Computers and Electronics in Agriculture 152 (2018) 101–108

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

# Wireless energy transfer by means of inductive coupling for dairy cow health monitoring

Ben Minnaert[a,*], Bart Thoen[a], David Plets[b], Wout Joseph[b], Nobby Stevens[a]

[a] Research Group DraMCo, ESAT, Technology Campus Ghent, KU Leuven, Belgium
[b] Department of Information Technology, IMEC-Ghent University, Ghent, Belgium

ARTICLE INFO

*Keywords:*
Automation
Dairy cows
Energy harvesting
Health monitoring systems
Inductive charging
On-body sensors
Wireless power transfer
Wireless sensor networks

ABSTRACT

The increase of herd sizes hinders the capability of the dairy farmer to timely detect illnesses. Therefore, automatic health monitoring systems are deployed, but due to their high energy consumption, the application possibilities remain limited. In this work, a wireless, inductive charging solution for dairy cow monitoring is designed. This system is mounted at the eating trough, and the amount of energy transferred each eating turn is determined experimentally. For the first time, inductive wireless power transfer is used to charge on-body sensor networks for cattle. Measurements at a research farm on 40 dairy cows show an average energy transfer of 96 J per meal, for an average eating time of 160 s. It is demonstrated that inductive power transfer is a viable technology to resolve the energy provision challenge for the automatic and real-time health monitoring of dairy cows.

## 1. Introduction

Dairy farmers aim at increasing their herd size, either out of necessity to survive in a cost competitive market or to generate more profits (Jones, 1999). The more dairy cows on the farm, the more milk can be produced per euro of investment, leading to a lower relative cost (Tauer and Mishra, 2006). This desire to increase the herd size on a farm can be seen in the numbers: in the United States, the average dairy cow herd size increased by 325% between 1980 and 2004 (Chase et al., 2006). Also in the European Union, the number of cows per farm is increasing with a growth of 30% between 2007 and 2010 (EU, 2014).

The total cost of milk production consists of many different components, e.g., machinery, land costs, veterinary costs, buildings, animal purchases, etc. By far, the two most expensive components are feed and labor costs (Hemme et al., 2014). An increasing farm size does not necessarily guarantee a lower cost per unit of produced milk since the associated labor cost can cancel out the added cost reduction. Indeed, if the herd size is limited, the farmer has the ability to individually follow up all the cows frequently. However, the larger the herd, the more labor intensive and less practical it becomes for the farmer to monitor all the dairy cows. Nevertheless, a strict monitoring of all cows remains necessary to timely detect anomalies in the health of the farm animals as a late detection may lead to significant costs. For example, a cost of at least 150 euro is associated with a missed case of mastitis or per missed calving and 250 euro or more per missed heat or per late detection of lameness (Krieter et al., 2007; Haugen, 2011).

To manage the increasing herd size in an economically efficient way, the farmer can rely on automatic health monitoring systems for the collection and interpretation of animal data. Even for farms with less than a hundred dairy cows, automatic animal monitoring can be economically beneficial since it reduces the associated labor (Tauer and Mishra, 2006).

Automatic monitoring systems can be implemented for the detection of illnesses, predicting the calving moment, and tracking the movement and location of the animal (Lopes and Carvalho, 2016; Arcidiacono et al., 2017; Rutten et al., 2017; Pastell et al., 2008; Benaissa et al., 2017). On-body sensors allow measuring different parameters of the animal, which can be wirelessly transferred to a back-end server for data interpretation (Benaissa et al., 2016a,b). The back-end system can, when a possible anomaly is detected, alert the farmer through portable electronics, e.g., the farmer's smartphone (Fig. 1). A timely detection and reliable interpretation of the data requires a near-real-time collection and processing of the measurements.

Table 1 lists several important animal monitoring systems available on the market, the parameters they monitor and which anomalies they detect. The systems listed in the table all monitor only one or two parameters at once, often not in real-time. None of them combine multi-parameter information. Medria, eCow and Nedap have the expertise to monitor multiple parameters (e.g., movement, temperature, or location), but these features require separate systems (e.g., Heatphone,

* Corresponding author.
*E-mail address:* ben.minnaert@kuleuven.be (B. Minnaert).

https://doi.org/10.1016/j.compag.2018.07.010
Received 19 December 2017; Received in revised form 15 May 2018; Accepted 4 July 2018

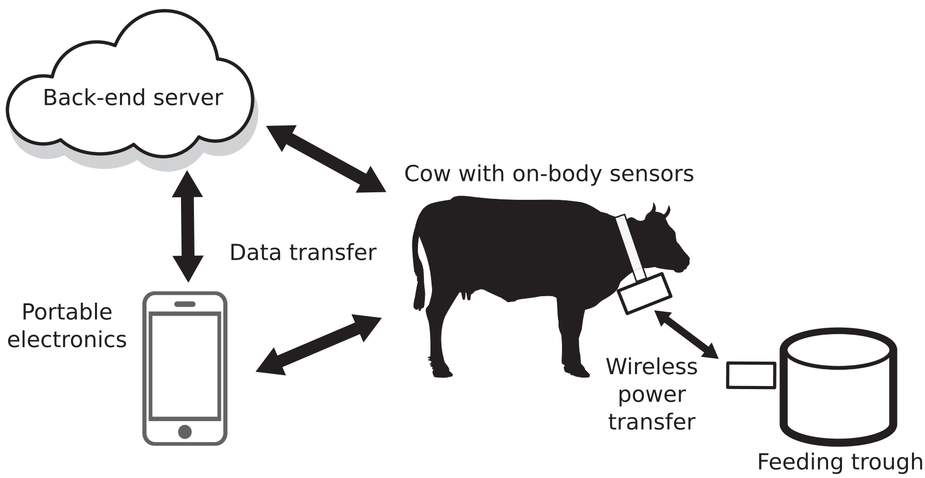


**Fig. 1.** On-body sensors measure different parameters of the animal, which are wirelessly transferred to a back-end server for data interpretation. The back-end system and the on-body system can share their information with the farmer's portable electronics and e.g., alert the farmer when a possible anomaly is detected. The on-body health system is wirelessly charged at a feeding trough.

**Table 1**
Selected dairy cow monitoring systems on the market.

| System | Localization | Real-time updates | Lifetime | Number of monitored parameters | Detects |
|---|---|---|---|---|---|
| Bella AG | No | Yes | Limited | 1 (temperature) | Illness |
| Boumatic StepMetrix | No | No | N/A | 1 (step pattern) | Lameness |
| Cowmanager SensOor | No | Yes | Limited | 2 (temperature, movement) | Heat, illness |
| CowScout GEA | No | Yes | Limited | 2 (movement, eating duration) | Heat (illness, lameness) |
| eCow eCollar | No | No | Limited | 1 (movement) | Lameness |
| eCow farmBolus/eBolus | No | No | Limited | 2 (pH, temperature) | Illness |
| DeLaval HerdNavigator | No | No | N/A | 1 (milk parameters) | Heat, illness |
| Medria Heatphone | No | No | 6 years | 1 (movement) | Heat |
| Medria San'Phone | No | No | Limited | 1 (temperature) | Illness |
| Medria Vel'Phone | No | No | Limited | 1 (temperature) | Calving |
| Moocall | No | No | Limited | 1 (contractions) | Calving |
| MooMonitor + | No | No | Cow lifetime | 1 (movement) | Heat |
| Nedap Cow Positioning | Yes | Yes | Limited | 1 (location) | Location |
| Nedap Heat Detection | No | Yes | Cow lifetime | 1 (movement) | Heat |
| Telespor | Yes | Yes | Limited | 1 (gps position) | Location |

San'Phone and Vel'Phone). An integrated animal monitoring system which is able to detect several different parameters as illness, calving, movement and location at once currently not exists. This requires the farmer to buy and integrate different measurement solutions.

An important barrier for an integrated system is the high energy consumption. Indeed, powering different accurate sensors and wirelessly transferring the data in real-time to a back-end server requires a significant amount of energy. Even when only one or two parameters are measured, the lifetime of current devices are often limited. Solutions that claim a lifetime equal to the cow's lifetime have to focus on only one monitored parameter (Table 1). Therefore, in a lot of systems, the farmer has to manually replace the battery every few months or every year. This contradicts with the objective of a maintenance-free, automatic health system to reduce the labor cost.

A solution to the above problems is wirelessly charging the monitoring system at the drinking or eating trough by inductive coupling (Fig. 1). In this way, the system can wirelessly receive enough energy every day to continue operation. As a result, not only more energy can be made available to the system, allowing the real-time measurement of multiple parameters, but the system allows for a maintenance-free solution during the entire lifetime of the cow, under the condition that the lifetime of the sensors (including their reliability and accuracy) is sufficiently large. Moreover, the wireless charging avoids the regular replacement of single-use batteries, leading to a reduced impact on the environment.

By installing a transmitter coil at an eating trough and a receiver coil in the collar (which can serve as a central hub for on-body sensors), wireless power transfer can be realized during the eating time slots at a dairy farm. Measurements were performed at a dairy farm on 40 lactating cows to experimentally determine how much power transfer can be expected through inductive coupling every time the cow eats. This allowed to determine the daily energy transfer, leading to an evaluation of the feasibility of using inductive coupling as a way to wirelessly charge automatic on-body health systems for dairy cows. The main novelty of this work is that, for the first time, inductive wireless power transfer was applied to charge on-body sensor networks on cattle.

The paper is organized as follows: in Section 2, the principle and background for wireless inductive charging is described. In Section 3, the methodology for our setup is discussed. Finally, the results of the field tests with dairy cows can be found in Section 4.

## 2. Inductive wireless charging

To wirelessly charge the system, the principle of inductive coupling is applied: an alternating current through a transmitter coil generates a time-varying magnetic field (Fig. 2a). This field generates an alternating voltage in a receiver coil, thus enabling energy transfer from the transmitter to the receiver coil, located in the collar of the cow.

Inductive wireless power transfer has already entered the market, as well for low power (e.g., electronic portable devices) as higher power applications (e.g., electrical vehicles) (Lu et al., 2016; Mou and Sun, 2015; Hui, 2013). However, the devices on the market are all static and deterministic. This means that the position of the receiver with regard to the transmitter is defined and unaltered over the charging time, resulting in a constant inductive coupling.

Applications for non-static wireless power transfer applications, where the relative transmitter–receiver positions are highly time-