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ZigBee-based wireless sensor networks for classifying the behaviour of a herd of animals using classification trees

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An in-depth study of wireless sensor networks applied to the monitoring of animal behaviour in the field is described. Herd motion data, such as the pitch angle of the neck and movement velocity, were monitored by an MTS310 sensor board equipped with a 2-axis accelerometer and received signal strength indicator functionality in a single-hop wireless sensor network. Pitch angle measurements and velocity estimates were transmitted through a wireless sensor network based on the ZigBee communication protocol. After data filtering, the pitch angle measurements together with velocity estimates were used to classify the animal behaviour into two classes; as activity and inactivity. Considering all the advantages and drawbacks of classification trees compared to neural network and fuzzy logic classifiers a general classification tree was preferred. The classification tree was constructed based on the measurements of the pitch angle of the neck and movement velocity of some animals in the herd and was used to predict the behaviour of other animals in the herd. The results showed that there was a large improvement in the classification accuracy if both the pitch angle of the neck and the velocity were employed as predictors when compared to just pitch angle or just velocity employed as a single predictor. The classification results showed the possibility of determining a general decision rule which can classify the behaviour of each individual in a herd of animals. The results were confirmed by manual registration and by GPS measurements.

1. Introduction

Animal behaviour monitoring represents a class of wireless sensor network applications with enormous potential benefits for practical farming. The knowledge of the herd behaviour phases (activity, inactivity) can be monitored by measuring relevant behaviour parameters. Such a behaviour classification is potentially useful as a management tool in grazing and production optimization. Furthermore, behavioural monitoring would allow us to gain a better understanding of animal behaviour, detect individual animals with potential health problems and generally optimize the grazing process.

In order to monitor herd behaviour, data relevant to the behaviour should be measured, aggregated, processed and finally sent through a network to infrastructure facilities. In

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animal science applications, the natural mobility of the herd makes wireless sensor networks a good candidate for such monitoring of animal behaviour parameters. Furthermore, wireless sensor networks represent a significant advance over traditional invasive methods of monitoring. The integration of local processing and storage allows sensor nodes to perform complex filtering and triggering functions, as well as to apply application- or sensor-specific data compression algorithms. Low-power radios with well-designed protocol stacks allow generalized communications among network nodes, rather than point-to-point telemetry. The computing and networking capabilities allow sensor networks to be reprogrammed or re-tasked after deployment in the field. Therefore, monitoring animal behaviour parameters using wireless sensor networks appears to provide a flexible and robust monitoring system capable of remotely registering the behaviour parameters which are of interest.

A herd of animals differs in many ways from man-made systems of mobile robots because the behaviour of each individual is governed by unpredictable natural instincts and the environment into which it is placed (e.g. motion patterns influenced by food sources and water). Therefore, by monitoring a variety of behavioural parameters different aspects of animal behaviour have been studied by different researchers. For instance, the positions of animals in the field were tracked and monitored by White et al. (2001); Butler et al. (2004); Zhang et al. (2004); Schwager et al. (2007); and Wark et al. (2007) while Oudshoorn et al. (2008) investigated the location and velocities of the movements in the field. The different behaviour phases of dairy cows in a barn, such as standing and lying down, were evaluated by Munksgaard et al. (2005) and Wilson et al. (2005). However, none of these studies used an online monitoring system based on wireless sensor networks that classifies the behaviour of the animals when they are in the field.

Behavioural parameters can be measured using different types of sensors and consequently different strategies. GPS is the most popular system employed in outdoor applications to register position (Butler et al., 2004; Oudshoorn et al., 2008; Schwager et al., 2007) but high energy consumption is one of the main drawbacks of such a localization method. Furthermore, satellite connection loss in the areas of the field covered by trees has been frequently reported by Oudshoorn et al. (2008). This makes GPS less practical in terms of long-term studies and less reliable for animal monitoring in some specific environments.

Using an accelerometer attached to the leg of the animal together with an offline data logger inside the barn was the approach used by Munksgaard et al. (2005). They classified cow behaviour into two phases, moving or stationary, while Umstatter et al. (2006) used an offline pitch-roll sensor around the neck of the animal. Sallvik and Oostra (2005) used video processing combined with a radio frequency synchronization unit (RFSU).

In this work, a wireless sensor network was established in which ZigBee was implemented as the wireless communication protocol. Each node in the network was equipped with an accelerometer in order to measure the pitch angle of the neck. The nodes were programmed to measure received signal strength (RSS) allowing the distance between wireless sensors and a gateway to be estimated. Based on successive distance estimates, the velocity could be estimated.

In order to fuse the measured behaviour parameters (i.e. pitch angle of the neck and the movement velocity) and consequently classify the animal behaviour into active or inactive, different classification methods such as decision trees, fuzzy logic and neural networks have been reported. Comparing the advantages and disadvantages of decision trees compared to fuzzy logic and neural network classifiers, decision trees are the best candidate in terms of simplicity and accuracy to evaluate the herd behaviour and as a result they were employed here as the classification method.

The objectives of this paper were to classify the behaviour of a herd of animals into two classes (active and inactive) using the pitch angle measurements of the neck of the animal together with the movement velocity estimates from a wireless sensor network. A further objective was to solve a specific problem regarding packet loss using data post-processing.

2. Problem statement and background

2.1. Problem statement

In this paper, the problem of online and robust classification of animal behaviour using a wireless sensor network has been addressed. The main deficiencies were reported by Umstatter et al. (2006), Nadimi et al. (2007) and Schwager et al. (2007) and these were:

- Local, non-representative peaks may occur because only the minimum value of the pitch angle of the neck was recorded during each sampling interval (Umstatter et al., 2006).
- Online measuring becoming temporarily disabled (Umstatter et al., 2006).
- Simple non-robust classification method (Nadimi et al., 2007).
- High energy consumption method to estimate the behaviour of animals (Schwager et al., 2007).

The first two problems can make the classification results unreliable. Therefore, they are solved by using a Kalman filter and using a weighted moving average window together with velocity estimation using RSS measurements. The simple threshold method (two-dimensional classification tree) that was used in the research carried out by Nadimi et al. (2007) did not provide a robust classification. Hence, in order to reduce the risk of an improper classification, decision trees, fuzzy logic and neural network classification methods were applied. Consequently, due to its simplicity for training, accuracy and applicability, a decision tree was chosen as the most suitable classification approach.

To employ a low-cost and low-power monitoring system, wireless sensor networks have been implemented in the present research; therefore, high energy consumption introduced in the research carried out by Schwager et al. (2007) needs to be addressed.