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# Evaluation of IR micro-grid livestock wellbeing monitoring stand

To cite this article: Stefan Rizanov *et al* 2022 *J. Phys.: Conf. Ser.* **2256** 012045



# Evaluation of IR micro-grid livestock wellbeing monitoring stand

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**Abstract.** Infrared thermography (IRT) and its application for livestock state-of-health monitoring has been a focal point of many research works over the past 10 years. IRT is a powerful tool for detection and evaluation of localized inflammation sites. With most works centered around utilization of complex and expensive IR imaging devices - we investigated the prospect of developing a cost-effective automated monitoring stand with the application of simple IR micro-grid scanning end-devices.

## 1. Introduction

Infrared thermography has been proposed as a non-contact method for the evaluation of state-of-health (SOH) of livestock animals such as equine, bovine and swine. Most research proposed the utilization of complex and expensive infrared cameras to perform the analyses. Our goal with this work is to propose a cost-effective and easy to implement automated monitoring stand, with the design centered around a micro-grid infrared sensor device. The following chapters of our work discuss some aspects concerning the application of IRT in medical imaging of farm animals; description of the developed system and the performed evaluation tests.

## 2. Related research

Infrared Thermography (IRT) is a non-invasive tool applicable for localization of inflammation sites. Inflammation induces changes in blood flow dynamics and metabolic activity. Circulation and tissue metabolism are controlled by the sympathetic nervous system and noradrenergic sympathetic neurons in the mammary gland. Thermal stress causes an activation of the autonomic system initiated by the skin thermal receptors resulting in latent heat loss by sweating and respiratory rate increasing.

Psychological stress induces activation of the hypothalamic-pituitaryadrenal axis which changes cortisol levels, triggers an adrenaline release by the sympathetic nervous system [1], changes blood flow dynamics and these accumulative effects result in core body temperature deviations. This motivates the reasoning that diagnostic tests of animals have to be performed in a stress free environment and at a thermal neutral zone, around the optimal 20 degrees due to the reduction of sweating induced heat losses [2].

In the past there have been different observation-based methods for evaluating abnormalities and assessing the wellbeing of animals. Such methods have been applied for lameness in cattle and equine by monitoring weight distribution, associated with impaired locomotion, and horn tissue softness observation. These methods are capable of detecting inflammation instances only in later stages of severity. [3 - 5].

Additional observational methods such as breathing patterns are used for detecting pregnancies in swine, equine and bovine. These methods all require the presence of a qualified medical professional to evaluate the animals, which is a subjective and often non-definitive measure of the health status of the farm animals. Additionally such external interference cause stress in the animals and also limits the scale of applicability, due to human factors such as operational fatigue and limited work hours. This motivates our work in designing an automated IRT-based system for evaluating the health-status of animals. Such a system is not subjective in its evaluation, due to the application of defined and fixed criteria for measurement data analytics. Equine, bovine and swine suffer from many health-affecting illnesses. A large portion of these illnesses induce changes in blood flow dynamics, cause inflammation and resultantly change the localized thermal profile of the animal. Areas of interest for IRT-based observation are - the coronary band in feet; the plantar aspect of the pastern; posterior surface of the udder in cattle [6]; mammary gland; vulva; pelvis; thorax; left and right abdomen/flank; wither; [7, 8] the medial posterior palpebral border of the lower eyelid and the lacrimal caruncle [9].

The number of different possible sites introduces a difficulty in choosing where to perform the measurements. There are several ground rules and good practices which aid the process of IRT measurement in farming animals:

- sparse local hair coats are desired and preferable at the observation site, with heavy hair coatings, hair length, thickness and colour affecting the measurements, changing the surface emissivity and reducing the measured temperatures by 4-5°C;
- dry cleaning of the site prior to measurement is advised, removing the debris-presence induced reduction of surface temperature and emissivity changes, but washing the feet has been shown to increase foot temperature variability and heat loss because wetting the hair and friction during brushing disturbs the temperature profile of the affected area; [10] ;
- prior motion or changes between postural states such as lying to standing create temperature spikes, but also in some instance allow for a better correlation with internal core body temperature of the observation site; external environmental factors such as ambient temperature, relative humidity, sunlight loading effects and wind presence heavily influence measurement values.

Because of these described reasons we propose an automated farm animal testing stand, based on IoT IRT, and utilizing a rail movement system.

## 3. Performed tests

For the purposes of this work we designed an IoT-based IRT system. The block structure of the designed system is shown in Figure 1. The proposed monitoring stand is shown in Figure 2. The rail system would allow movement of the measurement device in a controlled manner and a fixed trajectory. Current position of the system in respect to the supporting frame will be automatically read-out from the rail control system.

The utilization of movement creates a possibility for an automated means of performing full scanning of the animal's body without necessitating external operator observation or operational involvement. Full-body scanning allows for a more complex evaluating of the state-of-health of the animal to be performed by analyzing multiple sites of interest and performing more complex correlation zonal analyses.

The system utilizes two sensors - a 8x8 IR matrix thermopile sensor AMG8833; a ToF (Time-of-Flight) VL53L1 sensor.

The IR grid sensor has the following parameters:

- •Range: 0°C – 80°C;
- •Absolute accuracy within the range: ±2.5°C;
- •Sensor resolution: 12 bits; 1LSB = 0.25°C;
- •NETD: ±0.05°C.

The ToF sensor has the following parameters:

- •Distance measuring range: 0-90cm;
- •Absolute accuracy in the measuring range: ±1%.

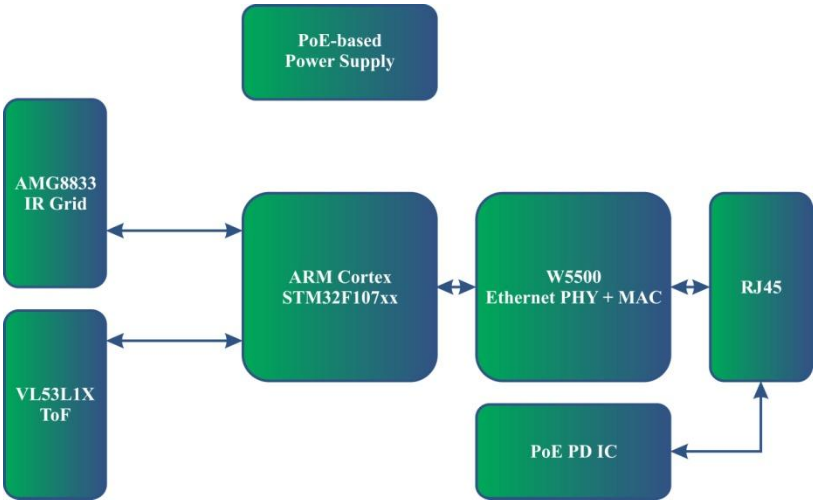


**Figure 1.** Systemblockstructure.

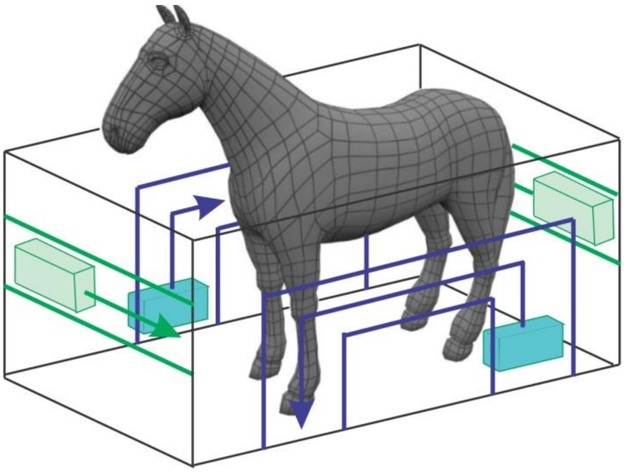

**Figure 2.** Monitoring stand and rail-system.

Two crucial factors affect to a large extent the measurement accuracy of captured thermograms - distance to the object and emissivity. Emissivity is a coefficient which is indicative of the ratio between the spectral density of the energetic brightness of a given surface and of an absolute black body. Emissivity values for grey objects are always bellow 1.0,with the value being affected by different factors such as: surface colour, angle of observation, hair coating (for animal surface tissues), surface irregularities and others. Emissivity of human skin has a value of 0.97, cattle skin has an emissivity of 0.95 and equine skin has an emissivity of 0.98. IR sensors typically are internally configured for a default value of emissivity, with some more complex and expensive sensors having additional internal registers where this value can be reconfigured. The used AMG833 sensor does not have such a capability, but because the sensor is of the thermopile type - this emissivity correction can be performed by reading the internal substrate temperature of the sensor and utilizing the following formula:

$$T_{pixel} = \sqrt[4]{\frac{C.m}{A.\varepsilon_S.\sigma.\alpha}.U_{OUT}.\frac{1}{\varepsilon} + T_{substrate}^4} \quad (1)$$

where: $T_{pixel}$ - temperature of the measured pixel; C - constant, dependent on the membrane material; m - mass of the membrane; A - optical coupling coefficient; $\varepsilon_S$ - membrane emissivity; $\sigma$ - thermal conductivity of the membrane; $\alpha$ - sensitivity coefficient, dependent on the materials which form the thermocouple; $U_{OUT}$ - thermocouple output voltage; $\varepsilon$ - emissivity of the analyzed surface; $T_{substrate}$ - substrate temperature [11].

This emissivity correction was performed in the presented developed system.

In order to evaluate the effect of distance to the object we built a testing setup with an absolute black body Fluke Calibration 4180, MLX90614 IR point sensor and VL53L1 ToF sensor. The resultant empirical formula was generated by constructing a polynomial regression model and evaluating it using the response surface methodology (RSM).

The model has the following formula:

$$\begin{aligned} \Delta \mathrm{T} &= 51.4 - (3.27 * T_{MEAS}) - (0.596 * D_{MEAS}) \\ &+ (0.053 * T_{MEAS}^2) - (0.002025 * D_{MEAS}^2) + (0.02623 * T_{MEAS} * D_{MEAS}) \end{aligned} \quad (2)$$

where $\Delta \mathrm{T}$ is a correction component, which has to be added to each pixel value after its measurement; $T_{MEAS}$ and $D_{MEAS}$ are respectively the measured pixel temperature and distance to the object.

In order for the system to be easily adopted and integrated in different farms, its data communication technology and power supply source have to be chosen carefully as to reduce as much as possible the requirements towards the supporting infrastructure. Because of these reasons we have chosen to utilize the Ethernet + PoE technology.

Ethernet allows for high-speed communication to be performed with the end-device while requiring a relatively simple network infrastructure to be implemented, containing network switches and routers. Ethernet communication also allows scalability of the system. The Power over Ethernet (PoE) is described within the 803.AT and 803.BT standards, designating devices into distinct classes depending on their required power consumption. PoE end-devices draw power from PoE injectors, part of the network infrastructure. The end device and the injector communicate in order to determine what PD (Powered Device) class the end-system is. For the purposes of this work the device is configured as a PD class 4, hence allowing power consumption of up to 25.5W from the injector.

## 4. Performed tests

In order to evaluate the developed system's performance in comparison to another IRT system - we performed tests in a controlled environment. The testing environment had an ambient temperature of T = 26.52 ℃ and a relative humidity of Rh = 43%. The environmental parameters were measured via a Fluke 971 TH meter. In order to evaluate the measurement data - we performed surface temperature measurements with 3 different systems:

- The developed IR micro-grid system;
- FLIR One PRO device from Teledyne FLIR;
- Contact based Pt1000 measurements with a Fluke 867B high-precision multimeter.

Contact-based measurements are considered the gold standard in evaluating real surface temperatures when additional precautions are made for its thermal coupling to the site of interest. The

Pt1000 sensor was fixed to the palm of the tests subject by means of black adhesive tape with an emissivity of 0.985 with the site of contact left visible. The tests were evaluated at three different conditions:

- The test subject's hand temperature was measured with the 3 methods at ambient environmental conditions;

- A cooling object (melting ice filled container) was held by the subject for a duration of 1 minute with monitoring of when the contact based sensor system detects thermal equilibrium conditions, after that the subject's hand surface was measured with the two IR-based methods;
- A heating object (a container filled with hot water, kept at 45°C with a PID regulator) was held by the subject for a duration of 1 minute with thermal equilibrium being monitored with the Pt1000 sensors, after that the subject's hand surface temperature was measured with the two IR systems. The subject's hand was placed at a measured distance of 20cm from the two IRT devices.

The resulting testing data is: 50 micro-grid thermograms and 50 FLIR sensors thermograms of the subject during the ambient test; 43 migro-grid thermograms and 41 FLIR thermograms during the cold test; 47 micro-grid thermograms and 49 FLIR thermograms during the cold tests.

The contact-based Pt1000 measurements showed: an ambient test palm temperature of 34.50 ℃; cold test palm temperature of 28.72 ℃; hot test palm temperature of 39.98 ℃. These three value were used to evaluate the IR data. The captured 8x8 micro-grid thermograms were evaluated by means of firstly detecting object boundaries by means of a fixed cut-off threshold of 2 ℃ difference between neighbouring pixels.

After this had been done the average temperature of the localized objects was calculated, with this being performed on the thermograms from all 3 tests. The results showed an additive offset of $\Delta T$ = 2.03 ℃, in respect to the contact surface temperature measurements, which was subsequently subtracted from all pixel values during the calibration phase - effectively centering all data around the contact temperature.

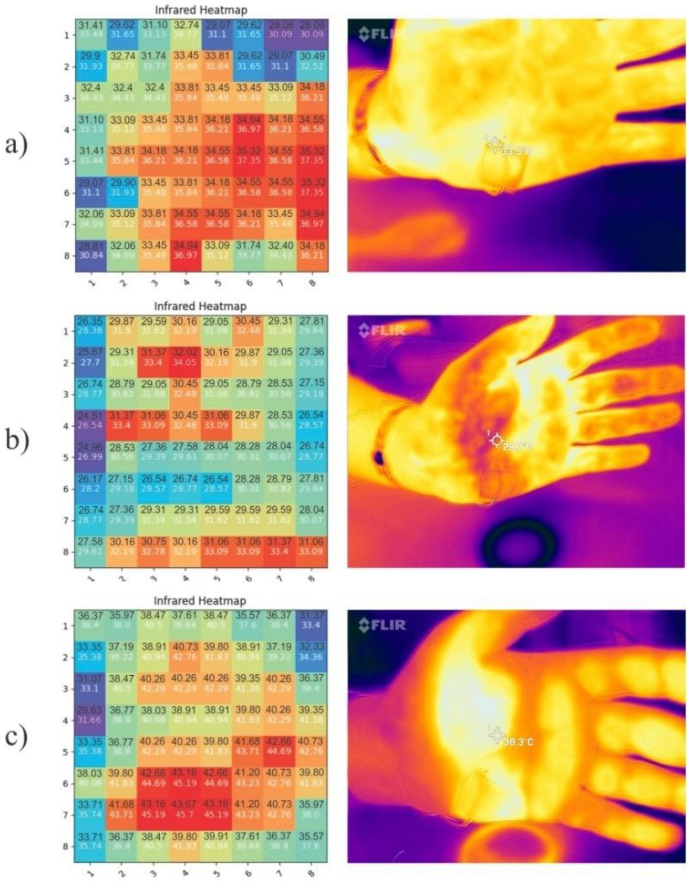


**Figure 3.** Captured thermograms from three different tests.

Figure 3 shows a sample of the results from the performed tests with on the left side shown the micro-grid thermograms, in up-down order as: a) A-test; b) C-test; c) H-test.

Additionally with black font are written the post-calibration values of each pixel. The FLIR thermograms were evaluated at different points of the palm during the tests and a mean surface temperature was calculated from these points. In order to perform a comparative analysis between the two systems - we will have to select an area of interest from the micro-grid thermograms which would be used. During the tests, the subject's hand was placed at the central optical axis of the AMG8833 sensor so that the object is centered within the thermogram. Because of this reason, we chose to evaluate the central 16 pixels from the micro-grid thermogram and calculate an average value for it. Table 1 lists the test results, Table 2 lists the measured temperature differences by the 3 systems.

**Table 1.** Average measured temperatures.

| **Average temperature** | **Micro-Grid** | **FLIR** | **Contact** |
|---|---|---|---|
| Ambient Test | 33.99 ℃ | 33.22 ℃ | 34.50 ℃ |
| Cold Test | 28.70 ℃ | 29.37 ℃ | 28.72 ℃ |
| Hot Test | 40.47 ℃ | 36.69 ℃ | 39.98 ℃ |

**Table 2.** Measured temperature differences.

| **Temperature differences** | **A→C** | **H→A** | **H→C** |
|---|---|---|---|
| Contact | 5.78 ℃ | 5.48 ℃ | 11.26 ℃ |
| Micro-Grid | 5.29 ℃ | 6.48 ℃ | 11.77 ℃ |
| FLIR | 3.85 ℃ | 3.47 ℃ | 7.32 ℃ |

The experimental results show a good correlation between the contact measurements and the developed micro-grid IRT system, the system over-estimates the temperature changes possibly due to poor object detection resulting from the limited spatial resolution of the sensor and because of the arbitrarily chosen 2 ℃ cut-off temperature difference for object boundary identification. Additional environmental effects were not included in our data analytics with the goal of assessing what precision can be achieved with a lower cost system. The test results show that such a system is applicable for a multi-sensor rail-based automated test stand for livestock. Multi-point observation has been proposed in literature as a means of detecting lameness in cattle and equine by capturing the temperatures of the 4 limbs and using the front 2 limbs as points of estimation of cut-off thresholds for temperature spikes in the hind limbs, indicative of lesions and inflammation presence.

Additional data processing steps typically utilized for IRT thermogram analysis are: the implementation of median filtering, for outlier removal and dynamic range conservation; Tukey tests; ROC curve utilization and application of nonparametric statistical analytical procedures such as Pearson correlation coefficients, but this is outside the scope of the presented work.

## 5. Conclusions

We investigated the prospect of developing an automated cost-effective micro-grid testing stand for livestock state-of-health monitoring. The designed system was presented as well as results from performed evaluation tests and comparative analysis with a FLIR One PRO system.

The test results showed a good correlation between contact measured surface temperatures and captured IR thermograms. The developed system is in the process of real tests and large scale data acquisition with the goal of SOH evaluation, information-measuring and expert system improvements.

**Acknowledgments**
The authors would like to thank for the financial support from National Science Fund under which Project No. DN 17/16 the present work was conducted.

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