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Photoplethysmography for bovine heat detection: the preliminary results

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ABSTRACT

In this study, we applied photoplethysmography (PPG) as an alternative, convenient, and affordable method for bovine heat detection. Heat detection is an essential part of effective herd reproduction management. Currently, there are many different heat detection techniques, but they can be ineffective or impractical to use. Since heat affects local vulvar blood circulation (resulting in swelling and erythema), photoplethysmography could represent an affordable alternative to detect this bovine phenomenon. In this study, we enrolled 20 animals in heat and other stages of the bovine reproduction cycle. We analyzed the PPG signal in terms of baseline (DC component), power, kurtosis, and erythema index. One vaginal measurement site, approximately 8 cm from the vulva, exhibited significant differences in mucous color (PPG green and red baseline, both erythema indices). What is more, cows in heat displayed higher PPG signal power and kurtosis, but differences were not significant. Photoplethysmography exhibited the potential to detect bovine heat.

Keywords: Heat detection, photoplethysmography, pulse oximeter, cow, estrus, signal quality index, erythema index, kurtosis

1. INTRODUCTION

Fertile cows need to be inseminated soon and efficiently to keep the profitably of the herd[1]. One lost reproduction cycle causes $110 of opportunity costs[2]. Professionals usually execute artificial insemination, which success depends on animal observation to detect heat (i.e., estrus). During heat, the ovulation happens, the animal behavior and physiology change (e.g., mounting tolerance, increased levels of estrogen). Usually, the farmer has only between 4 and 30 hours to notice heat signs and to call for insemination. Due to the short heat period and often not apparent changes, estrus is easily missed, or false positives happen.

There are many different techniques for bovine heat detection[3]. Pedometers and activity trackers are common and quite accurate (up to 96%) since cows become more active and restless during estrus. However, some false positives appear. Techniques with markers on the chin, back, and tail still require a lot of physical monitoring. On the other hand, analyzing hormonal balance, vaginal smear, fern pattern of cervical mucus discharge, or endometrial tissue is accurate but highly impractical.

Since heat also affects local vulvar blood circulation (resulting in swelling and erythema), photoplethysmography (PPG) could represent an affordable alternative to detect this bovine phenomenon. PPG is an optical technique, which evaluates the tissue-scattered signal in time normally acquired by the pulse oximeter. The optical probe first emits and then receives the transmitted or reflected green, red, and infrared (IR) light[4]. The PPG signal includes non-pulsatile (DC) and pulsatile (AC) components (Fig. 1). The non-pulsatile component (DC), also called a signal baseline, reflects the collective light absorption due to blood and tissues. On the other hand, the pulsatile component (AC) appears due to local blood volume changes following the cardiac cycle.

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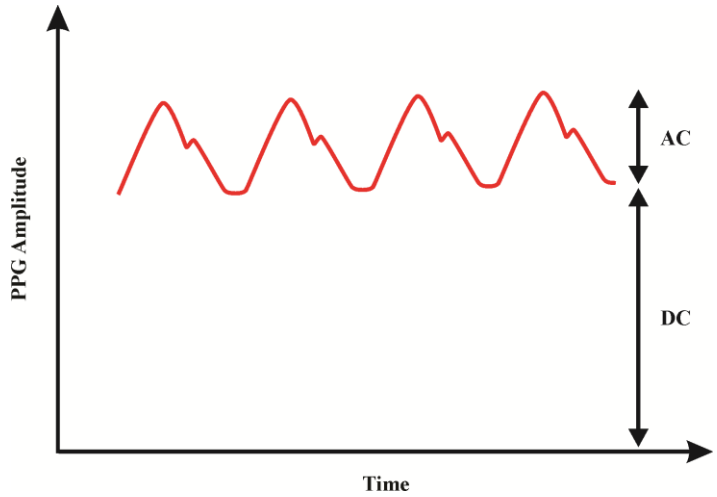

Figure 1. Non-pulsatile (DC) and pulsatile (AC) components of the PPG signal.

In humans, PPG is a popular clinical monitoring tool for pulse rate and blood saturation[5]. In research, PPG was applied for measuring blood pressure, cardiac output, respiration rate, for detection of various vascular diseases, and assessment of regional anesthesia efficiency[6–8]. The PPG signal varies significantly among body sites (like fingertips, toes, and ears) due to differences in the cutaneous blood supply of the different anatomic regions[9,10]. Additionally, various physiological conditions can affect PPG signal[11]. For example, the AC amplitude increases when vasodilatation occurs (e.g., regional anesthetic blocks, sepsis), but decreases with vasoconstriction (e.g., stress, cold) or with tissue congestion.

As in humans, PPG enables pulse rate (PR) and blood saturation (SpO2) monitoring in small animals like dogs and cats[12]. There were also some studies on controlling health, perfusion, and blood pressure[13–15]. In cows and other farm animals, a pulse oximeter is often a part of extensive wearable sensor systems for (remote) health monitoring[16–18]. Additionally, tracking PR and SpO2 could be used for preclinical detection of respiratory disease[19].

Inadequate heat detection is one of the significant factors limiting a high reproductive performance in herds. In our study, we applied PPG as an alternative, convenient, and affordable method for bovine heat detection. We enrolled 20 animals (10 in heat, 10 in other stages of the reproduction cycle), and we compared vaginal PPG signal's baseline, erythema index, power, and kurtosis.

2. MATERIAL AND METHODS

2.1 Animals

Twenty female cows of various ages were enrolled in this study (14 of Holstein and 6 of Simmental breed). The same operator took all PPG measurements during scheduled control visits, related to the artificial insemination. We investigated two vaginal measurement sites, 4 and 8 cm from the vulvar surface (Fig. 2). The operator pressed the PPG sensor gently against the vaginal wall and acquired the signal with a length of 30 seconds. We manually checked each signal for abnormalities and possible artifacts. In order to determine a stage of the reproduction cycle, all animals were examined by the rectal ultrasound (Kaixin KX5200) with the linear 7.5 MHz probe. Cows in estrus exhibited the absence of *corpus luteum*, and the presence of dominant follicle and endometrial edema (the myometrium-endometrium ratio was 1:2 or 1:3).

According to the Slovenian laws and European directive 2010/63/EU, our work was approved by the Administration of the Republic of Slovenia for Food Safety, Veterinary Sector, and Plant Protection and the owner's written permission was collected.

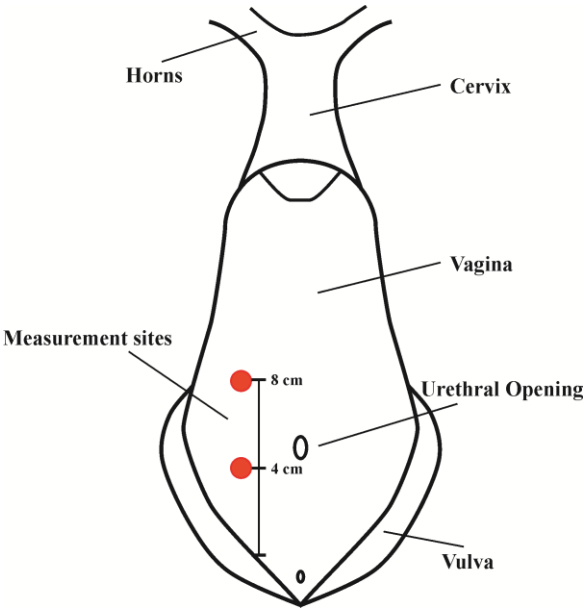

Figure 2. We investigated two vaginal measurement sites, 4 and 8 cm from the vulvar surface.

2.2 Device and signal processing

We used the same PPG device and methodology as in our previous study[12]. Briefly, we built a small and portable custom-made PPG device, which worked in the reflectance mode. It included the pulse oximetry sensor MAX30105 (Maxim Integrated, USA) with three LEDs: green (peak wavelength – PW = 537 nm, full width at half maximum – FWHM = 35 nm), red (PW = 660 nm, FWHM = 20 nm) and near-infrared (IR) (PW = 880 nm, FWHM = 30 nm). The data were processed by the microcontroller (Pro Micro 5V/16MHz, SparkFun Electronics) and stored on a micro SD card (DEV-13712, SparkFun Electronics).

We extracted four signal quality indices (SQI). First, we studied a signal baseline (*B*), which represents the signal's DC component or mean $\bar{x}$. Secondly, we calculated PPG signal power (*P*) in the limited frequency range with the *bandpower* function (Matlab R2015a, MathWorks Inc, USA) as:

$$P = \int_{0.7\,Hz}^{3Hz} S_x(f)df\,, \tag{1}$$

where S_x is a power spectrum of PPG signal *x(t)*. We selected the frequency range between 0.7 and 3.0 Hz based on the bovine pulse rates, which had ranged between 68 and 122 bpm (1.1 – 2.0 Hz).

Thirdly, we estimated the signal's kurtosis, which described the shape of the power spectrum (S_x) from the filtered PPG signal. Kurtosis (*K*) was based on the *kurtosis* function (Matlab R2015a) as:

$$K = \frac{E(S-\mu)^4}{\sigma^4}\,, \tag{2}$$

where μ is the mean of *S*, *E* is an estimated value of *E(t)*, and σ is the standard deviation.

Finally, we studied two erythema indices (EI)[20] as the ratio between the green (B_G) and red baseline (B_R):

$$\mathrm{EI_{RG}} = \frac{B_R}{B_G}\,, \tag{3}$$

$$\mathrm{EI_{GR}} = \frac{B_G - B_R}{B_G + B_R}\,. \tag{4}$$

The results were compared with the two-sided Wilcoxon rank-sum test (*ranksum* function, Matlab R2015a).

3. RESULTS AND DISCUSSION

In this study, we acquired PPG signals on two vaginal sites from 20 cows; 10 were in the estrus (heat), and 10 were in other reproductive stages. Table 1 lists the values of all four SQI. The superficial measurement site did not show any optical differences between groups. On the other hand, the deeper site exhibited significant differences in mucous color (B_G, B_R, and both *EI*). What is more, cows in heat displayed higher PPG signal power (P_G) and kurtosis (K_G), but differences were not significant (p-value between 0.05 and 0.09).

Table 1. Median, 25th and 75th percentile (in squared brackets) and p-value of a two-sided Wilcoxon rank-sum test for each SQI: baseline (*B*), power (*P*), kurtosis (*K*), and *EI*. PPG signal channels are denoted with *G* (green), *R* (red), and *IR* (infrared).

	Superficial measurement site			Deep measurement site		
SQI	Estrus (heat) (n = 10)	Other (n = 10)	p value	Estrus (heat) (n = 10)	Other (n = 10)	p value
B_G	0.96 [0.69, 1.17]	0.80 [0.67, 1.09]	0.47	0.93 [0.80, 0.99]	0.46 [0.34, 0.54]	< **0.01**
P_G (10^{-4})	0.70 [0.23, 1.71]	0.53 [0.06, 0.78]	0.43	1.12 [0.39, 2.35]	0.25 [0.06, 1.48]	0.05
K_G	13.04 [7.49, 24.42]	10.17 [7.36, 23.09]	0.79	20.28 [8.77, 31.76]	10.54 [8.22, 14.82]	0.09
B_R	3.65 [3.43, 3.87]	3.31 [3.08, 3.77]	0.19	3.50 [3.22, 3.90]	3.04 [2.58, 3.44]	**0.05**
P_R (10^{-4})	0.77 [0.07, 2.28]	0.32 [0.16, 0.53]	0.34	1.64 [0.47, 4.40]	0.92 [0.35, 2.29]	0.38
K_R	8.16 [5.74, 12.99]	8.22 [7.17, 9.44]	0.97	8.81 [6.00, 11.86]	7.42 [6.58, 9.92]	0.73
B_{IR}	3.09 [2.70, 3.21]	2.90 [2.79, 3.00]	0.38	2.69 [2.44, 2.93]	2.40 [1.84, 2.51]	0.06
P_{IR} (10^{-4})	0.62 [0.19, 1.97]	0.43 [0.15, 0.69]	0.47	2.07 [0.42, 3.95]	0.68 [0.29, 2.50]	0.38
K_{IR}	9.09 [6.44, 15.10]	8.74 [7.12, 21.90]	1.00	10.74 [7.61, 14.87]	7.49 [6.34, 9.37]	0.21
EI_{RG}	3.96 [3.30, 4.97]	4.23 [2.90, 4.58]	0.97	4.06 [3.66, 4.13]	6.82 [6.39, 7.59]	< **0.01**
EI_{GR}	-0.59 [-0.67, -0.54]	-0.62 [-0.64, -0.49]	0.97	-0.60 [-0.61, -0.57]	-0.74 [-0.77, -0.73]	< **0.01**

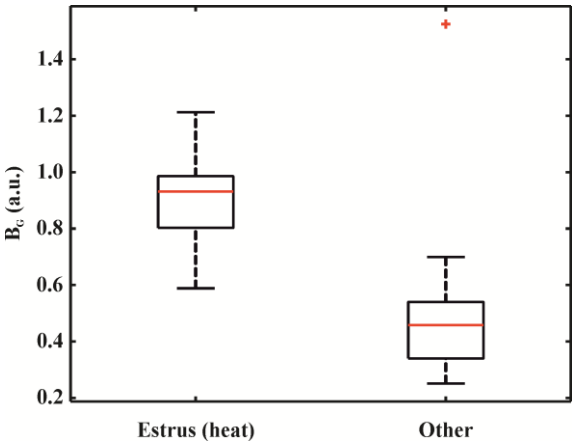

Figure 3. Green PPG signal baseline from the deep measurement site. The red line represents the median. The bottom and top box edges indicate the 25th and 75th percentiles, respectively. Both whiskers present extreme data points. We mark outlier as a cross.

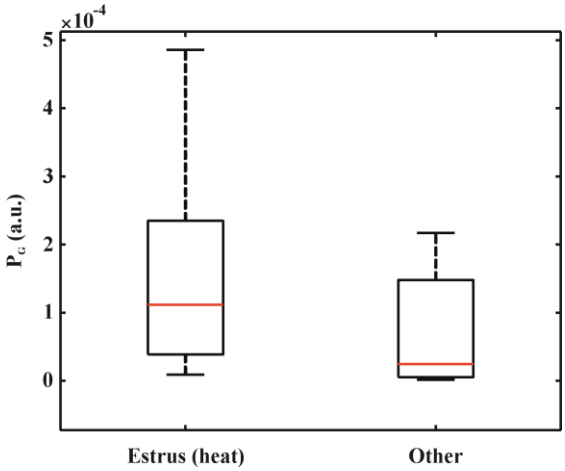

Figure 4. Green PPG signal power from the deep measurement site. The red line represents the median. The bottom and top box edges indicate the 25th and 75th percentiles, respectively. Both whiskers present extreme data points.

4. CONCLUSION

A deeper measurement site (8 cm from the vulvar surface) exhibited better potential to detect bovine heat based on PPG. Expectedly, the mucous color differs significantly. What is more, also PPG power and kurtosis were higher in cows in heat. In the future, the measuring approach should be improved (e.g., the clip could replace manual PPG sensor placement), and more animals should be enrolled.

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