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Monitoring the movement of housed animals by means of wireless technology

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Abstract: Currently, several, more or less, suitable means for detecting, identifying and monitoring the position of housed animals exist. However, these means suffer from various limitations, which could be eliminated with regard to the current technical and technological possibilities. One possible solution could be the use of some wireless technologies from the Internet of Things (Wi-Fi, Bluetooth, Zigbee, etc.). The uninterrupted supervision of individual housed animals would bring important information about the daily routine of individuals and then, based on the deviations from this daily routine, the opportunity to derive their physical and mental state from these deviations would be potentially possible. This article presents a proof of concept of a low-cost monitoring system of the movement of housed animals. The proposed system is able to detect the client's (prototype's) position in the space by means of Wi-Fi (IEEE 802.11 standard) and received signal strength indication (RSSI) technologies. A fingerprint method and a triangulation method of analysing the space are used to calculate the position in space with a resulting accuracy within metres of the real position.

Keywords: animal health; IoT; positioning system; tracking; triangulation; Wi-Fi

The first, oldest and most frequently used marking method is the use of ear tags. The data obtained are based on accidental observations or from the repeated interception of the animal. In this application, a large number of individuals must be tagged to increase the amount of recovered data (Jarolímek et al. 2012).

The second method is radio telemetric observation. This is a time-consuming process (Jarolímek et al. 2012), which uses active RFID (radio frequency identification) transponders and gates basically composed of an antenna, a reader, and a power supply. Such a conventional system combines a coherent receiver and an antenna field, resulting in high complexity on the reader side. The accuracy of this method depends on the number of individual observations, which are recorded only when an animal passes through a gate (Eberhardt et al. 2015).

The third method consists in fitting an animal with a global positioning system (GPS) collar using a global mobile communication system (GSM). The data obtained are then most often transformed into a geographic information system (GIS) (Halbich and Vostrovský 2011; Jarolímek et al. 2012). This method is often applied in connection with a radiotelemetry method (Zviedris et al. 2010; Ascher et al. 2016). However, it is not suitable for use in interiors due to the shading of the locators by building structures (Chen et al. 2021).

A method using Wi-Fi could then be a more suitable technology, which is generally widespread and easily available in interior areas. Wi-Fi-based

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localisation systems can generally be divided into three categories: fingerprint-based (Xiong and Jamieson 2012), angle-of-arrival (AoA)-based (Xiong et al. 2000) and time-of-flight (ToF)-based (Bahl and Padmanabhan 2000). The fingerprint-based method is a solution based on received signal strength indication (RSSI) reading from multiple access points (APs). The AoA-based technology needs, for localisation, to synchronise information about the angle from more APs, which leads to increased localisation accuracy, but demands higher computing power. Localisation based on ToF is popular with the ultra-wideband (UWB) technology, but not with Wi-Fi due to its narrow Wi-Fi channel bandwidth (Xiong et al. 2015; Vasisht et al. 2016).

Wi-Fi fingerprinting creates a radio map of the area based on RSSI reference values. These values are compared with the values measured during passage, subsequently determining the closest match. The task of the Wi-Fi triangulation is then to map the RSSI as a distance function. This method requires a steep characterisation curve to be properly implemented. The function describing this curve is then used with real RSSI values at the input to generate the position prediction (x, y). Therefore, fingerprinting creates a signal force database for the area. The triangulation subsequently maps the signal strength as a distance function (Navarro et al. 2010; Jiangfan and Yanhong 2012).

The application, as such, consists of hardware components with a program that records the transmitter signal intensity – in this case, using AP devices. The measured intensity is sent to the application, which is specially designed for this implementation. The program operates on the application layer with the task of processing the measured data that are recorded into the database and then it performs their presentation on a plan of the monitored area. This application brings the possibility of the continuous monitoring of animals. At the same time, these data can be analysed to determine the health and condition of the monitored individuals (Tremetsberger et al. 2019). Additionally, for analysis and predictions, the use of neural networks is suitable, to which the database output of the implemented program can be submitted as a learning dataset, therefore, a structured dataset (Meena and Loganathan 2020). The significant advantage of this application is the possibility to use the existing Wi-Fi technology, which is characterised by low acquisition and operating costs. The main objective of this article was to design, implement and test a system for detecting the position of individual housed animals, at a minimum cost of the implementation, integration, and subsequent operation of the system.

MATERIAL AND METHODS

The presented system for monitoring the positions in a building consists of three main parts, which are: the client (prototype), Wi-Fi access points (TP LINK TL-WA801ND) and the server part (synology RT2600ac and synology DiskStation DS218). The designed prototype, seen in Figure 1 (block diagram in Figure 2), is comprised of the following components: a voltage source (4 × 1.5 AA batteries), a voltage converter from 5 V to 3.3 V, an IC2 voltage stabiliser and a programmable Wi-Fi module ESP 8266.

The ESP 8266 module itself operates on a voltage of 3.3 V, which is why the voltage is reduced using the IC2 voltage converter. In order to reduce the cost and energy intensity of the device, the original ESP module firmware was reprogrammed to automatically measure the power of the access points in the area and to send the data obtained via the Wi-Fi network (synology RT2600ac router) to the server (synology DS218), where the subsequent processing is carried out, see Figure 3. An AMS 1117-5 V voltage stabiliser was used for the stable data transfer to the server and the stable measurement of the signal strength, which the voltage stabiliser is able to manage the peak

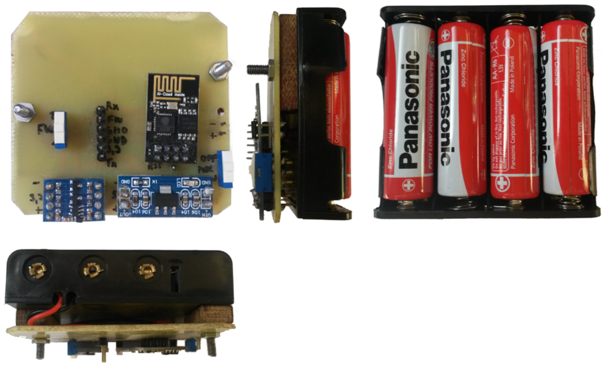

Figure 1. Designed prototype

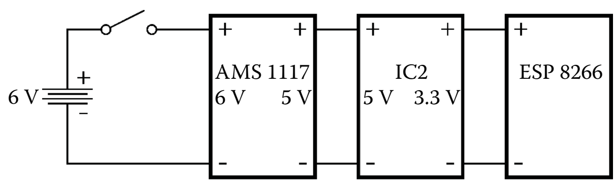

Figure 2. Designed prototype – block diagram

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currents up to 800 milliamperes. The individual phases of the client position (of the prototype) and system development methodology are described below.

At the CULS laboratory of computing applications, on the 8th and 9th of November 2019, the signal strength was measured depending on the distance and the direct visibility of the client (prototype) from the access point (TP Link TL-WA801ND). The measurement was carried out in the interval <0.5; 30 m> from the transmitter and back in 0.5 m steps with ten repetitions. The detected values were recorded 10 times at each point with a 10-second break between each individual record. The arithmetic mean was calculated from the measured values, and, by means of approximation, a mathematical relationship between the distance from the transmitter (x) and the signal strength (y) was derived:

$$y = -11.27\ln(x) - 14.219 \tag{1}$$

Furthermore, the maximum distance of the client (prototype) from the access point could be determined from the measured values when using the selected low-end Wi-Fi device, which was 7.5 metres. Past this limit, the drop in the signal strength, depending on the distance from the transmitter, is not sufficient to determine the client position, see Figure 4.

Due to the fact that obstacles absorbing electromagnetic waves (e.g. a human body) and obstacles extending into the first Fresnel zone (90% energy transmission) reduce the quality of the transmission, respectively increases the attenuation, it was necessary to determine the optimal location of the access points (room ceiling). The Equations (2) and (3) clearly show that in case the maximum distance (7.5 m) of the client (prototype) from the transmitter (access point) is maintained, the maximum diameter of the first Fresnel zone will be 0.5 metres.

$$\lambda = \frac{c}{f} \tag{2}$$

where: λ – wavelength; c – light velocity; f – frequency (2.4 GHz).

$$r_1 = \sqrt{\frac{\lambda \cdot d_1 \cdot d_2}{D}} \tag{3}$$

where: r_1 – the radius of the first Fresnel zone at a given distance; α – wavelength (2.4 GHz ~ 12.5 cm); d_1, d_2 – obstacle distance from the receiver/transmitter; D – distance between the transmitter and receiver.

Due to the minimisation of the necessary computing power, the triangulation method of analysing space (fingerprint-based method) was selected to determine the position. Triangulation is usually used to track an entity's position moving in a plane, in real time. At least three reference points (Wi-Fi access points) are required to determine the position (in the plane). If we know AP1 (x_1, y_1), AP2 (x_2, y_2) and AP3 (x_3, y_3), the distance from each AP can be calculated using the Pythagorean theorem [Equation (4)].

$$d_n^2 = (x - x_n)^2 + (y - y_n)^2 \tag{4}$$

By means of Equation (4), the distance is measured using the RSSI value between each AP.

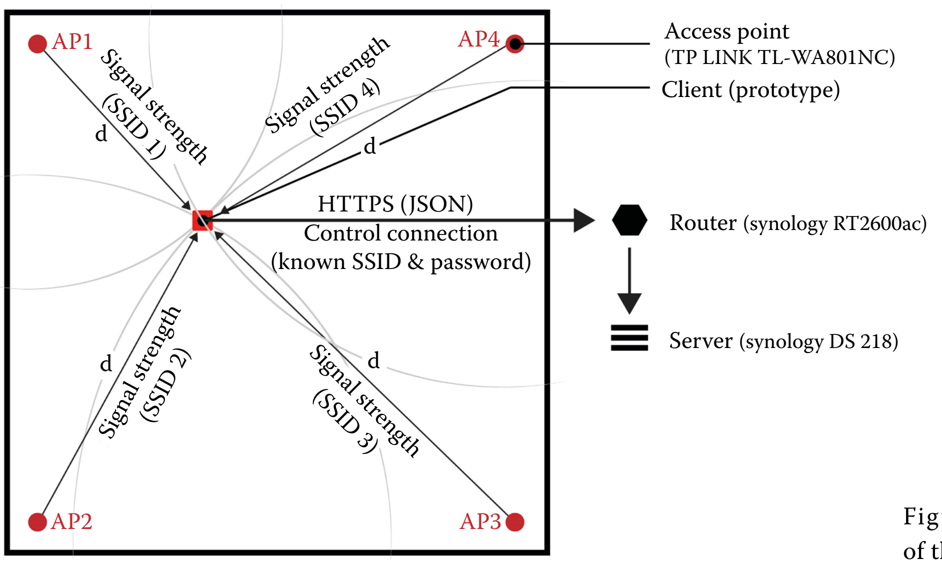

Figure 3. Summary scheme of the technology

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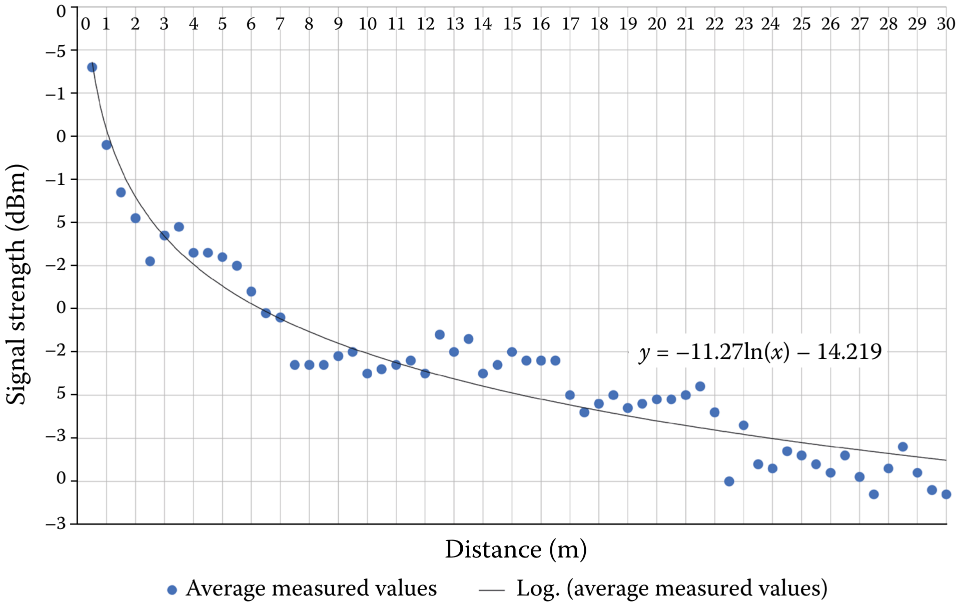

Figure 4. Signal loss depending on the distance from the transmitter

Equation (5) is used to calculate the loss (L) of the transmitted signal of a moving entity and the RSSI Equation (6) is used to determine the distance (d), where λ indicates the wavelength of the radio waves. Furthermore, it is possible to find the current value of the position coordinates by replacing d_1, d_2 and d_3 in the above-mentioned Pythagorean theorem.

$$L = 20 \times \left(\frac{4 \cdot \pi \cdot d}{\lambda} \right) \quad (5)$$

$$d = \frac{\lambda}{4\pi} \times 10^{\frac{L}{20}} \quad (6)$$

where: L – loss of the transmitted signal; d – distance (dB); λ – wavelength.

Nevertheless, in the triangulation technique, a large number of errors due to the multi-route radio wave phenomenon occurs, in which various signals are reflected and cause interference (Kim and Lee 2020).

The fingerprint method uses basic service set identifier (BSSID) and RSSI, which are inherent Wi-Fi AP values. The inner space is divided into small grids and access points (see Figure 5) creating a database by collecting the RSSI values in each grid, which is called a radio map. In this method, the accuracy and error in determining the entity's

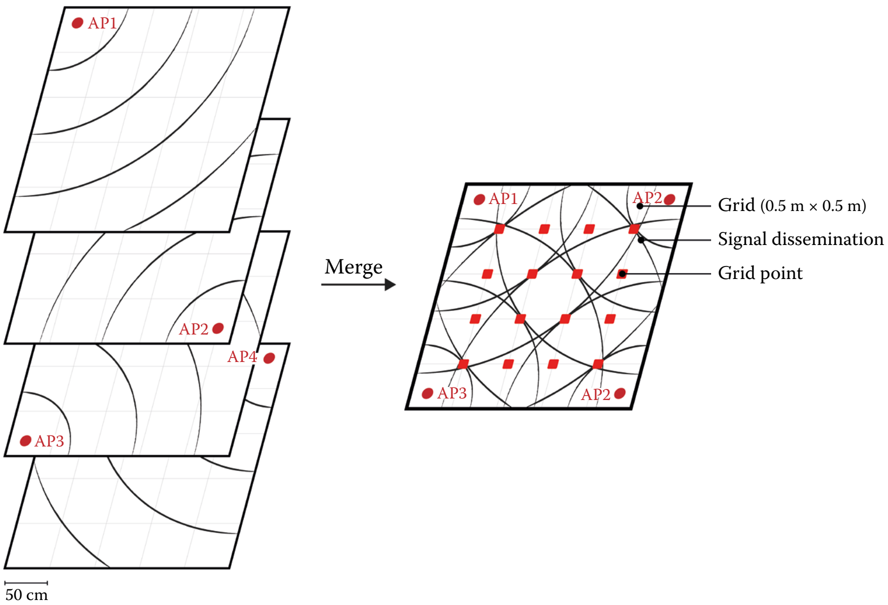

Figure 5. Signal map merging principle

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position differ depending on the size of the cells that divide up the space. Generally speaking, the greater the grid density, the higher the accuracy, because the probability of the entity's location in the corresponding grid increases. However, with an increase in the size of the grid, the size of any possible error also grows, which can reach up to the size of the grid itself. Therefore, it is important to define a suitable grid size (Kim and Lee 2020).

Thus, for the basic part of analysing the space, it was suitable to create a map of the monitored area based on a virtual grid, with the possible correction of the triangulation and fingerprint-based methods. The size of the spacing of the virtual grid was based on Equation (1) and was set at 0.5 m × 0.5 m. This value is mainly dependent on the radiated power of the used access points and, therefore, the calibration sequence is created in the application part of the server.

To increase the position monitoring accuracy in space, key points (room corners, entry spaces) were added to the virtual grid. Using the client (prototype), the signal strength per each accessible access point was measured at the key space points. The measured data can be sent to the server in any interval that can be edited in the source configuration file of the prototype (respectively, the ESP module). The read strength of the signal from access points (RSSI), which are designed for monitoring, was ensured by the service set ID (SSID) and media access control (MAC) address of the device. This filtered out the access points that could negatively affect the client's (prototype's) position accuracy, e.g. indirect (AP-client) visibility. The resulting values were then used, on the server side, to calculate the arithmetic mean of the signal of the individual access points. The result was recorded in the database and entered on the corresponding coordinate in the virtual grid. After focusing on the key points in space, an algorithm was started, which, on the basis of the mentioned equations, calculated the signal strength of the individual access points at each point of the virtual grid. The already known values and equations are used for the calculation (1–5).

Therefore, the client position monitoring in the area is based on information about the signal strength of individual access points. This information is sent to the server, by means of a hypertext transfer protocol secure (HTTPS) protocol in standardised JavaScript object notation (JSON) format, where it is stored in the database and processed by the created program. From the data received, this program detects the signal strength of the known access points, which are identified via the device's MAC address, and compares these values with the values in the virtual grid and on the basis of the comparison of the data, it determines the best possible position in space. If the position corresponds to multiple points in space, it selects a point that is closest to the previous positioning point that is recorded in the database.

Laboratory testing of determining the reliability of the positioning was carried out at the CULS laboratory of computing applications, on the 6th–8th of February 2020. In the monitored space, eight access points were deployed, see Figure 6.

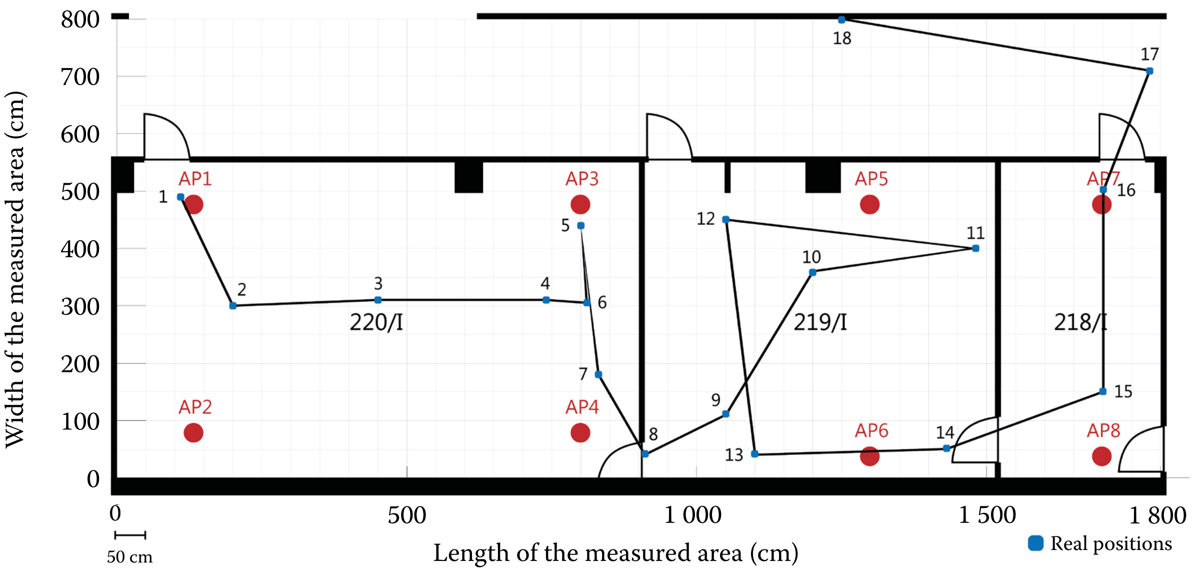

Figure 6. Layout of the APs and points of interest

APs – access points

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The number of access points was selected so that the measured area is sufficiently covered, and the selected triangulation method was applied. The location of the access points was deliberately selected to slowly increase the requirements for the accuracy of determining the position of the prototype. The determination of the positions was tested by thirty passages through a dedicated space (always along the same route). During the passage, 18 points of interest were determined in the area. In these points, the real location of the device was recorded compared to the determined location, as located by the applied positioning system, see Figure 7. Based on the average deviation of the determined distance from the real distance, the accuracy of the developed positioning technology was determined.

RESULTS AND DISCUSSION

Within the framework of the research, a low-cost system for positioning by means of a Wi-Fi signal at 2.4 GHz was developed. One of the first objectives was to establish a mathematical function representing the signal loss depending on the distance from the transmitter. The results of this measurement are interpreted in Figure 4.

We can see from these values that the most accurate positioning can be reached within 7.5 m of the transmitter, where the signal sharply decreases with the distance from the transmitter, and this decrease can compensate the signal fluctuations at a given point in space. The distance within which the client's position can be accurately determined depends on the access point transmission power and the client's antenna gain. In the project, the low-cost devices were used which were equipped with smaller antennas with low gain and low transmission power. After thirty passages, the average deviation of the determined position from the real position was determined in each of the 18 points of interest in the monitored space, see Table 1.

The most accurate results were achieved at measured points 1–3 (see Table 1), where the average deviation was 0.68 metres. These measured points were placed in an empty space without obstacles and in a direct line of sight to AP1–AP4 within distances up to 7.6 metres. The accuracy of the technology is limited by the selected density of the grid, which, in this case, was set to 0.5 metres. The accuracy of determining the position with a deviation of 0.68 m can be considered very accurate in this case.

Table 1. Average deviations

Point	Real position		Determined position		Deviation (cm)
	X	*Y*	*X*	*Y*	
1	110	490	116	491	69
2	200	300	195	304	68
3	450	310	447	308	69
4	740	310	738	295	107
5	810	305	794	286	148
6	800	440	787	441	100
7	830	180	790	219	142
8	910	40	906	49	74
9	1 050	110	1 053	128	84
10	1 200	360	1 204	360	74
11	1 480	400	1 472	377	114
12	1 050	450	1 073	462	87
13	1 100	40	1 102	136	146
14	1 430	50	1 412	97	154
15	1 700	150	1 724	132	192
16	1 700	500	1 672	529	215
17	1 780	710	1 718	694	347
18	1 250	800	1 222	841	507

X and *Y* – the coordinates of the 2D space in cm

Although points 4–7 are located similarly to points 1–3 in a direct line of sight to AP1–AP4, they also receive a signal from AP5 and AP6. The signal from these two APs is influenced by the passage through a wall, see Figure 7. At these points, the average deviation of the determined position from the real position amounts to 1.24 metres.

The largest deviation, on average, up to 5 m from the real position was achieved at points 16–18. This deviation is caused by the position of the measured points, which are outside the boundary of the selected grid, and the signal of the individual access points was affected by solid obstacles in the form of walls and furniture.

Based on the values measured at 18 points of interest after thirty passages, the average deviation of the determined position from the real position for the proposed low-cost system was determined at 1.498 metres. This value also comprises points of interest 16–18, which are not in a direct line of sight to any of the access points. The average deviation at these points is 3.56 metres. At the points of interest 1–15, the direct line of sight is guaranteed at least to two access points, and the

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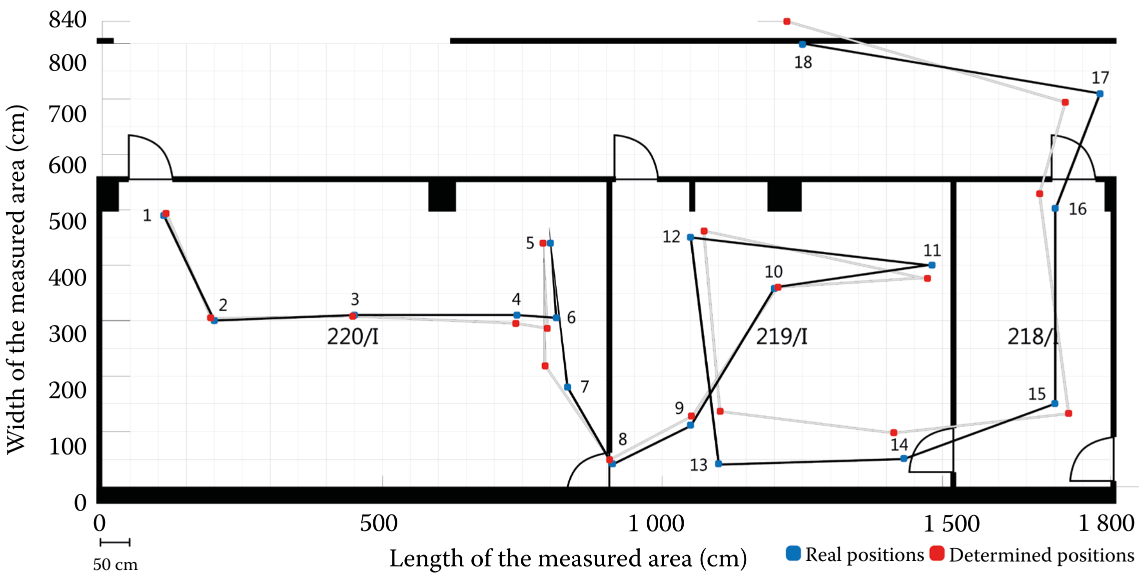

Figure 7. Visualisation of the average deviations

average deviation is 1.09 m at these points. These results achieve greater accuracy compared to (Navarro et al. 2010) with an accuracy up to 2–4 m in a typical indoor environment. The positioning accuracy depends on the number of access points within reach (ideally at up to 7.5 m distance) and on the degree of the signal interference. Furthermore, it is necessary to select a suitable grid density, according to which the current client position is determined. In this respect, it would be appropriate to use a density of less than 0.5 metres. When determining the position, it is advisable to obtain a signal strength of more than 5 access points, allowing the position algorithm to exclude any measurement of an extreme value that is caused by temporary signal interference.

To achieve the minimal interference caused by moving obstacles, it is necessary to properly place the transmitter and receivers to ensure, if possible, a direct line of sight throughout the position monitoring. Therefore, placing access points on the ceiling of the room and the receiver to the back of the animal is advisable.

This low-cost technology brings a great advantage compared to the commercial solution as far as the acquisition and operating costs are concerned (Yu et al. 2014). Based on 24/7 monitoring, it allows one to estimate the health and mental state of individual animals and detects changes in the animals' daily routine.

In this research, the battery life was not evaluated. In this respect, it will be necessary to carry out additional testing and estimate the cost in connection with battery replacement/recharging.

This technology needs a high transmittance power of the individual access points (and also relatively large quantities) to cover each point by the signal using at least 4 access points. For this reason, it is necessary to assume that the 2.4 GHz electromagnetic radiation frequency may have an adverse effect on the animals.

CONCLUSION

Within the framework of the research, a complete monitoring system was developed to determine the positions of the housed animals. This system consists of a server that contains storage for the acquired data, a web server for the data reception from the monitored device, software that determines and shows the location of the monitored device and the monitored device itself that can be fastened to a housed animal.

When testing the proposed technology, it was found that the loss of signal strength required to calculate the triangulation is acceptable up to 7.5 m from the signal transmitter. At a greater distance, the signal strength is unstable and causes inaccuracies in the positioning. The tests showed that the average deviation of the determined triangulation position is 1.498 m from the real position of the object. The accuracy of the positioning is influenced to a great extent by the surrounding interference caused especially by obstacles between the

https://doi.org/10.17221/66/2021-RAE

object and the transmitter, as well as by the used low-cost device which has an unstable transmittance power. This method proved to be suitable for monitoring the movement of individuals around the area, but it cannot be recommended as a complete replacement of technologies using RFID gates, although it is appropriate to use a combination of these two technologies. This system has great potential regarding the passive acquisition of data on housed animals (for example dairy cows, pigs, etc.), particularly to analyse the changes in the behaviour of individual animals on the basis of the obtained data related to their position.

In the next phase, this technology will be applied to a real operation and other research will focus on obtaining other passive data based on the animals' behaviour in time and space. The obtained data will be analysed, for example, by means of neural networks, allowing the health and mental welfare of the housed animals to be estimated.

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