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Internet of things infrared imaging device for assessing lameness in racehorses

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ABSTRACT
Lameness is a clinical condition that heavily affects racehorses. As a result, their competitive performance is dramatically deteriorated and side effects such as changes in feeding patterns may manifest. Within this work we have presented a developed portable Internet of Things (IoT) infrared imaging device, whose application is aimed towards on-site farm level detection of lameness in equine. Additionally we have presented an in-debt review of the causes of lameness, the underlying biological changes that it induces, its influence over tissue thermal patterns and how exercise affects a racehorse's temperature profile.

Section:RESEARCH PAPER

Keywords: bio-monitoring; infrared thermography; inflammation; internet of things; lameness; measurement; racehorses

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1. INTRODUCTION

In terms of how the process of evaluating the State of Health of animals is performed, the applicable methods can be classified into two broad groups - invasive and non-invasive methods. This work is directed towards the application of Infrared Thermography (IRT) which falls under the category of non-invasive methods, and is used to capture the thermal patterns over an animal's tissue surface by most often using un-cooled microbolometer matricies. One of the big deficiencies in IRT clinical observations is that the method has a physical limitation of the depth to which anomalies are detectable - typically this limitation range is 2-3 mm from the surface [1]. The major deficiency of IRT is that thermographic equipment and the instrumentation, necessary for its calibration, are expensive and increasingly difficult to use. There are existing opinions amongst the scientific community that IRT is better suited for clinical evaluations and the captured results are more accurate for animals who have a larger surface area-to-mass ratio [1]. This makes IRT a method that, in theory, has many advantages, but that is very difficult to utilize in a real farming environment and whose automation is typically complicated [2]. This research focuses on horses for two major reasons: they are expensive animals (especially race horses) and a lower level of stress in the diagnostics is preferable because lower stress improves the feeding and the sport performance as well.

The paper is organized as follows – the equine lameness and tissue heat patterns are described in the next section, the effect of exercising is discussed in section 3, the development of the hardware platform is considered in section 4, the system prototyping and the preliminary pre-clinical trials are presented in section 5, the conclusions and the future work are in section 6.

2. EQUINE LAMENESS AND TISSUE HEAT PATTERNS

An animal's internal temperature is directly related to its homeothermic process status. In bovine an internal temperature of 38.0-39.3 °C is typical for a healthy animal [3], [4]. For equine this temperature is 37.0-40.0 °C [5], [6] and for swine this temperature range is respectively 37.1 °C - 38.5 °C [1]. Vasodilatation and vasoconstriction are the two main mechanisms that regulate locally the blood flow - affecting the on-site tissue heat pattern. These two processes result from the vasomotor control of the sympathetic noradrenergic fibbers within the smooth muscles, which regulate the blood vessels' diameters - stimulating these fibbers causes a neurosecretion of epinephrine and norepinephrine [7], [8].

In equine medicine, IRT has successfully been utilized in detecting inflammatory conditions such as inflammation of fetlock, carpal and tarsal joints; bucked shins (dorsal metacarpal disease) and arthritis [5], [9]-[11]. Joint dysfunction is detectable by IRT methods because it affects the autonomic nervous system, which controls the underlying blood flow dynamics [12]. Normally, when a joint is inflamed - an oval area above the joint increases in temperature, but if a pastern joint is inflamed - a circular area above the joint decreases in temperature, surrounded by a ring of increased temperature (similar to edema IR imaging) [11]. Such skeletal injuries are typically related to physical trauma or the presence of lesions with trauma or the formation of tissue lesions always leading to changes in the underlying circulation [6].

In equine medicine, back pain and lameness are related, with back pain diagnosing preceding the diagnosing of lameness in many cases. The primary clinical sign of back and lumbar pain is the loss of performance in equine athletes, spinal distortions, resented or restricted spinal ventroflexion, bad posturing, asymmetrical development and behavioural changes such as lowering or raising their neck (depending on whether there is thoracic or lumbar pain) [13]. Diagnosing the source of lameness in horses is a difficult task when the pain is located in the proximal hind limbs and not related to the synovial structures [14]. The main source of back pain in horses is the prolification of lesions, such as supraspinous ligament lesions and lesions of the interspinous space. Example for these lesion types being supraspinous desmitis, myositis and intervertebral osteoarthritis. The pathogenesis of these lesions is primarily due to thoracolumbar musculature overloading and injuries due to the contact with the saddle and bearing of the rider's weight [15], [16]. Lesions are characterized by their echogenecity, fibber parallelism, the presence of hyperechoic points. By utilizing IRT it is possible to diagnose the existence of such lesions, by detecting hotspots (localized temperature spikes of above 1 °C) along the dorsal midline for desmitis lesions and in the lumbar region for myotis lesions. Exercising has been shown to intensify the hot-spots when inflammatory conditions such as abscesses, bruises or fractures are present [11]. Cold spots (localized temperature dips of bellow 1 °C) in the lumbar region of a horse are indicative of the presence of intervertebral osteoarthritis. These cold spots result from the presence of local pain without the presence of an inflammation at the lesion site. Cold spots are indicative of a site where a nerve dysfunction has occurred [12], [17]. Cold spots can be induced by other clinical non-inflammatory conditions such as navicular syndrome - IRT detectable signs for this being the lack of thermal increase in a limb after exercising [9], [11], [18], [19].

Navicular syndrome is related to the reduction of blood supply to the caudal hoof [11]. Some authors argue that only hot-spot inducing lesions are painful to the animal. As in bovine, multiple lesions of different size can be found on a single animal. All colds-pot inducing lesions are detectable, but not all hot-spot inducing lesions are detectable by IRT means. One of the reasons for this effect is that some hot-spot inducing lesion lead to small deviation in temperature, hence they mimic the thermal patterns of chronic latent and inactive processes. A second example is the clinical condition of kissing spines, which is difficult to detect in general due to the animal's asymptomatic behaviour [14]. In many cases, there are underlying nerve disorders such as sympathetic dysfunction responsible for sympathetic neuropathic chronic pain and which is anatomically displaced from the lesion [13]. Examples for such disorders are Horner's syndrome, thoracic melanoma and hyperhydrosis. In equine medicine, IRT is also useful in detecting: vasospasms and spinal-driven sympathetic disorders, inducing muscle ischemia; temperohyoid osteoarthropathy; lumbosacral neuromuscular disease; abscess and granuloma complexes; superficial digital flexor tendinitis - by observing asymmetrical thermal patterns over the animal's body [11], [18]-[20]. Observed asymmetry within the range 0.5-1.5 °C is typically indicative of acute cases, in chronic cases these differences are smaller and are more difficult to detect [19]. Differences of 1.25 °C between the contralateral distal parts of the limbs has been shown to be indicative of the presence of inflammation [18]. IRT analysis of the coronary band of horses has been shown to be able to detect early signs of laminitis [9], [11]. Laminitis presents an inflammation of the sensitive laminae of the foot, with such a case leading to a disappearing hoof-to-coronary band thermal gradient (he coronary band in a non-clinical state is hotter than the hoof by 1 °C – 2 °C) [11]. Bucked shins are another source of lameness in equine [11]. Early stage bucked shins can be detected by IRT means by capturing hotspots, located mid-shaft over the dorsal cannon bone, with a temperature 1-2 °C warmer than the surrounding tissue. In later stages, these hotspots increase to 2-3 °C difference to surrounding tissue [11]. Not all inflammations are lesion-related. Examples for such clinical conditions are if a tendon, ligament or muscle gets inflamed, hotspots of 1 °C can be observed, centred over the injured area. In some cases, edema is also present in an inflamed muscle, inducing cold spots in the thermal heat-map [11]. As in bovine, equine feet temperatures are closely correlated with the ambient environmental temperature which causes their variance (circadian rhythm) throughout the day with this effect being a potential source of measurement error or even able to mask the presence of a lameness inducing lesion [18].

In equine medicine chronic back pain has been shown to create localized cold-spots [13]. Chronic pain cases are related to prolonged sympathetic neural activity, which causes a localized hypothermia due to vasoconstriction. The difficulty in detecting of chronic bone injuries and joint degeneration is that they induce very small localized changes in the circulation. The sensation felt by the animal in such chronic clinical cases include the intolerance to pressure application and throbbing of the site.

3. THE EFFECT OF EXERCISING

Exercising leads to the increase in temperature of musculature and surface tissues due to the fact that metabolic heat production increases proportionally to exercise intensity. An example for this can be found when analysing horse athletes working with riders of different weight [5], [15]. From the total amount of consumed energy, musculature converts only 20-25 % into mechanical energy, with the remaining 75-80 % being converted into heat. This is a result of the fact that most bio-chemical reactions within the muscle are exothermic (exoergic) nature [6]. In order to prevent hyperthermia, this excess heat has to be dissipated by the body - an elevation of heart rate is initiated to dissipate the heat more quickly and if this is not sufficient a redistribution of blood flow to subcutaneous capillary beds is initiated in order to increase the cooling surface and dissipate the generated heat [5[, [6]. If heat dissipation is not effective enough, hyperthermia may occur. The size of the muscle unit (musculature structure) additionally determines the heat production and dissipation rate

- muscles with larger surface areas dissipate heat more quickly [6]. In a resting state, the metabolic activity of an animal produces a steady share of basal heat. When musculature becomes activated the heat generation increases proportional to the mechanical workload and type of movements (muscle contractions produce more heat) [6]. Heat activation is the term used to describe the generated quantified amount of heat during a muscle's contraction. Heat retention is the time accumulated value of the heat activation of a certain muscle. Heat relaxation is heat generated when the mechanical workload has ceased and the muscle has been released. The heat of maintenance is the amount of heat generated during the rebound to normalcy (rebound to resting state) of the muscle, with the rebound process involving ion pumping, ATP regeneration and the restoration of concentration gradients within deferent substrates [6]. This rebound process in horses takes 45-60 minutes and Body temperatures rise by around 6-8 °C in horses [6].

Exercising in horses has been shown to increase the temperature of the limbs asymmetrically - the front legs get hotter than the hind legs, with this being contributed to weight distribution during movement [20]. Exercising increases symmetrically the temperature of a horse's legs by roughly 0.5 °C in healthy animals [11]. There are reports that better-performing race horses have higher tissue temperatures than those of lower performance [21]. However, exercising and prior movement are useful in certain clinical observations, with some conditions being shown to be detectable only post-movement. Exercising improves the correlation between the internal and peripheral extremity temperatures, which leads to better IRT measurement accuracies [22]. One of the utilities of prior motion is that it allows for the detection of asymmetrical load bearing over the limbs, typically indicative of a related underlying inflammation present in the colder limb and hidden (masked) under stationary conditions [18]. In many cases, exercising is a contributing factor towards the formation of inflammatory conditions. In equine medicine and sports there are recommendations regarding the maximum load conditions that an animal should be exposed to, with an animal's load bearing should not be exceeding 20% of its body mass. Exercising type is a contributing factor to the formation of different lesion types and their location in equine athletes [14]. Examples are the presence of acute sacroiliac strain in racing horses and impinged dorsal spinous processes in show jumping horses [15].

4. DEVELOPED HARDWARE SYSTEM

Figure 1 shows a graphical simplified representation of the developed IoT system and its targeted usage. Currently in most scientific research emphasis is pointed towards how IRT can be used, in general, to detect different clinical conditions but little attention has been pointed to the fact that in order for a diagnostic system to be applicable: it has to be robust, easy to use by non-trained operators and non-expensive. These details are the major deficiencies of all currently available on the market infrared cameras, with them being extremely expensive and notoriously difficult to use. Past research and experience of the authors in the development of systems, utilizing small thermographic imaging sensors, has shown that comparable accuracy values in temperature measurement can be achieved with them, with the whole hardware cost not exceeding 500 USD (estimate based on 2023 pricings). This fact creates a significant opportunity for equine farms to adopt such small imaging devices, either as portable tripod mounted cameras or including

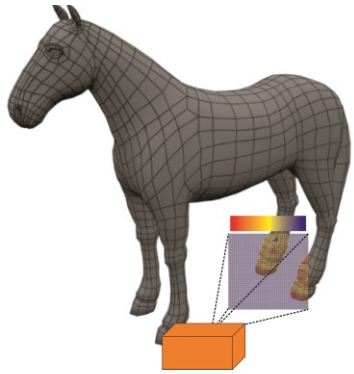

Figure 1. Conceptual representation of the developed IoT system.

several of them in an automated infrared scanner. A tripod mounted battery-powered device is simpler to use and can provide an easy way for farmers to assess the thermal patterns over different parts of the horse's body without necessitating the prior installation of additional networking infrastructure. The downsides to such a system is that the operator has to manually measure the temperature of different parts of the body of each animal, which is labour intensive and requires additionally for each operator to be given a laptop (portable computer) to log in the measurement data. When constructing an automated infrared scanner - some of the prior described difficulties are resolved. A scanner is a fixed system, similar to a tomographic scanner, which performs infrared imaging of different parts of the body by controlling the position of a measurement unit via highly precise motors. Such a scanner can be fitted with five imaging units, so that all sides (front, back, left, right and top) of the horse's body can be thermographically captured. The gathered imaging data is fed upwards to a centralized server and stored locally, allowing for its further diagnostic analysis. Such a scanner necessitates additional farm-level network infrastructure but it drastically reduces the labour, required by on-site farmers in evaluating the State-of-Health of their horses.

In Figure 2, we have shown a block diagram of the developed thermographic imaging unit. The developed sensory unit consists of five printed circuit boards (PCBs) - Master Board; TFT Display Board; Teensy 3.6 Board; FLIR Board; ArduCam Mini Board. The data acquisition and processing is handled by the Teensy 3.6 Board which has a computationally powerful MK66Fxx ARM Cortex-M4 microcontroller from NXP (Freescale); external SD card for data storage; external FLASH memory. The FLIR board contains a FLIR Lepton 2.5 IR matrix sensor with a resolution of 80 × 60 points, absolute accuracy of 5 °C, NETD < 50 mK. The FLIR board communicates with the Teensy 3.6 Board's onboard microcontroller via SPI and I2C interface. The ArduCam Mini Board allows for the system to be able to capture images and video within the visible spectrum. This functionality is important for such a system due to the fact that object detection and recognition in the visible spectrum is performed with a higher accuracy than within the infrared spectrum, because of gradual and non-sharp object contours in the infrared spectrum. The ArduCam Mini board contains a Latice LCMX02 CPLD IC; external RAM; an OV2640 2MP camera sensor. Communication and data exchange between the ArduCam Mini Board and the Teensy 3.6 Board is performed over a SPI and IC2 interface. In order for the system's operator to visualize and inspect on the spot the captured images - we added a TFT Touch-screen display. Touch-screen capabilities allow for a friendlier user interface and eliminated the necessity of placing addition buttons, making the device's form factor as small as possible. The TFT Display Board communicates with the Teensy Board via SPI. The Master Board's role is to allow interconnectivity between the described boards but it also serves two additional functionalities. On the Master Board we added a MLX90614 IR point sensor, which communicates with the Teensy Board via I2C and it allows for the system to be able to be calibrated with an absolute black body. External communication with the Master Board is performed via RS485 twisted pair cable, connected on-board to a RJ45 connector and using a RS-232 interface. Over the RS485 we supply 12V from an external DC power source to the sensory end device. Such a configuration allows for this device to be connected within a local on-site farm network, containing multiple sensory units. This functionality allows for such an end device to be installed as a scanning unit with the aforementioned thermographic scanner system. In order for this system to be portable - we added a Li-Ion battery, which is charged by the externally supplied 12V. The battery charging process is managed by a dedicated linear charger IC. All necessary power supplies – 5 V; 3.3 V; 2.8 V and 1.2 V are provided by on-board DC/DC converters and LDO voltage regulators.

The developed system falls under the category of IoT devices. In fact, the IoT concept encompasses a broad range of devices, which all include data acquisition and processing capabilities and also have some type of wired or wireless connectivity. The developed system can be deployed in either a stationary or portable configuration. When operated as a portable device all captured images are stored locally on-board in the inserted SD card. In developing bio-imaging systems, it is crucial for the captured images to be in their raw format and to not be modified. The reasoning for this is that if data compression techniques are applied, then some fine details of the medical images may be distorted. An example for this is the loss of information when raw images are converted and stored into a .jpeg format, due to the usage of an inverse cosine transform. Because of this reason, within the developed system all images are stored into a raw format.

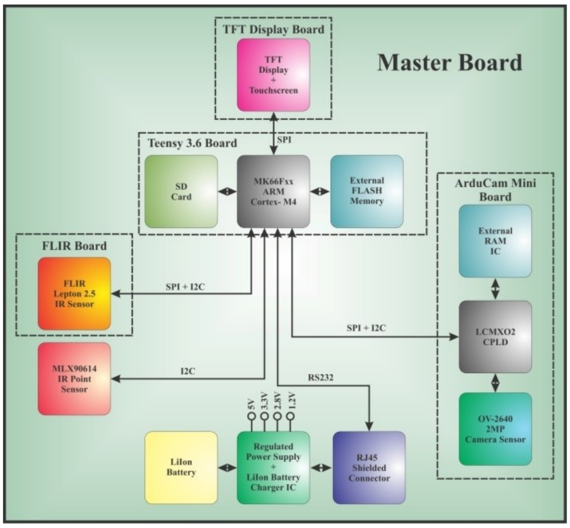

Figure 2. Block diagram of the developed sensory unit.

Figure 3. Prototype of the designed sensory device.

5. SYSTEM PROTOTYPING AND PRELIMINARY PRE-CLINICAL TRIALS

A prototype of the designed sensory device was produced. Figure 3 shows photographs of the prototype with a top, bottom view, display connected view and full stacked view. The device was developed in a manner that would be appropriate for all portable devices, where size and weight are of crucial importance. The device size defining feature are the physical dimensions of the used touch-screen TFT display.

In order for this system to be installed in a real farm environment - a specially designed plastic enclosure has to be designed and manufactured. The application of such a sensory unit in a farming environment, where close contact with animals and external environmental influences are present - a durable IP65 or IP66 plastic enclosure has to be designed.

Figure 4 shows photographs of the designed and prototyped custom plastic enclosure and of the full system's assembly.

In order for evaluate the functionality of the developed system and to determine whether infrared imaging is possible through it - we developed a small Python-based script. We captured several thermograms with the system, with them being shown in Figure 5. As can be seen, the system is capable of detecting temperature differences: the nasal area of the photographed dog is colder than its surrounding facial area.

6. CONCLUSIONS

In this work, an IoT thermographic portable imaging device for assessing lameness and inflammation in race horses was developed and presented. We presented an in-depth veterinary description of the causes of lameness in horses and what changes are induced in the surface tissue's thermal patterns. Additionally, we described the underling biological effect of exercising and how they affect the process of thermographic State-of-Health evaluation in equine. We presented the prototyped system and performed preliminary pre-clinical proof-of-concept testing of the developed sensory unit.

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Figure 4. Manufactured plastic enclosure and full system assembly.

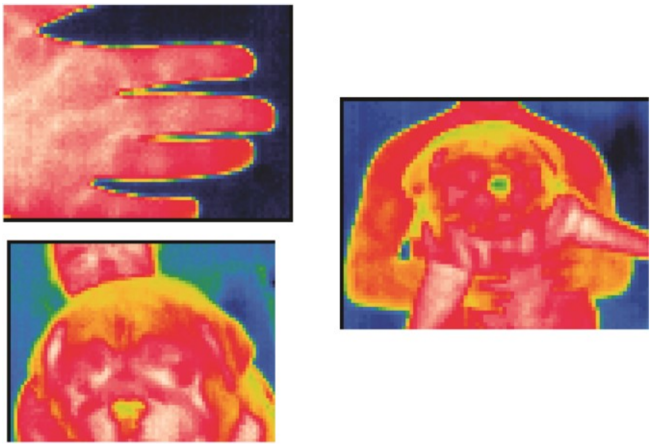

Figure 5. Captured thermograms with the developed system.

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