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Non-intrusive and effective positioning of precision livestock monitoring system for cattle

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Abstract— *Abstract*—Livestock farmers in Kenya face a number of challenges such as diseases and the inability to accurately identify oestrus and calving windows. These factors hinder productivity and lead to high livestock mortalities. Precision Livestock Farming systems are the solution to this, ensuring effective management of the livestock farming process. Existing systems have been able to monitor animal temperatures, location and movement of animals within the farms, and deliver this to the farmer visually, allowing them to observe the state of their animals in real-time and affordably. Positioning of sensors on livestock is critical in ensuring correct livestock data is collected. The placement of these sensors is dependent on three factors; the thermal windows on the animal's surface, fastening of the sensor and the power supply. Real time data on sensor temperature readings from various parts of a cow's body was obtained and analysed. The results were then compared alongside data from literature to come up with a preferred positioning of PLF sensor systems. By comparing the placement of the sensor on the cow's leg, dewlap and harness, it was noted that the harness provided for a more suitable placement of the particular PLF sensor, allowing for continuous and accurate collection of data.

Keywords—Precision livestock farming, machine learning algorithm, livestock, sensor positioning.

I. Introduction

PRECISION livestock farming involves the use of technology to increase the output of conventional animal farming processes. More specifically, PLF allows farmers to manage animals individually rather than collectively as a herd. A farmer may, for instance, use video cameras for weight measurement instead of using manual scales [1]. It also provides real time monitoring of livestock, giving early signals to farmers when animals are not performing optimally. This encourages quick treatment and remedying of the problem. Specific activities in PLF include the continuous monitoring of animal's health and welfare, monitoring and identifying key signs in the reproduction cycle and even monitoring animals' environmental impact [2].

The use of PLF is gaining traction, especially since the demand for animal products is set to increase by 70% by 2050 [2]. The number of farmers is however decreasing, with fewer farmers owning larger herds of animals. In this new environment, infections on the herd affect the farmers tremendously.

Despite the advantages of PLF use, its adoption is still in the initial stages. This is due to the high cost of PLF technologies and inadequate research on the efficient use of PLF [3]. This research aims to utilize Machine Learning to allow the prediction of livestock health using Internet of Things. It focuses on precision technologies aimed at animal localization and disease, oestrus and calving period detection. One crucial element of this research is the positioning of PLF systems. It is essential for the farmer to know the exact position to place the sensors on the animal's body, for efficiency purposes and collection of accurate data. This is the genesis of any significant PLF endeavour. This paper seeks to report on the testing of non-intrusive and effective positions for the placement of PLFs on animals.

II. Literature Review

To achieve the desired prediction, several parameters aremonitored as shown in Table I:

TABLE I
Parameters monitored in Precision Livestock Farming

Use Case	Parameters to be monitored
Early detection of disease	Travelled Distance per day. Lying & standing / eating time per day. Temperature.
Oestrus & calving window identification	Movement Activity. Heart rate & respiratory rate. Temperature monitoring
Identification & localization of individual animals	Physical location of animal within farm

A. *The PLF Technology*

Different specific tools are utilized to achieve PLF based on the desired parameters that one would like to monitor. First, a visual or electronic mode of animal identification is used to differentiate each animal. Different sensors are then utilized in order to obtain the desired measurements [4]. Various PLF technologies exist, as classified by their method of analysis. These include:

- Sound analysis technologies which analyse animals' coughs.
- Real time image analyses which monitor the gait

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and positioning of animals.

- Temperature and humidity monitoring technologies.
- Weighing scales for weight measurement and feeding management.
- Sensors that measure pH, hormones or gases within animals [3].

These sensors can be located in different places, whether on the individual animal or off and around the entire herd. Where the sensors are placed off the animal, they are placed in well-mapped out areas such as feeding and resting sheds where the animal is known to assume a particular position at given times of the day. This method is less preferred since it only allows for measurements to be made at specific times of the day when the animal is feeding, sleeping or being milked. Furthermore, the physical range of measurement of the sensors being utilized has to be significantly higher to obtain accurate measurements as the readings are made over a distance of 1 to 10 meters. An example can be seen in Figure 1 showing thermal imaging in a cow pen.

Fig. 1. Remote thermal imaging to detect cow temperature in a cow pen [5]

On-body measurement is more reliable and presents an opportunity to obtain readings in a cost-effective manner without compromising on the quality of data obtained.

B. Sensor positioning in PLF

A critical step in carrying out effective measurement is correctly positioning the sensors on the animal's body in order to obtain correct readings without harming or causing discomfort to the animal. For this research, positioning was considered with reference to temperature measuring sensors, as well as motion activity measurement sensors.

For effective positioning of these sensors, the following factors were considered:

1) Thermal windows on animal surface: Temperature measurement is most largely limited by the homoeothermy of mammals. Homoeothermy is the process of thermoregulation within warm blooded animals that ensures that the animal maintains a stable internal body temperature regardless ofexternal conditions [6].

Majority of the body's heat is generated by the running of principle organs such as the brain, heart, liver and kidneys. This heat defines the body core temperature. Thermoregulation involves a process where central heat is removed or dispersed through blood flow. The flow of this heat is dependent on the core temperature, environmental conditions and peripheral blood system regulation. In cattle and other warm-blooded animals, there are certain parts of the body surface which are either uncovered or relatively poorly covered by hair. These parts are considered thermal windows [7]. They present a greater range of cutaneous blood flow. In cattle, these areas include the ears, feet and muzzle [8]. Secondary thermal windows include the eyes, back of the ears, udders, the top of the tail, flanks and forehead [9]. These areas can be seen in Figure 2 as mapped out by Salles *et al* using infraredthermography.

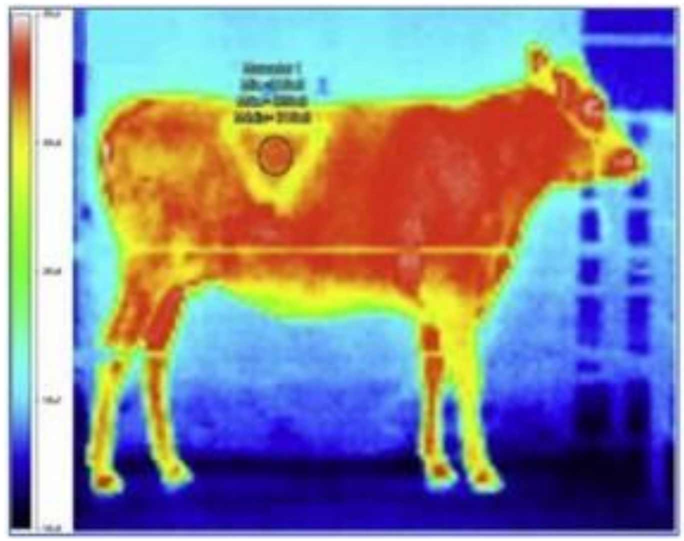

Fig. 2. Surface temperature of different parts of a cow as seen through infrared thermography [10]

Peripheral temperature measurement can best be realized with the sensor system being attached to these parts of the animal's body.

2) Fastening: Despite the existence of guides on the general use of animals for research such as the Guide for the Care and Use of Laboratory Animals [11] and the Guide for the Care and Use of Agricultural Animals in Research and Teaching [12], there exists little to no literature, formal guides or policies that dictate the manner in which foreign objects such as PLF sensor systems should be mounted on livestock.

However, fastening of the sensor system is critical to successful measurement. The system has to be fastened to the cow in a manner that allows the temperature sensor to be in continuous uninterrupted contact with the skin of the cow. This allows the temperature sensor to obtain valid readings every time the system polls it. A situation where the temperature sensor gives intermittently false readings would lead to a faulty prediction by the machine learning algorithm. Furthermore, the fastening should not choke the animal, causeconstriction or any blockage to the animal.

3) Power Supply: Given that the sensor systems utilized in PLF are active electronic devices, they require sufficient power supply. Whether or not the animals stay in or retreatto an electrified pen at the end of the day, it is critical tohave robustly powered sensor systems that are able to maintain power for extended durations of time. Jawad *et al* [13] discussed energy efficient schemes that could be utilized in agricultural applications, including power reduction techniques such as having sleep/wake cycles where the sensor system would be put in a low power state over a period of time where there is minimal data collection and woken up during periods of significant collection. Other techniques suggested include the reduction of the transmission of data to one ortwo consolidated bursts of filtered data within a day to reduce on power consumption [14].

Despite these power reduction methods, energy harvesting can be more consequential in facilitating the long term stayof the sensor on the animal. Researchers are continuing to embrace the use of solar powered devices for uninterrupted monitoring of livestock without the need to disembark the sensor system for charging [15].

4) *Ergonomics - Animal movement and resting positions:* The default positions assumed by the cow while resting, excreting and moving could not be ignored while designing a PLF sensor system. Figure 3 shows a cow urinating and a cow in its resting position.

Fig. 3. A cow urinating (a) and a cow in its lying position (b) [16] [17].

From these images, it is extremely clear that any sensor system attached to the hind leg of the animal has to be small and soft enough for the animal to be able to lie on, as well as designed in a robust manner so as not to be affected by urine splashes, other defecation or any other dirt that may get into contact with it.

III. METHODOLOGY

A. *Design considerations*

Key design considerations that the PLF system was required to meet include:

- The system must be able to read temperature and move-ment data continuously from the animal.
- The system must be cheap enough to be economically viable in a livestock farm setting.
- The tag must be light and comfortable enough to be carried by livestock without significant stress to the animal.
- The system must be able to power itself continuously without the need for disembarking from the animal for charging.
- The system must be dirt and fungus resistant and should have an animal friendly design.

B. *Sensors and materials utilized*

To achieve these design considerations, an animal tag was developed. The animal tag was built on top of an Arduino Pro Micro, a miniature microcontroller system preferred due to its small size, cheap cost as well as function ability. On top of that, the tag utilized a Negative Temperature Coefficient (NTC) thermistor to obtain temperature readings from the animal, and an ADXL 345 ultra-low power, 3-axis accelerometer to record the animal's motion.

To limit errors arising from attempting to send data, a local SD card shield was utilized with a memory card housed on the tag. A Real Time Clock (RTC) system was included to ensure the system kept record of time, and a 0.96 inch OLED display was utilized to allow for easy debugging. The various components were assembled as shown in Figure 4.

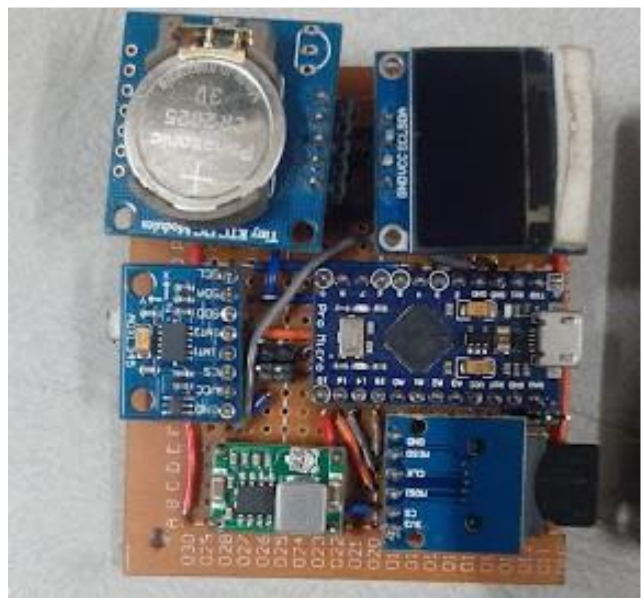

Fig. 4. The components of the PLF sensor system

C. *Power calculations*

Based on the selected sensors and electronic components, the power consumption of the tag was tabulated as shown in the Table II.

TABLE II
POWER CONSUMPTION OF TAG COMPONENTS

Component	Current(mA)	Voltage(V)	Power(mW)
Arduino Pro Micro	50	5	250
DCM01 - Power Supply	1.2	2	2.4
ADXL 345 Accelerometer	0.023	2.5	0.0575
Contact Temp Sensor	0.012	5	0.06
ADC Converter MCP3008	0.55	5	2.75
Real Time Clock	0.5	5	2.5
Display	70	5	350
Total	**122.285**		**607.7675**

A power pack was designed to power the system. In this case, the power pack was sized to allow for 2 days of autonomy in the case of lack of enough sunlight. The maximum energy required, E_{max}, assuming that all components are powered continuously was obtained by:

$$E_{max} = \sum_{i=1}^{n} P_i \times H \qquad (1)$$

Where P_i is the power consumed by the $i^{(th)}$ component as provided by Table II, n is the total number of components, and H is the duration of time that the system should be continuously powered. From the above equation, the maximumenergy was calculated as 29.28 Wh

A 3.7V battery was selected due to its compact size, aswell as the voltage requirements of the electronic components that averaged 5V. An onboard power regulation unit on the microprocessor would bump up the voltage to the required level. The capacity of the battery, C_{bat}, was calculated as follows:

$$C_{bat} = \frac{E_{max}}{V}\ x\ 1000 \qquad (2)$$

where V is the voltage of the battery packs utilized. From this,the desired battery capacity was found to be 7914 mAh. To achieve this, two batteries, each with a capacity of 4400 mAh each were selected. These batteries were selected specifically due to their availability and affordable cost. The batteries werethen arranged in parallel to achieve give a total of 8800 mAh that would be sufficient to run the system.

Machakos County, the location of implementation of the project, has an average daily Photovoltaic Power Potential (PVOUT) of 4.8 kWh/kWp [18]. A more local analysis performed by Muchiri *et al* demonstrated that the area received sufficient fixed plane clear sky solar irradiance between the hours of 8:10 am and 3:51 pm in March , 8:00 am and 3.15 pm in October, and 7.56 am and 3.32pm in June, giving an average of 7.5 hours of effective sunlight per day [19]. Two days of autonomy were considered to ensure the system was still powered when there was less than average sunlight. The wattage of the solar panels, C_{sol}, was calculated as shown below:

$$C_{sol} = \frac{E_{max}}{D_{aut}\, x H_{sol}} \qquad (3)$$

Where D_{aut} is the effective days of autonomy and H_{sol} isthe duration of effective sunlight per day. The wattage was obtained to be 1.952W. A 2 Watt solar panel was therefore selected.

1	RTC Date & Time					Accelerometer data					
2	Day	Hour	Min	Temp_re	Temp (m	x pos	y pos	z pos	x accel	y accel	z accel
336	1	0	20	1023	Invalid	22	12	239	0.09	0.05	0.84
337	1	0	20	497	38.766	24	5	242	0.09	0.02	0.85
338	1	0	20	497	38.766	23	6	239	0.09	0.02	0.83
339	1	0	20	496	38.688	23	7	240	0.09	0.03	0.84
340	1	0	20	498	38.844	23	7	240	0.09	0.03	0.84
341	1	0	20	497	38.766	24	6	242	0.09	0.02	0.85
342	1	0	20	497	38.766	24	6	241	0.09	0.02	0.84
343	1	0	20	498	38.844	24	7	242	0.09	0.03	0.85
344	1	0	20	498	38.844	25	7	242	0.09	0.03	0.85
345	1	0	21	498	38.844	23	7	241	0.09	0.03	0.85
346	1	0	21	496	38.688	24	7	242	0.09	0.03	0.85
347	1	0	21	498	38.844	24	6	241	0.09	0.02	0.84
348	1	0	21	497	38.766	24	6	242	0.09	0.03	0.85
349	1	0	21	498	38.844	24	6	241	0.09	0.02	0.84
350	1	0	21	498	38.844	24	6	241	0.09	0.02	0.84
351	1	0	21	497	38.766	23	6	242	0.09	0.02	0.85
352	1	0	21	498	38.844	24	6	241	0.09	0.02	0.84
353	1	0	21	497	38.766	24	6	240	0.09	0.03	0.84
354	1	0	21	498	38.844	25	6	241	0.09	0.02	0.84
355	1	0	21	498	38.844	25	6	242	0.09	0.02	0.85
356	1	0	21	498	38.844	24	6	243	0.09	0.02	0.85
357	1	0	21	498	38.844	24	7	242	0.09	0.03	0.85
358	1	0	21	498	38.844	24	6	243	0.09	0.02	0.85
359	1	0	21	497	38.766	23	6	242	0.09	0.02	0.85
360	1	0	21	498	38.844	25	6	242	0.09	0.02	0.85
361	1	0	21	498	38.844	23	6	242	0.09	0.02	0.85
362	1	0	21	498	38.844	24	6	242	0.09	0.03	0.85
363	1	0	21	498	38.844	25	6	241	0.09	0.02	0.84
364	1	0	21	497	38.766	24	6	242	0.09	0.02	0.85
365	1	0	21	497	38.766	24	6	241	0.09	0.02	0.84
366	1	0	21	498	38.844	23	6	242	0.09	0.02	0.85

Fig. 5. A snippet of the database showing time, temperature and motiondata collected

D. Programming & Parametrization

An Arduino program was written to collect the temperature and motion parameters. Temperature was collected as a continuous integer value between 0 and 1023. To reduce on computational resources spent, no computation was made to this value, and instead it was simply collected and evaluated as is. Motion was collected as the x-,y- and z- positions of the accelerometer system, as well as the x-, y- and z-acceleration values. Position values were used to determine the resting position of the sensor, while acceleration values were used to determine movement, as in the case of measuring steps. A sample of the dataset is shown in Figure 5

E. Design of tag

The tag was designed using 3D Computer Aided Design tools. Based on the specific positing required, different shapes and materials were utilized. For neck positioning, standard PLA material was utilized. There were no shape restrictions as the tag was to lie squarely on the neck surface. As such, a standard cuboidal shape was adopted to fit the electronic components inside. The tag was 3D printed as shown in Figure 6.

Fig. 6. The neck tag

For positioning on the leg, a different shape had to be adopted. The tag was designed to fit around the leg ergonomically by having a semi-cylindrical extension that could easily wrap on the animal's foot. Furthermore, the tag utilized the flexible TPU material to allow for it to contort and assume the actual shape of the leg. The tag was 3D printed as shown in Figure 7.

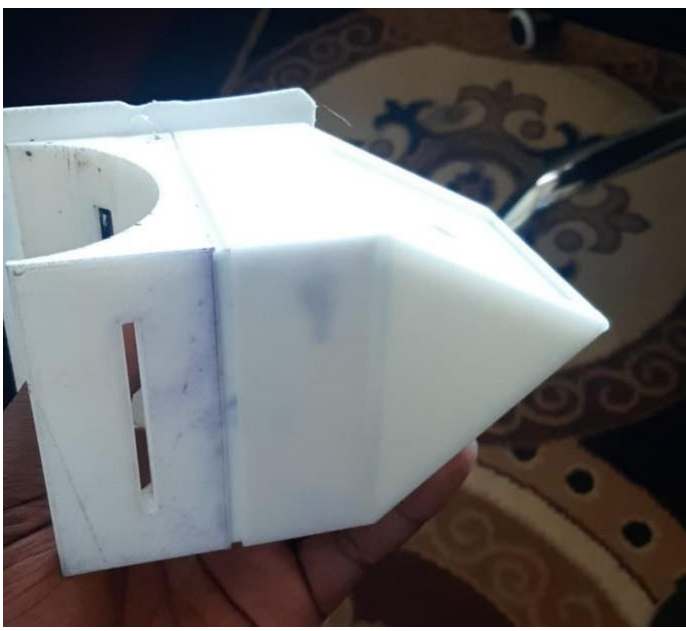

Fig. 7. The leg tag

IV. RESULTS AND DISCUSSION

Figure 8 shows attachment of the sensor system to the cow's neck.

Fig. 8. Sensor system attached to neck of cow

While initially the tag system was meant to rest on the top of the neck, it quickly fell to the lower portion due to the thin dimension of the cow's neck ridge. The tag could not be rigidly tied at this position so as not to constrict the animal's dewlap and cause discomfort and constriction to the animal. In this position, the solar panel faced a downward position and the amount of solar energy that was received was drastically reduced due to this positioning. When thetag settled in position, the temperature sensor held a very loose connection to the cow's skin, leading to the recording of inaccurate readings as shown in Figure 9.

1	RTC Date & Time					Accelerometer data					
2	Day	Hour	Min	Temp_readin g (Raw)	Temp (mapped)	x pos	y pos	z pos	x accel	y accel	z accel
1706	1	1	7	503	39.234	-58	104	213	-0.22	0.39	0.75
1707	1	1	7	503	39.234	-59	104	213	-0.22	0.39	0.75
1708	1	1	7	504	39.312	-57	103	213	-0.22	0.39	0.74
1709	5	19	1	1023	Invalid	-14	-68	230	-0.05	-0.26	0.8
1710	123	91	152	1023	Invalid	-14	-68	231	-0.05	-0.26	0.81
1711	154	145	33	999	Invalid	-15	-68	231	-0.06	-0.26	0.81
1712	5	19	1	1023	Invalid	-14	-68	230	-0.05	-0.26	0.8
1713	5	19	2	1022	Invalid	8	-19	241	0.03	-0.07	0.84
1714	5	19	2	1023	Invalid	6	-23	241	0.02	-0.09	0.84
1715	5	19	2	1023	Invalid	7	-23	240	0.03	-0.08	0.84
1716	5	19	2	1023	Invalid	8	-23	239	0.03	-0.09	0.83
1717	5	19	3	1022	Invalid	7	-22	239	0.03	-0.08	0.83
1718	5	19	3	1023	Invalid	7	-23	240	0.03	-0.08	0.84
1719	123	91	152	1023	Invalid	7	-23	241	0.03	-0.09	0.84
1720	5	19	3	1023	Invalid	7	-23	240	0.03	-0.09	0.84
1721	5	19	3	1022	Invalid	7	-23	239	0.03	-0.09	0.83
1722	5	19	3	1023	Invalid	7	-22	239	0.03	-0.08	0.83
1723	5	19	4	1023	Invalid	8	-23	239	0.03	-0.09	0.83
1724	5	19	4	1022	Invalid	213	90	142	0.8	0.34	0.5
1725	5	19	4	502	39.156	-151	-7	192	-0.57	-0.03	0.67

Fig. 9. Readings showing lapses due to sensor detachment

From the readings above, it can be observed that at some point, the contact of the temperature sensor was dislodged leading it to record minimum readings (1023). It is observed that eventually the sensor returns to contact position and displays accurate temperature readings again.

Figure 10 shows the attachment of the sensor system to the rear leg of the cow.

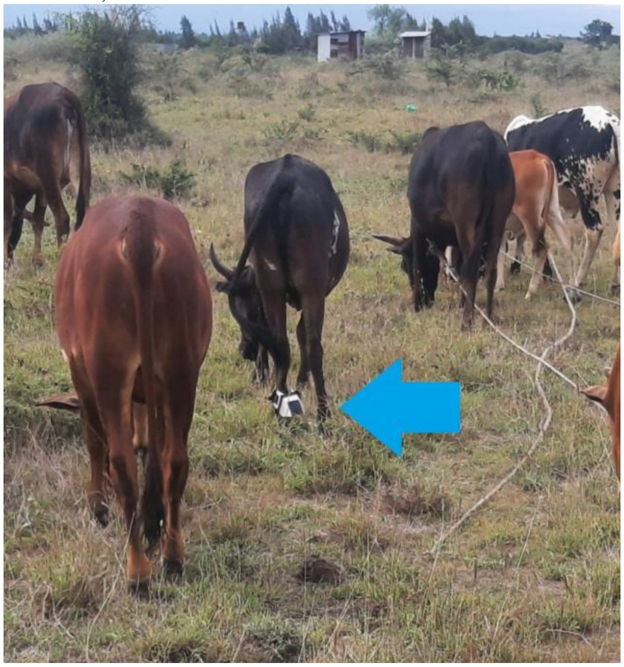

Fig. 10. Sensor system attached to hind leg of cow

In this position, attachment is relatively easy and does not constrict the cow. The small diameter of the cow's leg means a smaller strap is needed for attachment, and thus the cost is lower. This region was considered because of the presence of a thermal window allowing for temperature measurement as well as the ease of monitoring movement using the pedometer system attached to the leg

This position allowed for fairly consistent readings as the sensor was firmly held in place. However, key challenges arose when the animal tried to assume a resting position. When lying down, the sensor system caused some discomfort to the cow as it was too big and pronounced. Furthermore, when the animal defecated or urinated, waste material easily sputtered onto the sensor system. Due to this, the system was immediately removed from this position, and no readings were obtained. Figure 11(a) shows the fitting of the harness on the animal while figure 11(b) shows the positioning of the sensor system on the top of the harness.

Fig. 11. Fitting of cow harness (a) and positioning of sensor system atop the harness (b).

The harness was adjusted such that it did not prevent the cow from opening its mouth fully. The sensor system was then positioned atop the harness behind the cow's poll. It was observed that the sensor maintained a steady seating at this position allowing for steady contact of the temperature sensor with the animal's skin. Furthermore, at this position, there was no hindrance to the cow when standing, lying or eating.

The results were further compared with research from Rahman *et al* [20] where tags bearing an accelerometer were placed on the cow's harness, neck and ear. It was observed that better results were obtained from the harness-placed sensor system than positioning on the neck and ear. This could be attributed to the rigidity of the harness once fastened, as well as the upright position, that allowed for optimum collection of solar energy. Data collection with the tag at this position is ongoing.

V.CONCLUSION

From these placements, it was observed that for this specific case, in order to measure temperature consistently as well as movement of the animal, positioning the tag on the animal harness provided for a reliable method to obtain uninterrupted accurate readings. While those are the results of the current research, several advancements are making the positioning problem easier to solve. These include the development of skin-friendly adhesives that allow for sensors to be taped in place without the need to fasten, as well as nano-technologies that allow for smaller sensors that can be placed in a more versatile manner, on the skin or in a sub-cutaneous position.

Flexible solar panels also allow for better collection of solar energy and more versatile solar panel shapes. Lastly, it is also worth noting that the best solutions are often the simplest, with solutions such as incorporating sensor systems into conventional harnesses, ear and nose tags allowing for the technology to blend right into existing cow management systems.

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REFERENCES

[1] Y. Gómez, A. H. Stygar, I. J. M. M. Boumans, E. A. M. Bokkers, L. J. Pedersen, J. K. Niemi, M. Pastell, X. Manteca, and P. Llonch, "A systematic review on validated precision livestock farming technologies for pig production and its potential to assess animal welfare," *Frontiers in Veterinary Science*, vol. 8, may 2021.

[2] D. Berckmans, "General introduction to precision livestock farming," *Animal Frontiers*, vol. 7, pp. 6–11, jan 2017.

[3] H. Buller, H. Blokhuis, K. Lokhorst, M. Silberberg, and I. Veissier, "Animal welfare management in a digital world," *Animals*, vol. 10,p. 1779, oct 2020.

[4] M. O. Vaintrub, H. Levit, M. Chincarini, I. Fusaro, M. Giammarco, and G. Vignola, "Review: Precision livestock farming, automats and new technologies: possible applications in extensive dairy sheep farming," *Animal*, vol. 15, p. 100143, mar 2021.

[5] M. M. J. R.-Z. Przemyslaw Racewicz, Jakub Sobek, "The use of thermal imaging measurements in dairy cow herds," *Scientific Annals of Polish Society of Animal Production*, vol. 14, no. 1', pp. 55–69,

2018.

[6] A. W. Crompton, C. R. Taylor, and J. A. Jagger, "Evolution of homeothermy in mammals," *Nature*, vol. 272, pp. 333–336, mar 1978.

[7] D. V. Andrade, "Thermal windows and heat exchange," *Temperature*, vol. 2, pp. 451–451, may 2015.

[8] N. Sellier, E. Guettier, and C. Staub, "A review of methods to measure animal body temperature in precision farming," *American Journal of Agricultural Science and Technology*, 2014.

[9] D. Godyń, P. Herbut, and S. Angrecka, "Measurements of peripheral and deep body temperature in cattle – a review," *Journal of Thermal Biology*, vol. 79, pp. 42–49, jan 2019.

[10] M. S. V. Salles, S. C. da Silva, F. A. Salles, L. C. Roma, L. E. Faro, P. A. B. M. Lean, C. E. L. de Oliveira, and L. S. Martello, "Mapping the body surface temperature of cattle by infrared thermography," *Journalof Thermal Biology*, vol. 62, pp. 63–69, dec 2016.

[11] D. o. E. National Research Council, Institute for Laboratory Animal Re- search and L. Studies, *Guide for the care and use of laboratory animals*.NATL ACADEMY PR, 2011.

[12] F. of Animal Science Societies, *Guide for the care and use of agricultural animals in research and teaching*. Federation of Animal Science Societies, 2010.

[13] H. Jawad, R. Nordin, S. Gharghan, A. Jawad, and M. Ismail, "Energy-efficient wireless sensor networks for precision agriculture: A review," *Sensors*, vol. 17, p. 1781, aug 2017.

[14] L.-S. Liu, J.-Q. Ni, R.-Q. Zhao, M.-X. Shen, C.-L. He, and M.-Z. Lu, "Design and test of a low-power acceleration sensor with bluetooth low energy on ear tags for sow behaviour monitoring," *BiosystemsEngineering*, vol. 176, pp. 162–171, dec 2018.

[15] B. Panckhurst, P. Brown, K. Payne, and T. C. A. Molteno, "Solar-powered sensor for continuous monitoring of livestock position," in *2015IEEE Sensors Applications Symposium (SAS)*, IEEE, apr 2015.

[16] A. Vaughan, "Can cattle be trained to urinate and defecate in specific areas? an exploration of cattle urination and defecation habits and some aspects of learning abilities," 2014.

[17] D. Temple, F. Bargo, E. Mainau, I. Ipharraguerre, and X. Manteca, "Lying behaviour and performances in dairy cattle - practical case," *FAWEC - The Farm Animal Welfare Fact Sheet*, Jan. 2016.

[18] SolarGIS, "Global solar atlas 2.0 - technical report," tech. rep., The World Bank, November 2019.

[19] K. Muchiria, J. Kamau, D. Wekesa, C. Saoke, J. N. Mutuku, and J. Gathua, "Solar pv potential and energy demand assessment in machakos county," 2019.

[20] Rahman, D. Smith, B. Little, A. Ingham, P. Greenwood, and G. Bishop-Hurley, "Cattle behaviour classification from collar, halter, and ear tag sensors," Information Processing in Agriculture, vol. 5,pp. 124–133, mar 2018