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# Using a real-time locating system to measure walking activity associated with wandering behaviors among institutionalized older adults

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October 15, 2018

Aaron Berard, PhD
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Dear Dr. Berard and editorial office staff members,

Please accept this revised manuscript, "Using a real-time locating system to measure the walking activity associated with wandering behaviors among institutionalized older adults," which we believe will be of interest to the readers and reviewers of *JoVE*.

We carefully considered the comments and suggestions from the reviewers and editor and believe the manuscript is greatly improved. Specifically, we addressed the issue of proprietary hardware/software (and replication) and novelty. Finally, we added a colleague, Dr. William Kearns as an author - his work was suggested by a reviewer.

To our knowledge, this is the first manuscript to describe the use of a ultra-wideband (UWB) radio frequency identification (RFID) technology, or real-time locating system, and apply this technology to the science of ambulation. With the accompanying video, we feel this methodology will be more widely accessible to scientists interested in walking activity, increasing reproducibility and furthering the science in this area.

Thank you, in advance, for your consideration of this manuscript.

Sincerely,

Mary Elizabeth Bowen

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**TITLE:**

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

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**KEYWORDS:**

Wearable electronic devices, radio frequency identification device, walking, walking speed, postural balance, memory disorders, assisted living facilities

**SUMMARY:**

This paper discusses the use of a continuous and objective real-time locating system to measure walking activity associated with wandering behaviors, focusing on older adults with cognitive impairment. Walking activity is measured by walking distance, sustained walking distance, and sustained gait speed. Also assessed are gait quality and balance ability.

**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 s 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.

**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[1]. Previous work shows correlations between balance ability and self-reported physical activity among sedentary older adults[2]. These correlations remain across older adult populations. For example, among older adults in the community, self-reported activity levels are significantly correlated with balance[3] and walking capacity[4]; the physical activity of ambulatory long-term care residents is positively correlated with both gait and balance (using the Tinetti Performance Oriented Mobility Assessment)[5]. Institutionalization is associated with decreased walking activity in later life[6] and results in a high prevalence of sedentary behavior in this population[7]. In fact, a reported 80% or more of the waking hours of an institutionalized resident is spent sitting or lying down[5] and few long-term care residents achieve the recommended 30 minutes of daily moderate activity[7]. 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[8]. 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[9]. 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%[10] to 80% of older adults with CI will wander at some point over the course of the disease[11].

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[12,13]. 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 **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 20 cm is needed and there are few (if any) systems other than a RTLS using UWB that fulfills these requirements. For example, infrared and radio frequency technologies rely on creating "zones" that detail when a resident passes through, but is not specific enough to determine wandering behaviors except within 1-2 m, 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 20 cm -- *versus* 1 m or more for other systems -- making it the most precise and capable of capturing all activity patterns[14,15]. The RTLS using UWB discussed here is also stable, having been designed for industrial applications 24 h/day, 7 days/week. 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[13,16,17].

This article 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)**

1.1. 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[12].

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.

1.2. Obtain institutional review board approval including a HIPAA waiver to review medical charts prior to obtaining consent from eligible residents.

1.3. Equip the desired area of study with a RTLS (**Figure 1**). Mount sensors in the upper corners of all common rooms and hallways to triangulate resident location and movement in real-time.

1.3.1. 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 if would hit the opposite corner of the space about 5-6 ft 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 10 m x 13 m 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.

1.3.2. Ensure that each sensor has 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.

1.3.2.1. 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.

1.3.3. 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).

1.4. 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**.

1.4.1. 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.

1.4.2. 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."

1.5. Open the **Site Manager** and go to the **Areas** tab. Create a floor plan by opening the 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**.

1.5.1. 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).

1.5.2. 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.

1.5.3. 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.

1.6. 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.

1.6.1. 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.

1.6.2. 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.

1.6.3. 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.

1.6.4. 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.

1.7. 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.

1.7.1. 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 3 s to turn on the tag. It is on when the light in the upper right-hand corner is steady and begins to blink.

1.7.2. 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.

1.7.3. 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.

1.7.4. 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.

1.7.5. 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**

2.1. 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).

2.2. 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.

2.3. 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.

2.4. Prior to putting the tag on the resident, assign each resident a random and unique "patient ID" number and input into the GUI in the **Tag Association** tab GUI (see **Figure 2**). 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.*

2.5. 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.

2.6. In 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.

2.7. 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.

2.7.1. 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.

2.8. In **C: Ubisense Software** system files, set up a folder on the server to access the raw daily CSV data files.

2.9. Set up an automatic data backup system (external hard drive) and secure so it cannot be unplugged or moved from the server.

2.10. In a data management program, smooth RTLS raw data using a 5 s 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 s.

**3. Measuring Walking Activity and Wandering**

3.1. 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 and divided by 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.

3.2. 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).

3.3. 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.

3.3.1. 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.

3.3.2. When a tag is not working, replace the tag and/or check battery. Battery life may also be monitored in the "battery status" tab.

3.3.3. 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.

3.4. Every 3 months, replace the wrist/hang tag battery by using an eyeglass repair kit to unscrew the four screws holding the tag together.

3.5. Daily check that no wrist/hang tags have been submerged in water (resident takes a bath instead of shower); if water damage if visible, replace the tag.

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

4.1. 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)[18].

4.1.1. Input resident MoCA scores in a dataset that can be merged with the RTLS data through a data management program.

4.2. Recode raw MocA scores such that a MoCA score of ≥24 indicates no CI, a score ranging between 10-23 indicates mild/moderate CI, and a score ranging between 0-9 indicates severe CI[19].

4.3. Using the Tinetti Performance Oriented Mobility Assessment (POMA) and associated description[20], assess the gait and balance of residents consenting to participate in the study each week over the course of the study period[20].

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[1,21].

4.3.1. Input gait and balance subscale and total scores in the database with other variables along with demographic characteristics of interest (age, race/ethnicity, gender).

4.4. 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 step 2.9). Though controlled with default settings in the power plot tab during installation and set-up (see step 1.6.3), 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 that is linked to injurious falls, accidents, weight loss, sleep disturbances, getting lost, and death[8]. 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 s, 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[22]; 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[23]. 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 AND TABLE LEGENDS:**

**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.

**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.

**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.

**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.

**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.

**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.

**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.

**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.

## 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 10 m x 13 m 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[12]. 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 h/day, 7 days/week. 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,[24] link cognitive impairment with gait and balance defecits[15,22], predict fall risk[13,25], and examine how multi-drug resistant organisms (MDRO's) may spread[26]. 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[12,13]. Research suggests continuous observation of walking activity is important as subtle intra-individual changes are associated with poor health outcomes[13].

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**DISCLOSURES:**

The authors have nothing to disclose.

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Figure 1. Tags and sensors

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Figure 2. Tag association screen



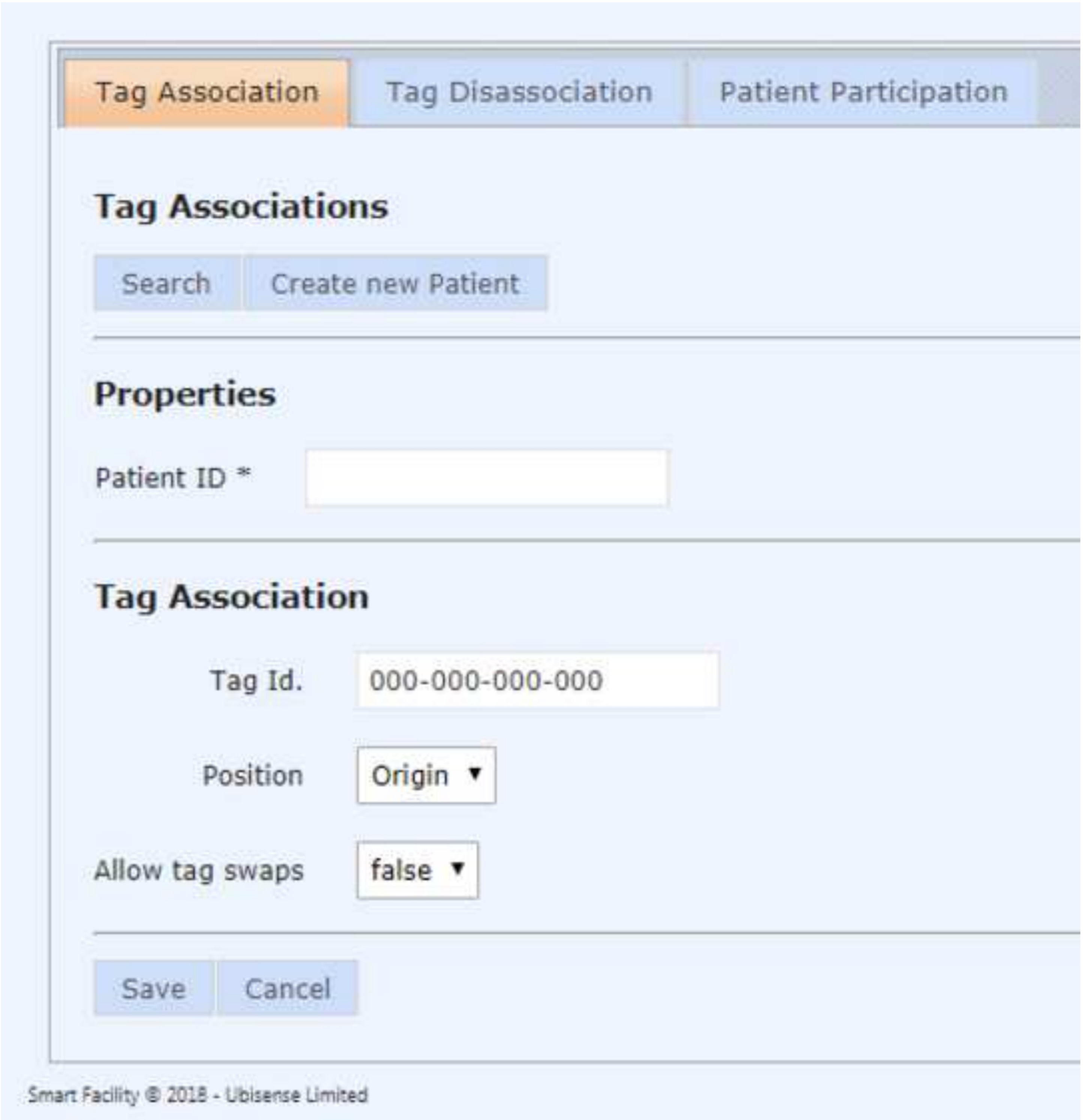

Figure 3. Location engine map with cells



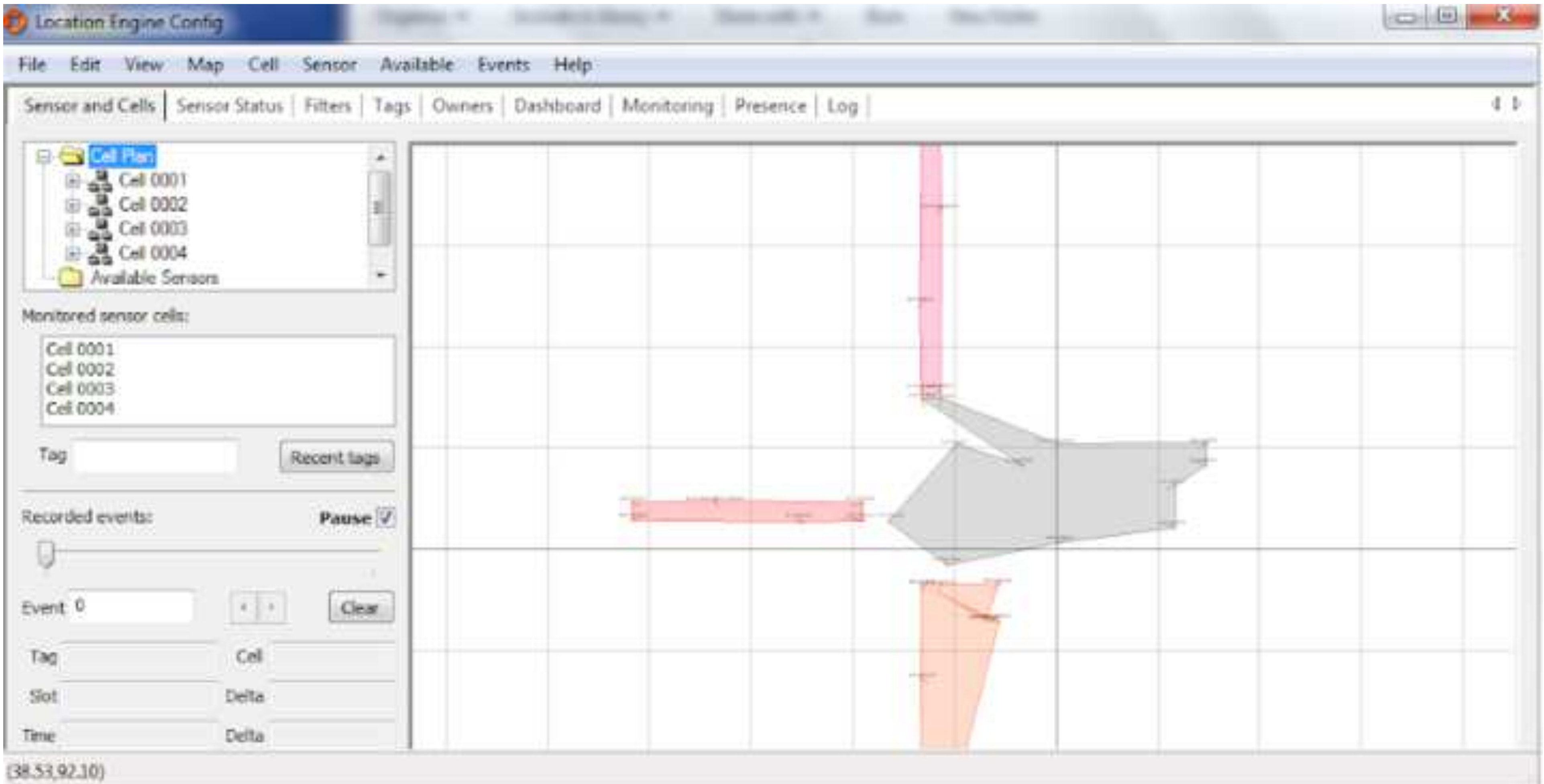

Figure 4. Location engine sensor status

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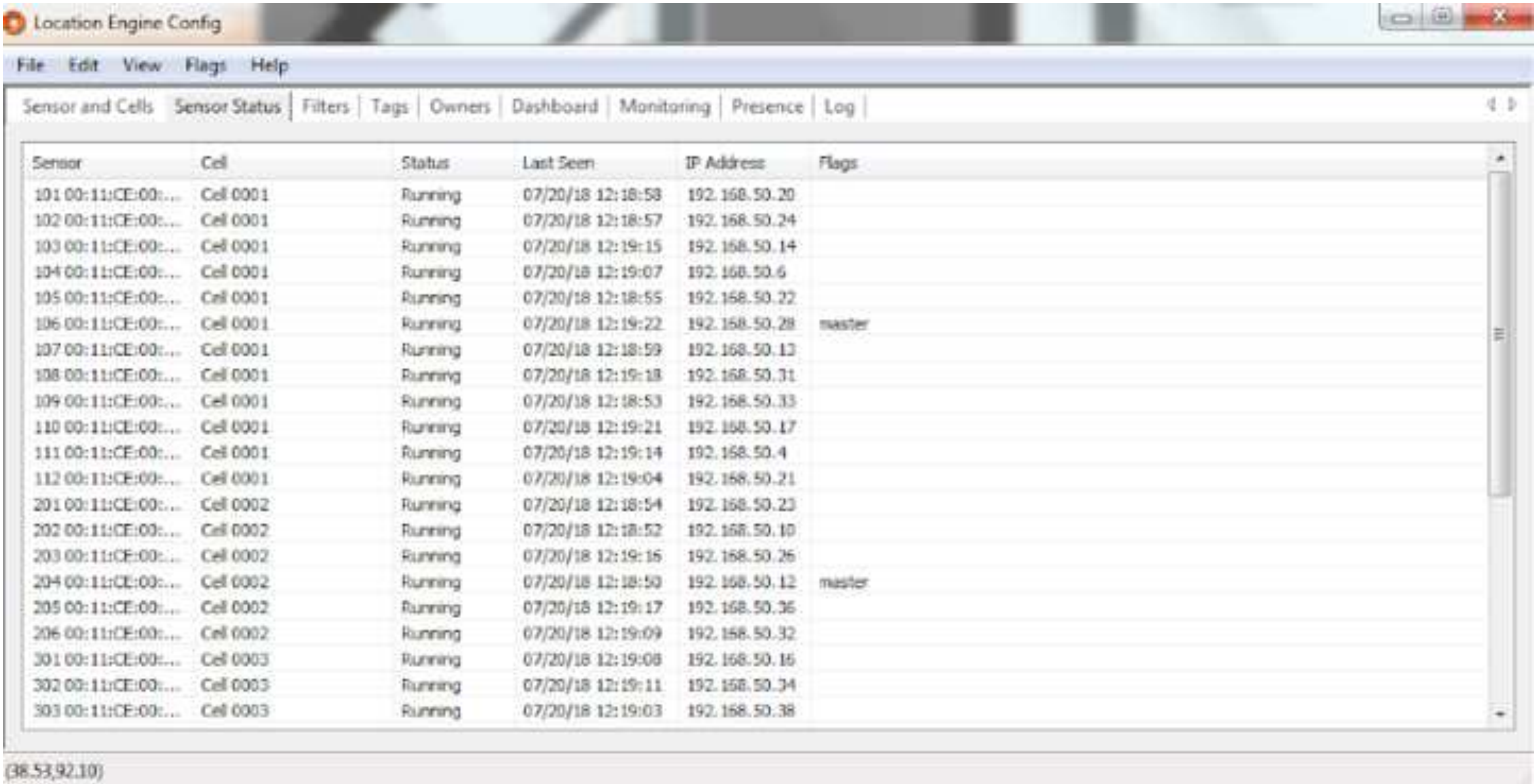

Figure 5. Map with tracking

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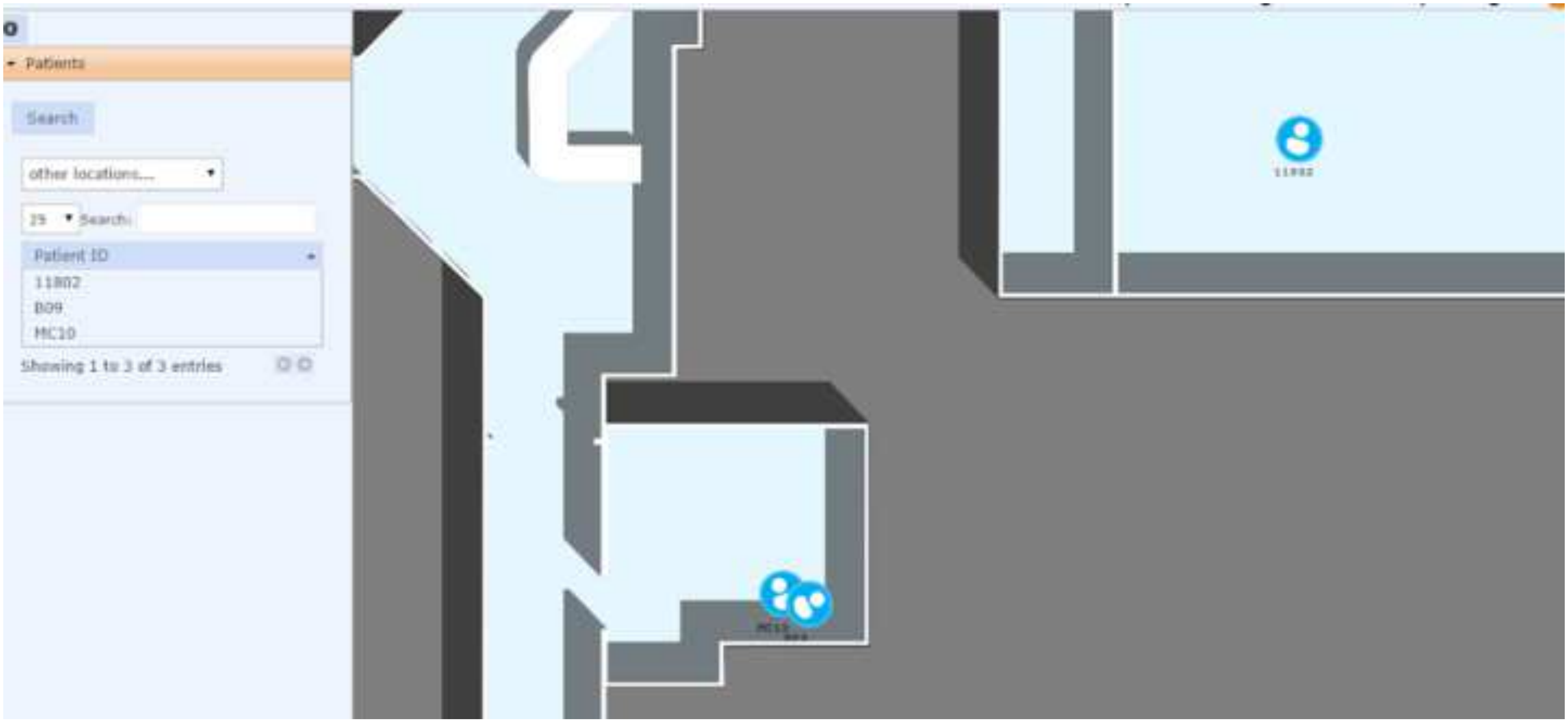


Figure 6. Movement report

Click here to access/download;Figure;Rev_Figure 6. Movement report.tif

## Movement by Day Report

Statistics about patients' movement broken down by day.

Patient... | this week

## Movement by Day Data

100

| 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 7. GIF of movement



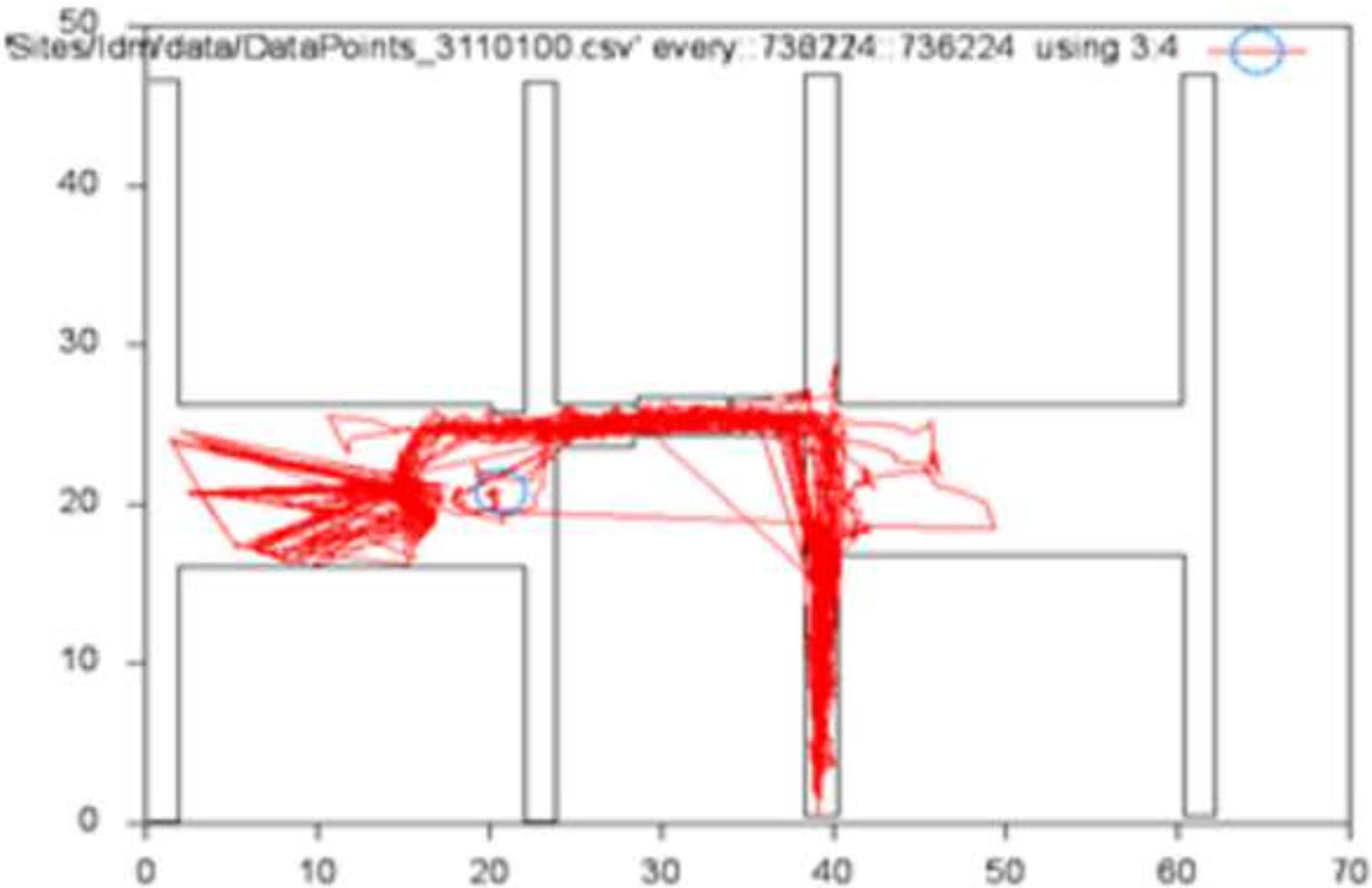
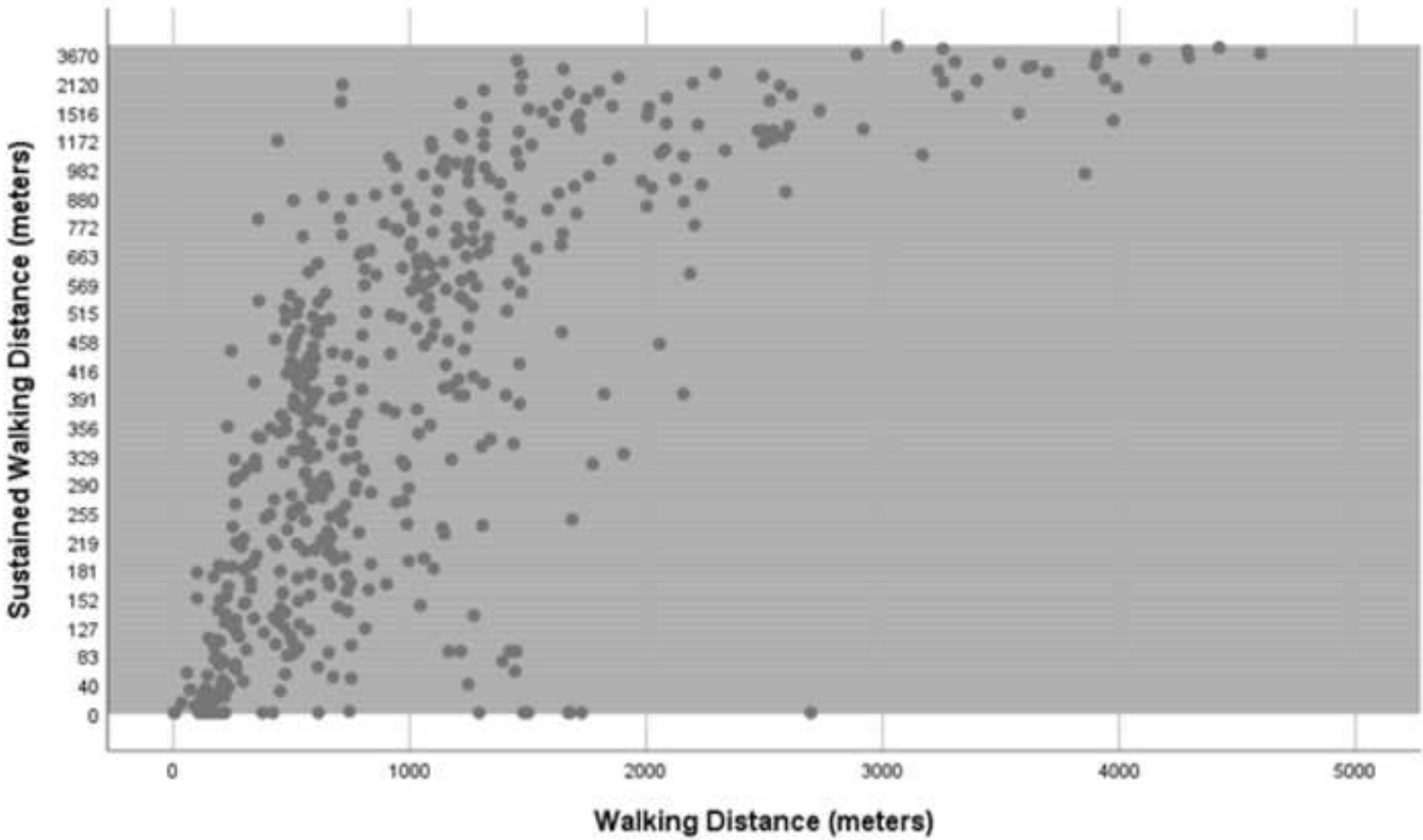


Figure 8. Walking distance





| Name of Material/ Equipment | Company | Catalog Number | Comments/Description |
|---|---|---|---|
| UWB Sensor | Ubisense | | There are two product lines to choose from; IP30 is the latest |
| Tags | Ubisense | | There are two types of tags to choose from; if IP30 sensors are chose |
| Timing Distribution Unit | Ubisense | UBITIMING | |
| Network and Timing Combiner | Ubisense | UBICOMSPL21 | |
| Home Base License | Ubisense | HOMEBASE | |
| Expert Support | Ubisense | MANDS2 | |
| Project Implmentation Services | Ubisense | PROJSERV | |
| Smart Factory | Ubisense | | specialized software designed to manage the RTLS |
| Server | Any | | Laptop with at least 8MB RAM |
| Network Cabling | Any | | 3rd party or subcontract |
| Tinetti Performance Oriented Mobility Assessment | | | Tinetti ME, Williams TF, Mayewski R. Fall risk index for elderly patients base |
| The Montreal Cognitive Assessment | | | https://www.mocatest.org |

ı, use DFLAT33 mini tags

d on number of chronic disabilities. *The American journal of medicine.* Mar 1986;80(3):429-434

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2. Please revise lines 32-33, 60-61, 70-71, 73-74, 107-109, [154-157 **this latter line is discussion of the algorithm and how to construct it]**, 207-211, and Figure 1 legend to avoid previously published text. **These are updated per request.**

3. Please adjust the numbering of the Protocol to follow the JoVE Instructions for Authors. For example, 1 should be followed by 1.1 and then 1.1.1 and 1.1.2 if necessary. Please refrain from using bullets, dashes, or indentations. **These changes have been made.**

4. JoVE cannot publish manuscripts containing commercial language. This includes trademark symbols (™), registered symbols (®), and company names before an instrument or reagent. Please remove all commercial language from your manuscript and use generic terms instead. All commercial products should be sufficiently referenced in the Table of Materials and Reagents. You may use the generic term followed by "(see table of materials)" to draw the readers' attention to specific commercial names. Examples of commercial sounding language in your manuscript are: Excel, IBM SPSS, IBM Corp., etc. **These changes have been made.**

5. JoVE policy states that the video narrative is objective and not biased towards a particular product featured in the video. The goal of this policy is to focus on the science rather than to present a technique as an advertisement for a specific item. To this end, we ask that you please reduce the number of instances of " Ubisense" within your text. The term may be introduced but please use it infrequently and when directly relevant. Otherwise, please refer to the term using generic language. **We mention Ubisense with reference to the GUI (Smart Factory) and also in the table of materials. Otherwise, we refer to the RTLS in general.**

6. Please revise the protocol text to avoid the use of any personal pronouns (e.g., "we", "you", "our" etc.). **Personal pronouns have been removed from the MS.**

7. Please revise the protocol to contain only action items that direct the reader to do something (e.g., "Do this," "Ensure that," etc.). The actions should be described in the imperative tense in complete sentences wherever possible. Avoid usage of phrases such as "could be," "should be," and "would be" throughout the Protocol. Any text that cannot be written in the imperative tense may be added as a "Note." Please include all safety procedures and use of hoods, etc. However, notes should be used sparingly and actions should be described in the imperative tense wherever possible. **These issues have been addressed in the protocol.**

8. Please note that your protocol will be used to generate the script for the video and must contain everything that you would like shown in the video. Software must have a GUI (graphical user interface) and software steps must be more explicitly explained ('click', 'select', etc.). Please add more specific details (e.g. button clicks for software actions, numerical values for settings, etc.) to your protocol steps. There should be enough detail in each step to supplement the actions seen in the video so that viewers can easily replicate the protocol. For example: Steps 8 and 8.1: As currently written, it is not clear how to smooth RTLS raw data. **Ok, and additional details have been provided.**

9. The Protocol should contain only action items that direct the reader to do something. Please move the discussion about the protocol to the Discussion. **Ok.**

10. After you have made all the recommended changes to your protocol (listed above), please highlight 2.75 pages or less of the Protocol (including headings and spacing) that identifies the essential steps of the protocol for the video, i.e., the steps that should be visualized to tell the most cohesive story of the Protocol. **Ok.**

11. Please highlight complete sentences (not parts of sentences). Please ensure that the highlighted part of the step includes at least one action that is written in imperative tense. **Ok.**

12. Please include all relevant details that are required to perform the step in the highlighting. For example: If step 2.5 is highlighted for filming and the details of how to perform the step are given in steps 2.5.1 and 2.5.2, then the sub-steps where the details are provided must be highlighted. **Ok.**

13. Figure 1: Please label panels A and B. **Figure 1 is updated per request.**

14. References: Please do not abbreviate journal titles. **Ok.**

**Reviewers' comments:**

**Reviewer #1:**

Manuscript Summary:
The manuscript is suitable for JoVE journal. Key steps of the protocol are presented adequately. However, more details can be included to clearly explain the protocol.

Major Concerns:
1. Line 191: description should be included to explain how the parameters (e.g. walking distance, sustained walking distance, etc.) calculated from the RTLS (line 143) can be linked or maybe used to measure gait and balance. This will show the relationship of the 2 key steps (line 98 and line 191) of the protocol. **Thank you for this comment. We introduce this idea in lines 97-100 and discuss gait and balance in terms of key factors associated with falls. We also point to the literature that has utilized a RTLS to measure cognitive impairment, gait and balance, alone and with paper and pencil tools (as this study does). Also, see lines 373-380.**

2. Between line 121 and line 127, there should be description to highlight how the Ubisense sensors are connected to the POE switches. And if there are more sensors than the number of slots/ports in the switch, what can be done to synchronize them? More importantly, it should highlight the steps or important notes (if required) in saving the locations shown on the "Location Engine Configuration" onto the host computer desktop. **Thank you for these comments. Please see lines 136-143 for more information about the POE switches. The C: Ubisense software location is given to save the raw CSV files to the desktop, lines 265-266.**

3. One of the previous works of Prof Kearns should be cited because he and other authors had demonstrated how ultra-wide band radio (Ubisense) is used for similar purposes. The title of the publication is "Ultra Wideband Radio: A Novel Method for Measuring Wandering in Persons with Dementia". Here is the link to the publication: http://scholarcommons.usf.edu/mhs_facpub/141/**. Thank you for this citation, it has been added on line 96.**

Minor Concerns:
1. Line 102: calibration is quite an important key step of Ubisense to ensure accurate tracking. Any highlighted lessons from this step can be very useful to readers or users who want to try the system. **Thank you for this comment. We added additional details about calibrating the system; see the installation and set up section throughout specifically lines 209-216.**

2. Line 107: should it be "based on x, y, and z coordinates" because in line 146 it mentions the raw location data are of x, y, z coordinates? In fact, the authors can share how the z coordinates are handled because sometimes the z (height) values are lower than their expected heights in my personal experience with Ubisense. **Thank you for this comment. The z coordinate has been used in previous work for fall detection but for the purposes of this project the z coordinate was not used. See: Bowen, ME, Craighead, J, Wingrave, C, Kearns, W. Real-Time Locating Systems (RTLS) to Improve Fall Detection. *Intl J Geron* 2010; 9(4): 464-471. doi:10.4017/gt.2010.09.04.005.00. We revised this section for clarity.**

3. Line 113: Authors might share some reasons on why wrist tag is used instead of hang tag. One issue with the hang tag is Ubisense sensor's visibility because it can be blocked from the sensors when the tagged subject walks. Also, how the tag is handled when the resident goes to sleep or goes to bath/shower. **Thank you for this comment. The hang-tag, while made for human tracking, suffers from two issues: if put on backward, the antenna is boxed between the circuit board and the human body, which is about 98%**

**water and attenuates the signal. The circuit board also attenuates the signal, albeit to a lesser degree, which affects RTLS accuracy. The compact tag has the benefit of being attached to an area of the body having a small cross sectional area and more limited absorption of radio frequency energy. A note about positioning each of these is discussed lines 216-218. We also discuss developing a protocol to remove a tag when bathing/showering (see lines 240-243) and also to check for water issues and a tag that is inactive (lines 318-319). We discuss how to turn the tag on for use lines 234-235. For this project, tags remain on the resident while sleeping, though this is optional.**

4. Line 164: is Smart Factory a program within Ubisense's Location Engine Configuration? Smart Factory program's introduction should be mentioned. **We minimize the mention of Ubisense and Smart Factory in this revision per editor request but we do introduce Smart Factory as the GUI line 149 and thereafter refer to it as just the GUI. Where applicable, figures note Smart Factory as well.**

5. Line 303: is the check of tag in Smart Factory done manually? If there is an algorithm to perform such checks, it should be mentioned. **In this project it is done manually in the GUI; however we discuss that there is a battery status tab in Smart Factory -- see lines 306-307.**

6. With the recent case of data privacy protection in Europe, authors may consider to highlight the protection to ensure safety and privacy in storing a person's personal location data. **Thank you for this comment. We discuss protecting subject data with a key located on a secure server behind a firewall on a locked computer. We also bring attention to the idea of remote monitoring and the protection of human subject data and running the project though the institutional review board. Finally, we discuss how the x and y coordinates cannot be linked to a city/town, area, person, etc., lines 247-250 given that subjects have a unique ID.**

**Reviewer #2:**

Authors of the manuscript stated they discuss the use of a RTLS that measures walking activity and also gait quality and balance ability measures on older adults with cognitive impairment. Unfortunately, numerous systems have been developed, in the past few decades, to monitor human activities using RFID, UWB, Wi-Fi or Ultrasound, and so on. I am sorry I didn't find any novelty in the manuscript. Only a system has been described, which can be used to measure cognitive impairment, gait and balance.

**Thank you for this observation. There is heterogeneity in the RTLS field and multiple systems may theoretically be used for these purposes. However, the majority of these are engineering exercises which have never been field tested much less have made it to market, hence the paucity of longitudinal studies of human movement variability and its evolution over time. Being able to monitor a single person in an enclosed space using Wi-Fi for a period of a few days is several orders of magnitude simpler than recording 50 individuals simultaneously for a period of 1 year. The logistics in terms of maintaining data flow and quality control, ensuring that noncompliance with protocol is corrected amicably not to mention the near real-time analysis and translation of findings for publication on an expanding body of information dwarf simple issues related to a laboratory demonstration of feasibility. The choice of the Ubisense system was based upon several considerations, not the least of which was that it is in widespread use in industrial settings with proven reliability – 99.99 uptime. While the system has been used to monitor worker productivity (BMW, Airbus, Aston Martin, Caterpillar and the petrochemical industry) its use as a practical tool for accruing longitudinal behavioral data on persons with mental health conditions, for example dementia, traumatic brain injury and the study of autism spectrum disorder is indeed quite novel. Based on this comment we added information on the RTLS using UWB to measure walking activity compared to other infrared, RFID, or other systems. Please see lines 80-100 and also where we discuss limitations, lines 445-464.**

Additionally, I think it is not proper to contain abbreviations (e.g., RTLS and CI) in the Abstract. **Thank you, we have updated the abstract.**

**Reviewer #3:**

First off, I think that the way the protocol is presented makes it really difficult to replicate in settings that may slightly differ from the one used (including tools). From reading the title "Using a real-time locating system to measure the walking activity of institutionalized older adults", it seems that I could use *any* RTLS to compute older adults' walking activity. This is far from the truth. As is, the paper describes a procedure on how to obtain walking activity with a particular proprietary technology i.e., Ubisense's RTLS. From the images and detailed click-by-click instructions, should one use a different version of the Ubisense software, not to mention other positioning system, this procedure could not be easily replicated.

**Thank you for these observations. There is heterogeneity in the field of RTLS technologies – and theoretically various systems and technologies may be used to track wandering behaviors. For example, there is the ultra-wideband (UWB) solution, which Ubisense, Inc., OpenRTLS, Inc. and Zebra, Inc. use, infrared + radio frequency, ultrasound and machine vision systems. However, this project requires 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 and there are few (if any) other systems that fulfill these requirements. For example, infrared + radio frequency technology relies on creating "zones" which detail when a person passes through them, but is not specific enough to determine wandering behaviors except within a meter or two, which is far too gross for these purposes. That is, though we would understand when a person crossed from one zone to another (for example, room to room), we would not have the precision to understand <u>what happened in that room</u> – how many miles walked, time spent walking, etc. Ultrasound and machine vision have issues with identification and reflections and machine vision systems have good resolution but cannot differentiate subjects without resorting to using an RFID tag to make up for the inadequate capabilities of current AI. With UWB, the Ubisense system has a wider range and spatial resolution on the order of 20cm, versus 1 meter or more for other systems making it the most precise. Thus, smaller "zones" are available for study much in the sense that a stronger microscope makes more phenomena available for investigation, and all activity patterns are captured, making it ideal for the measurement of wandering behaviors. The system is also quite stable, having been designed for 24/7 industrial applications that are mission critical. For these reasons, the Ubisense system has been used by other researchers and clinicians 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. While the Ubisense software evolves as all software must, the basic features of the system, and properties are consistent over time – e.g., the gathering and graphic representation of raw location data, generation of spatial maps and administrative processing of tracking tags. Please see lines 80-100 and also where we discuss limitations, lines 445-464.**

Second, although I agree that is important to acknowledge and describe the tools used, the Ubisense system in this case. In my view, a method should not necessarily be coupled with a particular proprietary technology, software, or tool. I would have loved to see a more abstract description of the steps shown in the paper, that can be applied to any accurate enough RTLS.

**We have reduced the discussion of the proprietary technology throughout the MS and made our discussion more abstract as recommended here and by the editor. However, as discussed in the comment above, the Ubisense system is currently the solution for the precision level needed and is used across health care environments and so we maintained the specific hardware and software components clinicians and investigators would need to install and utilize this system.**

Third, there are not enough details as to how to implement the protocol. In my view, this protocol relies too frequently on the company's workers skills, availability, and expertise e.g. "Work with Ubisense to establish an appropriate tag update rate." Or "Work with Ubisense contractors who will install the appropriate number of sensors required for the facility layout and calibrate all sensors for accurate location tracking". In a research protocol, in order to properly replicate results, it is my belief that this should not happen. Also, related to this, in the section called "Using a Real-Time Locating System (RTLS) to Measure Physical Activity and Wandering", more details are needed in Step 1 as to how the facilities will be ultimately *adequately equipped* with sensors. The paper currently reads "Ensure the facility is adequately equipped with enough active Ubisense sensors (see Figure 1)". How many are enough? What is adequately? The authors mention in no few occasions to rely on the Ubisense contractors, but again, I think this should not be the case.

**Thank you for this comment. We agree, and have removed the contractor pieces. We have also added multiple detailed sections throughout the MS entirely focused on installation, calibration, setting up the software, and so forth. There are several installation methods: have a member of the scientific team receive training, use a contractor, work with facility management/building engineers, or some**

**combination thereof. For this revision we provide enough detail that a member of the scientific team could get the system up and running with minimal support. We also address what we mean by "adequately equipped:" 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 could cover a larger area but this is depending on the environment – e,g., walls and glass partitions in the area which may have an impact on transmissions. Please see lines 130-134.**

Finally, there are steps that look more like pragmatic, anecdotic advice during the operation of the RTLS or during the implementation of it, which can be unrelated to a research method, but rather to issues with sensors or software from Ubisense (e.g., steps 11-14, Discussion), or to the users' behavior (e.g., having their tags soaking wet). Related to this, I think that some steps read like practical advice from users who have already implemented and perhaps struggled with some of those issues. For a novice, trying to implement this protocol, some questions may arise. For instance, at some point, there seems to be that some subjective criteria used. For instance, in the REPRESENTATIVE RESULTS section, authors state: "To ensure data are adequately smoothed, run several GIF files on resident travel over the course of a few weeks and visualize their walking activity." How the observer *knows* when a path has been adequately smoothed?

**We revised our discussion of smoothing as this is an important step in the analysis process. There is a default noise setting provided during installation/set up (see lines 192-198) and we provide these instructions in this revision. We also added more specifics on the smoothing accomplished after data are collected -- using a 5-second moving average time window (based on time provided in x and y raw data coordinates) and a threshold of 0.7m of movement (based on location provided in x and y raw data coordinates). 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." This provides the formula to ensure data are representative of the resident's actual activity and not jumps. See lines 271-276.**

Minor Concerns:
- In step 8.1, the authors refer to "custom algorithms in Python and PHP" for smoothing older adults' paths, which are not shared. **We revised the smoothing discussion, please see lines 271-276.**
- There are a few mistakes (or so they seem) in the numbering of consecutive steps e.g., Step 3 and then 4.1, and Step 6 and then 7.1. **Thank you, this has been addressed.**
- In Figure 3's caption, there seems to be a mistake in the writing. From the paper: "The Location Engine Configuration program, sensor and cells tab. This is used ensure the system is recording events (e.g., tag/resident location and movement)." **The Figure 3 caption is correct.**
- I would have loved to see more detail (or perhaps in an ordered fashion) about the formulas used to compute walking activity and related variables. **Please see lines 287-295.**
- Although by the end of the paper, it is clear that there is link between CI, the use of the RTLS, and other aspects of interest such as wandering or gait, this is not immediately clear at the beginning of the paper. What I mean by this is that, from what I could read, RTLS is not the *only* instrument needed to make a distinction between wandering and physical activity, for instance, but you need to measure their cognitive status using the Montreal Cognitive Assessment (MoCA). The RTLS in its own cannot be used to identify wandering behaviors. Similarly, with gait quality and balance, the Tinetti Performance Oriented Mobility Assessment (POMA) is needed, and this is based on annotations by a trained observer. **Thank you for this comment. We use additional paper and pencil tools to measure cognitive impairment level, gait and balance to better understand risk profiles for this project. Wandering behaviors are associated with fatigue and falls. Many older adults who wander already have poor gait/balance – but when coupled with wandering and fatigue this becomes even more pronounced. We introduce this idea in lines 97-100 and discuss gait and balance in terms of key factors associated with falls. We also point to the literature that has utilized a RTLS to measure cognitive impairment (e.g., Kearns, Nams, Fozard, 2010), gait and balance, alone and with paper and pencil tools (as this study does). Also, see lines 373-380 where we provide correlations between these measures.**