Real-time location systems in nursing homes: state of the art and future applications

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Abstract

Purpose – *In the domain of healthcare, both process efficiency and the quality of care can be improved through the use of dedicated pervasive technologies. Among these applications are so-called real-time location systems (RTLS). Such systems are designed to determine and monitor the location of assets and people in real time through the use of wireless sensor networks. Numerous commercially available RTLS are used in hospital settings. The nursing home is a relatively unexplored context for the application of RTLS and offers opportunities and challenges for future applications. The paper aims to discuss these issues.*

Design/methodology/approach – *This paper sets out to provide an overview of general applications and technologies of RTLS. Thereafter, it describes the specific healthcare applications of RTLS, including asset tracking, patient tracking and personnel tracking. These overviews are followed by a forecast of the implementation of RTLS in nursing homes in terms of opportunities and challenges.*

Findings – *By comparing the nursing home to the hospital, the RTLS applications for the nursing home context that are most promising are asset tracking of expensive goods owned by the nursing home in order to facilitate workflow and maximise financial resources, and asset tracking of personal belongings that may get lost due to dementia.*

Originality/value – *This paper is the first to provide an overview of potential application of RTLS technologies for nursing homes. The paper described a number of potential problem areas that can be addressed by RTLS.*

Keywords *Dementia, RFID, Nursing home, Tracking, Real-time location systems, Track and trace*

Paper type *Conceptual paper*

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1. Introduction

State-of-the-art technologies are available on the marketplace, which tell us our location within narrow margins of error. So-called real-time location systems (RTLS) are applied in a broad spectrum of industries, such as logistics, the food industry, the automotive, aerospace and defence sectors, mining, amusement parks, building and construction, and the retail sector (Malik, 2009; Curran, 2014; Li *et al.*, 2016). RTLS are used to manage the supply chain and monitor inventory (Attaran, 2012), schedule asset maintenance (Roe and Mba, 2009), optimise workflow and processes, increase safety and enhance the customer experience (Malik, 2009). These goals can be achieved by tracking people (personnel, clients and customers) and assets (mechanical parts, packages and equipment).

RTLS have been around for over a decade and found increasing usage in hospital care. Nursing home care is still a relatively unexplored context when it comes to the application of RTLS. In this paper, the potential of the use of RTLS in nursing homes is explored. Existing RTLS applications and technologies are compared to the requirements and opportunities that are identified in the nursing home context. This is done by providing an overview of RTLS, by presenting an outline of

RTLS and their applications in healthcare settings in general, and describing the potential of RTLS for nursing homes by evaluating the processes in nursing homes as well as the needs and challenges of stakeholders.

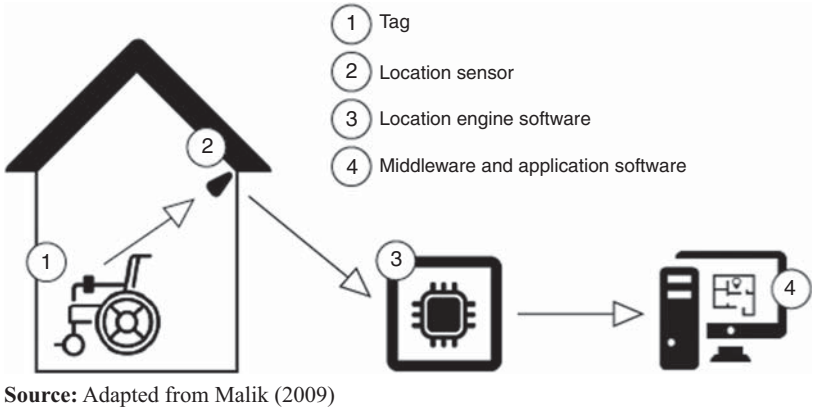
2. RTLS and the technologies used

RTLS make use of physical tags that can be connected to mobile objects or to people, and sensors and digital middleware (i.e. software that acts as a bridge between an operating system or database and applications, especially on a network) to process information in order to locate people or objects in real time. The signals that the sensors send to and receive from the tags are processed by location engine software, which turns the signals into readable information (Figure 1). RTLS can be applied both indoors and outdoors and cover a limited area, i.e., depending on the size and signal strength of the system. By placing location sensors throughout a building on strategic positions, the location of these tags (and thus the person or object) can be determined and communicated in real time.

Radio Frequency Identification (RFID) and Wireless Local Area Networks (also known as WiFi) are at the basis of most commercial RTLS applications (Wang *et al.*, 2013; Kirov *et al.*, 2015). Other solutions are based on infrared (IR), Ultra-Wideband, BlueTooth and ultrasound (Liu, 2007). In practice, a combination of technologies is often applied. Some of these technologies require the installation of new and separate hardware in a building, which increases the overall costs (Krohn, 2008). Every technology has its own set of advantages and disadvantages. WiFi is relatively cheap and easy to install, but the signal can penetrate walls and can, therefore, not be used to locate at room level (Krohn, 2008). IR is suitable for room-level location but requires a clear line of sight from the tag to the sensor (Kamel Boulos and Berry, 2012). Therefore, an environment has to be carefully analysed to determine which technology works for the requirements that are demanded from a system (Fisher and Monahan, 2012).

There are different types of tags used in RTLS, namely passive, semi-passive and active tags. The difference between these tags lies in their ability to transmit signals. Passive and semi-passive tags are not able to transmit signals and can only be detected by location sensors by returning a signal. Active tags are battery powered and actively send information about their location. This gives them a longer detection range than passive and semi-passive tags. Semi-passive tags use batteries too, but mainly for secondary functionalities, such as emergency push buttons, temperature sensors or accelerometers (Malik, 2009). Information from these sensors is included in the data the location sensors receive, and provide additional contextual information, for instance, whether a device is in use. The ability of a tag to transmit signals or collect additional data influences its price. Battery-powered tags require the replacement of batteries on a regular

Figure 1 Visualisation of the working of a real-time location system



Source: Adapted from Malik (2009)

basis, which adds to maintenance costs. There are tags available on the marketplace that only transmit a signal when the tag is being moved, which saves battery power (Shukla *et al.*, 2014). For most applications, the location data do not have to be available 24-7, but only upon request. Often assets are only moved once or a few times a day, or even less frequently. Moreover, tags can be located with different levels of accuracy, from knowing whether a tag is or is not present in a certain area to knowing the exact location of the tag. Different options for locating the tags are: locating at choke points (knowing when a tag passes a door), locating by associating (knowing which tags are close to each other), locating at room level (knowing in which room a tag is), locating precisely (knowing the exact spatial coordinates), and locating at sub-room level (knowing the location of a tag in a smaller area within a room) (Malik, 2009). Strategic placement of the location sensors can optimise the network coverage inside a building (Oztekin *et al.*, 2010; Pietrabissa *et al.*, 2013). In order to determine the position of a tag, various localisation methods are used to determine the distance between the tag and location sensor(s). Subsequently, estimation algorithms calculate the position of the tag (Malik, 2009). More elaborate overviews of RTLS technologies, localisation methods and algorithms are available (Kirov *et al.*, 2015; Liu, 2007; Zekavat and Buehrer, 2011; Goswami, 2012).

3. RTLS: applications in healthcare

Within the domain of healthcare, RTLS are predominantly used in hospitals (Kamel Boulos and Berry, 2012; Fisher and Monahan, 2012), and to a lesser extent in nursing homes (Raza *et al.*, 2013). Within hospitals, RTLS are used to track assets (like equipment, drugs and specimens), personnel and patients (Krohn, 2008; Fisher and Monahan, 2012; Fosso Wamba *et al.*, 2013). The tracking of people is mainly conducted in the USA and not in Europe due to privacy legislation (Ebbers *et al.*, 2017a, b). Within nursing homes, RTLS are mainly used to track residents, for instance, in the case of wandering behaviour. The localisation functionality of such systems is often combined with other monitoring technologies, such as fall detection (Charlon *et al.*, 2013; Doshi-Velez *et al.*, 2012; Lin *et al.*, 2014; Nishimura *et al.*, 2015). Elia and Gnoni (2013) found that numerous RFID projects were undertaken in the healthcare sector, mainly in the domain of asset tracking, as well as patient and staff management. In the following sections, these three applications are described in more detail.

3.1 Asset tracking

Asset tracking is currently the best use for RTLS application in hospitals, because tracking people (staff, patients) leads to resistance and tracking people is often motivated by unconvincing reasons, such as improving efficiency and processes (Fisher and Monahan, 2012). Assets that are being tracked include (medical) equipment and assistive devices like infusion pumps and wheelchairs, and materials and samples, including blood samples, medicines and biopsy specimens (Najera *et al.*, 2011; Iadanza, 2009; Coustasse *et al.*, 2015).

Castro *et al.* (2013) monitored the infusion pump usage in a Dutch hospital, and identified inefficiencies through the use of RTLS, including inventory shortages, asset sub-utilisation, waste of staff time, service delays, maintenance delays and information silos. Using RTLS for equipment tracking may, thus, fulfil various needs. Hospitals own a plethora of different mobile equipment, and these assets are at risk of becoming lost or mislaid. Inventories are often larger than required and some of this equipment remains unused (Najera *et al.*, 2011). Particularly when equipment is shared between different departments, it is not unusual for personnel to "hoard" equipment so they have enough in stock in their own department (Krohn, 2008). Estimates indicate that hospitals purchase an excess of 10–20 per cent mobile equipment than is required for adequate care (Kamel Boulos and Berry, 2012). This results in unnecessary expenses on purchases, renting and maintenance. Another major cause of unnecessary expenditure is theft. Van Lieshout *et al.* (2007) estimated a potential annual loss of $3.9bn in US hospitals due to asset theft. Also, medication, blood samples or blood bags could be tracked. Adding intelligence to these processes can help prevent patients from getting the wrong medication or even faulty blood transfusions (Iadanza, 2009; Coustasse *et al.*, 2015). In the case of medication, theft can also be a problem that is caused by both patients and personnel, for instance, due to substance abuse (van Lieshout *et al.*, 2007).

The deployment of RTLS in hospitals for asset tracking can help maintain an overview of the different mobile assets inside the building and alert technicians when maintenance is due or required (Castro *et al.*, 2013). It can help personnel to quickly locate equipment, and thus ensure improved safety and security in case of an emergency. Asset tracking can increase asset utilisation and decrease costs (Castro *et al.*, 2013; Tzeng *et al.*, 2008). Demircan-Yıldız and Fescioglu-Unver (2015) showed that even in a medium-sized hospital, asset tracking through RTLS can significantly reduce asset-to-patient time and the time staff spend on transferring assets. The less time is spent on looking for equipment, the more time can be spent on patient care. This, in turn, increases the efficiency and quality of healthcare processes (Castro *et al.*, 2013).

3.2 Patient tracking

Using RTLS to track patients can help the optimisation of care processes. First of all, it is important to know where patients are inside a facility. Often nurses and other staff spend time looking for their patients. RTLS can simplify the process of finding and identifying patients and requesting (medical) information (Yazici, 2014). Monitoring patient flows can help improve the services and indicate bottlenecks (Vakili *et al.*, 2015). Furthermore, RTLS can be used to associate and disassociate equipment and devices with a patient (Rezaee *et al.*, 2014). RTLS for patient tracking can enhance patient care by optimising patient flows, prevent medical errors and speed up processes (Tzeng *et al.*, 2008). Especially in nursing homes, RTLS are used to monitor wandering behaviour. By combining RTLS with smart actuators on exits, doors can be strategically and automatically locked and prevent residents from going somewhere that might expose them to risk. Finally, RTLS are useful for identifying whether people have been close to infectious sources, such as other infectious people (Swedberg, 2012).

3.3 Personnel tracking

The third common application is the tracking of staff. Many of the tags that are worn by personnel are equipped with emergency push buttons, which can be used in case of an emergency. In other cases, RTLS are used to monitor the adherence to hand hygiene protocols in order to reduce infection risk (Baslyman *et al.*, 2015). In this case, personnel are monitored or alerted whenever they forget to wash their hands at specified moments. Furthermore, RTLS can be used to monitor whether personnel have been in contact with infectious patients (Swedberg, 2012). RTLS have the potential to improve the productivity of staff by reducing mundane and repetitive tasks, for example, by the automatic registration of a call that has been followed up through the presence of the nurse in a patient room (Kamel Boulos and Berry, 2012). RTLS can be used to assess and optimise workflows. The time spent per patient can be measured and the data can be used to improve the logistics (Shukla *et al.*, 2014; Jones and Schlegel, 2014; Puiatti *et al.*, 2014). Additionally, the analysis of walk-rounds of staff has the potential to improve educative processes within the hospital (Ward *et al.*, 2014). Utilising the system in connection with smart actuators can automatically unlock and open doors when personnel are walking through corridors. However, numerous privacy issues often arise when personnel are tracked (Fisher and Monahan, 2012; Ebbers *et al.*, 2017a, b).

4. Analysis of RTLS applications in healthcare

Many insights can be learnt from existing RTLS projects described in the literature. Insights into the (potential) barriers are of particular interest, which include user acceptance, privacy and security, technical issues, financial aspects, and benefits of the technology (Fosso Wamba *et al.*, 2013; Reyes *et al.*, 2012; Lai *et al.*, 2014; Alemdar and Ersoy, 2010). In addition, there are challenges concerning the vendors of RTLS and the types of technologies they offer, such as off-the-shelf solutions.

4.1 User acceptance

User acceptance of technology is an important factor to consider when implementing RTLS in healthcare. In short, care professionals need to be “on board”, as multiple studies have pointed

out (Fisher and Monahan, 2008, 2012; Castro *et al.*, 2013; Yazici, 2014; Zigman *et al.*, 2009; Bowen *et al.*, 2013). Fisher and Monahan (2008) studied the social dimensions of RFID systems in hospitals. The surveillance possibilities of such systems worried the hospital personnel. Staff experienced an intensified work load because maintaining the system was given as an additional task. In a later study, Fisher and Monahan (2012) found that for a successful deployment many organisational barriers must be overcome, including a lack of clarity about the responsibility of use and maintenance of the system and a general sense of resistance. In one of the studies, tags were sabotaged by personnel because it was believed that their clinical activities were surveyed. Often myths arise about the technology, and the information that is being gathered. Especially nurses are concerned that the technology is designed to track their work habits (Kamel Boulos and Berry, 2012; Bowen *et al.*, 2013). In a study by Bowen *et al.* (2013), both nurses and residents of a long-term care facility were tracked, and both groups developed concerns about the technology. Nurses believed that the frequency and length of breaks were monitored.

Another aspect that influences user acceptance is how well the technology works. Fisher and Monahan (2012) identified underperforming technology as one of the main barriers for successful deployment. Okoniewska *et al.* (2012) found that staff were generally discouraged to use RTLS due to inaccuracies. Yazici (2014) argued that user acceptance is higher when needs on the work floor are understood. The readiness of staff before the adoption of new technologies plays a significant role in how healthcare facilities can benefit from such systems. Zigman *et al.* (2009) emphasised that an effective implementation requires understanding, experience and continuous education of staff.

Some researchers have tried to overcome the barriers posed by poor user acceptance. Guédon *et al.* (2014) presented an RFID-specific participatory design approach in which multidisciplinary user groups were involved throughout the design process. This was an effective approach to implement such RFID technologies. Castro *et al.* (2013) presented a phased implementation of an RFID-based system for asset management that facilitated getting familiar with the system and improved the acceptability.

4.2 Privacy and security

Privacy concerns influence the acceptance of RTLS. When information is collected about the location of a person, secondary information can be obtained, such as how long staff take breaks from work. The tracking of assets can also go together with privacy issues; when a tag is attached to a wheelchair, the location and movement of the user can be determined too (Ebbers *et al.*, 2017a, b). Especially when it comes to people with dementia, it is hard or even impossible to get informed consent required for collecting data. Pervasive technologies can have both beneficial and harmful ethical implications (Detweiler and Hindriks, 2016). Older adults may sacrifice privacy for the sake of remaining independent. When privacy concerns from stakeholders are not properly addressed prior to the implementation of RTLS, staff may refuse to wear the tags or use the system (Kamel Boulos and Berry, 2012). Also, systems should be checked for data security properly before implementation, i.e., that data are not inadvertently or deliberately obtained by an unauthorised individual or organisation. Safeguarding of patient data is a very important obstacle when using RTLS in healthcare (Rosenbaum, 2014). Encryption can help keeping data confidential. An additional challenge is posed by the intrusiveness of visible RTLS. People may only trust non-visible technology because people are unaware of it (Santoso and Redmond, 2015). Several solutions are presented in the literature for overcoming safety, security, privacy and technological issues in relation to RTLS (Najera *et al.*, 2011; Abu Rrub *et al.*, 2012).

4.3 Technical issues

Challenges related to technology may arise when RTLS are implemented. A major problem is that various technologies react differently to particular environments and structures. Every space where RTLS are installed should be evaluated individually (Fisher and Monahan, 2012). Sometimes existing networks in the building are utilised, especially WiFi networks, because this can reduce the installation costs. The quality of the network can be decreased by the

"competition" from other applications using the network, and such systems are often less accurate (Castro *et al.*, 2013). Another technological issue is the interference of the RTLS with other devices (Kapa *et al.*, 2011; Iadanza, 2009; Najera *et al.*, 2011), which is an unwanted side effect in healthcare as it may pose a risk to patient safety.

4.4 Commercial RTLS vendors

Numerous commercial enterprises supply RTLS and accompanying services to healthcare organisations (Krohn, 2008). Off-the-shelf solutions are not the way to achieve successful deployment of the systems. The unique environment of a healthcare facility poses such great challenges, that installing a standard system without properly analysing the environment is not viable (Fisher and Monahan, 2012; Iadanza, 2009). Vakili *et al.* (2015) presented a study on patient flow information in an outpatient clinic that compared a custom-made RFID-based RTLS that requires active swiping by the patient and an IR-based commercially available RTLS. They found that both systems were effective in providing patient flow information and were equally accurate. The custom-made RFID-based RTLS were installed at only 10 per cent of the costs.

5. RTLS applications in nursing homes

The majority of the existing RTLS projects in the domain of healthcare are used in the hospital environment. There are essential differences between hospitals and nursing homes in terms of processes and procedures. In the following paragraphs, the differences between the two context are explored, and current RTLS projects in nursing homes are reviewed.

5.1 Character of hospitals vs nursing homes

Hospitals mainly focus on "cure" and the treatment of patients, nursing homes mainly focus on "care" and have a residential model. The majority of hospital patients stay for a short period of time, usually a few hours to a few days. In nursing homes, residents stay for a prolonged period of time, often months or years. Residents live in the nursing home and are tenants of their own room. Many residents cope with dementia. Whereas hospitals deal with a daily, dynamic patient flow of varying individuals, the nursing home population is well known by staff members.

In both contexts, professionals (including nursing aides and medical doctors) are the main users of care and medical technologies, ranging from expensive, high-tech systems used in operation theatres, to patient hoists and wheeled walkers in nursing homes. There are substantial differences in how accustomed staff are to the use of technologies, which impacts the design of RTLS in terms of interface design, level of complexity, legibility and the functionalities of the system. Hospitals often have highly organised support systems including technicians, ICT support, and sophisticated logistics in comparison with nursing homes. In the case of the Netherlands, there is an increasing amount of outsourcing of such services in nursing homes, which results in an ever-increasing gap between technical support in both contexts. Moreover, hospitals have a much larger gross surface area than nursing homes.

In hospitals, all assets are owned by the hospital organisation itself or leased from specialised companies, apart from some small personal items brought along by the patient or staff. In nursing homes, most of the items inside private rooms are physically owned by the residents. Care technologies and the furniture inside communal living areas are mainly owned by the nursing home organisation.

5.2 Current RTLS in nursing homes

RTLS are used for two main purposes in nursing homes: to ensure the safety of residents and to support personnel in (efficiently) caring for the residents (Charlon *et al.*, 2013; Doshi-Velez *et al.*, 2012).

Risky wandering behaviour is managed by tracking the location of residents and preventing them for wandering off too far, exiting or accessing restricted areas. This can be done by

triggering a nurse call or in combination with automated (un)locking of doors. Doshi-Velez *et al.* (2012) tracked residents in a residential care setting with an RTLS system. The system increased the safety by alerting when residents left the building, and the operational efficiency due to decreased search times. The average searching time went down from 311 to 111 seconds. Tags for people with dementia can be designed as wearables like shoes (Nishimura *et al.*, 2015), incorporated in wristbands (Bowen *et al.*, 2013) or worn on the body (Charlon *et al.*, 2013). Smartphones are gaining popularity when it comes to the location of older people (Zhao *et al.*, 2012; Casilari *et al.*, 2015), and even real-time communication between staff and residents can be established through these tags (Yu *et al.*, 2015). However, Santoso and Redmond (2015) advocated that people with dementia cannot be expected to wear any tags independently.

Most available studies on RTLS in nursing homes focus on tracking residents and staff, rather than on asset tracking. The present application of RTLS in nursing homes stays limited to the improvement of safety of residents and carers, not the efficiency of workflow, minimising of financial losses and inventory inefficiencies.

6. Future applications of RTLS in nursing homes

This section provides an overview of how nursing homes can benefit from RTLS applications. In addition, new applications are presented for tracking assets, residents and personnel (Table I).

6.1 Tracking residents

As stated before, RTLS can be a valuable means of detecting wandering and can be linked to automated doors, depending on the location of residents and their personal accessibility profiles. This provides a greater sense of freedom and independence. Current RTLS applications are still rather linear in the utilisation of location information. Kamel Boulos and Berry (2012) proposed an application of resident tracking where the mobility (such as daily distance walked) of the residents is monitored. This can inform carers about the mobility and well-being of the residents. Such a system can also be used to detect whether residents have left their room or visited the toilet. When data collection takes place in an unobtrusive, non-invasive way, in the home environment that is considered to be a safe haven, one might forget about the implications of data collection and transmission (van Hoof *et al.*, 2007).

Table I An overview of the potential benefits of tracking residents, personnel and assets for different stakeholders in nursing homes

Tracking of	*Stakeholders*	*Potential benefits*
Residents	Residents	Safety by preventing wandering and elopement
		More independence due to remote monitoring
	Staff	Efficiency in healthcare processes: not having to look for residents long
		Data on well-being of resident (such as mobility)
Personnel	Staff	Automation and optimisation of processes
		Eliminating bureaucratic tasks
	Residents	Personnel have more time left to spend on care
Assets owned/rented by nursing home	Staff	No incentive for hoarding
		Decreased search time for assets
	Management	Better insight in asset utilisation
		Lower costs for (rental) equipment
	Technical staff	Better insight in asset utilisation
		Maintenance can be done more efficiently
Assets owned by resident	Residents	Not having to replace expensive medical aids
		Decreased stress/emotional strains caused by the loss of personal items
	Relatives	Not having to replace expensive medical aid
		Decreased search times
	Staff	Increased efficiency of processes

6.2 Tracking personnel

In the nursing home, the most important opportunity for tracking personnel is in efficiency and optimising processes. Some processes can be automated, for instance, the registration of answered nurse calls, the work time registration and registration of the time spent per resident. This may alleviate staff from doing administrative tasks and increase the time they can spend on actual care and social interaction.

6.3 Tracking assets

Figure 2 describes the different types of assets that can be found within the nursing home, which are either owned by the nursing home or by residents (van Hoof *et al.*, 2016).

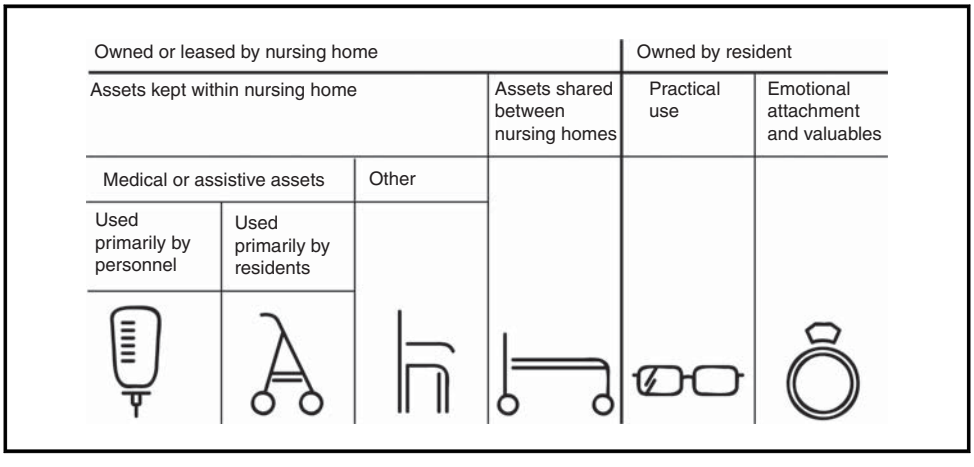
6.3.1 Assets owned by nursing home. There are numerous assets that are either owned by the nursing home or leased for an extended period of time from specialised vendors, including medical and assistive devices, and furniture. Sometimes, equipment is "hoarded" by personnel in order to have enough items in stock, equipment gets mislaid for a longer period of time, or residents and their relatives are the cause of objects becoming lost, for instance, residents taking wheelchairs that are not theirs, or relatives bringing chairs from communal living rooms into private rooms without returning them (van Hoof *et al.*, 2016).

Tracking assets owned by the nursing home has organisational benefits, resulting in more efficient workflows for personnel and lower (rental) costs for equipment if smaller stocks are needed due to better traceability. Furthermore, it allows care organisations and enterprises alike to benefit from user data. If information is available on how often and how intensively a bed, hoist or wheeled walker is used, these data show how equipment is being used, whether staff comply with occupational and safety regulations, and when maintenance is required. In addition, RTLS could allow for a better and more balanced use of equipment. When maintenance or repair workers arrive, they also know where to find the equipment they need to work on.

In the Netherlands, most nursing homes are part of a large organisation comprising many smaller homes on different locations. These locations share highly specialised equipment, including modified walkers and medical beds. In practice, the location of such equipment is unclear, and when the item is needed by a carer, the search is on in order to retrieve the object. An RTLS solution that can indicate whether or not an object is present in a building could make this process more efficient.

6.3.2 Assets owned by residents. Van Hoof *et al.* (2016) described a large number of goods that go missing in Dutch nursing homes, and described the problems associated with searching for the items Some of the objects that get lost are not only dentures, glasses and hearing aids, but also more personal and irreplaceable items, like jewellery, disappear. These personal belongings

Figure 2 Overview of types of assets that are found within the nursing home



may get lost during laundry by commercial laundry companies or are accidentally thrown away. In the case of hoarding behaviour, things may be hidden or stored away in bins, garbage bags and other containers that are disposed of without notice.

Again, search time for these items reduces the time staff can spend on care for the residents. Also, relatives and residents have to spend time searching, which is a source of stress and tensions. Older individuals can be particularly affected when items get lost, and one has to deal with the financial consequences when expensive aids need to be replaced. Tracking personal items could be done with different levels of accuracy, depending on the goal. When the items need to be found back in a room, then the systems need to have a high level of accuracy, but when the goal is to prevent expensive medical aids like dentures from being thrown away, it suffices to get an alert when the object leaves the building. A related problem that can be addressed is that one resident may take another resident's dentures and wear them like if it were her/his own. These dentures do not fit well, and this can remain unnoticed for a prolonged period of time. The same may occur with other personal items.

7. Future developments and conclusions

The design of RTLS for nursing homes requires a study into future systems and services. Santoso and Redmond (2015) predicted unobtrusiveness, inexpensive and simple indoor positioning systems that will no longer be based on tags and sensors that have to be worn by clients. Instead, the building itself and its infrastructures will monitor the people inside. The use of smartphone applications in relation to real-time monitoring of people and items is expected to become more dominant (Li *et al.*, 2016; Lopes *et al.*, 2014). Such approaches could potentially enhance the ease of use, as smartphones are familiar and frequently used devices. The size of tags is currently still rather bulky. Madrid *et al.* (2012) conducted a study in which RFID tags were successfully placed into artificial dentistry. Such technology takes away the need for carving names into the dentures for identification. The design of body-worn RTLS requires the active involvement of end-users in the actual design process in order to make the devices as acceptable as possible (Oude Weernink *et al.*, 2017). Instead of needing separate tags, all future medical assets may have integrated tags. Nowadays, active and semi-active tags still need battery power in order to be operational, and wireless charging possibilities may offer a solution to this problem.

This article provided an overview of potential RTLS applications for the nursing home context, of which asset tracking of expensive goods owned by the nursing home, and asset tracking of personal belongings are the most promising. The applicability of RTLS in nursing homes can also be extrapolated to other settings, such as residential care homes, provided that the scale of such homes facilitates the installation of infrastructures and devices.

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