Computers and Electronics in Agriculture 75 (2011) 238–242

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

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

Original paper

Energy generation for an ad hoc wireless sensor network-based monitoring system using animal head movement

E.S. Nadimi[a,*], V. Blanes-Vidal[a], R.N. Jørgensen[a], S. Christensen[b]

[a] Faculty of Engineering, University of Southern Denmark, Odense, Denmark
[b] Faculty of Life Sciences, University of Copenhagen, Copenhagen, Denmark

ARTICLE INFO

Article history:
Received 14 January 2010
Received in revised form 5 November 2010
Accepted 17 November 2010

Keywords:
Energy generation
Mobile ad hoc wireless sensor networks (MANETs)
Lagrange–d'Alembert Principle
Energy consumption

ABSTRACT

The supply of energy to electronics is an imperative constraining factor to be considered during the design process of mobile ad hoc wireless sensor networks (MANETs). This influence is especially important when the MANET is deployed unattended or the wireless modules within the MANET are not easily accessible. Therefore, exploring novel sources of energy generation rather than operating electronics only on limited power supplies such as batteries is a major challenge. Monitoring free-ranging animal behavior is an application in which the entities (animals) within the MANET are not readily accessible; however, animal movement can be potentially used to generate energy. In this study, the head movements of individual sheep in a flock during grazing were monitored in order to investigate the amount of energy that can be generated by these movements. By applying the Lagrange–d'Alembert Principle to this problem, the equations of motion from each neck-mounted sensor as well as the amount of mechanical energy generated per time instant (each second) during upward and downward head movements were calculated. This resulted in the production of 857 mW and 1660 mW during the downward and upward movements, respectively. Furthermore, the energy consumption of each wireless node within the MANET was estimated to be 117.8 mW per second. Conversion of energy from mechanical to electrical requires miniature electromechanical generators that can currently provide between 25% and 50% conversion efficiency. Even using the worst conversion efficiency (25%), a minimum of 214 ± 25 mW of electrical energy per second could be generated. This amount exceeds the energy consumed by the wireless sensors that can be used to gather parameters describing animal behavior such as neck and head movement. This study suggests that the amount of energy generated by the vertical neck–head movement of sheep during grazing can be converted to useful electrical power adequate to provide power for operation of wireless sensor nodes on a continuous basis within a MANET-based animal behavior monitoring system.

1. Introduction

A consistent and reliable energy supply is imperative to ensure the optimum performance of mobile ad hoc wireless sensor networks (MANETs). This is particularly challenging in networking, control and monitoring applications such as habitat monitoring, health care applications, home automation, transportation systems and animal behavior monitoring where either the MANET is deployed unattended or the wireless modules within the MANET are not readily accessible. The MANET becomes useless if the system runs out of power. Therefore, there is a need to provide consistent power for maximum efficiency from these systems to be realized. Such systems can integrate functionalities such as measuring, computation, and communication all while consuming the least amount of energy as possible. This goal motivates a unique challenge which is network design (Chang and Tassiulas, 2000).

Recent developments in software design process including optimization of routing protocols and processors allow researchers the ability to reduce the energy consumption within a designed MANET. Multi-hop routing protocols have focused on energy efficiency by deploying localized algorithms as proposed by Estrin and Govindan (1999) and Sohrabi et al. (2000). However, due to the large number of sensors, network-scale interaction is frequently too energy expensive. Moreover, a centralized algorithm (i.e. an algorithm in which one of the nodes or the base station has global information of the network) may result in a single point of failure and is not a satisfactory approach for built in redundancy. Therefore, minimizing the energy consumption of transmissions and exploiting the multi-hop aspect of network communications are two options for localized algorithms (i.e. an algorithm in which

* Corresponding author. Tel.: +45 27781929.
E-mail address: esi@kbm.sdu.dk (E.S. Nadimi).

0168-1699/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.compag.2010.11.008

each node makes a decision to which neighbors forward their message based solely on the location of one's self, its neighboring nodes and the destination). This approach provides a longer sensor network lifetime as discussed by Chang and Tassiulas (2000), Rabiner et al. (2000), Stojmenovic and Lin (2000), Li et al. (2006) and Bhattacharyya et al. (2008). Localized algorithms are distributed algorithms that resemble greedy algorithms, where simple local behavior achieves a desired global objective.

Recently, attention has focused on software-oriented algorithms to reduce energy consumption of MANET, while the importance of hardware-oriented algorithms has been underestimated. The advantage of hardware-oriented algorithms, especially those that focus on recharging a nodes' power supply (e.g. batteries), is to enable MANET to indefinitely run. These algorithms are strongly recommended when either the MANET is deployed unattended or the wireless modules within the MANET are not readily reachable. Monitoring free-ranging animals is one use of wireless sensor network applications in which the entities (animals) are not easily accessible (Nadimi et al., 2008a,b; Nadimi and Søggard, 2009). To overcome the constrains imposed on MANET by the power supply, Correll et al. (2008) and Anderson (2001) deployed batteries that were continuously recharged by a solar panel. According to the authors' best knowledge, the research carried out by Correll et al. (2008) and Anderson (2001) were the only real-time solution toward the energy generation challenge for a MANET-based animal behavior monitoring system. However, the main drawback of such an energy generation method is the inefficiency when deployed in northern latitudes where solar radiation energy density is very low during the most of the year. Furthermore, dust and dirt accumulation on the solar panels negatively affect the efficiency of the system.

The main objective of this research was to investigate a potential source for energy generation for a MANET-based animal behavior monitoring system that benefits from the inherent mobility of each entity within the MANET. To carry out this investigation, each animal in a small flock of 11 sheep (10 ewes and one ram) was equipped with a wireless module capable of measuring and monitoring head/neck movements. The behavior of the flock was recorded and observed prior to the deployment of the wireless modules and no change in the behavioral pattern due to the deployment of wireless modules was observed. Data were obtained from the sheep grazing herbaceous forage between 1000 h and 1600 h, a period of active foraging. This period represented an optimum amount of sustained head and neck movement. Other times during a 24 h period were not used to capture data since head/neck movements were less pronounced during the periods not characterized as predominantly grazing (Nadimi et al., 2008b). From these head and neck displacements, the amount of energy generated (mechanical energy) by the animals was calculated. The experiment captured energy generation from an object moving upward and downward (the same pattern that characterizes the head movement of grazing animals). In this research, no browsing behavior was observed as the paddock was not covered of woody plant species.

Recent advances in the design of miniature electromechanical generators to convert mechanical energy into electrical power have enhanced the efficiency of the conversion. Efficiency rate remains key factor when considering the relationship between the amounts of generated vs. consumed energy during a monitoring process, since only a percentage (25–50%) of the generated mechanical energy can be converted to the electrical energy necessary to power up the electronics of the wireless nodes.

The organization of this paper is as follows. Section 2 of this paper presents the detailed energy consumption of the components of a wireless node in a MANET. The amount of energy generated by head movements of an animal is calculated and presented in Section 3. Experimental setup is described in Section 4; results of this study together with the discussion are presented in Section 5 while the conclusions of this research are described in Section 6.

2. Energy consumption

The IRIS 2.4 GHz mote modules (Crossbow, Milpitas, CA) specifically designed for embedded sensor networks, were deployed as shown in Fig. 1. The modules were housed in 6 cm × 3.75 cm × 3.75 cm rectangular boxes that were attached to the halter. The MTS310 sensor boards were equipped with dual-axis ADXL202 accelerometers (Analog Devices, Norwood, MA) to measure the animals' head movements. Accelerometer readings were calibrated to account for temperature drift during the experiment using an ERT-J1VR103J thermistor (Panasonic, Osaka, Japan). Each sensor node in the patch network acted as a full function device (FFD) in a multi-hop IEEE 802.15.4 ZigBee based mesh network. Network-wide time synchronization to enable very low power operation was utilized (Nadimi et al., 2008b). To keep energy consumption at a very low level and to enhance communication reliability; relay nodes, handshaking protocol and over the air programming (OTAP) were used. In a system running as described, the energy budget must be divided among several system services, including sensor sampling, data collection, routing and communi-

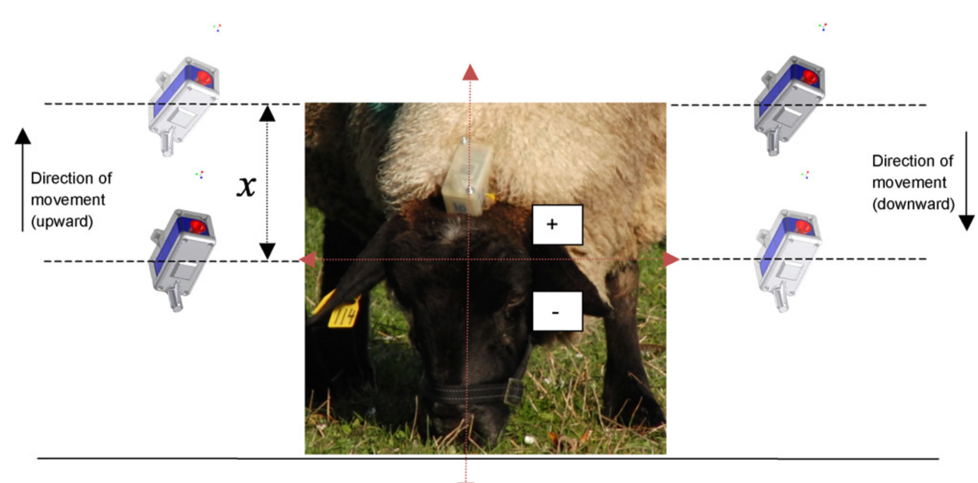

Fig. 1. Southdown ewe wearing commercial halter with a wireless node attached behind the animal's poll to record vertical displacement of the head and neck while grazing.