

Video Article

# Using a Real-Time Locating System to Measure Walking Activity Associated with Wandering Behaviors Among Institutionalized Older Adults

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## Abstract

A real-time locating system (RTLS) can be used to track the walking activity of institutionalized older adults in long-term care who are at risk for wandering behaviors. The benefits of a RTLS are objective and continuous measurements of activity. Self-report methods of activity, especially wandering, by health care staff are vulnerable to floor effects and recall bias, and continuous clinical or research observation over the long-term can be time-consuming and expensive. Health care staff also fail to recognize the onset and/or duration of wandering behaviors, which are associated with a variety of adverse health outcomes in this population but amenable to intervention. RTLS technologies can measure the walking activity of institutionalized residents with cognitive impairment over time with a high degree of accuracy. This is particularly useful for the study of wandering, defined as walking for at least 60 seconds with few (if any) breaks in activity. Wandering is associated with disease progression, hospitalizations, falls and death. Previous work suggests older adults with poor balance ability and high sustained walking activity may be particularly susceptible to poor health outcomes. RTLS's are used to assess cognitive impairment and factors associated with gait and balance; however, supplemental paper and pencil gait/balance tools may be used to further refine risk profiles. This project discusses the use of a RTLS to measure walking activity and also gait quality and balance ability measures on this population.

## Video Link

The video component of this article can be found at <https://www.jove.com/video/58834/>

## Introduction

An older adult's ability to perform daily activities of daily living and be physically active is associated with gait quality and balance ability.<sup>1</sup> Previous work shows correlations between balance ability and self-reported physical activity among sedentary older adults.<sup>2</sup> These correlations remain across older adult populations. For example, among older adults in the community, self-reported activity levels are significantly correlated with balance<sup>3</sup> and walking capacity;<sup>4</sup> the physical activity of ambulatory long-term care residents is positively correlated with both gait and balance (using the Tinetti Performance Oriented Mobility Assessment).<sup>5</sup> Institutionalization is associated with decreased walking activity in later life<sup>6</sup> and result in a high prevalence of sedentary behavior in this population.<sup>7</sup> In fact, a reported 80% or more of the waking hours of an institutionalized resident is spent sitting or lying down<sup>5</sup> and few long-term care residents achieve the recommended 30 minutes of daily moderate activity.<sup>7</sup> Inadequate physical activity is associated with de-conditioning, hospitalization and other poor health outcomes in this population. Understanding the walking activity of this population may aid in tailored gait and/or balance interventions to increase physical activity.

Some institutionalized older adults with cognitive impairment (CI) begin walking excessively as a result of disease progression. Wandering occurs when there are little/no breaks in activity over the course of several hours/days. Wandering is associated with fatigue, weight loss, injurious falls, sleep disturbances, getting lost, and death.<sup>8</sup> Compared to nursing home residents with no or mild/moderate CI, residents with severe CI demonstrate 20% more activity characterized as wandering, 26% of which are "lapping" behaviors, a type of wandering where a resident circles the room.<sup>9</sup> Despite this, it is difficult for health care staff and other observers to distinguish between physical activity and wandering. Intra-individual changes in walking activity can be subtle and wandering is not a behavioral problem to be curbed until the older adult attempts to elope (e.g., escape the facility). Wandering is common; the prevalence of wandering varies from study to study but an estimated 38%<sup>10</sup> to 80% of older adults with CI will wander at some point over the course of the disease.<sup>11</sup>

It is difficult to understand the walking activity of institutionalized older adults as the population is heterogeneous (e.g., varying cognitive levels, health conditions) and activity is difficult to objectively measure. Self-report methods of activity by health care staff better reflect elopement or attempted escapes from the facility, and continuous observation over the long-term is vulnerable to inter-rater errors, time-consuming and expensive.<sup>12,13</sup> Real-time locating system (RTLS) technologies have the potential to objectively and continuously measure walking activity

among older adults with CI. Notably, there is heterogeneity in the RTLS field and multiple systems may theoretically be used: ultra-wideband (UWB; see attached **Table of Materials**), infrared + radio frequency, ultrasound and machine vision systems. However, to assess wandering behaviors, a tracking technology that is small and unobtrusive, wireless, capable of wide-area tracking, with no line of sight issues and accuracy to within 20cm is needed and there are few (if any) systems other than a RTLS using UWB that fulfills these requirements. For example, infrared + radio frequency technology rely on creating "zones" which detail when a resident passes through, but is not specific enough to determine wandering behaviors except within a meter or two, which is far too gross for these purposes. Ultrasound and machine vision have issues with identification and reflections; machine vision systems have good resolution but cannot differentiate residents without resorting to using an RFID tag to compensate for the inadequate capabilities of current artificial intelligence. A RTLS utilizing UWB has a wider range and spatial resolution of about 20cm -- *versus* one meter or more for other systems -- making it the most precise and capable of capturing all activity patterns.<sup>14,15</sup> The RTLS using UWB discussed here is also stable, having been designed for 24/7 industrial applications. Researchers and clinicians have previously used this system where precision is essential - to prevent and predict falls, to assess dementia and changes in cognition - in a wide variety of settings -- assisted living, hospital, nursing homes, and rehabilitation units.<sup>13,16,17</sup>

This paper will detail the protocol of a RTLS using UWB to measure walking activity [walking distance, sustained walking distance, and sustained gait speed (average meters per second/week calculated during sustained walking only)] and paper and pencil tests of CI, gait ability and balance quality, as the latter of which are key components of walking activity. Study findings will focus on using RTLS to distinguish between walking distance, which is associated with physical activity and thus positive health outcomes, and sustained walking distance which is associated with wandering and thus negative health outcomes.

## Protocol

All methods described here have been approved by the Institutional Review Board at the Corporal Michael J. Crescenz VA Medical Center in Philadelphia, PA.

### 1. Installation and Set-Up of a Real-Time Locating System (RTLS)

1. Review facility policies, safety, and personal information protections for residents with facility stakeholders. Determine whether written or verbal support on the use of RTLS in the facility is required. In discussions with stakeholders include local protocols and procedures (e.g., local facility technology waivers, union sign-off, etc.) and a project timeline.<sup>12</sup>  
NOTE: Update protocols, procedures, and timeline as they change over the course of the project, meeting with stakeholders and acquiring sign-off from interested parties.
2. Obtain institutional review board approval including a HIPAA waiver to review medical charts prior to obtaining consent from eligible residents.
3. Equip the desired area of study with a RTLS (see **Figure 1**). Mount sensors in the upper corners of all common rooms and hallways to triangulate resident location and movement in real-time.
  1. Point sensors toward the middle of the area to utilize their antenna pattern which is +/- 90 degrees in the azimuth (Horizontal) and +/- 45 degrees in the elevation (Vertical). Tilt the face of the sensor downwards so that if a laser beam came out of the face of the sensor it would hit the opposite corner of the space about 5-6ft off the ground. Ensure the sensor is level by placing a level on the two plastic pegs on the top back of the sensor.  
NOTE: For a typical communal area in a long-term care facility (about 10m x 13m or 1,000 square feet), four sensors are needed. These sensors will cover a larger area but this is dependent on the surrounding environment -- e.g., walls and glass partitions in the area which may have an impact on transmissions.
  2. Each sensor needs a network cable running from the lower left port on the back of the sensor to the switch that the server is connected to; this cable is a Cat5e cable. With one sensor as the master, run the timing cable from the master to each other sensor, thus a star topology.
    1. To do so, plug a shielded cat5e cable into any of the 6 available ports on the master and run it to each other sensor where it will be plugged into the upper right port of the 6 ports. Run cables above ceiling tiles.  
NOTE: The number of sensors in the area determine the number of ports required for the power over Ethernet (POE) switch. Each sensor will require two ports. Multiple POE switches can be connected if needed.
  3. Measure where the sensors are located in the area and choose an origin point on the sensor (e.g., the lower left corner so that moving north is the positive y axis and moving east is the positive x axis). Measure the x, y, and z of each sensor (with a laser distance measurer) in relation to this origin. Record the MAC address off the back of the sensor and keep to enter into the graphical user interface (GUI; a specialized software developed to manage the RTLS).
4. In the GUI, open **Platform Control** and click on **Core Server** to highlight it and then click **start**. Repeat this for the **Service Controller**. Click **Apply** and then **OK**.
  1. Open the **Service Installer** and press **next**. Browse to **C:\Ubisense Software** and go into the **Location Engine** folder and highlight the "**packages**" folder. Click **OK** and **next**. Install all the services listed. Repeat this process again but go into the **Platform** folder and highlight the "**packages**" folder. Install all the services listed. Click on **Service Manager** and ensure all services appear as "running."
5. Open the **Site Manager** and go to the **Areas** tab. Create a floor plan by opening notepad and specify the start and stop point of each wall by giving the x, y coordinates of the starting point followed by the ending point. Save the file as a .dat file. After the last set of points (0,0) press enter.
  1. In the **Areas** tab go to **Walls>Load Walls** and load the .dat file. Go to **Regions>Set Origin** and choose the lower left corner. Click the draw wall mode button and add a dummy wall anywhere inside the square. This tells the system where to compute the regions (inside vs. outside the region).
  2. Click **Regions>Compute Regions**; this highlights the square blue. Delete the wall -- by selecting the **Wall Mode** button and pressing delete. Go to **Area>Save Area** and save the area. Go to the **Cells** tab and load the area by choosing it from the drop down **Area** box.

3. Click the **Add Extent** button in the lower left corner. To use the defaults click **Save**. Right click on **Site** in the left column and choose **New Geometry Cell**. Click the **Add Extent** button and again use the defaults. Right click on the **Geometry Cell** and choose **New Location Cell**. Click the **Add Extent** button and use the defaults.
6. Open the **Location Engine Configuration** and load the area by going to **MAP>Load Area**. Add a Location Engine cell which will be used to set up a cell of sensors by going to **Cell>New**. There are no available sensors in left column; go to **File>Import Sensors** and locate the .xsc file that located at: C:\Ubisense Software.
  1. Viewing all of the sensors, click on a sensor and drag it anywhere onto the map. It will also be under **Location Cell 0001**; right click on it and go to **Properties**. Enter the x, y, and z for that particular sensor and its MAC address. Do not enter in anything for yaw, pitch, or roll. Repeat this process for all other sensors and ensure the system places them correctly on the map.
  2. Click the **Sensor Status** tab; sensors are running – if not unplug and plug back in to the power source. Use the log tab to monitor the boot up process. Each sensor will download packets in groups of 100 and will eventually report sensor running. Refer back to the **Sensor Status** tab to make sure the sensors have booted and are running.
  3. Click on the **incident power plot** tab to examine the background noise level on each sensor. Let the graphs run. After a break, press the **Set Thresholds** button. This will set the Activity threshold on each sensor which will filter out background noise. Background noise is recommended below 1000.
  4. Right click on **Location Engine Cell 00001>Properties**. On the **Radio** tab set the RF Power to 255, which is the max radio level. On the **Geometry** tab set the Ceiling to 5, the Floor to 0 and the Max Standard Error to 0.05. The ceiling is the max height of the space, the floor is min, and the max standard error is for filtering poor readings.
7. Pick up a compact or hang tag and go to the **Tags** tab in **Location Engine Config** and click **Tag>New**. Enter tag number and set the upper Qos to 32, the same value as the lower Qos. These rates are the beaconing rates of the tag. Choose default information filter as the filter.
  1. Click on the **Sensors and Cells** tab. Right click on **Location Engine Cell 0001** and click **Monitor**. This sets the tags in the cell to transmit and never fall asleep. Press and hold the bottom middle of the compact tag and the middle of the hang tag for three seconds to turn on the tag. It is on when the light in the upper right hand corner is steady and begins to blink.
  2. Put the tag in the middle of the area where all sensors have it in the line of sight. Measure the x, y, and z of that spot in relation to the same origin on the sensor used before. Right click on any of three other sensors and choose **Dual Calibration**. Use the master as the reference, type in the tag number, type in the location measured and choose **Next**. After the calibration finishes save the values for all sensors.
  3. Run this above step again to ensure the values are +/- 2. Repeat this process for all the other sensors but do not save the master sensor values. If using a hang tag, rotate it so that the face of the tag is pointing between the master and another sensor being calibrated and make sure the tag is in a vertical position. The compact tag needs to be in one spot lying flat.
  4. Ensure the sensors are pointing correctly toward the center of the area and view the green angle of arrival lines converging on the tag. Click the TDOA box near the bottom of the window and view the time delay of arrival curves converging on the tag. Note that these lines and curves will not be perfect. Repeat the calibration if necessary. Then, following instructions from step 5.1, click the monitor flag off.
  5. Open the Map and load the Area under Area>Load Area and view the tag on the map.

## 2. Use the RTLS Tags to Locate and Track Residents in Real-Time

1. Review medical charts to identify ambulatory (with/out an assistance device) residents or residents who can propel with their feet age 55 or over with CI/dementia. Obtain consent. Or, if the resident is unable to consent on their own, use contact information provided in the medical chart to contact their legally authorized representative (LAR) or next of kin (NOK).
2. Outfit consenting residents with wrist or hang-tag (see **Figure 1**). Hold the middle of the tag to turn on the tags; the upper right corner light will be steady and then blink after 3 seconds. Ensure the hang-tag it is not on backward or the signal will be attenuated. Attach the wrist tag to an area of the body with a small cross sectional area and more limited absorption of radio frequency energy and provides better tracking accuracy.
3. Develop a protocol for health care staff to remove a resident tag during bathing and showering and train health care staff on these steps. Communicate a pre-determined location to health care staff where they may leave tags they find in the unit (e.g., behind the nurse's station) in the event research staff are not there to retrieve them.
4. Prior to putting the tag on the resident, click the **Tag Association** tab GUI (see **Figure 2**), assign each resident a random and unique "patient ID" number and input into the GUI. Using the number provided on the tag, input the Tag ID number associating it with the "patient ID." The tag will be wirelessly tracked once assigned in the GUI. Keep position at "origin" but in "allow tag swaps", select "true," and then click **save**. NOTE: If data are compromised the privacy and security of the residents is maintained as only a random identification number and x, y coordinates are available; these coordinates do not correspond to any home/institution, city/town, etc.
5. Create a separate document saved on a secured server behind a firewall and a password-protected computer linking the residents' personal information with their patient ID and tag ID.
6. Click the **Location Engine Configuration** click the **sensor and cells** tab. Unflag the "pause" button and view the system recording events (see **Figure 3**). Examine the events for tag/resident location and movement. Click the **log** tab to ensure there are no error messages.
7. Click the **sensor status** tab and view that all sensors are "running" (see **Figure 4**). If not, right click on the sensor and reboot. If timing or other statuses are noted after the reboot, check physical cables running to the problematic sensor.
  1. Ensure all cables are plugged in to the POE switch and that timing and power cables are working on the specific sensor. For example, if the power cable is not working, there will be no light on the sensor and a new power cable is needed. If there is power, a new timing cable is needed.
8. In **C: Ubisense Software** system files, set up a folder on the server to access the raw daily CSV data files.
9. Set up an automatic data backup system (external hard drive) and secure so it cannot be unplugged or moved from the server.
10. In a data management program, smooth RTLS raw data using a 5-second moving average time window (based on time provided in x and y raw data coordinates) and a threshold of 0.7 m of movement (based on location provided in x and y raw data coordinates).

NOTE: This creates a stable series of coordinates, resembling the observed resident walking activity. To manage the jumps in data, when computing a day's motion, only accrue distance and time (and path data) when time between points is less than 30 seconds.

### 3. Measuring Walking Activity and Wandering

- Download daily csv files into a data management/analysis program.  
NOTE: Based on project aim, RTLS data can be reduced to hourly, daily, weekly, bi-weekly, and so forth. For the purposes of this project, data are averaged weekly (summed daily/7) to examine intra-individual changes in ambulation by week. Note that the number of daily samples available for each resident will vary based on their level of activity. Residents who are largely sedentary will have several hundred data points/day or less; residents who are more active will have more like several thousand data points/day.
- Calculate average walking distance, sustained walking distance, and sustained gait speed, and calculate the extent of changes in these measures over time using the raw location data provided (weekly averages of x, y coordinates).
- NOTE: Walking distance = average total number of meters walked per week [e.g., to calculate between each point:  $\sqrt{(x_2-x_1)^2 + (y_2-y_1)^2}$ ], sustained walking distance = average number of continuous meters walked per week calculated *only* when the resident travels for at least 60 seconds with a stop not exceeding 30 seconds, gait speed = the average meters per second/week calculated during sustained walking only [to calculate between each point:  $\sqrt{(x_2-x_1)^2 + (y_2-y_1)^2}$  and then  $t_2-t_1$  to determine the time it takes to go this distance].
- Visually check all sensor light indicators on the RTLS sensors and tags once a day. Check all supplementary equipment provided (e.g., POE switches and timing boxes) for lights.
  - In the GUI, under "map" check to ensure all tagged residents are visible and being tracked each day (see **Figure 5**). If there is a resident missing on the map, click **report** to determine the last time the resident was seen by the system. Click hourly, daily, or weekly reports, which can also be filtered by Patient ID (see **Figure 6**).  
NOTE: This can also be accomplished by reviewing daily CSV files for Patient ID numbers.
  - When a tag is not working, replace the tag and/or check battery. Battery life may also be monitored in the "battery status" tab.
  - Some residents with CI may take off their tag (thrown away by mistake) when they forget about their participation in the project. If so, remind the resident of the project, ask if they wish to continue, and where applicable, replace the wrist tag. In meetings with health care staff remind the stakeholders to talk with residents and remind them of their participation in the project.
- Every 3 months replace the wrist/hang tag battery by using an eyeglass repair kit to unscrew the four screws holding the tag together.
- Daily check that no wrist/hang tags have been submerged in water (resident takes a bath instead of shower); if water damage is visible, replace the tag.

### 4. Measuring Cognitive Impairment, Gait and Balance

- Register, download and assess the cognitive status of residents consenting to participate in the study at baseline and every 6 months over the course of the study using the Montreal Cognitive Assessment (MoCA).<sup>18</sup>
  - Input resident MoCA scores in a dataset which can be merged with the RTLS data through a data management program.
- Recode raw MoCA scores such that a MoCA score of  $\geq 24$  indicates no CI, a score ranging between 10-23 indicates mild/moderate CI, and a score ranging between 0-9 indicates severe CI.<sup>19</sup>
- Using the Tinetti Performance Oriented Mobility Assessment (POMA) and associated description,<sup>20</sup> assess the gait and balance of residents consenting to participate in the study each week over the course of the study period.<sup>20</sup>  
NOTE: There are two subscales in the POMA with gait quality ranging from 0-12 and balance ability ranging from 0-16. Higher scores suggest fewer gait and balance impairments. These subscales gauge a variety of associated abilities and include tasks such as getting up from a chair, sitting and standing balance, balance while turning, step length, step height, deviation from a path and stance. Frail or institutionalized older adults, consistent with the population utilized in this project, have a mean score of 11-12 (SD=3.3-5.7) on the balance ability subscale and a mean score of 8.1-8.6 (SD=3.2-4.6) on the gait quality subscale.<sup>1,21</sup>
  - Input gait and balance subscale and total scores in the database with other variables along with demographic characteristics of interest (age, race/ethnicity, gender).
- Analyze the relationship between CI, gait, balance and ambulation activity in a data management/analysis program. Click **crosstabs** and input variables to examine bivariate relationships. Click **chi square** to examine the strength of the association between these variables of interest.

### Representative Results

RTLS raw data require smoothing to improve the location data's precision (see protocol step 9 under the section, "Use the RTLS Tags to Locate and Track Residents in Real-Time"). Though controlled with default settings in the power plot tab during installation and set-up (see step 1.6.3 in the associated protocol), without additional smoothing there will continue to be noise and jumps. With regard to noise, even when sedentary for several hours, the active RTLS tag continues to log motion—especially if the resident moves their limb where the tag is located—producing continuous movement that artificially inflates walking activity measures. The location of the resident will also jump - sometimes putting a path through a wall (see **Figure 6**) - if the tag sleeps (becomes inactive) due to a long period of inactivity and then wakes due to resident movement. Use a graphics interchange format (GIF) to visualize pre and post-smoothed data with several residents for a few hours.

Sustained walking is a measure of wandering among older adults with CI which is linked to injurious falls, accidents, weight loss, sleep disturbances, getting lost, and death.<sup>8</sup> To distinguish between walking distance and sustained walking distance, open CSV or data files in a statistical program. Use graphing tools to enter the weekly averages for sustained walking distance and walking distance. Given that walking distance is a measure of all walking activity and sustained walking distance is measured only when the resident walks for at least 60 seconds, ensure walking distance means are higher than sustained walking means for all residents (see **Figure 8**). Also compare the "movement report," which provides data on each resident by day, week, year, and so forth, in the GUI with these data. Note that additional measures of walking activity may be developed. For example, it may be of interest to calculate time spent in sedentary activity, track the resident to a specific location of interest or time spent in a known activity.

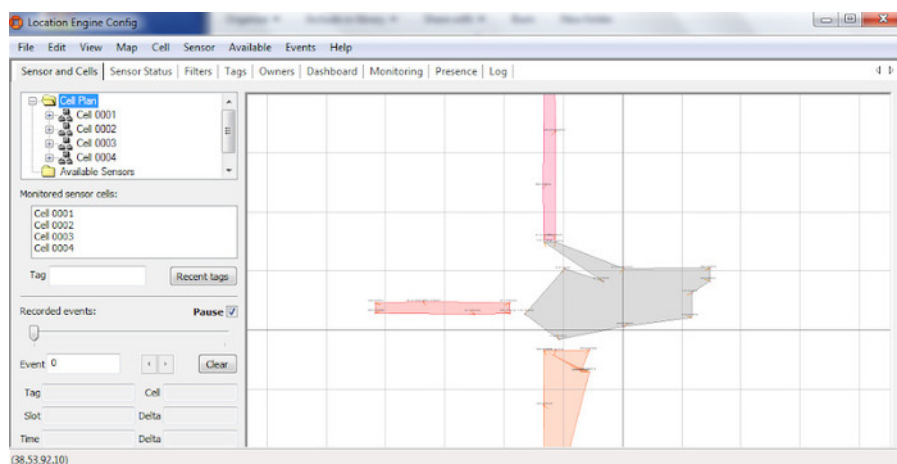
RTLS has 95% concordance in accuracy with walking distance and sustained walking distance based on observational studies. The RTLS may be also be used to differentiate between residents with/out CI;<sup>22</sup> deviation from the path of straight line (tortuosity) is correlated with stride-time variability measured by a Gait-Rite mat ( $p = 0.30$ ) the Mini-Mental State Exam ( $p = -0.47$ ). In addition, previous work has used a RTLS to examine gait and balance; walking activity measures are correlated with the Tinetti gait ( $p = 0.32-0.35$ ) and balance ( $p = 0.37-0.40$ ) subscales.<sup>23</sup> Thus, paper and pencil tools to measure CI, gait quality and balance ability provide supplemental information on residents for research/clinical purposes, but the RTLS may also be used to examine these factors.



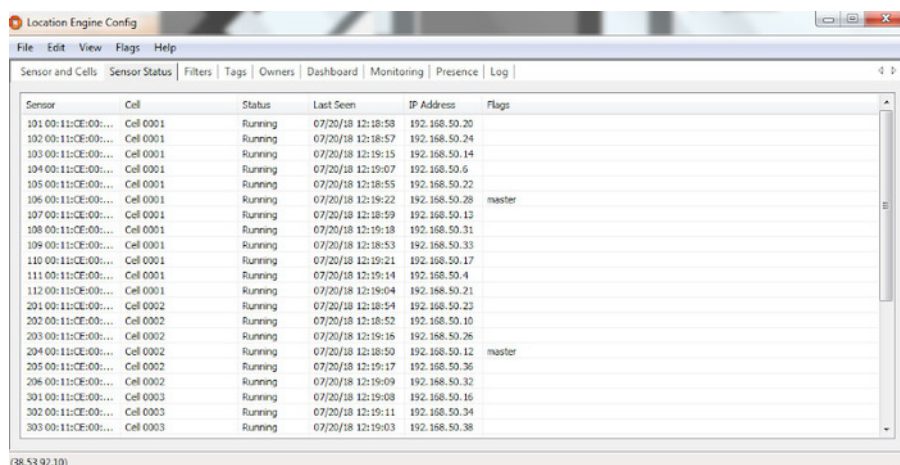
**Figure 1: Real-time locating system sensor (RTLS; mounted in the corners of ceilings) and two tags to track resident location and movement in real-time.** A compact tag can be worn on the wrist or a hang tag can hang from the neck or belt loop. These tags work by emitting an ultra-wide band radio (UWB) signal which is triangulated by the other sensors in the environment. [Please click here to view a larger version of this figure.](#)

The screenshot shows a web-based graphical user interface for tag association. At the top, there are three tabs: 'Tag Association' (selected), 'Tag Disassociation', and 'Patient Participation'. Below the tabs, the 'Tag Associations' section contains a 'Search' button and a 'Create new Patient' button. The 'Properties' section includes a 'Patient ID \*' text input field. The 'Tag Association' section contains a 'Tag Id.' text input field with the value '000-000-000-000', a 'Position' dropdown menu set to 'Origin', and an 'Allow tag swaps' dropdown menu set to 'false'. At the bottom of the form are 'Save' and 'Cancel' buttons. The footer text reads 'Smart Facility © 2018 - Ubisense Limited'.

**Figure 2: Tag association in the graphical user interface (GUI).** This is where the "patient ID," which is a random unique identifier of the resident, and the associated tag numbers are entered for location tracking. [Please click here to view a larger version of this figure.](#)

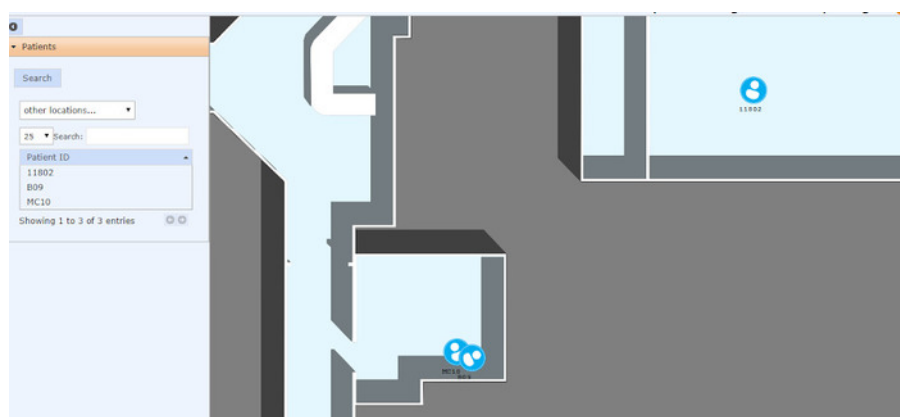


**Figure 3: The Location Engine Configuration program map with cells.** This is used ensure the system is recording events (e.g., tag/resident location and movement) which can be seen when active on the map. [Please click here to view a larger version of this figure.](#)

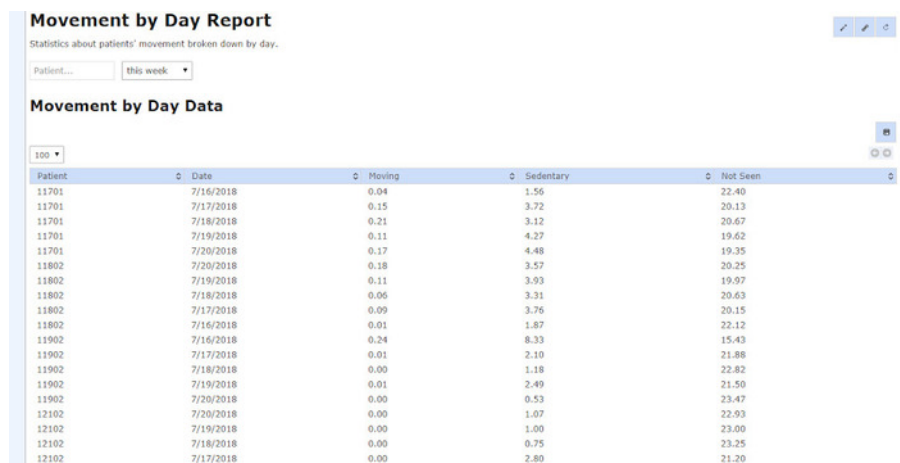


| Sensor              | Cell      | Status  | Last Seen         | IP Address    | Flags  |
|---------------------|-----------|---------|-------------------|---------------|--------|
| 101 00:11:CE:00:... | Cell 0001 | Running | 07/20/18 12:18:58 | 192.168.50.20 |        |
| 102 00:11:CE:00:... | Cell 0001 | Running | 07/20/18 12:18:57 | 192.168.50.24 |        |
| 103 00:11:CE:00:... | Cell 0001 | Running | 07/20/18 12:19:15 | 192.168.50.14 |        |
| 104 00:11:CE:00:... | Cell 0001 | Running | 07/20/18 12:19:07 | 192.168.50.6  |        |
| 105 00:11:CE:00:... | Cell 0001 | Running | 07/20/18 12:18:55 | 192.168.50.22 |        |
| 106 00:11:CE:00:... | Cell 0001 | Running | 07/20/18 12:19:22 | 192.168.50.28 | master |
| 107 00:11:CE:00:... | Cell 0001 | Running | 07/20/18 12:18:59 | 192.168.50.12 |        |
| 108 00:11:CE:00:... | Cell 0001 | Running | 07/20/18 12:19:18 | 192.168.50.31 |        |
| 109 00:11:CE:00:... | Cell 0001 | Running | 07/20/18 12:18:53 | 192.168.50.33 |        |
| 110 00:11:CE:00:... | Cell 0001 | Running | 07/20/18 12:19:21 | 192.168.50.17 |        |
| 111 00:11:CE:00:... | Cell 0001 | Running | 07/20/18 12:19:14 | 192.168.50.4  |        |
| 112 00:11:CE:00:... | Cell 0001 | Running | 07/20/18 12:19:04 | 192.168.50.21 |        |
| 201 00:11:CE:00:... | Cell 0002 | Running | 07/20/18 12:18:54 | 192.168.50.23 |        |
| 202 00:11:CE:00:... | Cell 0002 | Running | 07/20/18 12:18:52 | 192.168.50.10 |        |
| 203 00:11:CE:00:... | Cell 0002 | Running | 07/20/18 12:19:16 | 192.168.50.26 |        |
| 204 00:11:CE:00:... | Cell 0002 | Running | 07/20/18 12:18:50 | 192.168.50.12 | master |
| 205 00:11:CE:00:... | Cell 0002 | Running | 07/20/18 12:19:17 | 192.168.50.36 |        |
| 206 00:11:CE:00:... | Cell 0002 | Running | 07/20/18 12:19:09 | 192.168.50.32 |        |
| 301 00:11:CE:00:... | Cell 0003 | Running | 07/20/18 12:19:08 | 192.168.50.16 |        |
| 302 00:11:CE:00:... | Cell 0003 | Running | 07/20/18 12:19:11 | 192.168.50.34 |        |
| 303 00:11:CE:00:... | Cell 0003 | Running | 07/20/18 12:19:03 | 192.168.50.38 |        |

**Figure 4: The Location Engine Configuration program, sensor status tab.** The sensor status tab is used to view the status of the sensors, which indicates "running." Address sensors messages such as "unknown," "no timing," or other messages as this suggests an issue with tracking in the system, particularly if these are the "master" or "timing" sensors. Right click on the sensor and reboot to get an updated sensor status; change the timing cable or the power cable if rebooting produces the same issue. [Please click here to view a larger version of this figure.](#)

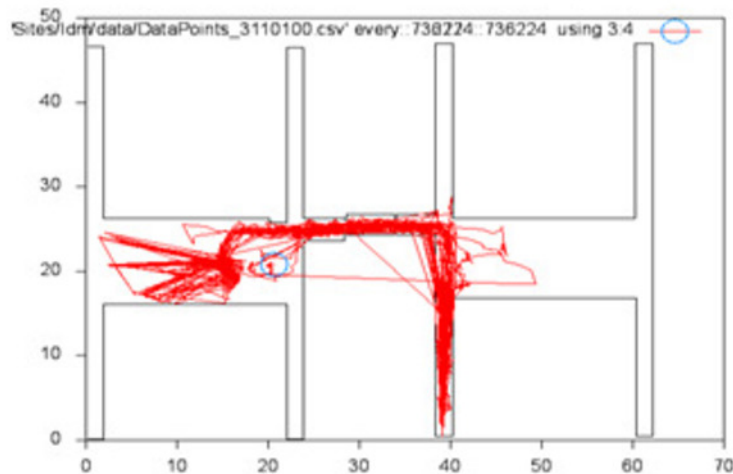


**Figure 5: The map in the graphical user interface (GUI).** The map is used to view residents being tracked in real time. If a resident is not seen on the map they may be out of the tracking area, missing their tag, have a dead battery. [Please click here to view a larger version of this figure.](#)

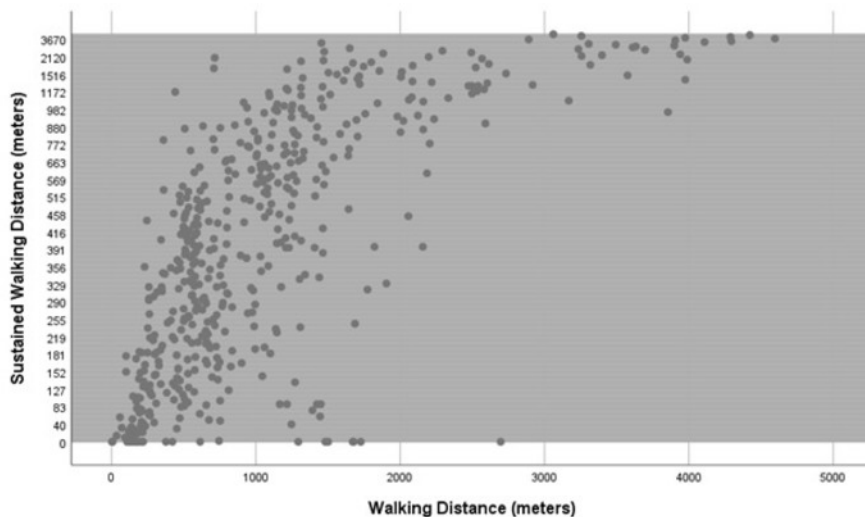


| Patient | Date      | Moving | Sedentary | Not Seen |
|---------|-----------|--------|-----------|----------|
| 11701   | 7/16/2018 | 0.04   | 1.56      | 22.40    |
| 11701   | 7/17/2018 | 0.15   | 3.72      | 20.13    |
| 11701   | 7/18/2018 | 0.21   | 3.12      | 20.67    |
| 11701   | 7/19/2018 | 0.11   | 4.27      | 19.62    |
| 11701   | 7/20/2018 | 0.17   | 4.48      | 19.35    |
| 11802   | 7/20/2018 | 0.18   | 3.57      | 20.25    |
| 11802   | 7/19/2018 | 0.11   | 3.93      | 19.97    |
| 11802   | 7/18/2018 | 0.06   | 3.31      | 20.63    |
| 11802   | 7/17/2018 | 0.09   | 3.76      | 20.15    |
| 11802   | 7/16/2018 | 0.01   | 1.87      | 22.12    |
| 11902   | 7/16/2018 | 0.24   | 8.33      | 15.43    |
| 11902   | 7/17/2018 | 0.01   | 2.10      | 21.88    |
| 11902   | 7/18/2018 | 0.00   | 1.18      | 22.82    |
| 11902   | 7/19/2018 | 0.01   | 2.49      | 21.50    |
| 11902   | 7/20/2018 | 0.00   | 0.53      | 23.47    |
| 12102   | 7/20/2018 | 0.00   | 1.07      | 22.93    |
| 12102   | 7/19/2018 | 0.00   | 1.00      | 23.00    |
| 12102   | 7/18/2018 | 0.00   | 0.75      | 23.25    |
| 12102   | 7/17/2018 | 0.00   | 2.80      | 21.20    |

**Figure 6: Movement by week report in the graphical user interface (GUI).** If a resident is missing from the tracking area and they are wearing an active tag, open up the "report" function and determine the last time the resident was seen by the system by clicking on daily, weekly, etc., reports. [Please click here to view a larger version of this figure.](#)



**Figure 7: A GIF of resident activity.** Shown here is the travel of one resident travel over the course of 24-hour period. Check there are no jumps through walls and that all stationary activity is recorded without jumps. [Please click here to view a larger version of this figure.](#)



**Figure 8: A point graph of walking activity.** This graph shows the relationship between walking distance and sustained walking distance for all residents in the sample; walking distance is higher than sustained walking distance. [Please click here to view a larger version of this figure.](#)

## Discussion

There are several critical steps to be followed prior to beginning the RTLS project that are worth discussion. While a typical common area in a long-term care facility (about 10m x 13m or 1,000 square feet) requires four sensors, this varies based on the environment and the number of sensors required for the project are based on the level of precision required and the environment. Protrusions and glass walls, for example, will require additional sensors. If there are no line of sight issues, four sensors will cover an even larger area. Also consider that there are likely some areas of a facility where total coverage is not needed. The update rate of the tags is also important as higher update rates produce additional location and movement data but decrease battery life. The factory update rates may be changed in the tags tab of Location Engine Configuration. Also, given that software updates can occur or there are hardware issues, purchase a maintenance and support contract for one year and purchase additional sensor(s) and wrist tags (in case submerged in water, thrown away, etc.). Remote access to the server may be required to troubleshoot some issues with the GUI: 1) internet connections in the facility are required and 2) the IRB or other stakeholders must have provided permission for this access (e.g., remote monitoring and the protection of human subject data).

Finally, develop relationships with stakeholders (leadership in the facility and hands-on health care staff). Conduct regular (e.g., monthly or bi-monthly) meetings with stakeholders to address their concerns about the technology to increase compliance and acceptance and to provide project updates.<sup>12</sup> Discuss potential glitches and delays to curb stakeholder expectations of the project timeline and outcomes. Ensure health care staff understand how these tags differ from other technologies in look and feel (e.g., Wanderguard). Have a continuous discussion of how this technology will benefit the unit and the facility more generally. This latter discussion is critical for continued stakeholder compliance and acceptance. In the protocol, develop a plan to train new health care staff on the unit.

There are several limitations to the RTLS discussed here. This system is expensive and there are other lower-cost RTLS choices. However, to examine wandering behaviors, the tracking technology requires a small, wireless active wearable tag, and a system capable of wide-area tracking, with no line of sight issues and good accuracy. There are few (if any) other systems with these capabilities. For example, infrared and radio frequency technology relies on creating "zones" which detail when a person passes through and is not specific enough to determine wandering behaviors. That is, though it is known when a resident crossed from one zone to another (for example, room to room), it would not be known what happened in that room – how many miles walked, time spent walking, etc. Ultrasound and machine vision have issues with identification that to overcome would need to combine with RFID (which is similar to the approach used here) and machine vision systems have low resolution. With UWB there is a wider range and spatial resolution, on the order of 6 inches, versus 36 or more for other systems making it the most precise. It also operates on smaller "zones" and all activity patterns are captured, making it ideal for the measurement of wandering behaviors. The system is also stable and can be used 24/7. For these reasons, the system described here is used throughout the health care environment – not just for asset tracking, but also to examine workflow, detect falls,<sup>24</sup> link cognitive impairment with gait and balance deficits,<sup>15,22</sup> predict fall risk,<sup>13,25</sup> and examine how multi-drug resistant organisms (MDRO's) may spread.<sup>26</sup> As more health care facilities adopt RTLS and this tracking becomes more cost effective additional applications are expected to emerge and RTLS may also be integrated with other smart technologies. Second, residents with CI can get confused and take off their tag frequently and tag batteries need to be changed every 3 months and with water submersion. This requires daily checks of the tags and review of movement using the GUI.

Despite these limitations, a RTLS using UWB is superior to observations of behavior as it is automatic, continuous and objective. This RTLS technology has high concordance with walking distance and sustained walking distance and may be used to examine gait quality and balance ability. In addition, it may be used in lieu of cognitive testing to determine CI/progression over time. Self-reports of walking activity from formal and informal health care staff are vulnerable to floor effects and recall bias and continuous observation of walking activity over the long-term is time-consuming.<sup>12,13</sup> Research suggests continuous observation of walking activity is important as subtle intra-individual changes are associated with poor health outcomes.<sup>13</sup>

## Disclosures

The authors have nothing to disclose.

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