Code

Real Time Asset Tracking in Hospital Care

Robert Wendlandt[1]
Jörg Schroeter[2]
Friederike Mathiesen[3]

Introduction

HealthCAT (https://healthcat.eu) is a German-Danish partner project developing the prototype of a robot, which takes on specific tasks in health care departments. The development is carried out in close collaboration with nursing institutions in order to ensure safety and use in everyday life. The task focus of nursing staff is thereby re-directed towards the most important aspect: the people.

In the first project phase, an in-depth needs analysis - published in Danish (https://www.healthcat.eu/wp-content/uploads/2019/06/HealthCatWP3_Public-Danish_2018.pdf) and German (https://www.healthcat.eu/wp-content/uploads/2019/06/HealthCatWP3_Public_German_2018.pdf) - identified two major use-cases of robot technology in the healthcare sector that were addressed in the second phase of the project: **transporting small equipment** and **finding large equipment**.

This report summarizes the results of the development and testing of the Real Time Localization System (RTLS) addressing the use case of **finding large equipment**.

Project funding

HealthCAT is supported by Interreg Germany-Danmark with funds from the European Regional Development Fund. Learn more about Interreg Germany-Danmark at www.interreg5a.eu (www.interreg5a.eu).

Funded by

Motivation

In both nursing homes and hospitals, time and energy is needed to locate equipment and other aids and transport them between patients. This is more than just a narrative of caregivers, as confirmed by a literature survey. Ersol and Fescioglu-Unver (2017) report a span of 7 - 15 minutes to locate a device in a ward and bring it to the patient where it's needed. In total, direct patient care is only 19% - 37% of a nurse's shift (Hendrich (2008), Westbrook et al. (2011), Desjardins et al. (2008), Desjardins et al. (2008), Higgins et al. (2017)). Creating technical means to allow nurses to focus on their most important task - caring for the patients' needs - is the motivation for the research project HealthCAT.

Aim of this report is to describe the evaluation of a Real Time Localization system (RTLS) for equipment in a hospital or care facility environment.
The RTLS is based on Bluetooth beacons attached to assets to be located with room-accuracy. The beacons are being tracked by receivers fixed in the different rooms of the ward and the hallway. Data from the receivers is being transmitted via Bluetooth Mesh to a central computer finding the current position of the individual devices.
By using Bluetooth Mesh for communication, the system is independent from the available infrastructure and communication means and thus is easily deployable.

Field Test of the Real Time Localization System

Introduction

To evaluate the performance of the Bluetooth Mesh based system for localization of assets in clinical use, a field test was conducted at the University Medical Center Schleswig-Holstein (UKSH), Campus Lübeck.
After brief training for the function of the system and the layout of the ward, the subjects were asked to move from room to room and presented with the task to

retrieve different assets (e.g. wheelchair or stretcher) that were located somewhere on the ward. The time from giving the assignment until return with the asset were recorded and analyzed.
During the trial the assets were rearranged randomly and marked being in-use or free by the test team.

Materials and Methods

Ward

The field test was conducted on a clinical ward currently not in use at the University Medical Center Schleswig-Holstein, Campus Lübeck (see Fig. 1).
Patient rooms are shown in green, ward rooms in purple, storage rooms in brown and the hallways in white. Rooms with an orange color are inaccessible, elevator are shown in blue and stairways hatched blue.
In total 14 patient rooms, two storage rooms, four ward rooms and 7 hallway segments were fitted with infrastructure nodes connected to plug-in power supply units or USB powerbanks to supply the nodes during the test. Two gateway nodes were deployed (in rooms R262 and R229) that were connected to a raspberry pi microcomputer dispatching the messages from the Bluetooth mesh-network to a MQTT server for evaluation.

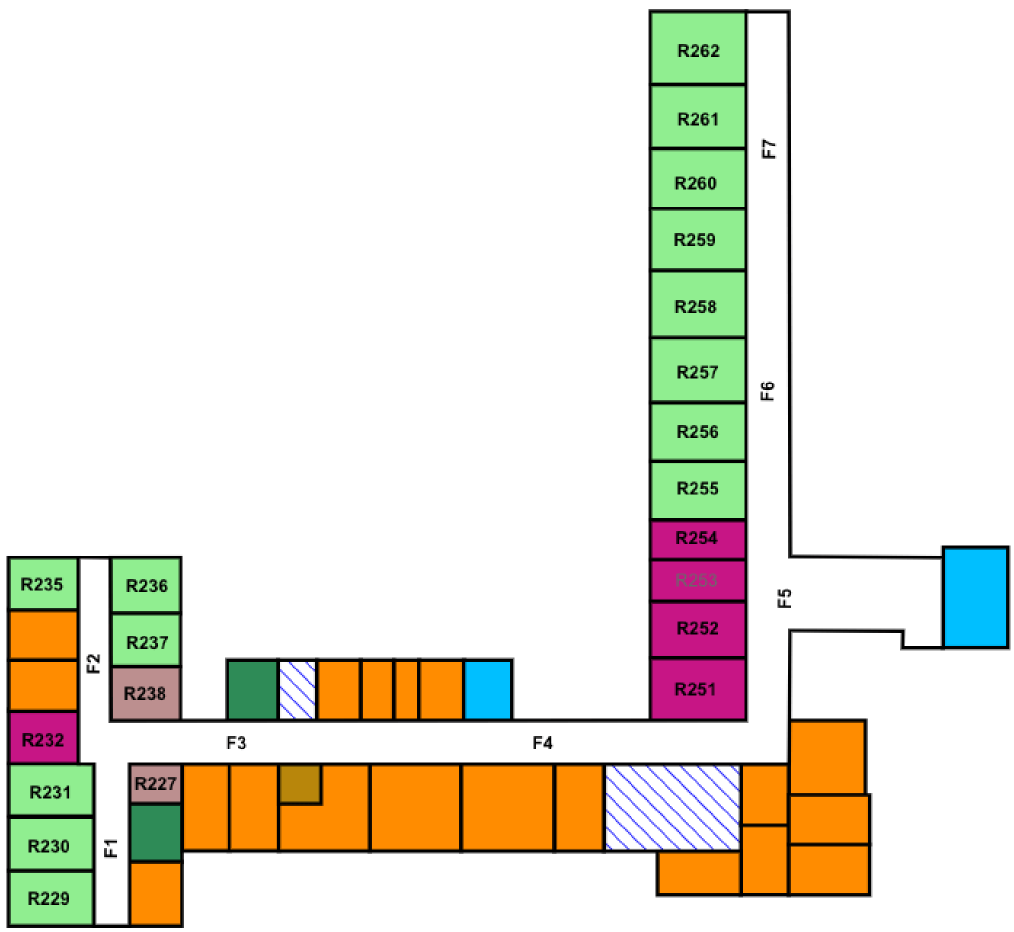


Fig. 1: Map of the test site

A total of 20 assets (see Fig. 2) were distributed throughout the ward and one additional asset was used to track the current position of the subject.
Following assets were for the test:

- 1 ECG device
- 1 Contraction recorder
- 1 Ultrasound device
- 4 Stretchers
- 4 Wheelchairs
- 4 Commode chairs
- 3 Rollboards
- 2 Rollators

The “rare” devices (ECG, contraction recorder and ultrasound device) were located in room 251. After being moved by the test subject they were returned by the test team. The other assets were spread over the complete ward at random.

Fig. 2: Assets on the hallway

Participants

The field test was conducted by two study nurses of the Clinic for Orthopedic and Trauma Surgery of the UKSH, Campus Lübeck who have several years of experience in patient care, and 3 scientific employees.

Technical aids for localization

To evaluate the effect of different user interfaces for the nurses using the system, four different cases were evaluated. The first three tests per subject were conducted with different technical aids for localization and finally without any aid.

Interactive Map

In the first test run, an interactive map was presented to the subjects (see Fig. 1) on a tablet computer (see Fig. 3) that was moved to the respective room were the assignment was given.

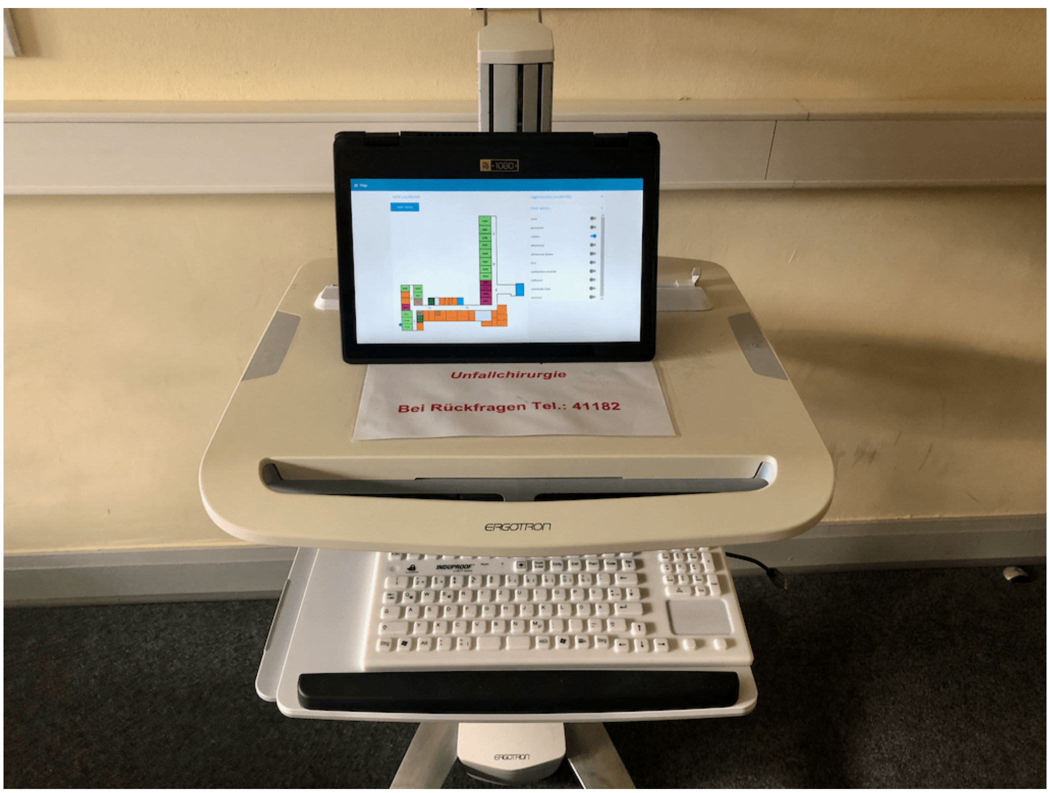


Fig. 3: Tablet computer showing the interactive map

The type of asset to be located is selected via touch input and shown as a blue pin on the map (see Fig. 4).

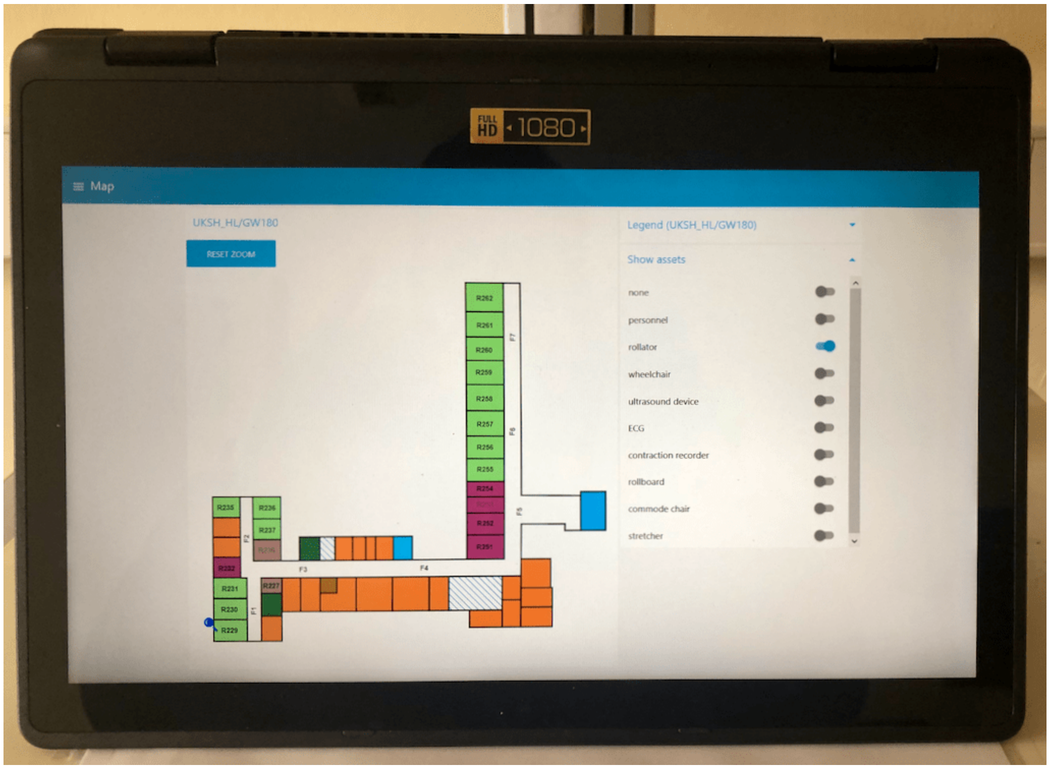


Fig. 4: Blue pin is indicating the position of available assets (here of type rollator in the lower left corner)

Web app

For the visualization of the device position and status, a web app was developed by macio GmbH (Kiel). A list of the available classes of devices is shown on the screen of the mobile device. After selecting a device class, a list of the individual items is shown and device status (free of in use) as well as the room of the device is given.

A screenshot of the mobile phone running the web app is shown in Fig. 5.

Before the test, the mobile phone was handed to the subject. After the specific task was presented, the subjects identified the next free device and started fetching it. Time from handing of the task until returning with the device was measured.

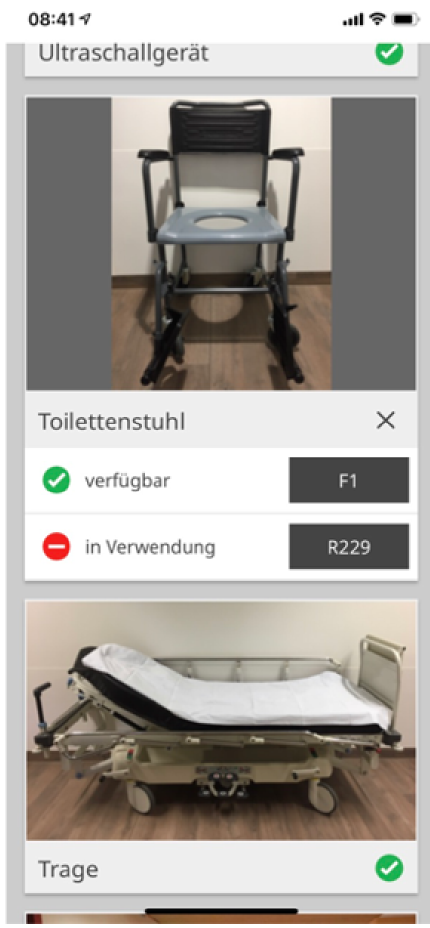


Fig. 5: Web app running on the mobile phone

Native App

Similarly to the web app above, a native app was created using the react-framework Expo (https://expo.io/). The code is available at github (https://github.com/soylentOrange/Assetfinder-expo). Differing visually only in details from the web app, a technical difference is the self-locating capability of the device. Using this feature, the device overview directly shows the next free device. A further touch still reveals the detailled list of all of the individual items.
A screenshot of the mobile phone running the app is shown in Fig. 6.
The test procedure was identical to the trial with the web app: The mobile phone was handed to the subject before the test. After the specific task was presented, the subjects identified the next free device and started fetching it. Time from handing of the task until returning with the device was measured.

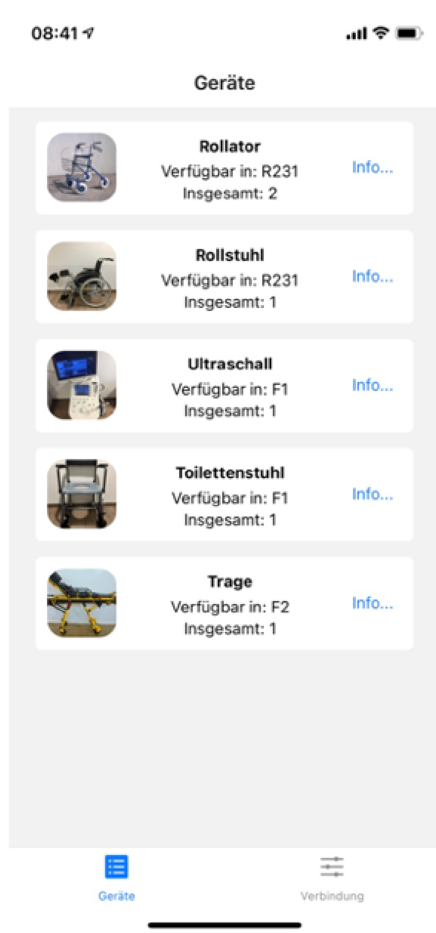


Fig. 6: Native app running on the mobile phone

Without technical aids

The last run of the trial for the subjects is the usual clinical procedure - without technical aid.
After handing the task to the subjects, they started searching for the device on the ward and inside the different rooms until it was found and returned to the starting room.

Recorded Data

For each of the test runs of the subjects, starting room and device to be found was set prior to the test. Using a stopwatch the time from giving the assignment until the subject returned with the item was recorded.
Additionally, a feedback of the subjects regarding the overall degree of satisfaction with the localization systems and their personal preference was surveyed after having finished the tests.

Results

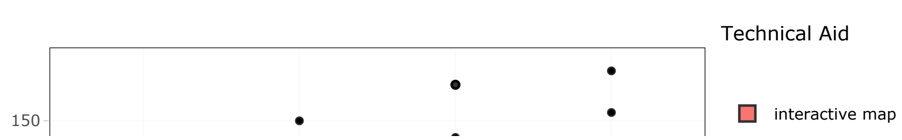
Time to retrieve devices

The median and mean time to retrieve devices by the subjects is given in Tab. 1

Tab. 1: Time to retrieve devices by technical aid

	interactive map (N=70)	web app (N=70)	native app (N=70)	none (N=70)
time (in s)				
Median (Range)	38.0 (2.0, 140.0)	44.0 (12.0, 150.0)	42.5 (6.0, 163.0)	31.5 (8.0, 168.0)
Mean (Std. Deviation)	42.7 (26.8)	50.0 (30.2)	49.6 (32.4)	46.7 (35.7)

A boxplot of the time to retrieve devices by technical aid used is given in Fig. 7



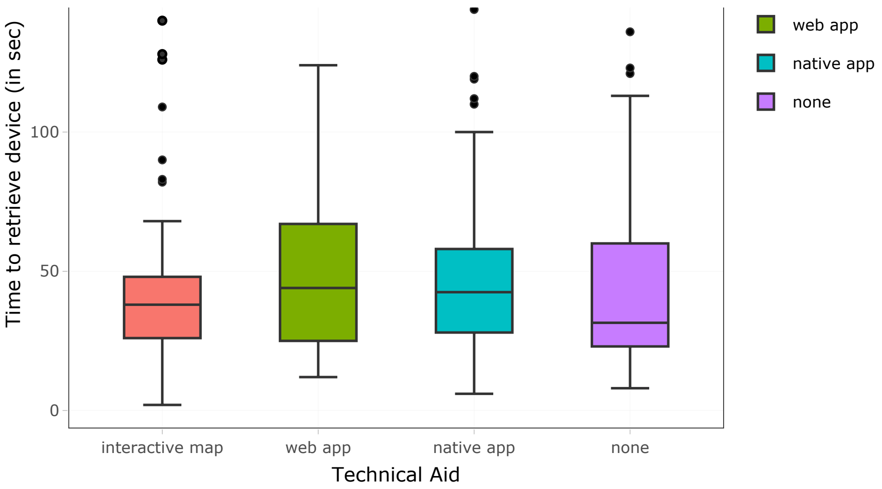


Fig. 7: Time to retrieve devices by technical aid

A robust ANOVA (with a trimming of 20% to exclude possible outliers - ref. Love and Mair (2018) and Mair and Wilcox (2020)) is not showing a statistically significant difference between the technical aid used for localization.

Tab. 2: Robust ANOVA of time to retrieve devices by technical aid

Factor	F	p-Value
technical.aid	1.4142	0.24396

Different factors might affect the time to complete the task.
A kernel density plot of the time to retrieve devices is given in Fig. 8 and a kernel density plot of the time to retrieve devices by the subjects is given in Fig. 9.

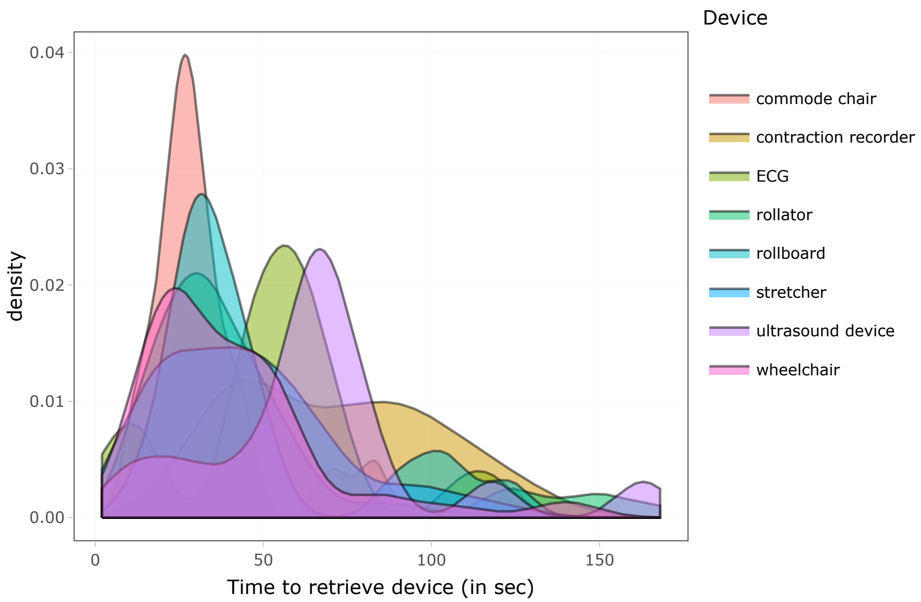
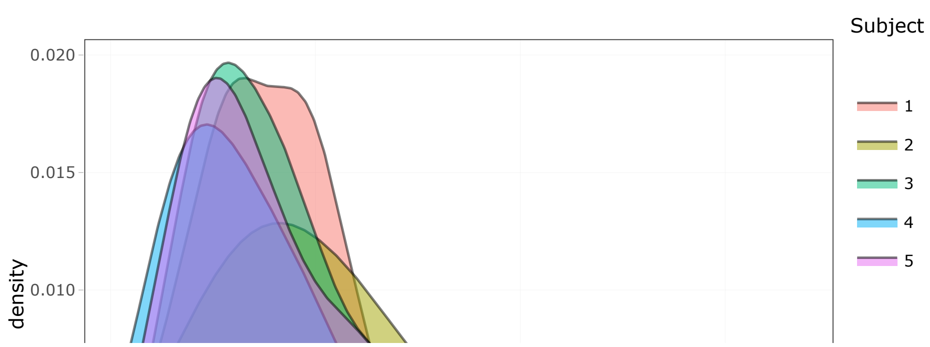


Fig. 8: Time to retrieve devices by device



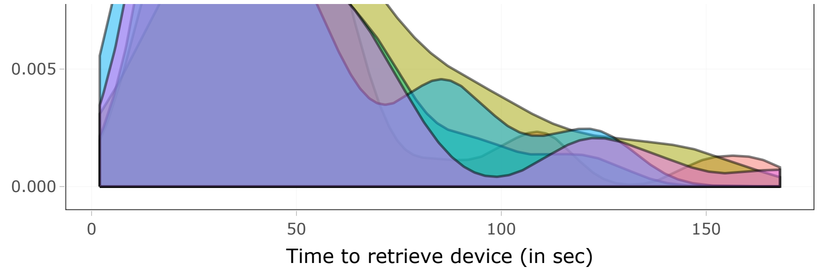


Fig. 9: Time to retrieve devices by subject

A robust two way ANOVA (bootstrapped with a trimming of 20% to exclude possible outliers - ref. Love and Mair (2018) and Mair and Wilcox (2020)) shows a higher effect of the subjects having participated in the trial than the technical aid used for localization (see: Tab. 3) as well as a significant effect of the device on the time to complete the task (see: Tab. 4).

Tab. 3: Robust ANOVA of time to retrieve devices by technical aid and subject

Factor	**p-Value**
technical.aid	0.47913
subject	0.10851
technical.aid:subject	0.68614

Tab. 4: Robust ANOVA of time to retrieve devices by technical aid and device

Factor	**p-Value**
technical.aid	0.69115
device	**< 0.0001**
technical.aid:device	0.9182

A robust linear model of the time to retrieve a device is given in Tab. 5.
The device specific effects are clearly visible, the “rare” devices (i.e. ECG, contraction recorder and ultrasound device) significantly increase the time required to bring the devices. A small but still significant effect is present for the stretchers that were genrally located in front of room 252. The subject specific effect seems to be attributed to subject 2 (see also Fig. 9) with a significantly longer time of ~9 seconds compared to subject 1 and slightly more compered to the other subjects.
Considering the different technical aids being used in the test run, the interactive map seems to be the quickest way of localizing and returning devices. The search without technical aid marginally slows it down by only 1/2 second. Further increase of the required time is visible when using the apps on mobile devices, with a significant increase in required time when using the web app.

Tab. 5: Robust linear model of time to retrieve devices

.	**Estimate**	**Std. Error**	**Lower 95%**	**Upper 95%**	**p-Value**
(Intercept)	28.21	4.776	19.957	36.586	**< 0.0001**
technical.aidweb app	7.248	3.598	0.505	14.708	**0.04499**
technical.aidnative app	5.655	3.611	-0.907	12.784	0.11849
technical.aidnone	0.553	3.611	-5.795	8.816	0.87837
devicecontraction recorder	36.357	5.876	20.969	55.64	**< 0.0001**
deviceECG	19.58	5.73	7.391	30.091	**0.00073**
devicerollator	6.293	4.361	-1.256	14.022	0.15018
devicerollboard	10.653	5.881	1.654	26.042	0.0712
devicestretcher	11.053	4.775	1.622	19.527	**0.02141**
deviceultrasound device	34.516	6.357	18.677	47.519	**< 0.0001**
devicewheelchair	5.21	4.301	-1.702	12.272	0.22686

.	Estimate	Std. Error	Lower 95%	Upper 95%	p-Value
subject2	8.819	4.119	-0.37	19.942	**0.03316**
subject3	-1.649	3.986	-8.331	5.78	0.67954
subject4	-4.378	4.042	-12.481	4.296	0.27969
subject5	-3.119	4.014	-10.253	4.616	0.43777

Summary and discussion

The aim of the test was to evaluate a real time localization system that is tracking various devices on a ward in a hospital.
The test was carried out on a ward at the University Hospital Schleswig-Holstein, Lübeck Campus, which is not currently in clinical use. A total of 14 patient rooms, two storage rooms, four ward rooms and 7 corridor segments were equipped with the infrastructure nodes. In order to be able to record all data, two gateway nodes were installed at the respective ends of the L-shaped ward. The study was conducted with five subjects, two of whom were long-term experienced nurses. The primary objective of the study was to record the time required for the subjects to locate a number of different devices on the ward and return them to the starting point. There were a total of 20 different devices in eight categories randomly distributed on the ward. During the test run, the position of devices was changed by another staff member and devices were marked as “free” / “occupied”. The test was performed by each subject four times, once each with an interactive map display of the position of the searched objects, the web app on a cell phone, the native app on a cell phone, and finally without technical support.

On average, a time of 42 to 50 seconds was spent searching for the devices. The statistical analysis generally could not provide evidence of superiority of the technically supported search. Only a minor, non-significant improvement when using an interactive map was identified. The apps seem to increase the time required to find and bring the devices.

On the other hand, the survey of the test subjects showed that the technical support was perceived as a help during the test. In contrast to the search without technical aids, where room by room was walked, the technical aids show a target for the search.

As a limitation, it should be noted that conducting the test on the ward that is not in active operation is a stronger deviation from the usual clinical routine than originally assumed. The absence of “distraction” by patients and colleagues, and also the unhindered visibility into each of the rooms of the ward, leads to rapid success of the search. In contrast to the times of less than one minute we found, the literature reports search times of about 7-15 minutes (Ersol and Fescioglu-Unver (2017)).

In general the technical system was functional yet still at the edge of the technical feasibility of our implementation. The Bluetooth Mesh network has severe limitation of bandwidth and packet throughput. Our implementation used a scanning windows of 20 ms resulting in a maximum of 50 packets per second. Surpassing this limit, resulted in unstable network conditions and sometimes complete network failures. Routine use of a Bluetooth based RTLS might require traffic reducing strategies while reporting the positions of the devices in order to work reliable or network techniques with higher bandwidth (e.g. WIFI mesh or thread network).

Appendix

Raw Test data

Download raw test data of the field test (Excel file) (data:application/vnd.openxmlformats-officedocument.spreadsheetml.sheet;base64,UEsDBBQABgAIAAAAIQBi7p1oXgEAAJAEAAATAAgCW0NvbnRlbnRfVHlwZXNdLnhtbCCiBAIooAACAAAAAAAAAAAAAAAAA

Evaluation Script

Download Evaluation script (R Studio Markdown) (data:text/x-markdown;base64,LS0tCnRpdGxlOiAiUmVhbCBUaW1lIEFzc2V0IFRyYWNraW5nIGluIEhvc3BpdGFsIENhcmUiCmF1dGhvcjoKICAtIFJvYmVydCBXZW5kbGFuZHReW1VLU

Report created with:

- R, Version 4.0.3, R Core Team (2020)
- RStudio, Version 1.3.1093, Ushey et al. (2020)

Packages used:

- tidyverse, Version 1.3.0, Wickham (2019)
- magrittr, Version 2.0.1, Bache and Wickham (2020)
- readxl, Version 1.3.1, Wickham and Bryan (2019)
- knitr, Version 1.30, Xie (2020)
- kableExtra, Version 1.3.1, Zhu (2020)
- rmdformats, Version 1.0.0, Barnier (2020)
- plotly, Version 4.9.2.1, Sievert et al. (2020)
- arsenal, Version 3.5.0, Heinzen et al. (2020)
- captioner, Version 2.2.3, Alathea (2015)
- walrus, Version 1.0.3, Love and Mair (2018)
- WRS2, Version 1.0.3, Mair and Wilcox (2020)
- scales, Version 1.1.1, Wickham and Seidel (2020)

- bestNormalize, Version 1.6.1, Peterson (2020)
- rstatix, Version 0.6.0, Kassambara (2020)
- knitcitations, Version 1.0.10, Boettiger (2019)
- MASS, Version 7.3.53, Ripley (2020)
- clickR, Version 0.5.27, Ferrer and Marin (2020)

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1. UKSH, Labor für Biomechanik, robert.wendlandt@uksh.de (mailto:robert.wendlandt@uksh.de)↩

2. UKSH, Labor für Biomechanik, joerg.schroeter@uksh.de (mailto:joerg.schroeter@uksh.de)↩

3. UKSH, Labor für Biomechanik, thyra.mathiesen@gmail.com (mailto:thyra.mathiesen@gmail.com)↩