Editorial

Internetless Low-Cost Sensing System for Real-time Livestock Monitoring

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Abstract—Smart Farming is a progressive domain marked by extensive research and solutions. The predominant approach involves the use of LPWANs for communication, with subsequent data transfer to a cloud server once Internet connectivity is established. In this letter, we present the design and development of a novel smart farming sensor system that combines heterogeneous short-mid range communication technologies with low-cost edge devices, sensors and a multi-hopping algorithm to transmit real-time animal alert data without internet connectivity or a cloud server. The system consists of smart collar devices for livestock, fixed gateway(s) for storage, and a mobile unit to exchange data with a farmers mobile phone. Our testing in a controlled real-world environment demonstrated the viability of such a network with over 90% real-time alerts that trigger a notification on a mobile phone in several unique test cases.

Index Terms—Smart Farming, Internetless, Cloudless, Edge Computing, LoRa, Bluetooth, Sensing

I. INTRODUCTION

The evolution of intelligent sensing technologies, coupled with the increasing population density in recent years, has spurred the progression of Internet of Things (IoT) in shaping and enhancing the paradigm of smart farming. The concept of precision farming, also known as smart farming, involves the use of sensing technology to measure, observe, and analyse the specific needs of fields and crops [1], [2]. Compared to a traditional approach, the aim of the concept is to optimise crop yields and profitability by managing and applying appropriate amounts [2].

Recent developments in sensor-based technologies have shown a significant use for crop and fruit monitoring [3], with very few applied to livestock farming [4]. Precision Livestock Farming (PLF) has developed the sensor approach using tools such as spatial and temporal variability to optimise the contribution tracking of each animal [5]. Farmers can optimise their results using PLF by acknowledging the unique value of each animal on the farm by leveraging advanced technologies [6]. Ongoing work in PLF using sensing technologies can support the monitoring of individual animals, making this individual monitoring significantly more manageable.

PFL is still an emerging research area with the prevalence of farming land in rural settings, particularly where limited internet connectivity and bandwidth is a key problem which compromises the functionality of the service [7], [8]. To overcome this, many previous studies [9]–[12] have suggested ways to tackle the connectivity issue in rural areas by leveraging Low-Power Wide Area Networks (LPWANs) to extend coverage in vast open agricultural spaces [9].

Smart sensing devices incorporating GPS are often commonly used to combat internet and coverage issues to capture detailed position data of an individual [13]. This approach could enable a more comprehensive understanding of the habits and factors contributing to the spatial distribution of livestock [4].

The SheepIT Project [10] is an effective sensor-based system approach that restricts animals feeding without the need for human interaction. Achieved with an IoT architecture consisting of a cloud server and wireless sensor network (WSN), developed with a series of collars and nodes as sensors attached to sheep in a real-world environment [14]. Although effective, this approach is unsuitable for areas with a lack of internet and connectivity. Further work in this approach has explored the potential of machine learning to analyse the collected data to detect animal posture and responses to unwanted behaviours [15]. An alternative to this, *mOOvement* [11] utilises ear tags that leverages GPS technology and a LoRaWAN to provide real-time location and alert notifications based on the animal's location. The gateway devices required for this solution have an upfront cost of ≈£1700 and have high operating costs. Although effective, they are relatively large and rely on an internet connection.

The authors of [12] introduced a livestock tracking system that does not use an LPWAN and instead employs the Sigfox network with BLE tags. The setup included GPS collars, which transmitted data through Sigfox and received information via BLE. Animals were equipped with either GPS collars or BLE tags. The collars recorded the presence of BLE tags in proximity and relayed both that data and the GPS location through Sigfox to a cloud server. At the time of writing, these collars were sold for ≈£150 each.

Multi-hopping algorithms in LoRa have long been investigated [16], some in smart farming [17], [18]. These showcase the benefits of a multi-hop approach, such as allowing for wider coverage and providing more routes for data to travel. They have been utilised for emergency cases, [19] includes a mobile application connected to a LoRa transceiver via BLE. Through this application, users can send emergency requests, which are then re-broadcast by other peers, until they reach rescue personnel. However, this requires multiple mobile phone devices along with additional LoRa hardware.

Many of the innovations discussed have brought a range of technologies such as Edge Computing, Machine Learning, IoT, Cloud into PLF by aiming to increase farmers' overall yield. The primary reason for connectivity requirements is for storing data in the cloud. However, challenges arise when farms are situated in areas lacking network coverage, preventing them from accessing the data; prompting the need to explore strategies for data access and network management. Tensions are also growing between farmers and cloud providers due to reported mishandling of farmers' data, leading to farmer dissatisfaction [20], along with privacy and security concerns

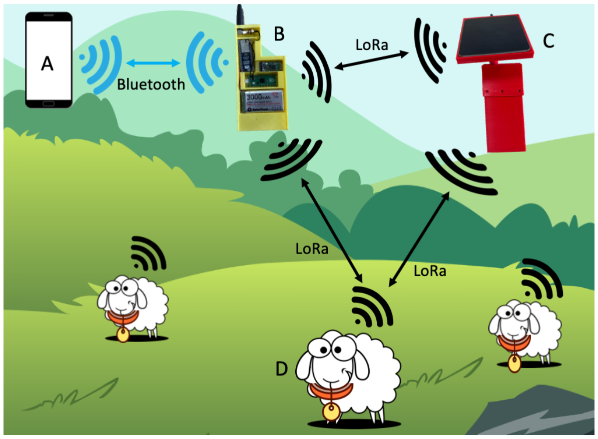

Fig. 1. Architecture of SFM using a sensor system depicting the several processes. (A) Custom-developed mobile application, (B) Link Device (C) low-cost affordable gateway, (D) low-cost animal collars.

being prevalent among farmers [21].

In this letter, we present a completely cloudless and internetless solution to provide farmers with a real-time alert about their livestock. This has been achieved utilising multiple devices and communication methods on low-cost hardware, utilising a multi-hop algorithm to transmit messages from on-device sensors across the network to the farmers mobile phone. The contributions of this letter include:

- The proposal of a new low-cost edge network, utilising short-mid range low energy communication technologies to provide a power-efficient and cost effective solution that may encourage adoption without significant cost.
- The design and development of a completely internetless real-time emergency alert system for monitoring animals that provides real-time notifications about their welfare.
- Performing a feasibility study that takes into account various real-world factors affecting network performance in a multi-hopping controlled environment.

II. SYSTEM PROTOTYPE

The Smart Farm Monitoring (SFM) system depicted in Figure 1, details the overall system architecture consisting of multiple Raspberry Pi Picos, LoRa HATs and batteries. The core of the network is powered by an LPWAN that uses LoRaWAN, ensuring connectivity for livestock and associated devices. Communication between devices is achieved using a mesh approach, allowing an emergency collar to broadcast to devices within range, then those devices will re-broadcast that message. This process repeats until an acknowledgement is received. Unique device IDs, unique message IDs, and message buffers allow message management within the network. Mobile phones are incompatible with LoRa, so an alternative solution has been implemented. An intermediary device that leverages Bluetooth serves as a bridge between mobile phones and LoRaWAN, enabling seamless communication between the network and the mobile application.

A. Sensing System

This section explores each of the sensing technologies associated with the smart farm monitoring system. Figure 1 devices B, C, and D use some of the same hardware, described below:

- **Raspberry Pi Pico**: a microcontroller board that comes with the RP2040 processor, a dual-core ARM Cortex M0+ chip, with 264kB of SRAM and 2MB of flash memory.
- **LoRa HAT**: a HAT designed for the Pico using the SX1262 LoRa module in the EU868 frequency range.

*1) **Collar**:* Illustrated in Figure 1 (D), each collar houses an array of components, including a Raspberry Pi Pico, LoRa HAT, a 10-DOF IMU sensor HAT, and a 3000 mAh battery for extended battery life. These collars are low-cost, totalling ≈ £40 for all the required equipment. This intricate setup is enveloped in a meticulously crafted 3D printed case, strategically designed to protect internal electronics from potential damage. The protective case boasts dimensions of 11.5 cm in height and 5.5 cm in width.

The LoRa device used consumes a transmit current (T) of $45mA@14dBm$ and a receive current (R) of $5.3mA@125KHz$. Using the 125KHz Bandwidth (BW) listed with a Spreading Factor (SF) of 12 should be able to give a range of approximately 6.5Km according to the Semtech LoRa Calculator [22], giving a battery life of approximately 7 months assuming that one emergency is declared a week (transmitting two and receiving one message). However, once we include the Pico constantly listening for incoming messages and the sensors, the battery life becomes just under 3 months (11.3 weeks) with energy efficient programming considered. The battery lifespan of the collar will vary depending on the frequency of messages exchanged and the LoRa configuration. The original is determined by the unpredictable number of times animals will trigger a real-time alert. Using a higher BW and a lower SF can save energy [23], for this study, we used a SF of 9 and a BW of 500KHz, which will use less energy, but provides a shorter range of ≈2.6Km [22].

*2) **Gateway**:* Figure 1 (C) details the core of our system with the gateway, which consists of a Raspberry Pi Zero 2 W, Pico, and LoRa HAT, each gateway is sustainably powered by a compact solar panel. The gateway is also low-cost, totalling to ≈£70 for all functionality equipment and sustainable power resources. The main purpose of this device is to provide the network with storage facilities, using the Raspberry Pi Zero 2 W; a mini-computer with a quad-core 64-bit ARM Cortex-A53 processor, 512MB of SDRAM, coupled with a 32GB memory card, as both the main network coordinator and for storage. Real-time emergency alert packets coming from the collars (D) will transmit here, as well as to mobile devices (A and B). The gateway also facilitates future development of the network, unlocking both general network management and other future work concepts, such as location tracking. This setup enables seamless communication with the active collars, allowing a single gateway to effectively monitor multiple devices within the network.

*3) **Link Device**:* Demonstrated in Figure 1 (B), the Link Device has been designed for the purpose of sensing incoming alerts via LoRa and transferring them to the mobile phone through Bluetooth using a HC-05 transceiver. The equipment for this device costs ≈£25. This functionality facilitates direct communication between the LoRaWAN and the mobile phone, granting the latter the ability to interact with and control the devices within the network. The casing for this device is shaped to that of the mobile phone, as it is designed to attach to the back of the phone, meaning that it will always be within range of the mobile device.

*4) **Mobile Application**:* Finally, Figure 1 (A) depicts an Android application that receives data packets on the network through constant communication with the attached Link Device.

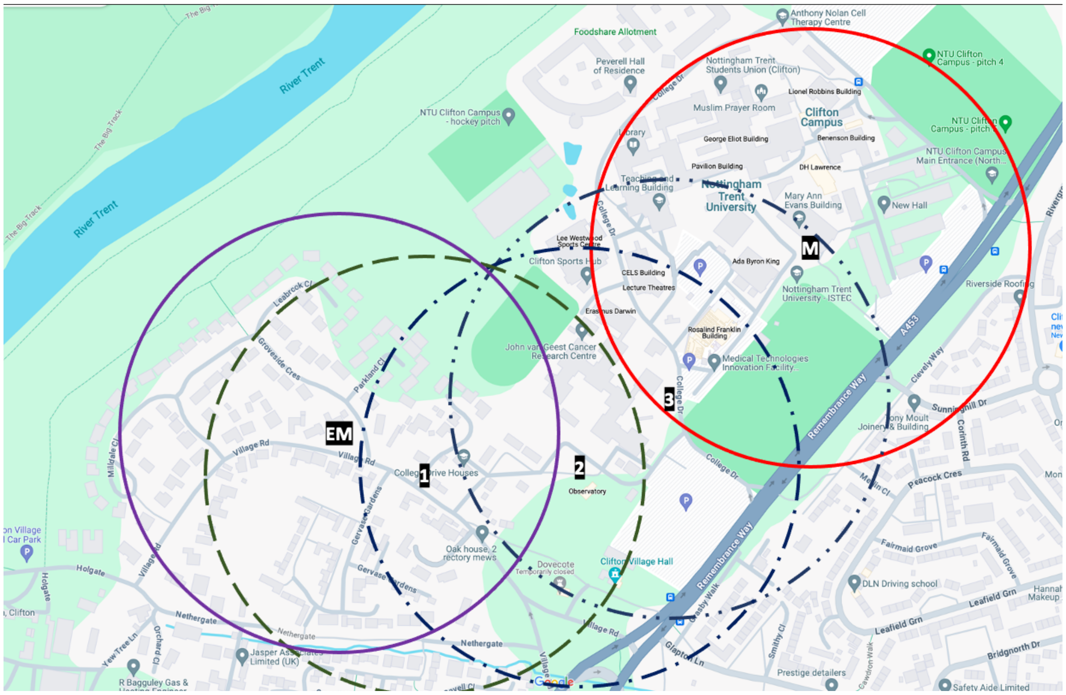

Fig. 2. Multi-Hop Testing Applied to Real-world Setup. EM = Emergency Device, 1, 2 and 3 represent the number of Hops and M = Link Device.

III. METHODOLOGY

A. Setup

To sufficiently test the SFM and the multi-hopping factor of the system, multiple collar devices with the emergency declaring collar (EM) and the Link Device (M) were deployed across an area of land where each device was only within range of the correct number of devices required for the hopping, as seen in Figure 2. This figure shows the application to the real world, showing the 'hopping' devices within range of each other, but not other devices on the network. For example, device 2 is within range of devices 1 and 3, but not the EM or the M. And the EM is within range of device 1, but not device 2, 3 or M. And M is within range of device 3, but not devices 1, 2 and EM.

The tests are intended to verify that emergency data can travel across a LoRaWAN using these low-cost technologies, with multiple hops in a real-world environment. These tests included a two-fold approach that tested stationary and moving collars to draw closer comparison to the real-world, providing more realistic results. The experiment was carried out in both good (sun) and bad (rain) weather conditions to observe any potential impacts of different variables. We also considered the number of 'hops' between the EM and the M by testing direct communications between the EM and the M, followed by one, two, and three hops between the devices. This resulted in 14 different cases, tested multiple times, resulting in over 40 tests being conducted. Each test consisted of 10 emergencies being declared and the success of each test being measured by the number emergency alerts being triggered successfully as a notification on the mobile app. This totalled more than 400 declared emergencies, which is sufficient for thorough testing. A clearer breakdown of all the different tests can be seen in Figure 3 (3 hop tests in poor weather conditions were not possible due to a lack of network observers).

B. Results and Discussion

This section presents the results of this feasibility study and discusses the key findings. Figure 3 plots the data per each test, while 4 plots the average for each test case. Both figures plot the data obtained using this approach by using statistical models like standard deviation, which is visible through error bars.

The study findings show that weather conditions and collar mobility did not have a significant impact on the success of real-time data transmission to the M, allowing the notification to trigger on the mobile device. With all the different tests outlined, more than 90% of the transferred packets successfully triggered an alert, demonstrating that this approach is feasible. The performance of the system is represented by P calculated with the number of successful emergency alerts Es over the total declared emergencies Et.

$$P = E_s/E_t$$

In total across the multiple tests, E_t=420 packets were transmitted with E_s=388 of them successfully triggering an emergency alert (P = 92.4%). The 32 packets that failed were due to the following:

- **Link Device (M) randomly freezing**: The most common failures were the M occasionally freezing, causing no further real-time alerts to be processed, causing 19 (≈59%) of the failed alerts. This was easily solved by restarting the M device.
- **Collar devices randomly freezing**: The collars also caused failures by freezing and requiring a restart, but this was significantly less frequent than the M with 8 (25%) failures.
- **Packet loss**: Packet loss was also a reason for failure, but this was the least frequent reason for any failures at 5 (≈16%).

The study also demonstrates that using low-cost technology, such as the Pico, could be a viable option to monitor livestock and communicate real-time alerts across a mesh LoRaWAN, given the results. However, the majority of failed alerts were caused by technical

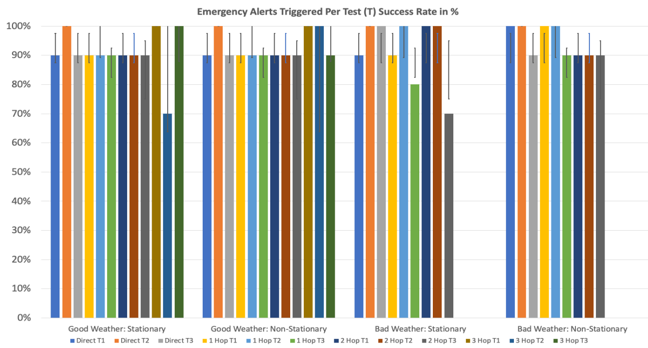

Fig. 3. Results of Successfully Transmitted packets per test.

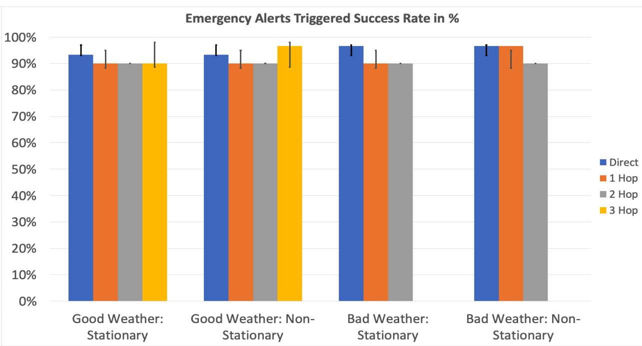

Fig. 4. Average of Successfully Transmitted Packets per test case.

limitations that come with low-cost micro-controllers, particularly on the M device that had to handle two communication channels. When looking at Figures 3 and 4, we observe a difference between Direct communications and 1 hop, this could be due to less chance of failure with Direct communications. However, we also observe that there not much difference between 1, 2 and 3 hops and this may be due to the strongly inconsistent failures, following no clear pattern and happening randomly. These failures could decrease with additional packet routes beyond the single route used in the controlled setting.

Multiple EM devices should also be possible on the network, as the collar devices are designed to re-broadcast emergency messages, each with their own minor time-delays to avoid packet collision, which can happen when multiple packets are transmitted simultaneously.

Although the existing research discussed in Section I has employed various methods of communication, all of them require Internet connectivity [9]–[11] or alternative coverage [12]. The primary reason for this connectivity requirement is when farmers need access to the data, typically stored in the cloud. Cloudless solutions could be preferable due to mishandling of data and security concerns from farmers [20], [21]. Considering these concerns from farmers, there may be demand for a novel approach that enables smart sensing and real-time processing over large areas of land with low-power and low-cost connectivity, excluding internet or cloud access.

IV. CONCLUSION AND FUTURE WORK

In this letter, we introduce an internetless alert system that has the potential to give farmers real-time updates about their animals, designed without the need for any cloud server. Providing the ability to notify farmers about their animals, anywhere on their farm in real-time. This solution used a diverse range of devices, each of which has some contribution to empowering this networks functionality. Our results show that such a network could be a viable option with more than 90% declared emergencies in different conditions triggering a smart phone notification. In the future, we aim to deploy the network in an actual farming environment to assess its practicality, leveraging attached sensors. Additionally, employing on-device ML models for detecting livestock emergencies would be beneficial, facilitated by additional embedded sensors integrated into the collar.

REFERENCES

[1] A. K. Singh, “Precision farming,” *Water Technology Centre, IARI, New Delhi*, 2010.

[2] E. F. I. Raj, M. Appadurai, and K. Athiappan, “Precision farming in modern agriculture,” in *Smart Agriculture Automation Using Advanced Technologies: Data Analytics and Machine Learning, Cloud Architecture, Automation and IoT*. Springer, 2022, pp. 61–87.

[3] R. Ramya, C. Sandhya, and R. Shwetha, “Smart farming systems using sensors,” 2017.

[4] A. Monteiro, S. Santos, and P. Gonçalves, “Precision agriculture for crop and livestock farming—brief review,” *Animals*, vol. 11, no. 8, p. 2345, 2021.

[5] E. van Erp-Van der Kooij and S. M. Rutter, “Using precision farming to improve animal welfare,” *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, vol. 15, 2020.

[6] G. Bucci, D. Bentivoglio, A. Finco *et al.*, “Precision agriculture as a driver for sustainable farming systems: state of art in literature and research,” *Calitatea*, vol. 19, no. S1, pp. 114–121, 2018.

[7] V. Sharma, A. K. Tripathi, and H. Mittal, “Technological revolutions in smart farming: Current trends, challenges future directions,” *Computers and Electronics in Agriculture*, vol. 201, p. 107217, 10 2022.

[8] D. Cutress, “Digital disregard and inequality in rural areas,” 2020.

[9] V. M. T. Aleluia, V. N. G. J. Soares, J. M. L. P. Caldeira, and A. M. Rodrigues, “Livestock monitoring: Approaches, challenges and opportunities,” *International Journal of Engineering and Advanced Technology*, vol. 11, pp. 67–76, 2022.

[10] “Sheepit project.” [Online]. Available: http://www.av.it.pt/sheepit/

[11] “moovement.” [Online]. Available: https://www.moovement.com.au/

[12] F. Maroto-Molina, J. Navarro-García, K. Príncipe-Aguirre, I. Gómez-Maqueda, J. E. Guerrero-Ginel, A. Garrido-Varo, and D. C. Pérez-Marín, “A low-cost iot-based system to monitor the location of a whole herd,” *Sensors (Switzerland)*, vol. 19, 2019.

[13] T. Johnson, E. Kanjo, and K. Woodward, “Digitalexposome: quantifying impact of urban environment on wellbeing using sensor fusion and deep learning,” *Computational Urban Science*, vol. 3, 12 2023.

[14] L. Nóbrega, P. Pedreiras, and P. Gonçalves, “Sheepit-an electronic shepherd for the vineyards.” in *HAICTA*, 2017, pp. 621–632.

[15] L. Nóbrega, A. Tavares, A. Cardoso, and P. Gonçalves, “Animal monitoring based on iot technologies,” in *2018 IoT Vertical and Topical Summit on Agriculture-Tuscany (IOT Tuscany)*. IEEE, 2018, pp. 1–5.

[16] R. P. Centelles, F. Freitag, R. Meseguer, and L. Navarro, “Beyond the star of stars: An introduction to multihop and mesh for lora and lorawan,” *IEEE Pervasive Computing*, vol. 20, no. 2, pp. 63–72, 2021.

[17] N. Ahmed, D. De, and I. Hussain, “Internet of things (iot) for smart precision agriculture and farming in rural areas,” *IEEE Internet of Things Journal*, vol. 5, no. 6, pp. 4890–4899, 2018.

[18] A. U. H. Ahmar, W. Joosen, and D. Hughes, “Smart-hop: Low-latency multi-hop networking for lora,” *Proceedings - 18th Annual International Conference on Distributed Computing in Sensor Systems, DCOSS 2022*, pp. 17–20, 2022.

[19] L. Sciullo, A. Trotta, and M. D. Felice, “Design and performance evaluation of a lora-based mobile emergency management system (locate),” *Ad Hoc Networks*, vol. 96, 1 2020.

[20] S. Neethirajan, “The role of sensors, big data and machine learning in modern animal farming,” *Sensing and Bio-Sensing Research*, vol. 29, p. 100367, 2020.

[21] E. Jakku, B. Taylor, A. Fleming, C. Mason, S. Fielke, C. Sounness, and P. Thorburn, ““if they don’t tell us what they do with it, why would we trust them?” trust, transparency and benefit-sharing in smart farming,” *NJAS - Wageningen Journal of Life Sciences*, vol. 90-91, 12 2019.

[22] “Lora® calculator | semtech.” [Online]. Available: https://www.semtech.com/design-support/lora-calculator

[23] H. Taleb, G. Andrieux, A. Nasser, and N. Charara, “Energy efficient selection of spreading factor in lorawan-based wban medical systems,” *Internet of Things*, vol. 24, p. 100896, 2023.