BIOSYSTEMS ENGINEERING XXX (2017) 1–13

Available online at www.sciencedirect.com

ScienceDirect

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

Special Issue: Engineering Advances in PLF

Research Paper

Image analysis to refine measurements of dairy cow behaviour from a real-time location system

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ARTICLE INFO

Article history:
Published online xxx

Keywords:
RTLS
Image analysis
Dairy cows
Behaviour
Precision livestock farming
Time-budget

Long-term monitoring of animal activity can yield key information for both researchers in ethology and engineers in charge of developing precision livestock farming tools. First, a barn is segmented into delimited areas (e.g. cubicles) with which an activity can be associated (e.g. resting), then a real-time location system (RTLS) can be used to automatically convert cow position into behaviour. Working within the EU-PLF project, we tested a system already able to determine basic activities (resting, moving, eating...) and logged a "big data" set of billions of data points (123 days × 190 cows × 1 location-per-second readings). We then focused on integrating image analysis techniques to help visualise and analyse the dataset, first to validate the data and then to enrich the information extracted. The algorithm developed using freely available tools quickly confirmed the ability of the system to determine cows' main activities (except drinking behaviour), even with 11% of positions missing. The good localisation precision (16 cm) made it possible to enrich the time-budget with new activities such as using brushes and licking mineral blocks. For both activities, using visual observations as gold standard, activity profiles with excellent sensitivity (nearly 80%) were extracted. This validation procedure is both necessary and generalisable to other situations. The improvement of biological information contained in such data holds promise for people designing alarm devices and health and welfare indicators for farmers and/or vets.

1. Introduction

Time spent by cows on various activities over the course of a day can be indicative of their welfare and health status. For instance, uncomfortable resting areas may prompt cows to spend less time lying (Veissier, Capdeville, & Delval, 2004) while sickness may prompt a cow to spend less time eating (Gomez & Cook, 2010; Uzal & Ugurlu, 2010). Monitoring livestock time-budgets manually, round the clock (24/7) is simply unrealistic in commercial farm conditions. Monitoring using animal-attached sensors such as accelerometers potentially included in commercial systems (e.g. IceTags-3D© IceRobotics, Scotland) is still in its infancy, and further research is needed

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http://dx.doi.org/10.1016/j.biosystemseng.2017.08.019

Nomenclature

24/7	round-the-clock
ACC	accuracy
CEP-R95	circular error probability at the 95% level
CSV	comma-separated value
CV	coefficient of variation
FN	false-negative
FNR	false-negative rate
FP	false-positive
FPR	false-positive rate
GIS	geographic information system
GNSS	global navigation satellite system
GPS	global positioning system
MV	missing values
NTP	network time protocol
PLF	precision livestock farming
PPP	precise point positioning
PV−	negative predictive value
PV+	positive predictive value
ROI	region-of-interest
RTLS	real-time location systems
TN	true-negative
TNR	true-negative rate
TP	true-positive
TPR	true-positive rate
UWB	ultra-wideband
VBA	visual basic for applications

on data mining or data validation (Arcidiacono, Porto, Mancino, & Cascone, 2017; Martiskainen et al., 2009; Nielsen, 2013). Research on wild animals outdoors is already identifying basic behaviours such as foraging, resting and moving, and is expected to identify many more behaviours in the near future (Wilmers et al., 2015). Indoors, location monitoring using computer vision can automatically quantify major behaviours such as lying (Porto, Arcidiacono, Anguzza, & Cascone, 2013) or drinking (Benvenutti et al., 2015). However, optical approaches are unsuitable for use in dusty environments, when a large area needs to be covered, and when large numbers of animals need to be individually monitored for long periods. In such conditions, the radar approach is generally the only way forward, as it facilitates efforts to both identify and track animals, both key information inputs for studying animal time-budgets, i.e. how much time animals spend on each identified activity during a day. Positioning data is thought to have the potential to give access to 15 out of 40 maintenance (e.g. rubbing against objects) or social behaviours (e.g. horn-to-horn contact) (Kilgour, 2012) as soon as the trajectory of each individual can be modelled. Several positioning technologies have already been identified and evaluated, first at pasture by mobilising a global positioning system (GPS) mounted on the animal with a collar (Anderson, Estell, & Cibils, 2013). With data filtration methods or even Precise Point Positioning (PPP) correction, the spatiotemporal resolution of this kind of sensor can reach 1 m in the plan with a data rate of 1 s, making it possible to correlate large animal track (>1 m) with relatively fine map information (10 m^2) to quantify time spent grazing and resting (Barbari et al., 2006), walking (Williams, Mac Parthalain, Brewer, James, & Rose, 2016), and at the watering point or in a specific patch (Handcock et al., 2009).

In closed environments and when the global navigation satellite system (GNSS) loses coverage, real-time location systems (RTLS) using ultra-wideband (UWB) frequency are one of the most reliable and accurate technologies available (Alarifi et al., 2016). Based on a network of fixed antennas (sensors), UWB–RTLS enables 3D tracking of thousands of mobiles, each equipped with an emitting tag smaller than a credit card, with high precision (<10 cm) and fast sampling rate (>10 Hz). This technology is already deployed in industries and hospitals to monitor both devices and people (Deak, Curran, & Condell, 2012; Judah, Huberts, Drassal, & Aunger, 2017; Maalek & Sadeghpour, 2016). In a barn – which is a known, fixed and segmented environment – this technology gives the opportunity not only to localise each animal in real-time but also to classify its behaviour—for instance, a cow may be identified as resting as soon as it is precisely localised in a resting area. All these features raise prospects for proposing precision livestock farming (PLF) tools, on condition that the technology solution is (i) biologically valid, i.e. capable of precisely measuring the behaviours of interest, (ii) reliable long-term, i.e. 24/7, and (iii) non-invasive, i.e. without risk of injury or disturbance to the animal. Gygax, Neisen, and Bollhalder (2007) demonstrated that it is possible to get less than 13% missing values (MV) and better than 0.5 m spatial precision with an UWB–RTLS (Abatec, Regau, Austria) mounted on a 2.5 kg collar. Porto, Arcidiacono, Giummarra, Anguzza, and Cascone (2014) evaluated UWB ear-tags (Ubisense, UK) on 8 dairy cows and obtained a mean accuracy of 0.51 m with 2% MV. The authors did not observe any sensor-related disturbance of cows' behaviour and the cow detection readings were validated with visual recognition of behaviours (feeding and lying) in the video-recordings. Recently, Shane, White, Larson, Amrine, and Kramer (2016) detected presence of calves in the drinking and eating area using the same Ubisense technology. They validated positive detections with video analysis and obtained a percentage of accurate classification varying from 42% to 88% according to target activity. These results, although promising, were obtained on a small dataset, with a specific commercial solution that was lightweight enough (<100 g) to assume it had little impact on animal behaviour, but too short on autonomy (2 months) to make it compatible with long-term analyses unless data acquisition rate is reduced enough to substantially increase battery life.

Here, we evaluate, in commercial farming conditions, the performance and possibilities given by another UWB–RTLS (Zebra, USA) already packaged and sold under the brandname CowView (GEA Farm Technologies, Bönen, Germany) as a PLF tool for dairy farmers, and protected under an international patent (Sloth, & Frederiksen, 2014). This system determines the main activities of cows based on their movements and their position in zones that have been predefined in the barn setting. The time-budget information based on these main activities (at feeding table, walking and standing in alleys, resting in cubicles) has been validated (accuracy > 95%) by Tullo, Fontana, Gottardo, Sloth, and Guarino (2016) in one