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Evaluation of Instrumentation for Cow Positioning and Tracking Indoors

A. Huhtala[1]; K. Suhonen[1]; P. Mäkelä[2]; M. Hakojärvi[3]; J. Ahokas[3]

[1]School of Agriculture and Forestry, Ilmajoentie 525, 60800 Ilmajoki, Seinäjoki University of Applied Sciences, Finland; e-mail of corresponding author: arto.huhtala@seamk.fi
[2]School of Information and Communication Technology, Kampusranta 9 A, 60320 Seinäjoki, Seinäjoki University of Applied Science, Finland; e-mail: petteri.makela@seamk.fi
[3]Department of Agrotechnology, P.O. Box 28 (Koetilantie 3), FI-00014 University of Helsinki, Finland; e-mail: mikko.hakojarvi@helsinki.fi

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It has been seen that changes in cows' behaviour are strong indicators of their health and welfare problems and thus they can be used as input to an early warning system. Many researchers have confirmed that lack of animal locomotion indicates lack of welfare. An automatic cow tracking system can be a solution, which can find the animals with welfare problems or oestrus. A lot of technologies have been used for location and tracking but only some are useable for animal tracking indoors. The possibility of using different indoor positioning systems for cow tracking was investigated. Based on the survey, the solution which uses wireless local area network (WLAN) has been chosen for a test installation. The installation was made to observe a loose housing system with 10 cows. In principle, the system accuracy was good (position accuracy 70% under 1 m) but in the actual case, the measurements were not stable enough. The system has shown its capability for the task but further development is needed before it is possible to use this solution for exact cow tracking.

1. Introduction

In animal husbandry the size of farms and the automation level have increased rapidly. The feeding of animals is carried out using automatic systems and also milking can be carried out by milking robots. At the end of the year 2003, about 2200 farms worldwide used a milking robot (de Koning & Rodenburg, 2004). This has led to the situation where less cattle tenders are needed and the contact of cattle with tenders has decreased. This has reduced cattle observations and cattle health has weakened because the tender sees the animals less frequently and in a large herd it is difficult to observe an individual.

It has been seen that changes in cows' behaviour are strong indicators of their health and welfare problems (Livshin *et al.*, 2005) and thus they can be used as input to an early warning system. For example, lameness causes changes in cows' behaviour (Pastell *et al.*, 2005). It has been confirmed that lack of animal locomotion will indicate a lack of welfare (Brandl, 2006). Also lying behaviour can indicate animal comfort in different housing conditions and physiological status (Livshin *et al.*, 2005).

In large cowsheds, the positioning of cows is an important parameter. It is needed for an estimation of behavioural patterns and activity, for health inspection, for an estimation of missed operations (for example milking) and for automatic isolation of individual animals, at risk.

The objective of this study was to find a suitable solution for cow tracking inside a building and to recognise the needs for further development for the chosen system. The future plan is to research and to develop the capability of the tracking solution to determine the changes in animals' behaviour. As this will be the base of an early warning system for cows' health, solutions were favoured which could produce a commercial solution for normal dairy cattle in the future. A wireless local area network (WLAN) based system was chosen and a test installation was established. This article discusses the system accuracy and usability. Measurements for cows' behaviour will be reported separately.

2. The tracking system requirements

A suitable system should tell cow location automatically inside the building and save it to a computer. As the future aim of this subject is to monitor cows' behaviour and health, the tracking system should be capable of tracking several animals at the same time and the resolution about locations should be about 1 m^2. This accuracy and several cows should be adequate for testing the system and for deciding whether it is possible to accomplish an early warning system or not. The optimum situation would be if the system could track 60 or more cows simultaneously, because this is needed if the system is used on a commercial farm with a single milking robot. This is a very common farm size in the Finnish dairy sector. The interval for sampling should be so short that it is possible to calculate walking speed of the cow. The precise sampling rate is not yet known but the target of this study was 1 Hz. Selected equipment should not disturb the animal's normal behaviour and it should stand dirty and hard conditions, which prevail inside a cow house.

3. Materials and methods

3.1. *Technologies for tracking*

In this section, technologies which can and have been used for location and tracking objectives are surveyed. The greatest efforts have been made in the technologies, which have tracking solutions readily available in the marketplace to assist in finding a solution for following cow's behaviour on the normal commercial farms, with minimal system development.

3.1.1. *Global positioning system*

Global positioning system (GPS) is a satellite-based positioning method. The determination of the position is based on receiving track and time mark signals from satellites, and calculating a receiver location on the basis of distances to satellites. Obstacles (walls, ceiling, *etc.*) weaken the signals and GPS does not work indoors.

Schlecht *et al.* (2004) used GPS when they monitored activities of 14 Zebu cows on pasture in western Niger. The system consisted of a mobile six-channel Trimble® GeoExplorerII (Trimble Navigation Ltd, Sunnyvale, CA, USA) GPS receiver with an external antenna and an external rechargeable 12 V, 3 Ah sealed lead-acid-gel battery. With this equipment, the GPS could work for more than 12 h. The total equipment weighed 5·50 kg.They used two GPS receivers to obtain the cows' positions. When cattle set out for pasture in the morning, the GPS receivers were switched on and then recorded the animals' positions every 10 s. When the animals returned from pasture in the evening the raw data files were transferred to a laptop computer.

3.1.2. *Global positioning system'pseudolite'*

'Pseudolites' are ground-based GPS signal transmitters that can improve the 'open air' signal availability or even replace the GPS satellites constellation for some indoor applications, (Wang *et al.*, 2001). The indoor solution with 'pseudolites' can give an accuracy of several centimetres' for positioning but signal reflections (multipath) and obstacles indoors can cause problems, (Lee *et al.*, 2004).

3.1.3. *Radio frequency identification*

Radio frequency identification (RFID) tags can be activated by a specific radiofrequency to send location information to a receiver. A passive RFID tag does not need any power source because it produces needed energy by an antenna. The reading distances can be a couple of metres (Rainio, 2003). The tracking system can also work otherwise, so that the moving objects have RFID tags and when a tag is close enough to a reader, the location is measured. The RFID technology is usually used like this for animal identification. The tracking resolution depends on the amount of readers and the reading distance.

3.1.4. *Radio tracking*

Briner *et al.* (2003) have developed a radio tracking system for automatic and continuous data collection which allows the radio tracking of several animals at the same time. It consists of a system controller, three fixed antennae, and small-size (14 mm by 12 mm by 4 mm) radio transmitters. The antennae, positioned at fixed points in the field, forward the signals from tagged animals to the system controller where the data is collected. The coordinates of an individual's locations are calculated through triangulation on the basis of the angles of incidence from the transmitter signal to each antenna. All transmitters work at the same frequency (148·75 MHz). First, the trigger antenna sends a starting signal to the transmitters which, after an individual fixed time, send a signal for 0·5 s. These signals are received by the direction-finding antenna (Watson–Watt method). When testing the accuracy of locations, they were using 17 transmitters placed at fixed positions at distances 5–25 m from the antennae. The miscalculation of transmitter coordinates was 0·13–2·58 m (median of 0·74 m).

The Tänikon research station in Switzerland uses a system (Abatec Electronic AG, Regau, Austria) which is based on radar technology for cow tracking. This is a local position measurement (LPM) system, which can determine positions from moving objects in real time (rate of 333 Hz). The system consists of active transponders which transmit signals to the base station. Then the position is calculated based on signal moving times and special algorithms. The accuracy for two-dimensional positions in the loose housing system for dairy cows at Agroscope FAT Tänikon is about 25 cm. The battery life is a problem in this system. The cow tracking solution can work only for a few hours without changing the battery. This system is quite expensive; the system price for tracking 10 animals in a limited area is about 60000€ (Zierfuss, 2005; Neisen, 2005).

3.1.5. *Bluetooth*

Bluetooth is a radio standard and communication protocol which can be used also for positioning. The range for a Bluetooth-signal is about 10 m and this is also the resolution which tells the location, (Rainio, 2003). The tracking system can be made with Bluetooth devices which give a signal when an other device is close enough. The principle is about the same than when using global system for mobile communications (GSM) for location.

3.1.6. *Wireless local area network*

Wireless local area network has been designed to offer a wireless connection to network but it is possible to use it also for location. AeroScout (San Mateo, CA, USA) has developed a system which uses standard Wi–Fi® (wireless local network based on IEEE 802·11 standards) wireless network and time difference of arrival (TDOA) algorithms to determine location. The location receiver (LR) receives standard 802·11b messages and executes sophisticated radio signal measurements, enabling the AeroScout Engine software to calculate the location of tags or other Wi–Fi enabled devices. A minimum of three LRs suffices to enable TDOA location processing. In Legoland, Denmark, there is a child tracking application, which has been accomplished by the AeroScout technology. With this solution, it is possible to locate a child in Legoland area within a 3 m accuracy (Peters, 2005).

3.1.7. *Ultrasound*

It is possible to use normal microphones and loudspeakers for ultrasound positioning. In this system, every loudspeaker sends individually coded sound and a receiver can calculate its position when it hears at least three speakers. If the sound has clear way between speakers and microphones, it is possible to achieve accuracy of centimetres or even millimetres. Sound reflections from the walls can be a problem (Rainio, 2003).

The Massachusetts Institute of Technology (MIT) has developed the ‘Cricket’ indoor location system. ‘Cricket’ uses a combination of radio frequency (RF) and ultrasound technologies to provide location information to attached host devices. Wall-and ceiling-mounted beacons placed through a building publish information on an RF channel. With each RF advertisement, the beacon transmits a concurrent ultrasonic pulse. Listeners attached to devices and mobiles listen to RF signals, and upon receival of the first few bits, listen for the corresponding ultrasonic pulse. When this pulse arrives, the listener obtains a distance estimate for the corresponding beacon by taking advantage of the difference in propagation speeds between RF and ultrasound. The listener runs algorithms that correlate RF and ultrasound samples and to pick the best correlation. ‘Cricket’ can provide positioning precision of between 1 and 3 cm. ‘Cricket’ uses software which is under an open source licence (Smith *et al.*, 2004).

3.1.8. *Video tracking/image analysis*

A video-based system for tracking normally consists of a video camera, a recording system and an image analysis program for tracking and identification of objects. At Foulum Research Centre in Denmark, the measuring of the travelling distance of pigs within their environment has been tested, using an image analysis system. In this research, they had normal video recording above a litter. After the recording, personal computer (PC) programs were used to subtract images with 4 s intervals and to measure the travel distance by determining the pig’s positions using a PC-mouse (a user click with the mouse to the determined the x,y coordinates) and software (Brandl, 2006).

In Alnarp, Sweden, Oostra (2005) used a video tracking solution, which was intended for an automatic and almost continuous determination of an individual cow’s location in the cowshed throughout the day. This system was called optical real-time location (ORTLS). The system consists of the following parts: a collar with a light-emitting diode (LED), a radio frequency synchronisation unit (RFSU), which synchronises the light emitting diodes, video cameras and a computer with video processing software (VPS) (*Fig. 1*). The system functions as follows. Each cow carries a special collar equipped with a LED that flashes once per minute. The LEDs are synchronised by the RFSU, which sends a signal that is captured by the radio frequency synchronisation receiving unit (RFSRU). The light flashes are captured by video cameras. The video signal from the cameras is ‘translated’ by the VPS into x and y positions and is stored, together with the actual cow identification (ID) and time. A group of up to 60 cows can be followed with this equipment. When the system was tested by a hand-held LED, it gave an accuracy of 0·39 ($\pm$0·18) m; when the system was used with cows, however, the detection rate in the feeding area was high (90%) but much lower in the lying area (10%). The big variation in detection rate was caused by camera location and because cows bend their necks or collars were rotated, so that the cameras could not see the lights. In the Swiss Federal Research Station for Agricultural Economics and Engineering, optical systems for determining cow location in a cowshed were also tested but this solution was abandoned because of problems in zones between the cameras and direct solar radiation.

3.2. *Comparison of technologies and selection of system*

3.2.1. *Analysis of technologies against the requirements*

The system requirements have been stated in Section 2. Table 1, contains the technologies and properties of different systems and mark'+'if the requirement was met and the mark '−' if not.

Some techniques were abandoned because they do not work indoors or in an environment which predominates in a cow house. Radio frequency identification is a good way to identify an animal but with this technique, it is not possible to get location in the whole building. With Bluetooth, it is possible to build cheap and small sizes of equipment for positioning but the accuracy is only some metres. Ultrasound could be one solution but reflections from walls and other structures can cause problems as well as the correct beam transmission between the beacon and listeners. It is also critical to choose the sound frequency which does not disturb the animals. Video tracking and radiotracking have already been used for animal location, and are relevant solutions for that purpose. Researchers have found some problems with using video tracking; cameras should be in the precise place so that cow identification succeeds. Also a cow's posture influences the results of identification. By a new radiotracking innovation, LPM, it is possible to get very precise location information but the battery life is too short for our purpose and also the price for the system is very high. A solution which can track 50 animals in a cow house will cost about 160000€ (Zierfuss, 2005). The location technology in a wireless network is a new innovation. The accuracy could be better but 1 m should be good enough for this purpose. The GPS 'pseudolite' technology is also a very new innovation. Its accuracy is good and it can also offer height information which can tell if a cow is standing or lying. One benefit is that the same GPS-receiver can work inside with 'pseudolites' and outside with satellites. So it is possible to track animals the whole day also during grazing season. The problem with this technology is the high consumption of power and that there are no commercial solutions. There remains a lot of special work to get the system operational and also the price would be high; about 60000€ to track some animals (Korpela, 2005).

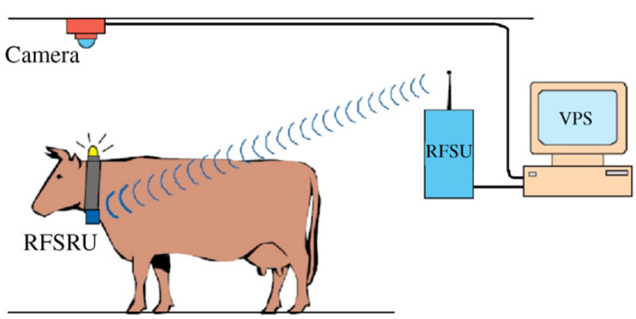

Fig. 1. Optical real time location system (Oostra, 2005): RFSRU, radio frequency synchronisation receiving unit; RFSU, radio frequency synchronisation unit; VPS, video processing software

3.2.2. *Selection of technology for cow tracking*

After comparing the properties of different technologies, concerning also the price and the existence of commercial solutions, the WLAN technology was chosen (AeroScout's solution) for the test use. This system can offer an adequate accuracy with a reasonable price. The accuracy by GPS 'pseudolites' and radiotracking (LPM) is a little better but the price for those

Table 1
Analysis of positioning system properties with the mark'+' if the requirement was met and the mark '−' if not

	Accuracy	*Sampling frequency*	*No. of tracking animals*	*Battery life*	*Environment resistance*	*Size of tag*	*Price*
GPS-pseudolite	+	+	+ +	−	+/−	+	−−
RFID	−−	+	+	+ + +	+ +	+ +	+ +
Radio tracking	+ +	+ +	+ +	−	+	+	−−
Bluetooth	− −	+	+	+ +	+ +	+ +	+
WLAN	+	+ +	+ +	+ +	+	+ +	+
Ultrasound	+ +/−	+	+/−	−	+	+	+/−
Video tracking	−/+	−	+	+/−	+/−	−	+/−

GPS, global positioning system; RFID, radio frequency identification; WLAN, wireless local area network.

are too high and also the consumption of power is too high. When thinking of the future, it is probable that the price for WLAN is going down faster because of a wider range of solutions (PC connection, location solutions, *etc*.), and might also offer a commercial solution for cow tracking in the future.

3.3. *Measurements*

The WLAN tracking system was installed in a cowshed with a special section for 10 cows milked with a milking robot (*Fig. 2*). The area to be covered inside the barn was 10 m by 9 m. It includes five LRs with an antenna. Four LRs were located in the corners and one in the middle (*Fig. 3*). The mounting level from the floor was 240 cm in the corners and 340 cm in the middle. The system needs clear sights from the middle antenna to the corners antennae and also clear sight at least from three antennae to cow (tag) to work properly. The LRs were connected to a PC *via* a hub. The manufacturer's measuring program was running in the PC and it displayed the tag locations and coordinates in the section layout. The sub-program which saved the positioning coordinates in a text file was developed in-house. The tags were installed first in the precise places to get accurate coordinates and later the tracking was tested by installing a tag on top in a cow's neckband and also on a cow's back with a special band (*Fig. 4*). A web camera was installed above the room and all events were recorded and stored digitally on the PC. Several sampling rate were evaluated: 256 ms, 512 ms and 1 s between tag transmissions (location). The system is capable of making 300 measurements per second but a higher frequency will use more power and thus reduces the battery life. With the sampling rate of 4 Hz, the estimated tag battery life is a few days and with 1 Hz a few weeks. The position accuracy and stability in the precise places (*Fig. 3*) were analysed by the manufacturer's analysing tools. The rough visual estimate for accuracy and stability in the actual case was done by comparing the location from the positioning display (*Fig. 3*) and the web camera display (*Fig. 2*). The saved coordinates were processed with Microsoft Excel and MATLAB (MathWorks, Natick, USA). After processing it was possible to compare locations and cow's route calculated from coordinates to real locations seen from a digitally saved web camera film.

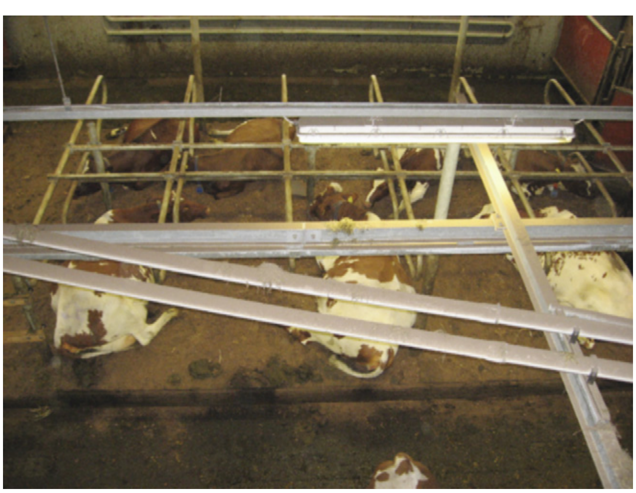

Fig. 2. The research section for 10 cows in an image captured from a digital video recording system

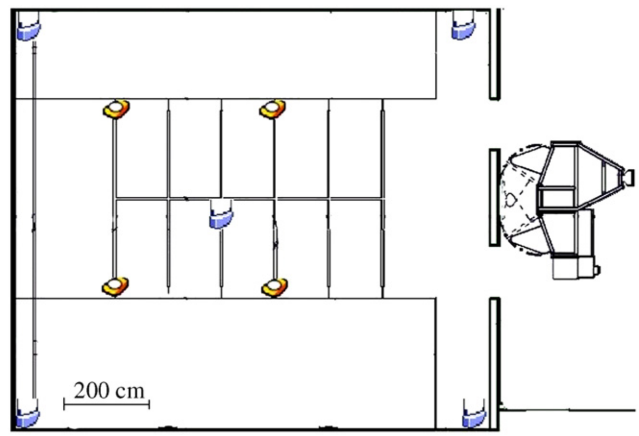

Fig. 3. The positioning display showing tags (cows') positions in the section layout; four location receivers are mounted in the corners and one in the middle; the tags are in precise undisturbed places due to basic accuracy analysis

Fig. 4. The tag on a cow's collar and on a cow's back with a special band

4. Results and discussion

The basic accuracy for the location has proved to be quite good. When a precise (steady) place for the tags

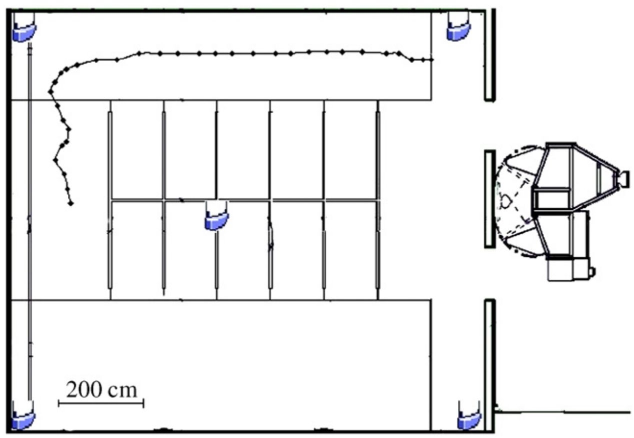

Fig. 5. The tracking for a walking cow during measurements over 17 s; the coordinates were processed with MATLAB

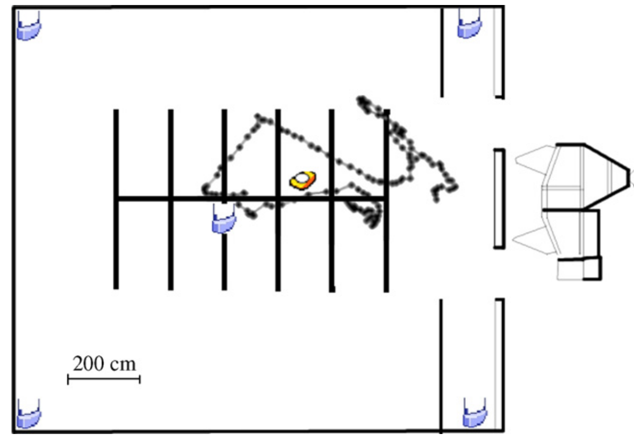

Fig. 6. Motion of dislocation; the tag shows the lying cow's position; measuring during one minute

were used (*Fig. 3*) in undisturbed conditions (no moving cows, clear sights between antennae and tags, *etc.*) the result of the manufacturer's analysis for ten minutes recording was that the resolution for the measured location values was 30% inside 65 cm, 70% inside 100 cm and 90% inside 200 cm. A visual perception from displays supported those results: the accuracy for a steady tag location was looking a good enough (~1 m) and also the stability was acceptable. In the actual case when a tag was fastened on the cow (*Fig. 4*) and all the 10 cows were in the section, the results were not so good. The location information was quite accurate (~1 m) when a cow was standing or walking (*Fig. 5*) but especially when a cow was lying, the stability was very poor. The motion of dislocation was more than 3 m (*Fig. 6*). The tag on the neck gave poorer accuracy than the tag which was on the cow's back. The poor accuracy and stability in the actual case are due to TDOA algorithms. When there is an obstacle between the sending tag and the receiving antenna, the signal arrival time is slower due to indirect path and the calculation gives a longer distance between the tag and the antenna than it is in reality. The tag on the cow's neck was lower when the cow was lying than the one on the back and was more frequently obstructed by the cubicle pipes, *etc.*, giving poorer stability.

In earlier researches cows' tracking has been carried out with video tracking and radio tracking. Our basic accuracy was about the same than it was in a video tracking study (Oostra, 2005) but the WLAN system did not miss any location reading as it happened with video tracking. Also our interval of sampling was much shorter. Radio tracking (Zierfuss, 2005) gave better accuracy than the WLAN but the equipment in a cow's collar were remarkably bigger and the batteries only lasted less than 1 day. It is not certain whether or not a better solution is more feasible with some technologies other than WLAN, but a solution which works for several days without battery change, and a tag in a cow's collar being as small as matchbox, giving reasonable accuracy at a reasonable price, is justifiably an effective choice. Our cowshed was quite a challenging test environment with many steel pipes and other obstacles and the results could be better with a less cluthered cowshed. It should be possible to get higher accuracy and stability in position information also in our kind of system by using more LRs. Then it would be possible to dismiss those LRs which give a belated arrival time and use only the three best ones (a signal arrival without any delay). However, this will also require program development.

5. Conclusion

Many technologies have been used for location and tracking. After studies, it was concluded that the wireless local area network (WLAN) technology is the most promising solution for an affordable research system or a commercial solution for cow tracking in the future. Tests showed that a WLAN can give location which is sufficient for monitoring cows' behaviour. Although the stability was not good enough in the normal situation, there is further potential develop the system and provide a more accurate and stable location.

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