Evaluation of Indoor Localisation and Heart Rate Evolution

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Abstract. The number of older adults and their proportion within the general population are expected to increase in the upcoming decades. Decision makers have turned to technology in order to provide cost-mitigating solutions. Assisstive systems have been developed for many of the challenges that can be addressed through technology. However, we find most of them to have singular focus, using proprietary equipment and communication protocols which makes them difficult to integrate into a comprehensive system. Our work was carried out in the development phase of a cyber-physical platform that enables seamless integration of third party vendor devices and applications into a configurable, extensible and cost-effective technological platform for elderly care. The present paper targets the integration of commercial off the shelf components into a real-time indoor localization system, which allows monitoring the older adult's level of activity and detecting potentially dangerous situations automatically. We present the initial results of our comparative evaluation on the accuracy of localisation and heart rate monitoring of persons within an indoor setting. We briefly present the integrated cyber-physical system developed as part of the project. We use intelligent luminaires that act as location beacons and detail the results of an experiment where we evaluated the performance of two different luminaire types. While our previous experiments have shown that room-level localisation of a moving subject was possible using custom-developed luminaires, we extended our evaluation to cover a cost-effective, commercially available alternative. Real-time location data was combined with heart rate information recorded using a commercially available smartwatch in order to obtain a more complete picture of the monitored person's level of activity. Our initial results showed that existing technologies can be configured and integrated into a more complex platform, which remains customizable according to each end user's needs.

Keywords: Ambient assisted living · Cyber-physical system · Indoor positioning · Trilateration · Heart rate evolution

1 Introduction

Population aging is expected to bring important long-term societal and economic changes to the developed world. The number of adults over 60 is expected to

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double by 2050 [24]. This is expected to increase healthcare, local and central government expenditures for assistance and care programs. Authors of [16] have found annual health expenditure to increase by 4% per year, with important funds allocated toward the care for the older adult population. This is compounded by recent medical advances not translating into an improved quality of life for older adults [24], where more targeted approaches are beneficial.

Existing technology-based solutions for assisted living allow intelligent automation at home through monitoring and controlling physiological parameters and the surrounding environment [17]. Assistance for autonomy at home allows remote control of the house and facilitates independent living for older adults or those suffering from chronic or short-term disability [5].

The current paper describes an integrative cyber-physical platform that aims to automate the process of developing customized, interconnected assistance solutions for home autonomy and assisted living. For instance, the solution allows tracing the movement path of the monitored person and lays the groundwork for value adding functionalities such as monitoring the level of activity and behavioural patterns. Our proposed system facilitates the design and implementation of various monitoring and assistance scenarios through an integrative system that allows for easy configuration of component modules such as additional hardware elements, software modules and the required communication protocols.

The proposed system is relevant to the current social and economic context that stimulates the creation of a new market for cost-effective home care solutions. The proposed platform allows easy integration of monitoring solutions for both physiological and ambient parameters. Thus, it is a generic solution for implementing a wide and varied range of monitoring scenarios targeting older adults or people with mild physical or mental impairments. Through the proposed functionality, the system will realize a substantial reduction in the production costs of customized home help solutions, with a significant impact on their commercial availability and market penetration.

The aim of the current paper is to report on our initial evaluation regarding the accuracy of indoor localisation when using commercially available smart bulbs as signal beacons, integrated with heart rate monitoring that is carried out using a commercially-available smartwatch. We used off-the-shelf smart bulbs to replace our previously developed custom hardware elements [15] of the i-Light Eurostars project in order to assess whether lower deployment and maintenance costs can be attained without sacrificing room-level detection of a moving person. We detail relevant related work in Sect. 2, and provide a brief description of our proposed system in Sect. 3. Our experimental evaluation in a home setting is detailed in Sect. 4, where we employ a common location and methodology to compare our custom developed hardware elements with a commercial alternative. The evolution of the heart rate is analyzed during the same period of time when indoor localization is performed. Finally, Sect. 5 provides our conclusions and future work.

2 Related Work

In recent years, the monitoring of physiological and ambiental parameters have become topics of real interest both within the scientific community and the industry. The European Union has recognized the long-term challenges heralded by the current wave of societal and demographic changes, and created the Active and Assisted Living Programme [1] to foster the co-creation of commercially-viable solutions based on technology.

Health-centric monitoring systems usually include several components, and have to address issues related to inter-device data exchange, recording and processing signals from ambient sensors and those reporting physiological parameters, as well as data storage and retrieval. In addition, as data includes health and location components, data security and confidentiality are of utmost importance, with special requirements related to its processing and storage, such as the European Union's GDPR regulations.

Such systems must also provide a way to represent the monitored environment. Some solutions are built around a two-dimensional map [11,18], while others use three-dimensional models [9,23]. They are used as data sources from which information such as door locations, furniture and gas sources can be extracted. They are also employed for storing the installation location for beacons and other physical equipment required for accurate indoor localisation.

In addition to processing sensor data, a monitoring system has to integrate ubiquitous communication technologies that provide real-time health services matching the context and the end-user requirements [19]. The Internet of Things (IoT) and the paradigm shift towards a system of interconnected smart devices [3] can bring additional value, with sensor-enriched nodes that can be used to monitor vital signs and other biometric parameters, collect data and transmit them over a network of nodes.

Numerous assisting devices are currently available commercially, and include those for drug administration, fall detection, alarm buttons, monitoring of vital signs, as well as complex solutions for recording and tracking more environmental parameters [21]. In the context of the COVID-19 pandemic, smart clothing has been designed for elderly users in order to non-intrusively monitor their daily habits, health and well-being [20]. Older adults are known to be in the highest risk bracket with regards to COVID-19, with the mostly likely chronic underlying conditions of heart disease (34%), diabetes (17%) and lung disease (15%) [26].

In the same context, quarantine code tracker wristbands made from waterproof paper and based on QR codes were used in China to monitor personal quarantine compliance [22]. The QR code was read by a dedicated mobile phone application which asked the user to walk around her/his home to determine the house boundaries. Monitoring was carried out over 14 d. If the person wearing the wristband wanted to leave their home before quarantine completion, a warning sound was played by their associated mobile phone. The person had to return back home after at most 15 s and confirm their presence.

Solutions that integrate multiple devices into systems for active living have yet to see wide scale commercial adoption. Most of the integrative solutions

developed so far are found in the form of prototypes described in the scientific literature [4,8,27]. The main barrier to building such solutions is that most of these devices come with proprietary applications, use custom communication protocols and do not expose programming interfaces, making them impossible to integrate into third-party applications.

Currently, development costs represent the main reason for the slow adoption of IoT-driven solutions for assisted living. Thus, the final price is greatly influenced by the complexity of designing and developing these systems and by the need to engage highly specialized human resources. Another important factor regards the absence of tooling that enables automating the design, development, implementation and installation procedures for such solutions.

The system for which we carry out the present evaluation aims to automate the development of home autonomy support solutions, provide an easy-to-use design and development environment, as well as the ability to reduce the time and cost of developing customized solutions for a wide range of scenarios. Our system was designed and is currently under development around international standards for inter-device communication. This allows the integration of a multitude of third-party commercially available devices from the health and home automation sectors, facilitates the transfer of data from third party proprietary systems into ours, achieving plug-and-play interoperability. We believe this will provide access to the continuously developing market of active living and home autonomy solutions, as well as leverage the commercial results of previous research in the domain.

3 System Architecture

The current section briefly details the architecture of the *SMARTCARE* cyber-physical system. Its main objective is to facilitate active and safe living among older and at-risk adults using intelligent automation of their home environment, as well as by monitoring their vital signs and a suite of configurable ambient parameters. Our aim is for the system to enable people to live independently within their own homes, even in cases of chronic conditions or that of mild mental impairment. The system provides an event-based monitoring, automation and alerting platform. It consists of a number of heterogeneous smart connected devices, a data access services platform, offline analysis based on artificial intelligence, notifications, software utilities for system configuration and adaptation to the needs of the beneficiary, together with services aimed towards solution designers and system integrators.

The development of the ongoing project is carried out through end-user centric design that covers their needs and preferences, as well as catering towards requirements for deployment, configuration and maintenance from integrators and system administrators. Under these conditions, the *SMARTCARE* application offers two user interfaces, one for administration and one for users such as formal or informal care givers as well as for the end-users themselves.

The *DeveloperUI* component is dedicated to users with the role of integrator or system administrator. It offers multiple functionalities such as user management, role-based user right configuration, management of deployed devices and tools for configuring several aspects related to indoor location, monitoring and alert scenarios, project management, establishing business rules, as well as visualization of different available reports.

The end-user interface is designed for caregivers and the monitored persons themselves. In the case of monitored persons, the system provides a Virtual Assistant type application, which transmits data via the Gateway component, with a voice interface that facilitates predefined dialogues, voice notifications and voice commands. A graphical interface is available for manually entering vital sign values and other biophysical parameters and observations related to health. The system can also respond to a suite of commands and present notifications. A panic button can be actioned by the user in case of critical situations.

System users in a caregiver role can alter settings related to deployed equipment, can configure scenarios that will trigger real-time notifications and can view reports based on recorded data. Additionally, users registered as medical personnel can manage patient lists, medical observation sheets, establish and follow patient-level treatment as well as configure and receive real-time notifications.

The *SMARTCARE* system consists of the main components illustrated in Fig. 1:

- ***Devices layer*** - comprised of the connected devices deployed and registered within the platform. Together, they form the system's configurable and extensible physical layer
- ***Gateway*** - has the role of communicating and interfacing with deployed devices, environmental monitors and actuators as well as telemedicine solutions. The *DeveloperUI* component for device registration and configuration is part of this layer.
- ***Expert system*** - a cloud service layer that facilitates intelligent processing of the information received from the sensor network by defining and following rules for monitoring and alerting.

Connected equipments are deployed using the *DeveloperUI* component implemented using Python as a back-end and HACS (Home Assistant Community Store) for the graphical interface to facilitate the discovery, installation, renewal and deletion of monitoring devices associated with system users. This module is aimed to facilitate the design of solutions for specific home care applications. The *DeveloperUI* provides design templates for creating custom monitoring and support scenarios and enables their design and implementation through the automatic configuration of the Gateway and Expert system components. The *DeveloperUI* allows the interaction with smart connected devices and responds to events transmitted by them.

Components that interact with an Internet of Things domain track the devices in the beneficiary's home and consist of a central part and module-specific logic. These components make their information available through the

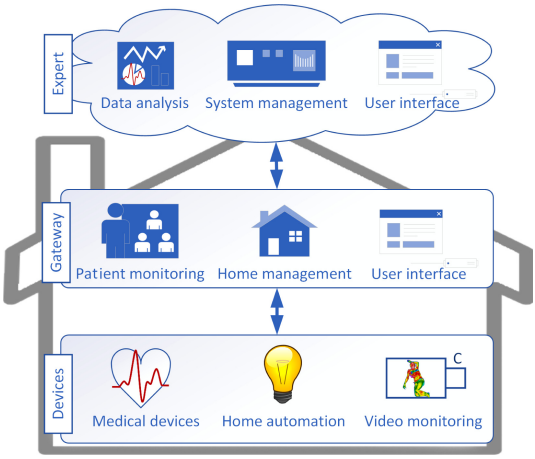


Fig. 1. *SMARTCARE* system architecture [2]

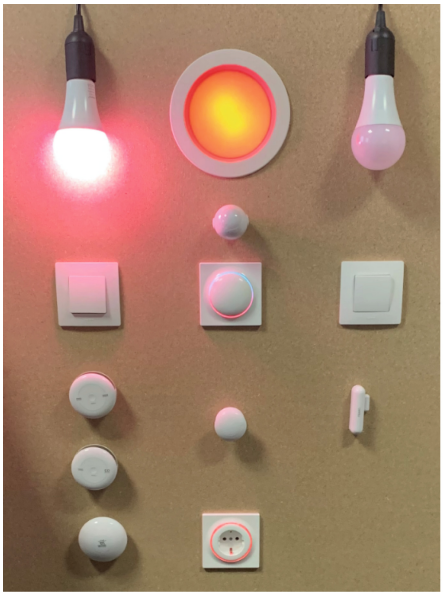
state machine and an event bus infrastructure which implements the publish / subscribe model. The event bus is used to disconnect components, such that components can react to each other's messages through the event bus. This enables integrating devices from different vendors and with different specifications using the event bus as an adaptation and translation layer.

Each user can subscribe to specific events. Users are notified when the event they subscribed to is posted on the event bus. Events can be published on the event bus when something happens. Components also record services in the service log to expose device controls. Components that respond to events that occur provide the logic for home automation, as well as involve services that perform common tasks. Each device is represented as an entity. An entity abstracts the internal operation of the *DeveloperUI* module. The device integrator extends an entity class and implements the properties and methods required for the specific device type.

Setting up a new device is done using a human-readable *yaml* configuration file. The provider is responsible for distributing the configuration on the *SMARTCARE* platform, redirects configuration entries and device discovery information, and collects entities for service calls. In addition, all platform entities are managed and updated when necessary. When adding entities, the feature register is queried to ensure that entities have correct identifiers. The entity register tracks entities and allows users to store additional settings for an entity. The *DeveloperUI* platform uses the configuration to query the external device and add entities.

The same module allows for the management of equipment and tools for configuring several aspects related to indoor localisation, monitoring and alerting. The configuration file is used to register new monitoring devices within the system. This is exemplified in Fig. 2a, which illustrates a number of smart connected

devices: two bulbs, a spotlight, a motion sensor (placed under the red spotlight), three switches for manually operating the bulbs and spotlight, three sensors (round shape) for smoke detection, carbon monoxide, flooding, a panic button (placed between the switch and the socket), an intrusion detection sensor (with the vertical shape) and a smart power socket. Figure 2b illustrates the intelligent lighting elements used in our comparative evaluation. The left hand side shows a smart device that was custom developed as part of a previous research project, and which integrates sensors for measuring temperature, humidity and volatile compound levels. The right hand side illustrates a cost effective, commercially available smart bulb that can double as a signal beacon for indoor localisation.



(a) Devices managed by the DeveloperUI module



(b) Custom developed smart lighting device (left) and Philips Hue bulb (right)

Fig. 2. Selection of intelligent luminaires

The system can help older adults who belong to the most fragile category during the COVID-19 pandemic, by monitoring their heart rate and the daily number of steps. For this situation, a Fitbit Versa 2 smartwatch was considered. It communicates with the associated smart phone of the older adult via Bluetooth. In order to retrieve data from the smartwatch, an account was created on the Fitbit platform[1]. The last part of the configuration *yaml* file contains the

[1] www.fitbit.com.

link to the smartwatch that monitors the heartbeat, calories consumed, and the number of steps taken during the current day.

The data from the Fitbit platform is imported into the DeveloperUI module every 30 min and includes the calories consumption, heart rate and the number of steps taken. The counter is reset at the end of each day.

4 Experimental Evaluation

The present section details our experimental evaluation and discusses its results. We dedicate the first subsection to describing the location and methodology of the experiment, as the presence and layout of walls and furniture can be the source of significant signal reflections that affect accuracy. We employ the same location and methodology as in our previous work [12], making results comparable. We present and discuss our findings within the second subsection, where we compare the accuracy obtained by replacing previously developed custom beacons with a cost-effective, commercially available alternative.

4.1 Experimental Setup and Conditions

The evaluation was carried out in an apartment situated in a multi-storey apartment building. The layout is illustrated in Fig. 3. Exterior walls are made of brick and cement and are 35 cm thick, while interior ones are made of brick and 17 cm thick. The expected effect of the building materials on the signal strength was described in our previous work [12]. Signal absorption appears because the corners of the rooms are made of iron-reinforced concrete pillars. During the movement of the monitored person, interference appears and the effects occur when computing the current indoor position.

4.2 Indoor Positioning Methodology

A Raspberry Pi 4 Model B was used to gather received signal strength indicator (RSSI) values from the three luminaires deployed where indicated by the yellow circles in Fig. 3. The device was connected to the system server via a stable WiFi connection. The monitored person carried a Bluetooth-enabled smart phone and was monitored by the deployed system. We repeated the scenarios from our previous research [12]. The person's movement is illustrated in Fig. 3. Starting next to the bed, the person moved near the hallway closet, from which they moved back next to the bed and then near the desk chair situated in the study room. At the start and finish, as well as between each movement phase, the person remained in the same place for a duration of about 60 s. The entire scenario was repeated a number of three times and in the same conditions. RSSI scans were carried out every five seconds.

The beacons employed in our previous research [12,15] were intelligent luminaires custom developed as part of a precursor research project and are shown on the left hand side in Fig. 2b. They consist of a Raspberry Pi unit and printed

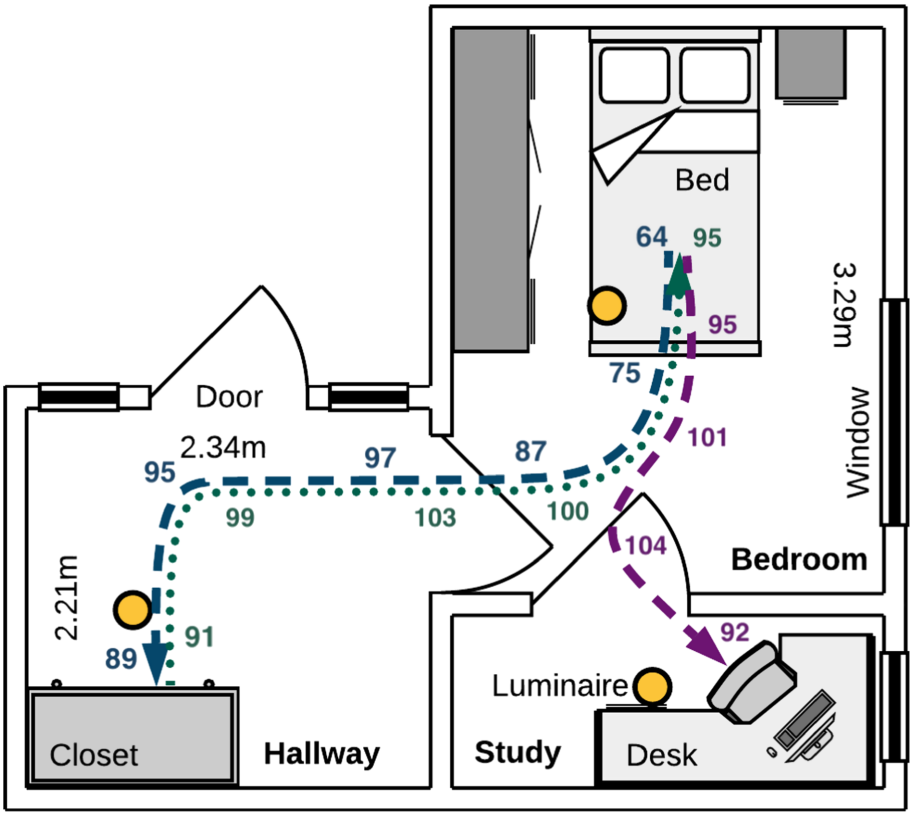


Fig. 3. Floor plan of the apartment used for the experiment. Arrows indicate user movement (a) from the bed to the closet (blue); (b) from the closet towards the bed (green) and (c) from the bed towards the desk (magenta) [12]; user heart rate is correlated with movement, with taken samples shown along the movement path. (Color figure online)

circuit board located inside a housing. The sensing elements, which include temperature, heat and volatile compound sensors are located in the center of the circular element in order to avoid heat emissions from the lighting module. Sensors were placed pointing downward to improve accuracy. For the present evaluation, we replaced these custom devices with a set of Philips Hue[2] intelligent bulbs, as shown in the right hand side in Fig. 2b. The Philips Hue bulb communicates with the Philips Hue bridge via the Zigbee protocol. While they lack additional sensing capabilities, adequate accuracy would allow them to be employed as cost-effective beacons that can replace custom hardware for localisation purposes.

Calculations for indoor localisation are carried out server-side, using the same approach regardless of deployed beacon type. First, trilateration is used in order

[2] https://www.philips-hue.com/.

to determine the distance between the monitored person and each deployed beacon using the [7] formula:

$$d = 10^{\frac{A-RSSI}{10 \cdot n}} \tag{1}$$

where:

- n is the path loss exponent and its value is determined empirically, with existing implementations using values between 2 and 6 for indoor environments.
- A represents the signal strength measured in dBm and computed at one meter. This value is a specific constant of each luminaire type.
- $RSSI$ is the received signal strength index, also measured in dBm.
- d is the calculated distance between the beacon and the user's device with activated Bluetooth.

The position of the monitored person is the intersection of the three circles constructed using the distances between each beacon and the user's device. However, multipath fading, differences in antenna orientation as well as the presence of objects and bodies (including the monitored person's own body) all lead to measurement errors. As such, the user's location must be approximated. We employ the Levenberg-Marquardt algorithm [6] illustrated in Fig. 4 to solve the resulting problem of nonlinear least squares by integrating the Gauss-Newton algorithm and the gradient descent method. The algorithm works iteratively, approaching the solutions in a way that is similar to gradient descent and switching to the Gauss-Newton method for fine tuning the result. The scenario was repeated three times to evaluate the consistency of the reported results.

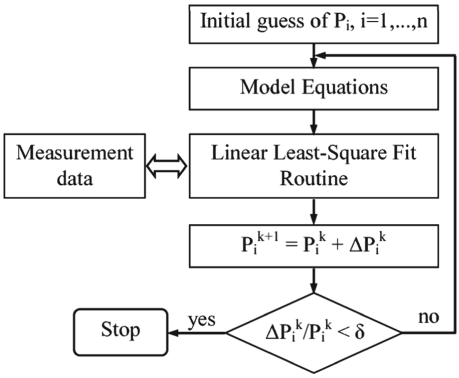


Fig. 4. Levenberg-Marquadt algorithm flow optimization [10]

The Levenberg-Marquardt algorithm determines an approximation of the (x, y) coordinates of the user's location from the following system of equations:

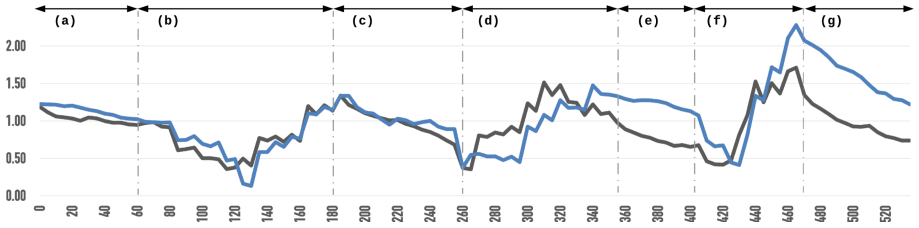


Fig. 5. Measurement of the mean localisation error (vertical axis, in meters, across three repetitions) when using custom developed (blue) and Philips Hue (gray) luminaires as beacons. Horizontal axis has the time expressed in seconds and is divided according to the evaluation stages: **(a)** standing near the bed; **(b)** walking towards the closet **(c)** standing near the closet; **(d)** walking back towards the bed; **(e)** standing near the bed; **(f)** walking towards the desk and **(g)** standing near the desk. (Color figure online)

$(x - x_i)^2 + (y - y_i)^2 = d_i^2$, where (x_i, y_i) are the coordinates of the i^{th} smart bulb, $i \in \{1, 2, \cdots, n\}$, where $n \geq 3$. The algorithm sets an initial value for the parameter vector $P = [x, y]^T$, and in each iteration it replaces it with an updated estimation $P + \Delta$ [10]. The process stops once the step falls below a preset threshold. At least three luminaires are required, with previous research showing that additional devices can improve accuracy, especially in the case of large enclosures [13].

4.3 Results

Figure 5 and Table 1 show the mean errors obtained over the three repetitions of the experimental scenario. Both include our previous results [12] obtained using the same methodology, the same location, and using the custom hardware devices detailed in the previous sections.

Based on our previous research, [14], at least 60 s are required for RSSI values to stabilize. Each obtained position was calibrated by having every smart bulb to consider the previous three RSSI readings. Every position has associated the person's heart rate value which was triggered by using the Fitbit Versa 2 smartwatch in order to analyze its evolution based on the performed activity. Longer durations with the user standing lead to decreased error rates and heart rate values. Conversely, we record the largest errors for indoor localization during the shorter stages (f) and (g), when the person also moves between rooms. This activity also determines the increase of the heart rate.

The data in Fig. 5 shows comparable error rates between our custom devices and the Philips intelligent bulbs. In all cases, we observed that accuracy improved over time with a stationary user, which was confirmed by our previous research [15]. Scenarios (a) and (e), as well as (b) and (d) are worth a closer look, as they are related. In the first case, both represent a monitored user standing near the bed. In both cases the location was resolved with room-level accuracy, with the commercially-available devices being more accurate in scenario (e). With

Table 1. Mean error and standard deviation for the three repetitions carried out using the custom developed device (Old) and the Philips Hue smart bulb (New). Each repetition represented on a table row.

Repetition	Mean error (m)				Standard deviation (m)			
	Walking		Standing		Walking		Standing	
	Old	New	Old	New	Old	New	Old	New
#1	0.76	1.10	1.05	0.70	0.27	0.23	0.17	0.30
#2	0.86	0.75	1.25	0.82	0.36	0.32	0.12	0.29
#3	1.17	0.51	1.61	0.74	0.60	0.20	0.28	0.36

regards to the second scenario pair, they represent the same path, but traversed in opposite directions. Table 1 details mean error measurements and standard deviations individually for each repetition. We do observe important variance between them using both sets of devices. However, the accuracy remained suitable for room-level user detection across each run, with both sets of devices.

The average error and the standard deviation values are better for the experiments which involved the usage of the Philips Hue smart bulb. The initial experiment used a Raspberry Pi 3 Model B with Bluetooth 4.0 connectivity and a Bluetooth 4.1 mobile device. Our current experiment was based on the Philips Hue smart bulbs, complemented by a Raspberry Pi 4 Model B and a mobile device, both supporting the Bluetooth 5.0 standard, which doubles the bandwidth over Bluetooth 4.0 [25]. In addition, version 5.0 extends both indoor and outdoor signal ranges four times when compared to version 4.0. These are important considerations when using Bluetooth RSSI for accurate localisation and we believe them to be the source of the observed differences.

During the three repetitions of the scenario, the average heart rate of the monitored person while lying in bed was of 64 bpm. When the person moved from the bed towards the closet, the heart rate increased and reached a mean value of 82 bpm. After walking and reaching the closet, the heart rate was recorded at 92 bpm, due to the physical effort. When heading towards the bed, the heart rate increased again, reaching 97 bpm. Based on the gathered data, there is a clear connection between the recorded position and activity of the person on one hand, and their heart rate on the other. When at rest, the person's heart rate decreases and then stabilizes. As the person moves, the heart rate increases gradually, denoting that an activity is taking place. Heart rate measurements can play an important role as they can be used to determine the existence of critical situations. For example, a sudden change in heart rate, or heart rate variability can signal that medical intervention is required. Events like heart attacks, fibrillation or arrhythmia can be detected early, as well as kept under observation in case of preexisting conditions. Caregivers can be notified by the software system when such events are triggered and the movement of the monitored persons, together with their current location and updated measurements can be made available to help make an informed decision.

The fact that commercially available and cost-effective solutions were straightforward to integrate into the system, together with them matching the accuracy of previously developed devices is an encouraging result. These can be used in deployments where additional sensing capabilities such as smoke and volatile compound detection are not required, or in the case where the monitored person can make better use of functionalities specific to these devices. In addition, using commercially available solutions can lessen the psychological observer effect on targeted users, as these devices do not look out of place for the end-user, family members or visitors.

5 Conclusion

Western society is in the midst of important societal and demographic changes, with a continuously expected increase in the number of older adults and patients with chronic conditions. While life expectancy has generally risen in the last decades, we find that this was not accompanied by a corresponding increase in the quality of life for older adults [24].

Decision makers are invested in exploring technology as a potentially viable solution that can address current and expected issues, help older adults retain quality of life, all in a cost efficient manner. Technologies such as the Internet of Things accelerate the digitalisation of ambient monitoring, while transforming the lives of many persons. We believe that societal needs and technological progress are well aligned to create solutions with a profound and lasting impact on wide demographics.

In the present work we evaluated one alternative for providing a cost-efficient scheme for indoor localisation and heart rate monitoring using commercially available technology. We aim to further our work and use the platform under development as an integrative hub where innovative devices can be integrated so that it brings added benefit to older adults and their caregivers.

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References

1. AAL - Active and Assisted Living Programme: ICT for ageing well (2016). http://www.aal-europe.eu/about/objectives/
2. Achirei, S.D., et al.: On the design of an iot based solution for assisted living. In: 2020 E-Health and Bioengineering Conference (EHB), pp. 1–4 (2020). https://doi.org/10.1109/EHB50910.2020.9280185

3. Bolívar Pulgarín, N.G., Cangrejo Aljure, L.D., Salcedo Parra, O.J.: eheart-bp, prototype of the internet of things to monitor blood pressure. In: 2019 IEEE/ACM International Conference on Connected Health: Applications, Systems and Engineering Technologies (CHASE), pp. 58–63 (2019). https://doi.org/10.1109/CHASE48038.2019.00025
4. Dias, M., et al.: A living labs approach for usability testing of ambient assisted living technologies. Lect. Notes Comput. Sci. **9186**, 167–178 (2015)
5. Dong, L.M., Piran, M.J., Han, D., Min, K., Moon, H.: A survey on internet of things and cloud computing for healthcare. Electronics **8**(7), 1–49 (2019)
6. Gavin, H.: The levenberg-marquardt method for nonlinear least squares curve-fitting problems. Department of Civil and Environmental Engineering, Duke University, pp. 1–15 (2011)
7. Goldoni, E., Prando, L., Vizziello, A., Savazzi, P., Gamba, P.: Experimental data set analysis of rssi-based indoor and outdoor localization in lora networks. Internet Technol. Lett. **2**(1), e75 (2019). https://doi.org/https://doi.org/10.1002/itl2.75, https://onlinelibrary.wiley.com/doi/abs/10.1002/itl2.75
8. Ham, S., Cho, H., Lee, H., Lee, G.: Prototype development of responsive kinetic façade control system for the elderly based on ambient assisted living. Architect. Sci. Rev. **62**(4), 273–285 (2019). https://doi.org/10.1080/00038628.2019.1614902
9. Jaworski, W., Wilk, P., Zborowski, P., Chmielowiec, W., Lee, A.Y., Kumar, A.: Real-time 3D indoor localization. In: 2017 International Conference on Indoor Positioning and Indoor Navigation (IPIN), pp. 1–8 (2017). https://doi.org/10.1109/IPIN.2017.8115874
10. Duc-Hung, L., Cong-Kha, P., Trang, N.T.T., Tu, B.T.: Parameter extraction and optimization using levenberg-marquardt algorithm. In: 2012 Fourth International Conference on Communications and Electronics (ICCE), pp. 434–437 (2012). https://doi.org/10.1109/CCE.2012.6315945
11. Lv, H., Feng, L., Yang, A., Lin, B., Huang, H., Chen, S.: Two-dimensional code-based indoor positioning system with feature graphics. IEEE Photonics J. **11**(1), 1–15 (2019). https://doi.org/10.1109/JPHOT.2018.2885985
12. Marin, I., Bocicor, M., Molnar, A.J.: Intelligent luminaire based real-time indoor positioning for assisted living. In: Proceedings of the 15th International Conference on Evaluation of Novel Approaches to Software Engineering (2020). https://doi.org/10.5220/0009578705480555
13. Marin, I., Bocicor, M.-I., Molnar, A.-J.: Indoor localization techniques within a home monitoring platform. In: Damiani, E., Spanoudakis, G., Maciaszek, L.A. (eds.) ENASE 2019. CCIS, vol. 1172, pp. 378–401. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-40223-5_19
14. Marin, I., et al.: Indoor localisation with intelligent luminaires for home monitoring. In: Proceedings of the 14th International Conference on Evaluation of Novel Approaches to Software Engineering, pp. 464–471. SCITEPRESS-Science and Technology Publications, Lda (2019)
15. Marin, I., et al.: i-light—intelligent luminaire based platform for home monitoring and assisted living. Electronics **7**(10), 220 (2018). https://doi.org/10.3390/electronics7100220
16. de Meijer, C., Wouterse, B., Polder, J., Koopmanschap, M.: The effect of population aging on health expenditure growth: a critical review. Eur. J. Ageing **10**(4), 353–361 (2013). https://doi.org/10.1007/s10433-013-0280-x

17. Mshali, H., Lemlouma, T., Moloney, M., Magoni, D.: A survey on health monitoring systems for health smart homes. Int. J. Ind. Ergonomics **66**, 26–56 (2018). https://doi.org/10.1016/j.ergon.2018.02.002, https://www.sciencedirect.com/science/article/abs/pii/S0169814117300082
18. Puertolas-Montañez, J., Mendoza-Rodriguez, A., Sanz-Prieto, I.: Smart indoor positioning/location and navigation: a lightweight approach. Int. J. Interact. Multimedia Artif. Intell. **2**, 43–50 (2013). https://doi.org/10.9781/ijimai.2013.225
19. Pustokhina, I.V., Pustokhin, D.A., Gupta, D., Khanna, A., Shankar, K., Nguyen, G.N.: An effective training scheme for deep neural network in edge computing enabled internet of medical things (IOMT) systems. IEEE Access **8**, 107112–107123 (2020). https://doi.org/10.1109/ACCESS.2020.3000322
20. Scataglini, S., Imbesi, S.: Human-centered design smart clothing for ambient assisted living of elderly users: considerations in the COVID-19 pandemic perspective. In: Marques, G., Bhoi, A.K., Albuquerque, V.H.C., K.S., H. (eds.) IoT in Healthcare and Ambient Assisted Living. SCI, vol. 933, pp. 311–324. Springer, Singapore (2021). https://doi.org/10.1007/978-981-15-9897-5_15
21. Kishorebabu, V., Sravanthi, R.: Real time monitoring of environmental parameters using IOT. Wireless Personal Commun. **112**(2), 785–808 (2020). https://doi.org/10.1007/s11277-020-07074-y
22. Walline, J.: Quarantine wristbands, face masks, and personal freedom in hong kong. J. Emerg. Med. **59**(4), 604–605 (2020). https://doi.org/10.1016/j.jemermed.2020.06.048
23. Wang, W., Zhang, Y., Tian, L.: Toa-based nlos error mitigation algorithm for 3D indoor localization. Chin. Commun. **17**(1), 63–72 (2020). https://doi.org/10.23919/JCC.2020.01.005
24. World Health Organization: World report on ageing and health (2015). https://www.who.int/ageing/events/world-report-2015-launch/en/
25. Yaakop, M.B., Abd Malik, I.A., bin Suboh, Z., Ramli, A.F., Abu, M.A.: Bluetooth 5.0 throughput comparison for internet of thing usability a survey. In: 2017 International Conference on Engineering Technology and Technopreneurship (ICE2T), pp. 1–6 (2017). https://doi.org/10.1109/ICE2T.2017.8215995
26. Zimmerman, S., Sloane, P., Katz, P., Kunze, M., O'Neil, K., Resnick, B.: The need to include assisted living in responding to the covid-19 pandemic. J. Am. Med. Directors Assoc. **21**, 572–575 (2020). https://doi.org/10.1016/j.jamda.2020.03.024
27. Zubiete, E., Gomez Gonzalez, I.M., Medina, V., Gómez, J.: Design and implementation of a prototype with a standardized interface for transducers in ambient assisted living. Sensors **15**, 2999–3022 (2015). https://doi.org/10.3390/s150202999