biosystems engineering 169 (2018) 22–31

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

Filtering methods to improve the accuracy of indoor positioning data for dairy cows

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ARTICLE INFO

Article history:
Received 8 September 2017
Received in revised form
12 December 2017
Accepted 24 January 2018

Keywords:
Indoor positioning
Ultra-wide band
Dairy
Extended Kalman filter

Several indoor positioning systems for livestock buildings have been developed to be used as tools in automated animal welfare monitoring. In many environments the measurements from positioning systems still contain unwanted noise and the quality of the measurement data can be enhanced using filters.

The aim of this study was to develop an efficient filter for positioning data measured from dairy cows with UWB-based indoor positioning system in a free stall barn. A heuristic jump filter combined with median filter and extended Kalman filter was developed and tested. The performance of the filters were compared against reference data collected from Insentec roughage intake feeders and scan sampling of animal presence in a specific lying stall with over 1500 reference observations from both methods.

The quality of the positioning data was significantly improved using filtering. The 9th order median filter provided best estimates for cow position when the cows were not moving with median 100% of measurements located in correct stall and 84% in correct feeding trough when compared to the reference observations and measurements. The extended Kalman filter also improved the positioning accuracy significantly when compared to raw data and provides better of estimates of the trajectory of moving cows.

1. Introduction

Several indoor positioning systems for livestock buildings have been introduced to the market during past years. These systems are interesting tools in automated animal welfare monitoring if sufficient positioning accuracy and sampling rate can be achieved. Initial studies analysing the data from positioning systems have shown that the data can be used to measure feeding time (Oberschätzl, Haidn, Peis, Kulpi, & Völkl, 2015; Tullo, Fontana, Gottardo, Sloth, & Guarino, 2016), the effect of hoof lesions on walking distance (Frondelius, Kajava, Lindeberg, Mononen, & Pastell, 2015), and the effect of lameness and estrus (Homer et al., 2013; Veissier, Mialon, & Sloth, 2017) on cattle behaviour.

One of the first published systems in dairy cows was based on radar technology (Gygax, Neisen, & Bollhalder, 2007). The system achieved accuracies below 1 m, but battery life of the system in continuous operation was only 24 h. Barn environments also present certain challenges for indoor positioning systems since metal structures and other obstacles that may cause reflections of signal and artefacts (Gygax et al., 2007). However, other experiments have shown that Ultra-

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https://doi.org/10.1016/j.biosystemseng.2018.01.008

Nomenclature

UWB	Ultra-wide band
TDoA	Time-difference-of-arrival
AoA	Angle-of-arrival
RIC	Roughage intake control
EKF	Extended Kalman filter
p_t	Data point at sample time t
$d(p_1, p_2)$	Euclidean distance between points p_1 and p_2
(x, y, z)	Three dimensional location of the cow
θ	Movement direction
v	Movement speed
ω	Time derivative of θ
a	Time derivative of v
D_v, D_a, D_ω	Damping factors
T_v, T_a, T_ω	Fall times
h_k	Discretisation time
$\tilde{f}$	Discrete state transfer function
F_{k-1}	Jacobian of the state transfer function
H	Jacobian of the measurement function
q_k	Process noise
r	Observation noise
Q	Process noise covariance matrix
R	Observation noise covariance matrix
x_k	State vector at time step k
y_k	Measurement vector at time step k

Wide band (UWB)-based systems can achieve positioning errors below 1 m after cleaning of outliers (Porto, Arcidiacono, Giummarra, Anguzza, & Cascone, 2014) and a battery life ranging from months to years depending on sampling rate and battery size.

In many environments the measurements from positioning systems still contain unwanted noise and the quality of the measurement data can be enhanced using filters. The Kalman filter (Kalman, 1960) is nowadays a widely established method that is used to estimate processes that can be modelled using a mathematical model. In agriculture, it has been extensively used in navigation applications (Backman, Oksanen, & Visala, 2010; Lenain, Thuilot, Cariou, & Martinet, 2005; Oksanen, Linja, & Visala, 2005). The Kalman filter is an ideal method to combine multiple measurement sources to get better state estimates, for example to reduce measurement noise, or to estimate states that cannot be directly measured, for example wheel slippage in navigation (Backman, Oksanen, & Visala, 2013). With indoor positioning data the Kalman filter has been previously used e.g. to estimate the position of cows based on Bluetooth radios (Tøgersen, Skjøth, Munksgaard, & Højsgaard, 2010) and to track humans using sensor fusion of UWB positioning and inertial measurement unit (IMU) (Pulido Herrera, 2009).

A median filter is a robust nonlinear filter that replaces the values in data with the moving median of the filtered point and neighbouring points. It has been shown to improve the accuracy of human activity recognition based on UWB positioning data (Piltaver, Cvetković, & Kaluza, 2015).

The aim of this study was to develop an efficient filter for positioning data measured from dairy cows with UWB-based indoor positioning system in a free stall barn. Several options for improving the quality of the data will be introduced and results will be compared against reference datasets from human observations and automatically recorded Insentec feeding trough data.

2. Materials and methods

2.1. Measurements

2.1.1. Indoor positioning system

The Ubisense real time location system (Ubisense GmbH, Düsseldorf, Germany) is based on UWB radio signals. Animals were monitored by means of a collar-mounted tag (Ubisense Series 7000 Industrial tag) that transmits UWB pulses of extremely short duration, and remote sensors (Ubisense Series 7000 IP Sensors) which enable location to be mapped by using time-difference-of-arrival (TDoA) and angle-of-arrival (AoA) techniques. The positioning system was set up to cover an area of 22 × 25 m with six sensors and calibrated for the area according to the system manual. A static accuracy of ±300 mm in the same barn was achieved with no cows present (Frondelius, Pastell, & Mononen, 2014).

The tags were attached to the collar of the cows, so that the tag was on the top of the neck and the counter weight (540 g) of the collar under the neck to keep the collar in place (Fig. 1). The dorsal position was chosen to minimise possible shielding of the signal by the body of the cow. Position of the collar and the tag was checked regularly and corrected if tag had moved more than 50 mm from its intended location.

2.1.2. Housing

Cows were loose-housed in a curtain-wall barn fitted with rubber-matted stalls, steel stall separators and slatted

Fig. 1 – Ubisense tag attached to the collar of the cow.