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Research Paper

Monitoring Cattle Motion using 3-axis Acceleration and GPS Data

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ABSTRACT:- *This paper examines feasibility of a cattle monitoring device that can sense, record, and wirelessly transmit the 3-axis acceleration and global positioning system (GPS) data of the cow for accurate and timely monitoring. The device is intended to use for estrus detection by interpreting the measured data to identify cow's behavior and act. The device also has capability to store the detailed cattle activity data and transfer them wirelessly to the main dairy management computer when cattle enter the barn.*

Measured tri-axis acceleration and GPS data through field tests in a dairy barn were performed post-processing for interpretation of data and plotted for diagnosis of behavior including frequency and distance traveled as well as the location of cattle. Specifically, the frequency of cow's activity was analyzed by power spectral density (PSD) for the 3-axis acceleration data and the distance traveled was realized from GPS data. The results indicated that the 3-axis acceleration and GPS data could be used to monitor motion of cattle including time spent prone, distance traveled, and overall activity levels.

The monitoring device's primary application is to automate estrus detection for artificial insemination, but the capability to track the cow's motion characteristics may provide dairy operators with the capacity to assess the cow's behavior and act to improve the overall well-being and health of the cow.

Keywords:- *Animal health monitoring, automated heat detection, GPS, interpretation of cow motion, power spectral density, 3-axis acceleration*

I. INTRODUCTION

The interest in monitoring cow's behavior for automated detecting estrus or unhealthy motion has steadily grown in recent years. In particular, large-scale dairy operations require an efficient automated heat detection system to accurately determine when the cows are ready for insemination. Accurate detection of estrus behavior for breeding on dairy farms is essential to dairy profitability as missed estrus periods cost dairymen. Many technologies have been attempted to detect estrus behavior in cattle with varying success. However, not all of commercial devices developed for automated heat detection and wireless data transmission provide required information such as activity level, traveling rate, and distance traveled of a cow.

The cattle monitoring system could support cattle reproduction by improving estrus detection for more efficient breeding, increase in milk production, and health and welfare by diagnosis of uncommon motion behavior such as lameness through analysis of measured motion data [1-3]. As for the cattle reproduction and milk production, key to increased milk productivity is ensuring that the cow is lactating at peak production rates for the maximum amount of time. In order to optimize lactation, milk producers must identify and exploit key phases of the bovine reproductive cycle [4, 5]. The constraints of the lactation cycle and the drive to minimize dry-off time require breeders to be able to accurately identify when the milk cow is in heat [6]. Identifying estrus followed by deriving optimal timing for artificial insemination (AI) is the preferred method of promoting reproduction because of its ability to limit the spread of genetic disease and enable milk producers to select breeds known to produce offspring with high-yield milk production [7, 8]. Specialists use a variety of direct or indirect techniques to determine when the cow is primed for insemination. Due to the brief window in which AI can successfully be performed, breeders must have timely and accurate information to determine if the cow is in heat. The ideal device would identify several key indicators of estrus and alert the user at the beginning of the estrus window without constant supervision of the technology [9].

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Chalking and monitoring temperature are currently the low-tech industry standards. Chalking consists of marking the cow's tailhead with colored chalk and monitoring the chalk mark. Breeders assume that disturbance of the chalk mark is indication that the marked cow has been mounted by another bovine and is in heat. The mount is known to be only true sign of estrus [10], but the labor-intensive methods that require constant supervision are logistically impractical for large farms. In this regard, the BullsEye® is a heat detection instrument that indicates that the cow has been mounted [11]. This device is an enhanced electronic form of chalking the tailhead that does not require constant visual monitoring of the animal. Several electronic detection instruments have also been developed to identify when the cow is in heat. Those devices include MooMonitor [12], Heatime® HR LD system [13], IceQube and IceTag Sensor [14], and HeatSeeker™ II [15] among many others. The electronic monitoring device is typically worn around the neck or leg of the cow and commonly uses 3-axis accelerometer, pedometer, and/or GPS to measure cow's activity. In addition, it sends a periodic signal to a central computer and notifies the user when the cow is in heat after interpretation of received data. The device uses common characteristics such as variation in the cow's walking pattern, change in gait, onset of mounting, and decreased tendency to remain prone to identify when the cow is in heat.

While pedometer and accelerometer are widely used to determine steps traveled and the activity level of the cow [16-19], neither instrument records the rate at which the cow is traveling or amount of area covered. To that end, GPS can be utilized to gather information of frequency and distance covered because a substantial increase in the frequency and distance that the animal walks may be another indicator of heat. Davis et al. [20] developed low-cost GPS Herd Activity and Well-being Kit (HAWK) as alternative to commercial GPS tracking collars. They also demonstrated that increasing sampling interval causes significant error in estimated of cattle motion. Tuner et al. [21] used GPS data for online monitoring of cows' presence and activity, and pasture time, while Nadimi et al. [22] adopted ZigBee wireless sensor networks. Furthermore, computer vision technique and image analysis were introduced to detect cows in heat by Tsai and Huang [23], and Choi et al. [24] recently.

This paper presents an alternative cattle motion monitoring device that uses 3-axis acceleration and GPS data to characterize increase in walking behavior and distance traveled for possible detection of estrus through interpretation of field test data [25].

II. ALTERNATIVE CATTLE MOTION MONITORING DEVICE

The key to development of the alternative cattle monitoring device is analysis of the characteristics to be measured. It may be considered three motion characteristics such as distance traveled, time spent lying down, and overall activity to indicate cow's estrus [26]. The dairy cow has a marked increase in distance traveled when in heat. Not only is the animal likely to pace, it also travels over a larger distance. In between these periods of pacing, the cow is likely to be standing rather than prone. It was determined that, to most accurately identify when the cow is in heat, the device would need to track all three characteristics. With these objectives identified, the KinetaMap [27] of commercial off-the-shelf (COTS) products equipped with 3-axis accelerometer and GPS capability was chosen. The acceleration data was use to determine the overall activity of the cow, while GPS to identify distance and speed traveled. Instead of using developed analysis software or algorithm in order to utilize the accelerometer data to identify specific characteristics in the cow's normal gait as compared to when in heat [26, 28-31], the acceleration data was analyzed by power spectral density (PSD) in MATLAB used in this work [25].

2.1 KinetaMap assembly for measurement

2.1.1 Fabrication of rugged Kineta Map assembly

The KinetaMap was procured from Spark Fun, which contains a 3-axis accelerometer, GPS, and Bluetooth capability. This product was preferable over other COTS products because it offers Bluetooth wireless data transmission and does not utilize unnecessary sensors that consume battery life. The 1100 mAh battery supplied with the KinetaMap offered only seven hours of life. Extended testing sample times were necessary to produce a wider and more representative data range, requiring the selection of an alternative power supply. To lengthen test times, alternating battery packs using Tenergy-2600PCB-18650 lithium-ion battery were fabricated to eliminate the need to stop testing to recharge. The packs of five batteries were wired in parallel to provide battery power more than two days. An IP-rated, commercially-available electronics enclosure was procured to provide waterproof and rugged protection for the electronics. The Pelican Micro Case 1010 enclosure [32] was water and strength-tested prior to the field testing. Fig. 1 shows the KinetaMap assembly includes onboard triple-axis accelerometer ($ADXL_{345}$) and Bluetooth module (RN41), flash memory micro SD card, GPS module (EM-408), battery pack, and the Pelican case.

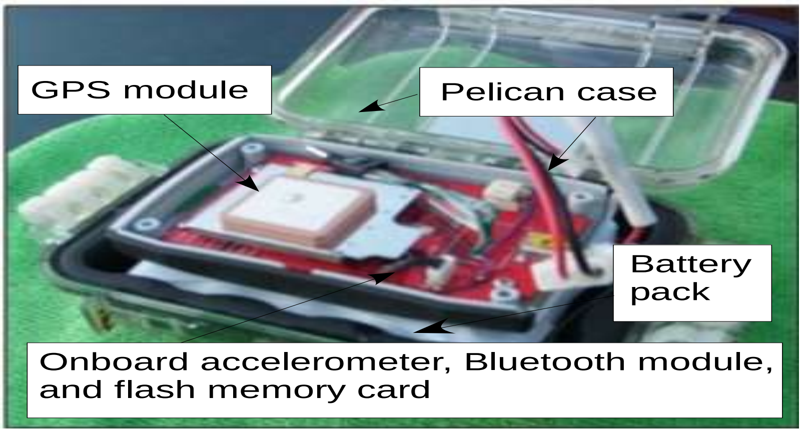

Figure 1. KinetaMap assembly

2.2 Characterization of cattle motion using three-axis acceleration

2.2.1 Calibration of the digital accelerometer data

Since data from the digital accelerometer is in a code format called 2's complement, the value recorded in the data table needs to be converted to acceleration in the units of gravity. The 2's complement value is a number between 0 and 65536. This range represents positive values between 1 and 32767 and negative values between 32768 and 65536, with 0 in the middle. Using these criteria, a formula was developed to convert the raw data to positive or negative voltage numbers. Voltage then needed to be converted into acceleration. This formula was based on the 16 g range of the voltage output converting to one increment per 100 mg [27]. Table 1 displays the calculations used to convert the 2's complement to acceleration into g value.

Table 1. Convert 2's complement number to acceleration in units of g

	A	**B**	**C**
1	2's comp data from the KinetaMap, number from 0 to 65536	Conversion to +/- voltage =IF(A2>32767, A2-65537, A2)	Conversion from voltage to g's =B2*0.016
2	65534	-3	-0.048
3	65535	-2	-0.032
4	65536	-1	-0.016
5	0	0	0
6	1	1	0.016
7	2	2	0.032
8	3	3	0.048

2.2.2 On-cow testing and analysis [25]

The rugged electronic device was built to withstand harsh dairy conditions as shown in Fig. 2 (a) and was attached to the cow's ankle (Fig. 2 (b)). As shown in the figure, the Pelican case with the electronics inside was mechanically fastened to the cow leg strap with tape and zip ties.

Figure 2. KinetaMap assembly (a) rugged electronic device and (b) attached to a cow

Using the KinetaMap assembly, field test was performed to gather data for the motion characteristics in a dairy barn in Sunnyside, WA. The device was configured to sample acceleration on all three axes at the rate of 60 Hz and record location of cow using the GPS at 1 Hz. The faster sample rate was used to obtain more accurate frequency resolution [20]. Testing with the KinetaMap assembly recorded 624 hours of data and sampled 5 different cows with the device attached to the rear right ankle. The list of cows tested with the KinetaMap assembly is seen in Table 2.

Table 2. List of cows for testing with the KinetaMap

Cow Number	Start Test	End Test	AI Date
3897	10/9	10/14	10/13
13460	10/14	10/16	N/A
297	10/16	10/20	10/20
12639	10/20	10/25	N/A
10755	10/25	11/01	10/25

Cows #3897, #297, and #10755 were the only cows verified to have come into heat and been inseminated while wearing the KinetaMap prototype. It is unknown if any of the cows that were inseminated have become pregnant. Measure accelerometer data from the field testing could not be easily used to characterize changes in gait. Acceleration data in x-axis was analyzed using PSD. The acceleration data was grouped into 1024 sample segments to look for fundamental frequency shifts. Fig. 3 shows the PSD curve for cow #297's normal movement (blue) as compared to its movement on the day it was inseminated (red). PSD curves for two set of data were plotted for the normal movement and three set of data for the possible heat indication. Fig. 4 shows a PSD comparison for time segments when cow #3897 is not in heat (blue) and when it is thought to be in heat (red). PSD curves for three set of data were plotted for both the normal movement and the possible heat indication. The PSD analysis shows a general shift in the dominant frequency from normal movement to possible estrus movement. Further data will need to be gathered to positively identify how the PSD curve shifts when the cow is in heat.

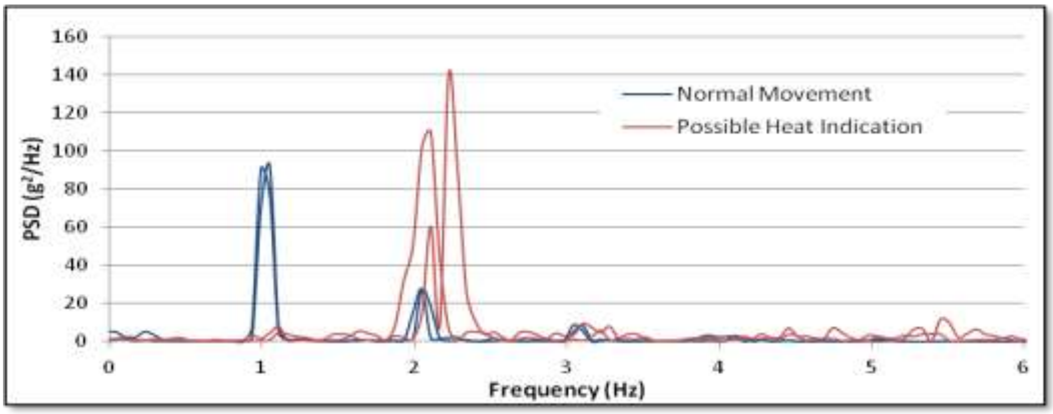

Figure 3. PSD of cow #297 while not in heat and with indications cow may be in heat

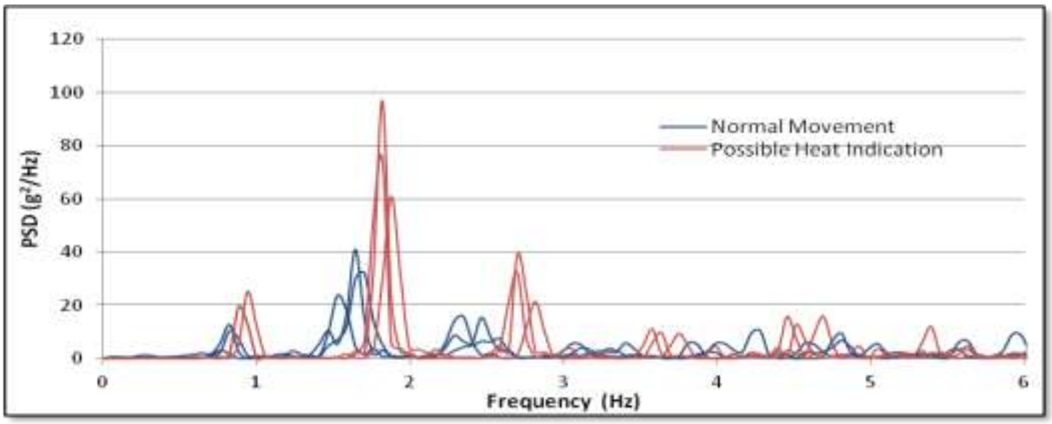

Figure 4. PSD of cow #3897 while not in heat and with indications cow may be in heat

Analysis of the acceleration plots of the same time segment from the PSD demonstrates that the overall activity of a cow increases when presumed to be in heat. Fig. 5 shows acceleration plots of a cow that is not in heat, while Fig. 6 demonstrates acceleration of a cow presumed to be in heat in time domain.

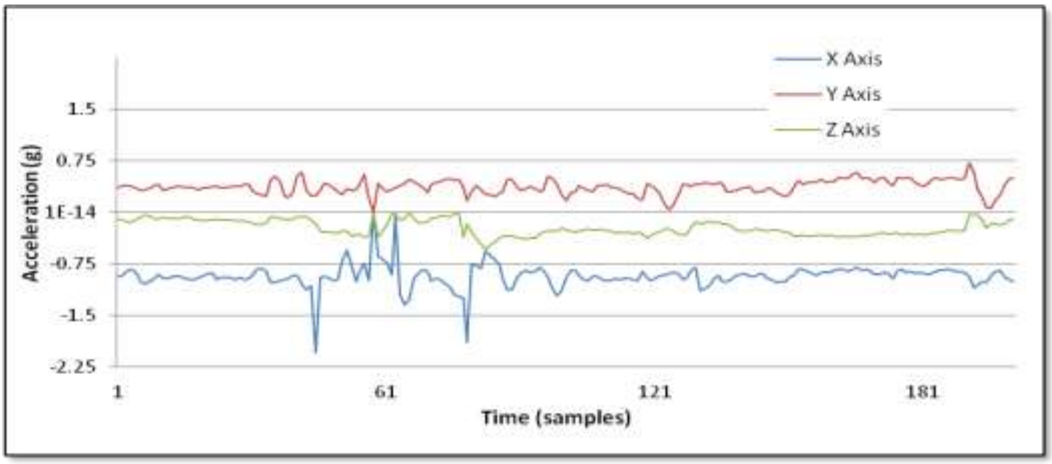

Figure 5. Activity of cow while not in heat

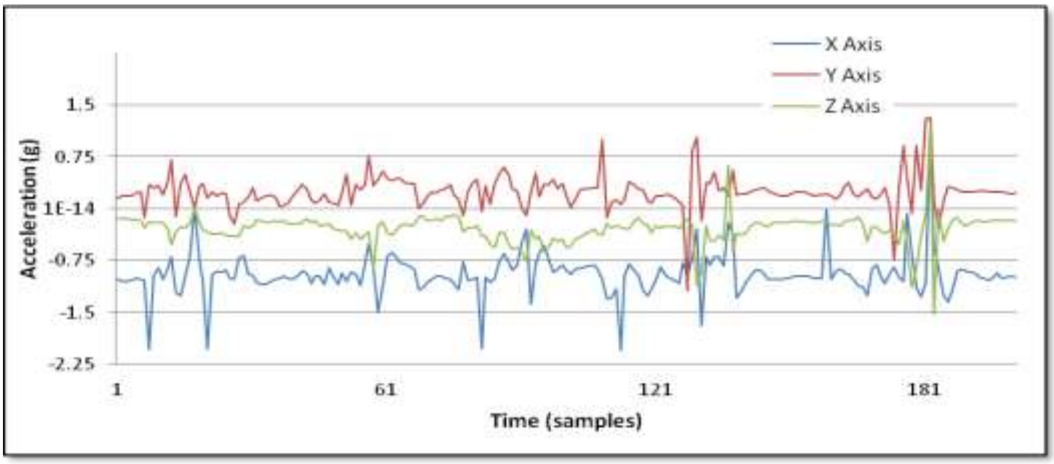

Figure 6. Activity of cow while presumed to be in heat

The acceleration plots in time domain also demonstrates that the activity of a cow increases when presumed to be in heat.

Further analysis of acceleration data shows how gravity affects the accelerometer when the cow is lying down. The cow did not lie down in the samples used for the PSD analysis. The cow #3 did lie down during testing. The acceleration data for this event is shown in Fig. 7.

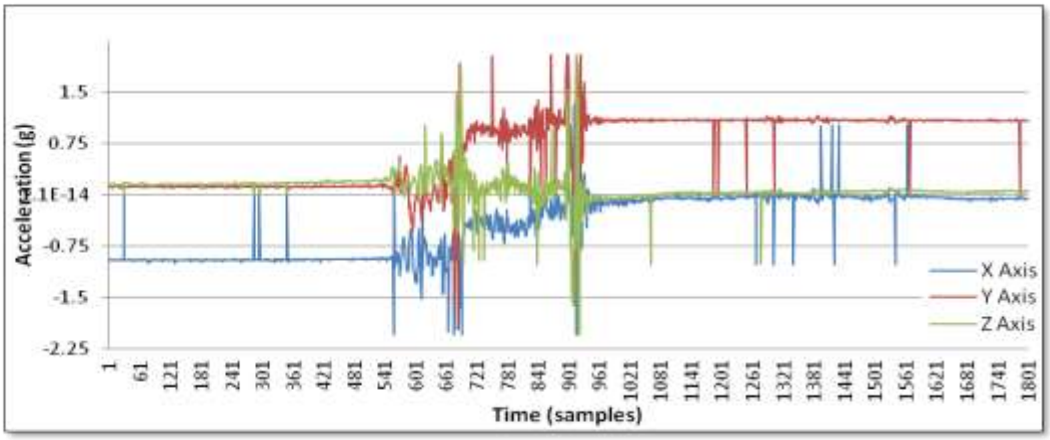

Figure 7. Acceleration change when cow lies down

When the cow moves from the standing position to prone, the orientation of the sensor rotates from the normally horizontal axis to vertical. This is due to the effect of gravity shifting from the sensor's x-axis to the y-axis. Fig. 8 depicts how the cow's leg is orientated with the normally vertical axis as horizontal while lying prone. While in a standing position, the accelerometer's x-axis is orientated with positive acceleration up; when in the prone position, the y-axis's positive orientation is pointing down. The segment time for this plot of 1800 samples at 60 Hz is 1800/60 = 30 seconds. In the time it took for the cow to lie down, about 480 samples were registered, which equates to 8 seconds.

Figure 8. Orientation of cow's leg while prone

2.3 Characterization of cattle motion using GPS data

Based on the characteristic that the cow's total distance traveled increases over a larger area when in heat, GPS was used to identify distance and speed traveled. GPS data had to be manipulated to change the output of longitude and latitude coordinates to radians, as well as to find the distance and speed traveled between points. Table 3 shows the calculations used.

Table 3. GPS data manipulation from longitude/latitude to speed

	A	B	C	D	E	F	G
1	Data From the KinetaMap			Convert Long/Lat/Time to Feet/Sec			
2				(((B5-4600)/60)+46)*(PI()/180)	(((C5-11900)/60)+119)*(PI()/180)	ACOS(SIN(D5)*SIN(D6)+COS(D5)*COS(D6)*COS(E6-E5))*(6371*3280.839895)	F6/(A6-A5)
3	Time	Latitude	Longitude	Latitude to radian	Longitude to radian	Distance (ft)	Feet/Sec
4	2208	4619.49	11953.426	0.808522118	2.092482803	-	-
5	2208	4619.49	11953.426	0.808522234	2.092482861	2.549471471	1.274735
6	2208	4619.49	11953.426	0.808522292	2.092482891	1.284213452	1.284213
7	2208	4619.49	11953.426	0.808522322	2.092482978	1.392925061	0.696462
8	2208	4619.49	11953.427	0.808522322	2.092483327	5.051154231	1.262788
9	2208	4619.49	11953.428	0.808522322	2.092483414	1.284213452	1.284213

Time segments of five minutes were used to compare the paths taken by a single cow. Fig. 9(a) shows the path traveled by the cow when not in heat. The calculated overall distance for the path is 77 m (252.49 ft), with an average speed of 0.52 m/s (1.71 ft/s). Fig. 9(b) shows the path taken when presumed to be in heat. During this time segment the cow covered 92 m (301.53 ft), having an average speed of 0.62 m/s (2.05 ft/s). The overall distance traveled and average speed increased by 20 percent when comparing time segments for when the cow is not in heat and when it is believed to be pregnant. The online resource GPS Visualizer [33] was used to generate the paths over a map. These maps demonstrate that, while not in heat, the cow tends to stay in the same general area. When presumed to be in estrus, the cow covers a greater area.

(a) Path of cow while not in heat

(b) Path of cow while presumed to be in heat

Figure 9. Path of cow established by GPS data

Analysis of the data returned by field testing the KinetaMap assembly verifies that accelerometer and GPS data can identify the motion behavior that indicates when a cow is in heat. Three characteristics were observed through the field testing: overall activity increases, increase of total distance traveled, and decreased amount of time spent prone. Software will need to be developed to automatically interpret the data to determine if the cow is in heat. The software will be able to register preset time segments and identify trend changes in the cow's motion characteristics.

This device could easily identify the length of time an individual cow spends eating, standing, or lying and alert the operator to any significant changes in behavior. The device could also be used to store the cow's immunization and health information. Having the ability to monitor this type of information would result in an overall increased well-being of cows [1-3].

III. CONCLUSION

An alternative cattle monitoring device having 3-axis accelerometer and GPS capability was proposed to use for possible detection of cow's estrus. Field test results indicate that the device that records three-axis acceleration and GPS location data as well as wirelessly transmits this data to a central computer for analysis is a beneficial tool to determine when a cow begins its heat cycle. In particular, based on testing, GPS data can be utilized to identify the cow's location, speed of movement, and distance traveled. This device could be also used for alternative trending and observations to benefit the well-being of the cow for higher quantity and quality of milk production. As future work, a compact and low-maintenance cattle motion tracking device will be designed.

REFERENCES

[1] K. Smith, A. Martinez, R. Craddolph, H. Erickson, D. Andresen, and S. Warren, An integrated cattle health monitoring system, Proc. of the 28th IEEE EMBS Annual International Conf., 1, New York City, USA, Aug 30-Sept 3, 2006, 4659-4662.

[2] J. Rushen, A. M. De Passille, M. A. G. Von Keyserlingk, and D. M. Weary, The Welfare of Cattle (Animal Welfare), 2010, 310.

[3] E. Kokin, J. Praks, I. Veermäe, V. Poikalainen, and M. Valls, IceTag2D^{TM} accelerometric device in cattle lameness detection, Agronomy Research, 12(1), 2014, 223-230.

[4] R. E. Pearson, L. A. Fulton, P. D. Thompson, and J. W. Smith, Three Times a Day Milking during the First Half of Lactation, Journal of Dairy Sciences, 62, 1979, 1941-1950.

[5] H. D. Goff, https://www.uoguelph.ca/foodscience/dairy-science-and-technology/milk-production-and-biosynthesis.

[6] IDEXX Laboratories, Inc., Animal Health Update: http://www.idexx.com, 2011.

[7] D. W. Webb, Artificial Insemination in Dairy Cattle, University of Florida Institute of Food and Agricultural Sciences, 1992.

[8] R. L. Nebel, New Strategies for Heat Detection and Timing of Artificial Insemination, Western Dairy Management Conference, The Western Dairyman Magazine, 1997, 107-117.

[9] P. Gordon, Oestrus detection in dairy cattle, In Practice, Journal of the British Veterinary Association, 33, 2011, 542-546.

[10] G. Perry, Detection of Standing Estrus in Cattle, South Dakota State University, 2004.

[11] M. Beach, Operating Manual: BullsEye Electronic Heat Detection Systems, http://www.bullseyeheatdetection.com.

[12] E. Harty, Automating Heat Detection, Kerry, Ireland.

[13] Heatime HR LD system - SCR, http://www.scrdairy.com/cow-intelligence/heatime-hr-system.html.

[14] IceRobotics Ltd: http://www.icerobotics.com/products/.

[15] BouMatic LLC: SmartDairy Activity Module Literature, http://www.boumatic.com/us-en/products/smartdairy.

[16] T. Watanabe, A. Sakurai, and K. Kitazaki, Dairy cattle monitoring using wireless acceleration-sensor networks, IEEE Sensors Conf., Lecce, Italy, 26-29 Oct., 2008, 526-529.

[17] P. Martiskainen, M. Järvinen, J. –P. Skön, J. Tiirikainen, M. Kolehmainen, and J. Mononen, Cow behaviour pattern recognition using a three-dimensional accelerometer and support vector machines, Applied Animal behaviour Science, 119, 2009, 32-38.

[18] E. D. Ungar, I. Schoenbaum, Z. Henkin, A. Dolev, Y. Yehuda, and A. Brosh, A., Inference of the Activity Timeline of Cattle Foraging on a Mediterranean Woodland Using GPS and Pedometry, Sensors, 11(1), 2011, 362-383.

[19] J. R. D. MacKay, J. M. Deag, and M. J. Haskell, Establishing the extent of behavioural reactions in dairy cattle to a leg mounted activity monitor, Applied Animal behaviour Science, 139, 2012, 35-41.

[20] J. D. Davis, M. J. Darr, H. Xin, J. D. Harmon, and J. R. Russell, Development of a GPS herd activity and well-being kit (GPS HAWK) to monitor cattle behavior and the effect of sample interval on travel distance, Applied Engineering in Agriculture, 27(1), 2011, 143-150.

[21] L. W. Turner, M. C. Udal, B. T. Larson, and S. A. Shearer, Monitoring cattle behavior and pasture use with GPS and GIS, Canadian Journal of Animal Science, 80(3), 2000, 405-413.

[22] E. S. Nadimi, H. T. Søgaad, T. Bak, and F. W. Oudshoorn, ZigBee-based wireless sensor networks for monitoring animal presence and pasture time in a strip of new grass, Computers and Electronics in Agriculture, 61, 2008, 79-87.

[23] D. –M. Tsai and C. –Y. Huang, A motion and image analysis method for automatic detection of estrus and mating behavior in cattle, Computers and Electronics in Agriculture, 104, 2014, 25-31.

[24] D. Choi, H. Kim, Y. Chung, and D. Park, D., Automatic detection of cattle mounting using motion and color information, 3rd international Conf. on Computational Techniques and Artificial Intelligence (ICCTAI'2014), Singapore, Feb. 11-12, 2014.

[25] D. Hanson, Electronic Device to Track and Characterize the Motion of Cattle, MS Project, Mechanical Engineering, Washington State University Tri-Cities, Richland, WA, 2011.

[26] M. L. O'Connor, Heat Detection and Timing of Insemination for Cattle, The Pennsylvania State University, 1993.

[27] SparkFun Electronics, http://www.sparkfun.com/products/.

[28] K. M. Scheibe and C. Gromann, Application testing of a new-three-dimensional acceleration measuring system with wireless data transfer (WAS) for behavior analysis, Behavior Research Methods, 38(3), 2006, 427-433.

[29] B. Robert, B. J. White, D. G. Renter, and R. L. Larson, Evaluating three-dimensional accelerometer to monitor and classify behavior patterns in cattle, Computers and Electronics in Agriculture, 67, 2009, 80-84.

[30] Y. Guo, G. Poulton, P. Corke, G. J. Bishop-Hurley, T. Wark, and D. L. Swain, Using accelerometer, high sample rate GPS and magnetometer data to develop a cattle movement and behaviour model, Ecological Modelling, 220, 2009, 2068-2075.

[31] D. N. Ledgerwood, C. Winckler, and C. B. Tucker, Evaluation of data loggers, sampling intervals, and editing techniques for measuring the lying behavior of dairy cattle, Journal of Dairy Science, 93(11), 2010, 5129-5139.

[32] Pelican 1010 Micro Cases, Pelican Cases: http://pelican.com.

[33] A. Schneider, Google Maps Output, GPS Visualizer: http://www.gpsvisualizer.com/, 2011.