheimer's disease patients.

We propose that WSNs which include static nodes be deployed together with medical devices, healthcare devices, and other appliances needed for Alzheimer's disease patients, so that a WSN is available to collect environment data or vital data from patients or environment wherever patients are in their home. In such a WSN, we assume that there are two different categories of nodes based on the difference of mobility: one category of nodes consists of static nodes, and another of mobile nodes, some examples are shown in [7] [8]. The latter category includes any nodes not fixed in one location, whether they are carried by patients or doctors, or are mobile devices.

The mobile nodes and static nodes in WSNs for Alzheimer's are not pre-defined; a static node can be converted into a mobile node, while that node is moving or is detected to have been moved.

3. IMPORTANCE OF LOCATION IN IN-HOME CARE

In this section, we discuss the importance of localization in WSNs that will be used in in-home care for Alzheimer's disease patients.

3.1 Data Fusion

In a WSN specifically for Alzheimer's disease patients in which there are heterogeneous types of sensors attached in different medical devices and mobile nodes, there will often be cases where

there is redundancy in data from multiple sensor nodes. While decision making may rely mainly on small pieces of this data, and while the memory inside of nodes usually is limited and can't store as much data as are collected, there will be cases where it is beneficial to consolidate or combine data. Much more importantly, data fusion from different sources can often achieve better accuracy than any single data source, as it may reveal patterns not available to any single sensor.

In WSNs for in-home care of Alzheimer's disease patients, data usually are collected based on different sensors which are deployed in different physical locations, or focus to the location of patients or other objects, so such sensor data processing is much more location-aware than general data fusion. One key problem for data fusion in such a scenario is how to do data fusion and aggregation on collected data based on location, or more specifically how to collect data according to location of nodes, and transport them into a base station based on priority, such as by considering data to be more important if they are collected by nodes closer to a patient or particular devices or locations.

GDL can help data fusion in several different features: GDL middleware provides support for data fusion/aggregation with the following features:

1. Provides location context not only for static nodes but also for mobile nodes, such as nodes carried by robots.
2. Provides additional location data in conjunction with the data collected by WSNs.

3.2 Information and Location-Aware Deployment

WSNs for in-home care combine mobile nodes and static nodes, all of which focus on collecting data from and deploying sensors. The location of patients or devices may change unpredictably over time; in addition, if mobile sensors are included, some particular sensor nodes may need to be deployed to a certain location at a certain time for efficient sensing and on-demand sensing for WSNs in-home care.

Including mobile sensors and actuators, such as robots, can facilitate the repositioning of network nodes to increase coverage, accuracy, and information gathering capabilities during monitoring and sampling. The overall sampling objective is the accurate estimation of dynamically evolving conditions subject to navigation, energy and communication constraints. Of particular interest is the determination of efficient and context-aware sampling strategies that effectively utilize available resources. In order to integrate such mobile nodes in WSNs for in-home care, a location discovery mechanism is needed for such WSNs. Such localization should provide location information for nodes, including updates on location for moving or recently moved nodes, since such cases may occur frequently in WSNs used for in-home care.

3.3 Collaboration needs Localization

In a WSN for in-home care, there are different types of medical devices that can be applied for medical needs, life needs and health monitoring for Alzheimer's patients, as well as different types of nodes for environmental monitoring and vital information monitoring. Since different healthcare applications may wish to

deploy different nodes (e.g. from different manufacturers) and will need these systems to work together collaboration [2] in WSNs is important and necessary for the in-home care application.

Location is a powerful concept. There are two broad classes of needs that knowledge of location serves here: (1) location provides information about patients' activities and intent, allowing nodes in a particular location to be selected based on how their location corresponds to a particular need; and (2) location provides information about the interactive devices that are available to a patient, which allows determination of what will be effective means of communicating with him or her.

4. GDL MIDDLEWARE

In order to provide efficient service to elderly individuals, especially Alzheimer's disease patients, in current WSNs for in-home care service, we provide a GDL (Geographic Distributed Localization) middleware layer. Here we describe the GDL middleware briefly, with its interface to higher-layer applications and protocols.

4.1 Overview of GDL Middleware

GDL middleware is intended to be deployed on top of the standard hardware interface and MAC (media access control) layer for sensor nodes, and provides location information to higher-level protocols or applications. Figure 2 provides an overview of the GDL middleware.

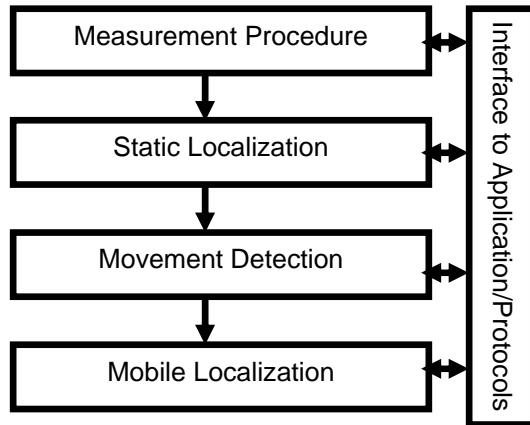


Figure 2. A Diagram of GDL Middleware.

Figure 2 shows how the GDL middleware is constructed from five main components. Inside GDL, a measurement procedure is used to measure the distance between each pair of nodes using only connectivity information. A static localization component computes the location of static nodes based on these measurements, and stores the local map in each node, which is part of the global map for the whole network.

In order to support mobile nodes in WSNs for in-home service, a movement detection component is included in the GDL middleware. With the help of accelerometer sensors, this component decides whether a node should be considered a currently mobile node or not. Any node considered to be moving will trigger the mobile localization component.

An interface is provided to support higher-level protocols such as geographic routing, or applications.

4.2 Measurement Procedure

As a first step for localization, we need some means to measure the distance between nodes in a WSN. In GDL middleware, we use a method similar to hop-counting called “hop-coordinates” for this purpose. We first introduce the concept of a “*Hop Coordinate*” [3], which is the basis of the measurement procedure. Unlike other measurement techniques, which only count the number of hops or track connectivity between nodes, our approach not only counts the number of hops from some bootstrap node but also offsets this count with local network information specific to a given node.

Definition 1: A *Hop Coordinate* is constructed from two parts: a *number of hops* and an *offset*. The first part is a positive integer which equals the number of hops in a minimum hop route from some bootstrap node to a given node. The second part can be seen as a decimal fraction generated from local network information that refines the hop number:

$$hop_A^i = \begin{cases} \min_{B \in N_A} (hop_B^i) + 1, & \text{when } |N_A| \neq 0; \\ \infty, & \text{when } |N_A| = 0. \end{cases}$$

$$offset_A^i = \begin{cases} \frac{\sum_{B \in N_A} (hop_B^i - (hop_A^i - 1)) + 1}{2(|N_A| + 1)}, & \text{when } |N_A| \neq 0; \\ 0, & \text{when } |N_A| = 0. \end{cases}$$

$$\text{Hop coordinate: } h_A^i = hop_A^i + offset_A^i$$

Here, A is a node, hop_A^i is the minimum number of hops to reach node A counting from some bootstrap node i , N_A is the set of nodes that can be reached by node A in one hop, and $|N_A|$ is the number of nodes in N_A .

The measurement procedure works as follows:

- (i) In bootstrap node: A bootstrap node creates a message with $hop^i = 0$ (here, i is the ID of some bootstrap node) to flood the network. After that, the bootstrap node will drop any message that was originated by itself.
- (ii) In all other nodes in the WSN: based on the previous equation, each node will compute the hop coordinate for the node.

4.3 Static Localization

Static nodes are defined as nodes that have stayed in a particular location for a certain time. Based on this definition, we can reduce the computational and communication costs by only computing the location once for such nodes if they keep statically. The static localization component of GDL computes the location for static nodes.

With the help of the measurement procedure, the static localization component in each node will collect the distance measurements from its neighbors, and then each node will geographically compute the shortest paths between all pairs of neighbor nodes to that node, using Dijkstra's algorithm or other similar algorithms. Then we apply MDS to the shortest path

matrix inside of that node, and retain the first two (or three) largest eigenvalues and eigenvectors to construct a 2-D (or 3-D) local map. This produces in each node a local map for itself and its neighbor nodes. Next, we convert the geographically distributed local maps into a global map with a transformation procedure. This transformation procedure will compute and transmit a transformation matrix for each pair of adjacent nodes.

4.4 Movement Detection

Until now, we have only talked about how to do localization without considering mobility of nodes. In this section, we will solve the problem of how to decide whether a node has moved or not, or in other words how to decide whether a node should currently be considered a moving node.

In order to detect the movement of nodes, we need some sensor that can detect and quantify node movement. In our GDL middleware, we make use of accelerometers installed in standard nodes to detect their movement. An accelerometer is a device that measures its own acceleration. We can use 2D (X-Y) accelerometer to measure 2D acceleration, or 3D (X-Y-Z) version to measure 3D acceleration. The component we currently use for 2D in GDL middleware is a standard component in current commercial nodes, such as the Moteiv Inventor mote [6]. In order to detect 3D movement of the node, one can install an inexpensive external 3D accelerometer, such as the MMA7260Q accelerometer [5] from Freescale.

With the aid of a 2D accelerometer, we can roughly measure the acceleration vector \vec{a} in a plane. Since the accelerometer can't detect the rotation of a node, it is of limited use as a direct way to measure position changes. Therefore, we use the integral of the absolute value of the acceleration to compute an approximation of the moved distance $d = \iint |\vec{a}| d^2t$. If this value is beyond a threshold, we then say this node has moved and consider it to be moving.

Based on the idea in the previous paragraph, first we assume that at the beginning of time $t = 0$, every node inside of the network is at rest. Consider an arbitrary node: suppose its acceleration $\vec{a} = 0$, its velocity $v = 0$, and the distance it has moved $d = 0$. Then, we will sample the accelerometer in that node periodically. Here, we assume that the interval time for sampling is dt , and the reading of acceleration from the accelerometer in that node is shown as \vec{a} , so the current velocity for this node can be approximated as $v = \int |\vec{a}| dt$, and the distance moved from the beginning location (when $t = 0$), can be approximated as $d = \iint |\vec{a}| d^2t$. If d is beyond a threshold, we then say this node has moved, and we let $v = 0$ and $d = 0$ to restart measurement. Thus, though the values of \vec{a} , v , and d are not accurate, in comparison to their real values, they are sufficient to detect the movement of a node.

4.5 Mobile Localization

If the movement detection component detects that a node has moved, then this mobile localization component will be triggered

in that node to recompute its location while the movement continues to be detected.

The first step for mobile localization is resampling. On detecting that a node is moving, we mark this node as a mobile node. Then, we will resample the distance measurement for this node from its neighbors. In order to increase the accuracy of resampling, we only measure nodes that are not marked as mobile, instead of using all neighboring nodes.

After the resampling procedure a step similar to Section 4.3 will be used for local map computation, but without the transformation procedure. A key problem for mobile localization is how to transform the local map in a moved node into the global map, or in another words, how to find a new transformation matrix for a node when the existing transformation matrix is out of date. In order to obtain a new transformation matrix for a local map, we first find the closest static node, and then compute a new transformation matrix based on its closest neighboring static nodes and its transformation matrix.

A threshold in movement detection will determine when a mobile node should recompute its location. The smaller the threshold is, the higher the frequency with which the node computes its location, leading to higher localization accuracy as well as a higher communication cost.

4.6 Interface for Up-layer Protocols and Applications

Since GDL middleware will be used as a service for higher-level protocols and applications, it is necessary to define an interface that they can use. Here, we define two basic functions for such an interface:

- (1) The first function provides the location of the local node (where execution is occurring) upon request. In addition, some data structures, such as the node's local map, transformation matrix, and node states, which are computed from components inside of GDL middleware, will be available.
- (2) A second function is used to get feedback on the usage of location from the higher-level protocol/applications that use the GDL middleware. The GDL middleware will use such information to update the data structures it creates. For example, if a message delivery in an application that used location information provided by GDL fails because of a possibly incorrect location, then GDL should be alerted so it can update the location of the corresponding node.

5. CONCLUSION AND FUTURE DIRECTIONS

With the emerging development in Wireless Sensor Networks, it is promising that a new shape to take care of Alzheimer's patients in-home is possible by introducing a low-cost, wireless networked, tiny, battery-powered, smart sensing devices. Such WSNs, which are specific to Alzheimer's patients' in-home care, may include different type of nodes with different mobility comparing regular WSNs. There are challenges that will need to continue to be met in developing, deploying, and using these devices; one of the most central of these, apart from the communication and interoperation issues discussed here, is energy use. In the paper

we have mentioned that these tiny devices consume very little power—but they also have small power supplies, and without external power input will have a finite power lifespan. For motes mounted on appliances or furniture, this may not be a problem, since wired power delivery can be used; however, for small motile devices, particularly if there are many individual units, it may require a significant effort for people to ensure that all devices remain charged and ready for use.

Two important topics that have been addressed in the paper are (1) why location information is important and how it can be used; and (2) how to collect location information and make a location map. In addition to these, prediction of the future location of people, events, and devices is an important and interesting topic (e.g.: given a patient's current location, where will he be in 5 minutes, and where should a mobile node move to when not currently needed?). One application of such prediction is to improve movement detection: if you have a good idea of where an object is going, you will have a better chance to detect its actual movement. This is especially useful if sensors are fixed and cannot cover the whole region of interest. In the context of this paper, prediction can be used in conjunction with localization to communicate with desired local sensors in order to quickly locate an object. For mobile sensors, prediction information is also very valuable, since it can guide sensors to appropriate regions to observe an object or event of interest. In general, it seems clear that prediction can improve node deployment for efficient sensing and on-demand sensing for in-home care WSNs; we also expect it can also help support and synchronize collaborations between different nodes. One idea for helping make such a prediction is to borrow ideas from Geographical Information Systems (GIS) and incorporate additional information on the in-home environment, such as floor plans and furniture layouts, thus allowing devices to identify key areas (e.g. “choke points”, like a staircase or the entrance to a closet or bathroom) that may be of interest for sensing.

To improve the quality of life of Alzheimer's patients is an ongoing struggle. In the future, we anticipate that scientists will develop more complex algorithms that can extend our current

system to handle more complex situations faced in in-home care scenarios. A simulation environment for WSN specific to Alzheimer's will be also be a meaningful contribution that will facilitate both algorithm and system development. Development of new sensors and devices to help those suffering from Alzheimer's is also an area we expect to see many further advances.

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