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Exploration of Indoor Tracking Systems as an Architectural Research Tool for the Study on the Housing for the Elderly

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Abstract: With the increasing elderly population, there is a heightened demand for knowledge about housing that best fits their needs, particularly in the event of increased impairment. More specifically, greater understanding is required of those with limited mobility and reduced spatial usage. This research examines the use of indoor tracking systems as an architectural research tool, to investigate the spatial use of the elderly in their private house. Data on equipment performance specifications, cost and operability was gathered through a literature review, through a review of technical specifications and eliciting further information by emails to the suppliers and finally the physical testing of one system. This data was subjected to a comparative analysis. The research found that there were a complex set of requirements for accurate recording of spatial use, which are derived from housing setting, research design and the required scale of movement to detect. The systems that meet all requirements for tracking the elderly indoors are scarce. Improvements to currently available indoor tracking systems would enhance the potential for using them as part of user focused architectural research and provide a more precise and effective knowledge for the design of housing for the dependent elderly.

Keywords: Architectural research methods; Indoor tracking devices; spatial use; housing for the highly-dependent elderly.

1. Introduction

The population of older people in New Zealand, as is the case in many other countries, is growing rapidly. Among this population, the proportion with high care needs are projected to increase more rapidly than the population at large (LiLACS NZ, 2017). As people experience greater difficulties with mobility, they typically spend more time in their home, and as a result, the home becomes more important for creating meaning (Hale *et al.*, 2010; Cooney, 2012). However, as people become more dependent, they often experience a decrease in quality of life (Hale et al, 2010). To maintain a highly impaired body at home usually requires 'the reorganization of space,' such as; the re-modelling of a kitchen; the closing off of spare rooms that are no longer accessible; the placing of necessary items conveniently to hand such as on small tables on either side of the individual's chair; and to facilitate as little movement as possible. However through spatial reorganization, material possessions which mark social identity are often removed and control over space is eroded. Consequently, as needs for assistance and external care increase, the private spaces of highly dependent people are often violated (Hale *et al.*, 2010).

There is a requirement for housing that better fits the needs of the elderly people, as the degree of their impairment increases. In order to effectively design supportive spaces greater information is needed on the requirements of space that maintains elderly people's privacy and identity as well as their independence. The increased knowledge of detailed special usage of the elderly with high-care needs in their homes could provide valuable insights for the design of housing that enhances their well-being.

1.1. Use of an Indoor Tracking System for an Architectural Research Tool

In order to obtain intimate knowledge of spatial use by those with high dependency, an impersonal tracking system is desirable to avoid the influence of an observer and to practically collect data over long periods of time. The system must be capable of collecting detailed information on daily activities such as the time taken and the location. To obtain the qualitative aspects of use such as the individual's feelings and perceptions, a mixed-method strategy is required to complement their physical movements. As such, a three-part survey was also included, consisting of time-diaries to be kept by the elderly relating to their activities; researcher's observation of the care practises; and a follow-up interview to collect their perceptions. Time-dairy maintenance has proven a useful method to provide information on activities as well as their perceived duration, frequency and location; and has been used for a range of analytic purposes directly related to well-being (Gershuny and Robinson, 1988). A researcher's direct observation in private space while useful, can influence the natural behaviours of the elderly (Sommer and Sommer, 1991). Follow-up interviews provide the means for collecting information that is not adequately obtained or not well understood through the other techniques. To obtain an accurate record of physical movement a number of devices were investigated. Instruments that could record activities as well as location and time such as video cameras were considered; however, most had the potential to influence behaviours, not to mention ethical concerns, particularly when installed in spaces that require higher levels of privacy such as the bathroom (Kayser-Jones and Koenig, 1994). To collect the most accurate information with the least influence on behaviour, a mixed-method strategy using an indoor-tracking system was deemed the best possible method.

1.2. Indoor Tracking Systems

There have been remarkable developments in positioning systems during the last decades, especially, in outdoor positioning systems, which are typified by the Global Positioning System (GPS). However, GPS is not suitable for indoor positioning as the attenuation caused by roofs and walls affects the localization estimation (Schutzberg, 2013; Karimi, 2015). Systems designed for indoor environments, known as indoor positioning systems (IPS), have also become very popular and in demand for a variety of uses; such as applications for 'navigation,' 'wayfinding,' 'proximity,' 'geo-fencing' and 'people and asset tracking.' IPS for the 'navigation' and 'wayfinding' are commonly used in hospitals and malls, and there are applications for 'proximity' such as providing real-time information via audio for tours in museums and connecting people of interest in proximity to one another (Schutzberg, 2013; IndoorAtlas Ltd., n.d.). 'Geo-fencing' enables you to set-up triggers when a mobile device enters or exits the defined boundary, as is commonly used in the healthcare sector (IndoorAtlas Ltd., n.d.).

IPS is most commonly used for people and asset tracking in two main areas: the accurate, automated, and error-free tracking in transport and logistics organizations (as well as healthcare organisations) and streamline asset tracking to eliminate loss and improve supply management; and for use tracking people in healthcare and life sciences organizations (IndoorAtlas Ltd., n.d.). Other uses for people tracking systems include customer analysis for better marketing (Spink *et al.*, 2013; Hwangbo *et al.*, 2017) and tracking location of players in sports to inform and aid coaching (Lee and Lee, 2009; Mäkinen, 2015). The applications of IPS for research focusing on people's spatial use include tracking outpatient movement (Singapore International Chamber of Commerce, 2016) and tracking wandering patients in hospitals or nursing homes (Kearns *et al.*, 2008). However, few cases were found using IPS as an architectural research tool to investigate people's spatial usage, particularly when focusing on small movements in a confined house setting.

Due to the limitations of the literature, a number of challenges were anticipated when considering IPS use for tracking impaired elderly people indoors. These included the suitability of the device for the proposed settings, the ease of application and its user friendliness. Moreover, there were operator concerns for system accuracy; requirements for specific technical knowledge such as that needed for programming, and budget considerations. There was need to explore IPS that were best suited for the practical use for this specific research.

1.3. Aims and Methods

This paper aims to explore the possible IPS which are most suitable for practical use in the study of detailed spatial-use by the elderly with limited mobility living in their own homes. Data on equipment performance specifications, cost and operability was gathered and the requirements and the possibility of the IPS meeting them were examined through the two phases of the study. First, six products with different sensor systems were examined for suitability through a literature review and eliciting further information by emails to the system providers. Next, physical testing of the system that had been identified as most suitable was conducted to examine the operability and the tracking accuracy. Finally, the findings in two phases were integrated to examine the requirements for the IPS for the accurate tracking and the practical application for the specific research. Improvements and possible IPS suited for the study are then discussed.

2. Findings

2.1. Comparison and identification of possible IPS through literature review

2.1.1. Sensor systems and selection of IPS products

An IPS is characterised by the sensor technology it uses, such as magnetic fields, radio waves and sensory signals relayed through mobile devices, which can detect the locations of objects or people within buildings (Schutzberg, 2013). The systems based on magnetic field detect variations of the magnetic field caused by building structures to estimate the location (Sterling, 2014; IndoorAtlas Ltd., n.d.). Radio waves used for IPS include radio frequency identification (RFID), Ultra-Wideband (UWB), Bluetooth Low Energy (BLE) and WiFi signals. RFID refers to the technology that uses radio waves to automatically identify people or objects, and unpowered RFID tags (Passive RFIDs) are not suited for obtaining detailed location information (Kearns *et al.*, 2008; *Frequently Asked Questions*, n.d.). UWB is a variant of RFID, which is radio frequency signal with specific frequency spectrum. Its features, such as penetrating a wide variety of materials including the human body and walls and low power consumption, make it highly desirable for applications in location tracking as well as other uses (Kearns *et al.*, 2008; Alarifi *et al.*, 2016). Due to the widespread adaptation of the Bluetooth standard, BLE solutions are cheap and easy to integrate into other systems and everyday devices such as phones (Augur, 2017). IPS based on WiFi signals are now well-established due to the ubiquity of WiFi (R. Faragher, 2014). Near-field electromagnetic ranging (NFER), an emerging IPS technology. Its features include the use of low frequencies, which diffract around the human body rather than being blocked by the body experienced in microwave systems like UWB, which makes tracking people possible (Schantz, 2007). Other sensory systems include those based on the ultrasound signal, such as the high accuracy and a low cost of the transducers compared to radio-frequency-based systems (Medina *et al.*, 2013).

One product was selected from the IPS using each sensor system described above except for Passive RFID, which was identified as not suited for obtaining detailed location information. A high level of accuracy is required for tracking the elderly's small movement in the small space. Due to the lack of similar precedents, the precise accuracy required for this study was not clear from the literature. However, the products which provide accuracy of approximately up to 2m was included for the consideration. The products that could provide enough accuracy were selected. Using these criteria, six potential systems (A-F) were identified (

Table 1).

Table 1: Selected products

Product	Manufacturer	Main sensor system	Accuracy
A	Estimote	BLE	0.5-1m
B	Accuware	WiFi/BLE	up to 2m
C	IndoorAtlas	Magnetic field	1-3m
D	DecaWave	UWB	up to 10 cm
E	Q-Track Corporation	NFER	Better than 30-40cm
F	Marvelmind	Ultrasound	1-2 cm

2.1.2. Requirements for IPS products

The requirements for the tracking system that can enable tracking the movement of those with limited mobility in their houses, are identified as below, which include work environment, ways of putting the device on, requirements of special knowledge and cost.

- **Work environment:** The settings to be studied are houses specifically designed for the elderly such as housing units in retirement villages and public-sector housing complexes, which include detached, semi-detached and apartment-type houses with 1-3 bedrooms and bedsit/studio types. All settings are expected to have inner walls that separate rooms such as those between the bedroom and the bathroom. The system should be able to work in multi-room sites. It should also be able to function in a variety of construction types, as the construction systems may vary and include timber, steel and reinforced concrete.
- **Practical ways to wear the** device**:** It is essential that the highly-dependent elderly with mobility impairments can wear the device in a practical way, for long-duration surveys.
- **No technical IT knowledge being required:** Some devices required high levels of technical IT knowledge (including programming skills), that a general architectural researcher would not normally have acquired.
- **Cost:** The system should be affordable, with a budget ceiling of 1,000 NZD.

2.1.3. Evaluation of products

Six IPS products were evaluated in terms of the requirements identified above. The results are summarised in Table 2.

- **Product A:** This system requires iBeacons which costs approx. 500-900 NZD depending on the number required for the size of the site, which meets the requirement of cost. A smartphone was also required, which was not included in the purchase price. The sensor works Non-Line-of-Sight, which makes it possible to track in multi-room sites. The person being tracked must hold an iPhone parallel to the floor, in front of the body at chest height. Even if it was fixed parallel to the floor in front of the body on a harness, this would likely affect daily and social activities. Moreover, it requires knowledge in programming for mapping manually using Xcode and the SDK provided by the company, which is required for the system to work in multi-room sites (Estimote, n.d.).
- **Product B:** It only requires a suitable smartphone in the setting with dense WiFi coveragein the venue; where there is not enough WiFi, extra equipment such as a portable WiFi and WiFi extenders is required. The software platform is offered by the provider at the monthly cost of approx. 250 NZD/month (Accuware, n.d.), which would be within the budget, depending on the duration of the survey, even including the extra equipment.The device, can be placed in a pocket or attached to a belt.
- **Product C:** This product requires a smartphone and provides the basic operation for free. However, the environments that suit this system are limited to those with a steel or concrete structure. Another disadvantage is that the product does not provide a visualising system suited for tracking; it only allows the user's location to appear on their own smartphone (IndoorAtlas Ltd., n.d.), which then requires the programming skills to develop a suitable visualising system.
- **Product D:** The system works both in multi-room sites and in various types of structures. The device allows various ways of holding it while being tracked. However, the most basic kit costs over 1,000 NZD, which doesn't meet the requirement in cost (DecaWave Ltd, n.d.). It also requires technical knowledge to deal with the special modules that can be used as anchors and tags (that mounts an IEEE802.15.4-2011 UWB compliant wireless transceiver IC, an antennaand so on).
- **Product E:** It works both in multi-room sites and in various types of structures. The tags allow the user to carry it in various ways. However, the system costs over 20,000 NZD (Q-Track Corporation, 2016), which was acritical disadvantage.
- **Product F:** The basic set is approx. 500 NZD, which is within the budget (Marvelmind, n.d.). However, because it requires unobstructed sight for the sensor system to work, it doesn't work in multi-room venues without deploying substantial number of devices, which would impose very high costs. The mobile device requires to keep 'direct line of sight to 2 or more stationary beacons,' which forces the person to hold it in the high part of the body; however, this affects their behaviour and is therefore not realistic.

Table 2: Requirements and evaluation of IPS

Product	Requirements				
	Working in multi-room venues	Working in various types of structure	Practical ways to put the device on	Technical IT knowledge not being required	Cost (up to 1,000 NZD)
A	Yes	Yes	**No**	**No**	Yes

B	Yes	Yes	Yes	Yes	Yes
C	Yes	**No**	-	**No**	Yes
D	Yes	Yes	Yes	**No**	**No**
E	Yes	Yes	Yes	Yes	**No**
F	**No**	Yes	**No**	Yes	Yes

2.1.4. Conclusion: the possible product

Some sensor systems do not allow the use of the system in multi-room settings or in certain types of building structure. The technical IT knowledge is required in most products. The IPS designed for 'asset/people tracking' provides a visualising system best suited for tracking, as compared with those designed for 'navigation', which require users to develop the visualizing system themselves. The products which could provide both adaptability to work in various types of venues and most other requirements, such as those based on NFER, were characterised by very high cost.

Product B, which use BLE and/or WiFi for the main sensor system, were identified as the most suitable systems. However, there are concerns in the accuracy as well as usability and operational issues, which were examined in the following physical examination of one system.

2.2. Physical Testing

Physical tests were conducted on the system identified as best suited to personal tracking with high accuracy in order to evaluate theiroperability and performance (accuracy etc.). For the tests, information was elicited by emails from the system providers to supplement online documentation, due to the complexity of the systems and to evaluate their user friendliness for an architectural investigator. The test was conducted in a typical timber-structured house of approximately 80 m^2 with 2 bedrooms. This location was deemed typical in terms of the size, layout and structure.

This IPS works with radio signals (WiFi and/or BLE), and requires WiFi access points and/or iBeacons, a certain type of smartphone (on which the special app is installed) and the software platform provided by the company at a monthly cost. Both WiFi access points and iBeacons, which were available at the test site, were used for the test. It was anticipated that some survey sites may not have WiFi access points; however, mobile WiFi access points (WiFi hotspot and WiFi extenders) could be used. This system is suited for inside the building with walls (Accuware, n.d.).

- **Operability in Set-up:** Prior to the configuration of the space, a floor plan should be prepared in an image file and uploaded to the server (Figure 1 left). In the deployment of radio signal source devices, the devices should be placed along the perimeter of the area; however, the exact location can be decided to suit each case (Figure 1 centre). The devices may be placed on the ground as well as on the ceiling. Spatial calibration is made by walking along the defined routes twice, once in each direction, tapping the points on the app on the smartphone (Figure 1 right). However, walking speed must be constant even when turning corners and tapping the device, which is physically difficult. Training for this process is essential.

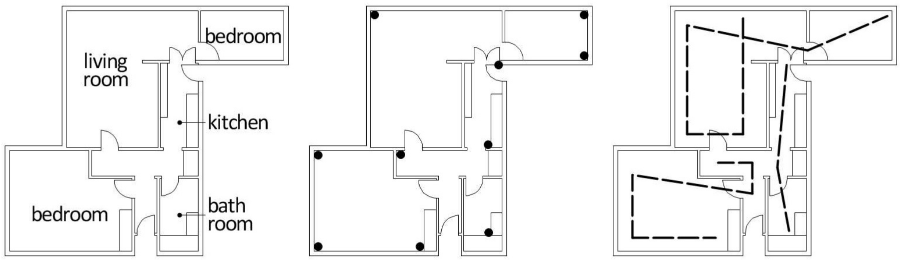

Figure 1: the house plan (left), deployed devices (centre) and walking routes for spatial calibration (right)

- **Performance in tracking (accuracy etc.)** The difference between actual position and that on the map was approximately 2 m at most, and the tracked person was often located in a different room to the one that they were in (Figure 2). However, the tracking was unstable; for example, there was movement in the displayed position even if there is no change in the actual position. This accuracy and stability would not allow to track small movements.

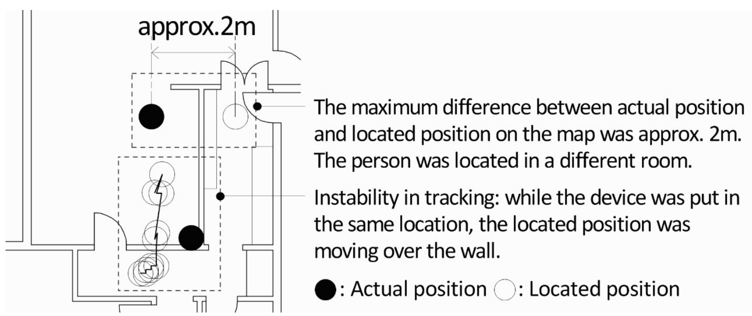

Figure 2: Evaluation of performance in tracking

- **Other:** It was made clear through emails from the supplier that the size of the fingerprinted area is recommended as at least 100 m^2 for better tracking accuracy, which means the test environment as well as most sites for the study might not provide the best results.

3. Discussion: Application of IPS for Spatial-Use Study on Housing for the Elderly

The application of IPS for spatial-use case studies for housing for the elderly is complicated by a complex set of requirements. Evaluation was undertaken through examinations in two phases. Considerations for specific spatial-use in the confined context of housing for the elderly, the possible IPS best suited for this type of study, and the possible improvements are discussed following a comparative analysis.

3.1. Required IPS specifications for the use in the older person's house setting

The performance requirements derive from various features of the setting in a typical elderly person's residence. The system should be able to work in various types of construction types, rather than specific types such as those based on magnetic field, which are only well suited for steel-structure buildings. As a house is typically made up of more than one room, the system should be work in multi-room setting, which is affected by the type of sensor system and systems such as those based on ultrasound are not suitable. There should be consideration of the minimum space the system can perform in, as well as the maximum space. The performance of some systems is compromised in smaller settings. Consideration should also be given to the operability of set-up.

3.2. Required IPS specifications to suit the research design

Research of this nature typically includes many individual case studies. It is desirable for the set-up procedure to take as little time as possible and to be simple enough to accommodate a variety of situations. The devices must allow for repeated use and be easily attached and detached from typical wall surfaces. The iBeacons used for the tests were designed to stick to walls permanently and had the potential to both damage wall surfaces on detachment and subsequently lose the ability to refix to another surface. The system must also permit practical application by the user holding the device. Rigid requirements for use such as being held at the fixed angle in front of the body throughout the survey are not appropriate for this type of study.

3.3. Required accuracy for tracking the movement of the elderly indoors

Tracking the movement of the elderly with limited mobility in the small room in a house requires high degrees of accuracy and stability. The tested system, reported a 2m accuracy; however, the results identified insufficient stability producing false results--detecting movement in an inaccurate direction and locating users in a different room than the one they were in. This level of accuracy, combined with its instability, did not provide useful information for location and movement of a person. Considering the effect of instability/technical error, as high degrees of accuracy as possible would lead to the best results. As such, systems which could provide the accuracy of 1m or less would be required.

3.4. Possible improvements

Systems that meet the accuracy requirements as well as all other requirements for tracking the elderly indoors are scarce. There is need for higher degree of accuracy. Tracking accuracy is greatly affected by any inaccuracy in the configuration of the space during set-up (Accuware, n.d.; Estimote, n.d.). Improvements in accuracy could include improved operability in set-up, enabling configuration of spaces with multiple obstacles, thereby reducing operational errors. The systems which provide high levels of accuracy are characterised by high cost; a reduced cost would widen the application of IPS.

There should be improvements in the device to be held by the people who are tracked, in terms of flexibility in how to wear or carry the device to best suit high-dependency elderly people. For long-duration surveys, consideration should be given to putting it on the wheelchair or putting it in a pocket or a pouch. There should be consideration of the weight of the device; even the weight of smartphones can tire the elderly, depending on how they hold it. Benefits of using smartphones include the improved accuracy by the use of their internal sensors; however, they typically require impractical methods of holding them as well as relatively heavy weight. Lighter devices that provide enough accuracy would be more suitable.

A lack of operator technical knowledge limits the options for types and models of IPS; the systems that provide higher accuracy typically require IT knowledge, such as competency to work with programming languages and modules. Acquisition of specialised knowledge or inter-disciplinary collaboration between teams specialised in the system development and those with other specialities would widen the possibilities application of IPS. There is a product which was not included for comparison in this paper, that is an integrated solution in which the device, software and the service are provided to achieve the implementation, would be ideal; however, at present it is cost prohibitive (over 40,000NZD) (SDR Scientific, 2016).

Some UWB-based systems such as Product D, which can meet all the requirements except for requirement of technical knowledge and the cost, which is slightly above the budget, have possibility to be used in the research, given the reduced cost and acquisition of or support in technical IT knowledge (DecaWave Ltd, n.d.; Pozyx Labs, n.d.).

4. Conclusion

This research has examined the use of indoor tracking systems as an architectural research tool, to investigate the spatial use of the elderly with limited mobility in their house. The research found that there were a complex set of requirements for accurate recording of spatial use and practical application of IPS, which are derived from housing setting, the research design and the required accuracy to track the individual's movements. Careful selection of the IPS to match the specific application is necessary.

Improvements to currently available indoor tracking systems would include improvements for accuracy, operability and cost. These improvements would enhance the potential for using them as part of user focused architectural research in general and provide a more precise and effective knowledge for the design of housing for the dependent elderly.

The limitations of this study include that the physical testing was not conducted for the duration which is required for the real surveys (8 hours), which would have hindered the examination of the aspect of battery consumption of the device. The tracking in the house with interior walls made of concrete or bricks, which would affect performance of some sensor systems, was not considered, because most of the interior wall linings were assumed to be plaster board, softboard or hardboard; however, consideration of the wider variety of wall material types would widen the possibility in application of indoor tracking systems in architectural research.

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