Low-power networks and GIS analyses for monitoring the site use of grazing cattle

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Computers and Electronics in Agriculture

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Abstract:	In the last years the use of wearable sensors for monitoring and tracking animals and, mostly, for early detection of diseases and improving the quality of production has shown increasing interest. Only recently, their application has become significant in extensive livestock systems, where the farmer-to-animal contact is less frequent than intensive ones. Furthermore, the extensive livestock systems can cause several environmental impacts, that are not easy to compute or model due to the difficulties in continuous long-distance monitoring of the herd. Internet of Things (IoT) technologies could be a valid solution to overcome these issues since they allow monitoring both remotely and in real time. In this regard, the aim of the present study was to prove the feasibility of an IoT-based low-power global positioning system (LP-GPS), developed for locating and tracking cows in extensive livestock systems. Two case studies were compared to prove the suitability of the proposed system with regard the battery life and loss samples. In this regard, the system was adopted to test its battery life and signal coverage after the installation of a SigFox repeater in the grazing area and to examine animals' behaviours within the considered grazing areas by using the Kernel Density Estimation (KDE) tool available in Geographic Information Systems (GIS) software. As result the installation of a Sigfox repeater contributed to reduce losses of position-related samples, and it was possible to define further improvements of the developed system for detecting, locating, and tracking cows in extensive livestock systems. In details, it is important to analyse the behavioural activities of the cows, by combining motion sensors such as accelerometers GPS data to reach the most accurate way for measuring animal activity on extensive farm.
Suggested Reviewers:	Marcella Guarino Full Professor, University of Milan marcella.guarino@unimi.it Expert on this field
	Carlo Ingrao University of Bari carlo.ingrao@uniba.it expert on this field
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Response to Reviewers:	All che comments and suggesdtions were adopted and point-by point addressed in the file "Response to reviewers". Reviewer #1: Dear authors, I found this manuscript adequate as technical note. I have just a couple of questions. Have field checks been made to verify the correctness of the GPS position provided by the collars? What could be the cause of the high losses found for some cows of both case I and case II? A failure or damage or trouble? The authors thank a lot the reviewer for the positive comment. The correctness of GPS position was checked by the breeder. As for the lost data, the authors suggested further developments of the proposed system by considering the combination of GPS and accelerometers, with related behaviour detection systems, in order to understand if the losses are related to some specific behaviours. Moreover, this combination should allow more precise monitoring of the herd and above all avoiding loss data. Reviewer #2: The paper "Low-Power networks and GIS analyses for monitoring the site use of grazing cattle" was submitted as application note to "Computers and electronics in agriculture". The work focuses on the application of an IoT-based low-power global positioning system (LP-GPS), developed for locating and tracking cows in extensive livestock systems. The proposed system was previously developed and shown in "Porto, S. M. C., Castagnolo, G., Valenti, F., and Cascone, G. (2022). Kernel density estimation analyses based on a low power-global 200 positioning system for monitoring environmental issues of grazing cattle. Journal of Agricultural Engineering , LIII(1323).". and is applied to two chosen case-study in Sicily Region (Italy) taking advantages of the Sigfox net. The results were analyzed using the Kernel Density Estimation (KDE) in GIS environments and show the efficacy of the proposed solutions. Considering the Application Note requirements, the paper is in line with the GFA, the introduction is sufficiently explanatory and clear, the methodology section is well structured. Results are detailed and comprehensive. Conclusions are supported by results. However, before considering the work for publication. I suggest to address the following issues: The authors thank a lot the reviewer for the positive comment. All the suggestions were addressed and included in the revised version of the manuscript (yellow highlighted in changes marked version). Thanks for the opportunity of improving the quality of our research work. - KDE is the chosen technique to assess the density estimation. However, in the work, the method is not explained as well as the reason why it has been chosen (why is it preferred to other density estimation methods? such as finite mixture models, diffusion estimator, etc.). I suggest firstly to briefly explain the method when it first appears in the text (excluding the abstract, the Authors refer to the method just using the acronyms) and its potentialities related to the submitted work and why it is preferred to possible alternatives. Thanks a lot for the suggestion. The chosen technique was better detailed within the manuscript. Explanations about the adopted methodology were added. Moreover, as suggested, the acronym was clarified. - The proposed system looks like efficient also thanks to the SigFox net. Since the

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Thanks for the comment. All figures were replaced by enhancing their quality.
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In this paper, the aim of the study is to compare two case studies to prove the feasibility and suitability of a low power global positioning system, developed for locating and tracking cows in extensive livestock systems, considering the battery life and a power supply of the low-power network, in rural locations. In my opinion, the problem studied in this manuscript is very interesting. However, some issues have to be solved. See specific comments below:
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In Table 1 the data of "cow 5" are missing and the total of expected samples is 20,160. Please, complete the table with the correct values.
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Thanks for the comment. A sentence was added related to the cows' favorite areas.

Line 124: The Table 4 is not present in the text, probably is Table 2
Sorry about that. It was a mistake. It was modified. Thanks.

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Thanks a lot for the comment. Text was revised accordingly.

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Thanks a lot for the comment. Different areas were reported in Figure 1 which was modified to be clearer.

Line 141-143: Please, delete this sentence, it is the same information that you gave in Line 128
Thanks for the suggestion. It was deleted.

UNIVERSITÀ degli STUDI di CATANIA
Dipartimento di Agricoltura, Alimentazione e Ambiente
Di3A

Catania, March 31, 2023

Editor-in- Chief
Computers and Electronics in Agriculture

Dear Andrea Pezzuolo,

Thanks a lot for the opportunity of revising and increasing the quality of the manuscript entitled "*Low-Power networks and GIS analyses for monitoring the site use of grazing cattle*", developed in collaboration with my colleagues Simona Porto, Giulia Castagnolo, Parlato Monica, and Dominga Mancuso from University of Catania.

Based on the comments and suggestions provided by the reviewers the manuscript was revised and its quality was increased. Please accept it as a candidate for publication in *Computers and Electronics in Agriculture.* It will be a great privilege for us to publish again in your magnificent journal.

All issues mentioned in the reviewers' comments were point by point addressed, and suitable rebuttals for any comments were provided in the file "Response to reviewers". All changes were yellow highlighted within the revised version of the manuscript.

In general, the manuscript aims at proving the feasibility of an IoT-based low-power global positioning system (LP-GPS), developed for locating and tracking cows in extensive livestock systems, by testing its battery life, and the signal power and coverage and a power supply of the low-power network (i.e., SigFox communication network) in rural areas. In detail, the addressed topic, which falls within the context of advances in the development and application of control systems for solving problems in agriculture and extensive livestock systems, could be worldwide interesting for the journal readers, especially nowadays, where climate change is the imminent environmental issue facing the world, and mostly of the research are still focused on the intensive livestock systems.

The manuscript is about 3800 words and contains 2 figures and 2 tables.

Submission declaration

I affirm that the content of this manuscript is original. All authors of this paper have read and approved the final version submitted. The contents of this manuscript have not been copyrighted or published previously. The contents of this manuscript are not now under consideration for publication elsewhere. The contents of this manuscript will not be copyrighted, submitted, or published elsewhere, while acceptance by the Journal is under consideration. There are no directly related manuscripts or abstracts, published or unpublished, by any authors of this paper.

We hope you will find the paper to be suitable for Your magnificent Journal and you will subsequently send it out for review, so that we will be provided constructive review comments enabling improvement of the paper.

Sincerely

Francesca Valenti

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Department of Agriculture, Food and Environment - University of Catania - Via Santa Sofia, 98-100, 95123 Catania (Italy)
Email: francesca.valenti@unict.it - Phone: +390957147580

Ref.: Ms. No. COMPAG-D-23-00428R1

Title: Low-Power networks and GIS analyses for monitoring the site use of grazing cattle

Computers and Electronics in Agriculture

Reviewers and Editor's comments to the Author:

(all changes in the manuscript changes marked version have been yellow highlighted)

Reviewer #1:

Dear authors, I found this manuscript adequate as technical note. I have just a couple of questions.
Have field checks been made to verify the correctness of the GPS position provided by the collars?
What could be the cause of the high losses found for some cows of both case I and case II? A failure or damage or trouble?

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Highlights

- Wearable sensors for locating and tracking animals has shown increasing interest
- Reliable telecommunication networks and a long-life battery are the crucial issues
- The combined use of GPS and GIS provide a remote screening of animal well-being
- An IoT-based LP-GPS for cow monitoring in extensive livestock systems was developed
- KDE analysis provides a density estimation of the site use of grazing cattle

Low-Power networks and GIS analyses for monitoring the site use of grazing cattle

Mancuso Dominga[1], Castagnolo Giulia[2], Parlato Monica C.M. [1], Valenti Francesca [1]*, Porto Simona M.C.[1]

[1] University of Catania, Department of Agriculture, Food and Environment (Di3A) Building and Land Engineering Section, via S. Sofia 100, 95123, Catania, Italy

[2] University of Catania, Department of Electrical, Electronic and Computer Engineering (DIEEI), viale A. Doria 6, 95125, Catania, Italy

*Corresponding author: francesca.valenti@unict.it

Abstract

In the last years the use of wearable sensors for monitoring and tracking animals and, mostly, for early detection of diseases and improving the quality of production has shown increasing interest. Only recently, their application has become significant in extensive livestock systems, where the farmer-to-animal contact is less frequent than intensive ones. Furthermore, the extensive livestock systems can cause several environmental impacts, that are not easy to compute or model due to the difficulties in continuous long-distance monitoring of the herd. Internet of Things (IoT) technologies could be a valid solution to overcome these issues since they allow monitoring both remotely and in real time. In this regard, the aim of the present study was to prove the feasibility of an IoT-based low-power global positioning system (LP-GPS), developed for locating and tracking cows in extensive livestock systems. Two case studies were compared to prove the suitability of the proposed system with regard the battery life and loss samples. In this regard, the system was adopted to test its battery life and signal coverage after the installation of a SigFox repeater in the grazing area and to examine animals' behaviours within the considered grazing areas by using the Kernel Density Estimation (KDE) tool available in Geographic Information Systems (GIS) software. As result the installation of a Sigfox repeater contributed to reduce losses of position-related samples, and it was possible to define further improvements of the developed system for detecting, locating, and tracking cows in extensive livestock systems. In details, it is important to analyse the behavioural activities of the cows, by combining motion sensors such as accelerometers GPS data to reach the most accurate way for measuring animal activity on extensive farm.

Keywords: Grazing cows; IoT; cow behaviour; spatial analysis; GPS; Kernel Density Estimation, tracking.

1. Introduction

Over time, consumers have become increasingly careful to the quality of food, and for this reason farmers must achieve high standards production but at the same time maintain an excellent state of animal welfare and improve environmental sustainability (International Office of Epizootics, 2004). In this context, the support of technology and innovations is becoming ever more important. In recent years, with the development of increasingly efficient Internet of Things (IoT) systems, it has been possible to use sensor networks in extensive livestock systems located in rural areas which are often lacking in electricity and internet networks. Many researchers have focused their attention on the development of global positioning systems (GPS) to monitor the location of animals in real time with the aim of producing alerts for farmers when the animals exceed the boundary of the territorial area available to the herd (i.e., virtual fencing) (Rivero et al., 2021) . Since GPS devices could also retrieve animal identification, each identified animal position could be tracked during the monitored period and showed at territorial level by Geographical Information System (GIS)-based software. Barbari et al. (2006) , proved that the combination of using GPS and then GIS for tracking and locating animals in several grazing areas, is a key element in reaching important conclusions on the territory and on biological matters. In last years, several research studies have used GPS to locate herd, indicating a common need to solve the difficulties associated with sensor downsizing and the development of high-energy-density batteries, since it is necessary to have a long battery life because the contact between the farmer and the animal is limited to a few times during the year. Another crucial and severely limiting element for extensive farming is the unavailability of an efficient and continuous telecommunication signal, and low-power consumption telecommunication network (Arcidiacono et al., 2020). To solve these problems, many Low Power Wide Area Networks (LPWANs) have been recently developed (i.e., Sigfox and LoRa), which are composed of long-distance wireless communication networks that are characterized by low power consumption and low transmission rates (Qadir et al., 2018).

Porto et al. (2022) demonstrated in their study the feasibility of an automatic system for detecting and monitoring cows in extensive livestock systems by using space-time data from a low power global positioning system (LP-GPS). Data were adopted to examine the herd's pasture utilization in order to estimate the environmental implications of extensive livestock systems by using GIS. The developed system was then tested by Castagnolo et al. (2022) in another case study to investigate its feasibility for locating and tracking animals within territorial areas not properly covered by LPWAN networks. In both the analysed case studies attention was paid to test the feasibility of the developed LP-GPS based system for detecting and monitoring cows, and estimate the environmental implications, without considering the battery life, and the Sigfox signal power and coverage. Therefore, the aim of the present study was to prove the feasibility of the developed system (i.e., LP-GPS based), developed for locating and tracking cows in extensive livestock systems, by testing its battery life and a power supply of the low-power network (i.e., SigFox communication network), considering its signal power and coverage, in rural locations. A comparison between the experimental analyses and the results achieved by Porto et al. (2022) and Castagnolo et al. (2022) was made, by paying attention to the improvements made in terms of data loss achieved through the installation of a Sigfox repeater.

2. Materials and methods

2.1. Data collection system and analysis

The Low Power GPS-Based System (LP-GPS system), composed of wearable devices that could receive position information from up to three global navigation satellites systems (i.e., NAVSTAR/GPS, Galileo, GLONASS) was applied a two different case studies (i.e., Case I and Case II). The developed system showed that the combination between a low sampling rate and the Low Power communication network provided a longer battery life than other system investigated in literature (Bailey et al., 2018). In detail, the wearable devices, after receiving position information (e.g., latitude and longitude, time of detection and distance travelled by each animal), send it to a cloud server by using SigFox telecommunication network, for their processing and visualization through a WebApp. The SigFox antenna located close to Monte Lauro, within the province of Syracuse, was used for both the considered case studies. In details, the wearable device was equipped with an omnidirectional GPS antenna and receiver with -167 dBm sensitivity and 72 channels, an ultra-low power microcontroller, a SigFox radio module 868MHz, 14dBm E.R.P., an omnidirectional SigFox antenna, a powered by high-capacity Li-SOCL2 batteries.

2.2. Case I

In the Case I the experimental activity was carried out in the territorial area belonging to the municipality of Melilli, in the province of Syracuse, for 21 days from January 1 until January 21, 2020 (Figure 1). Data were acquired with an acquisition-time interval of 20 minutes as well as the time interval for sending messages to the cloud server. The 20 minute-time interval was chosen to acquire long-time data for both carrying out tailored GIS analyses, such as the application of Kernel Density Estimation (KDE) tool and guaranteeing long lasting battery life. KDE tool, available in QGIS software, was applied by considering the placements of each animal outfitted with the devices. In detail, the KDE analysis, which is frequently used in biology studies, allows the calculation of the home range of the species (i.e., the area of the agricultural land in which a species lives) and provides a density estimation of the use of the landscape (i.e., Home Range (HR) and Core Home Range (CHR)). By applying KDE analysis, the maps (i.e., a raster or a vector image), obtained both for each animal of the sample and for all the selected cows to classify the preferred territorial areas, represents the area of the territory most frequently used by animals, in terms of density. In detail, the HR represents the area in which the probability of finding the monitored items is 95%, while the CHR represents the area in which the probability is 50% (Porto et al., 2022). During the experimental activity the cows were grazed in an area of around 100 hectares, subdivided into ten different zones, which was delimited by an electric fence to prevent livestock trespassing. Ten different animals out of a herd of 90 animals that differed in age and number of births, but all belonging to the same breed (i.e., mix breed), were chosen by the farmer to carry out the experimental activity. Due to a problem with fitting a collar on a cow (i.e., *case I_cow 5)*, the related data could not be analysed therefore, data from only nine wearable devices were collected and elaborated. On acquired data, both spatial and statistical analyses were carried out by using QGIS software for the first ones and KDE for the others through which six thematic maps were obtained, one for each considered cow. Moreover, acquired acquisitions were further analysed to assess possible devices signal losses for each individual cow during the entire observation period.

2.3. Case II

The second case study (i.e., Case II) was carried out in an extensive farm located in Aidone municipality, belonging to the province of Enna, for a period of 38 days between July 2021 and August 2021 (Figure 1). The herd was grazing in an area of about 300 hectares, divided into three different territorial areas, bounded by electric fence to prevent livestock trespassing. The animals generally stayed from 6 AM to 5 PM in area 1 where they had access to the feeder and watering trough, then from 5 PM to 6 AM, the cooler hours, the farmer moved the herd in both areas 2 and 3, where the cows were free to graze. In this case study, six animals out of a herd of 130 cows, all belonging to the Limousine breed, that differed in age and number of births, were chosen by the farmer to carry out the experimental activity. The time interval for data acquisition was set to 10 minutes with the aim of increasing the battery life, that reached four month-duration. As well as for Case I same spatial and statistical analyses were carried out.

Following the results obtained in Case I, a Sigfox repeater was installed in the study area (Figure 1) aimed at increasing the signal power and coverage of the telecommunication network, and consequently reducing the data loss. In order to verify the exact location of the lost data, for each cow all data, detected before and after the lost one, were localized based on their GPS coordinated in QGIS software. Then, the Mean Coordinates plug in available in QGIS, which calculates the mean of the coordinates of a layer starting from a field of the attribute table, was applied, by creating a new points layer containing the simulated lost data for each of the six selected cow. Based on this new layer, in order to better understand the link between data losses, the signal coverage, and the devices, tailored heatmaps, through KDE tool, were carried out.

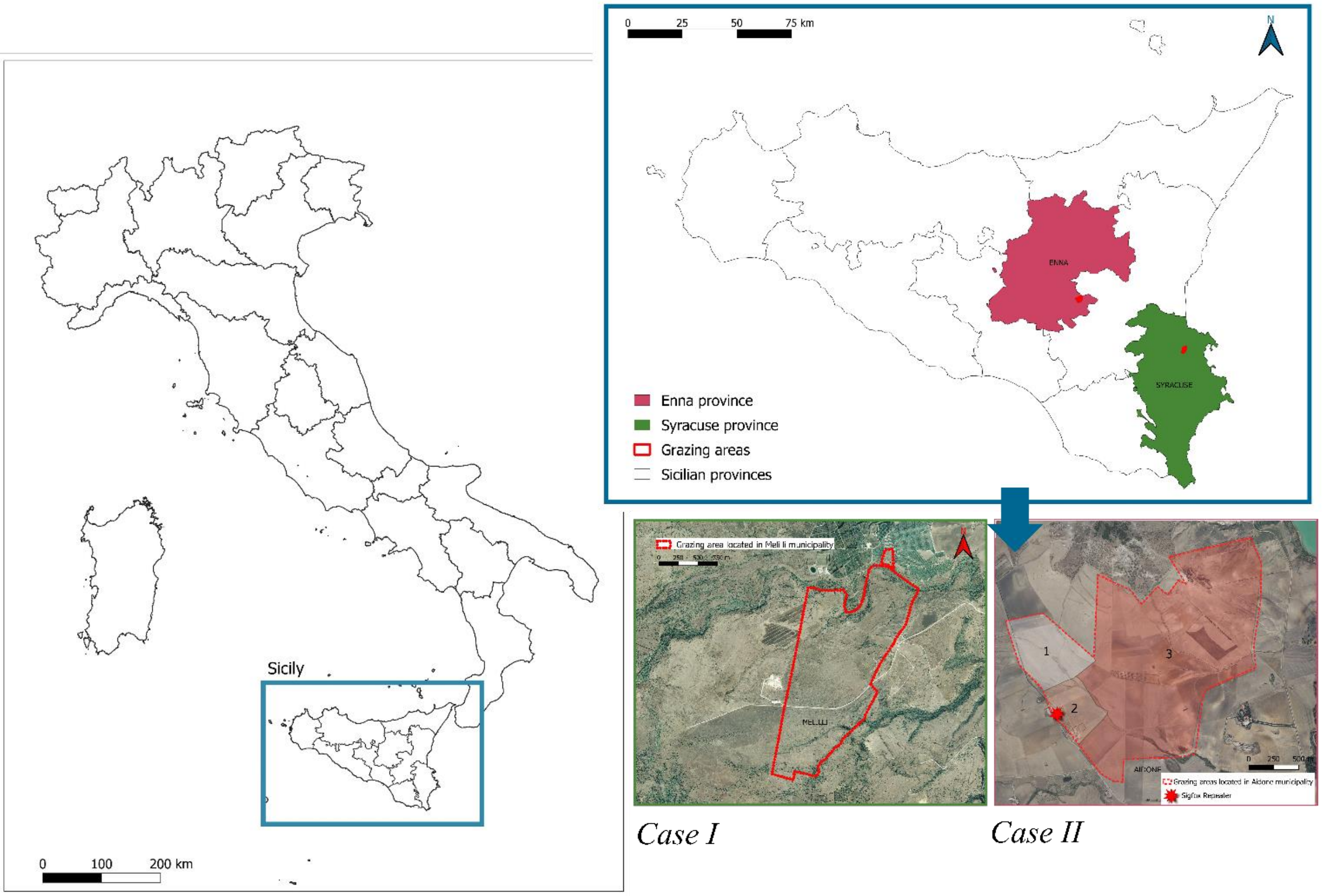


Figure 1: Localization of the grazing areas in the provinces of Syracuse (Case I) and Enna (Case II).

3. Results and discussion

3.1. Case I

Collected data from the LP-GPS device and acquired from both direct surveys and visual inspections, were combined, and elaborated for locating and tracking the ten selected cows. By using QGIS, it was possible to highlight those grazing areas most frequently used by animals during the whole data collection period. The area, that resulted as the most preferred by the animals, was that one richest in forage and far from the road. Further analyses and tailored evaluations were carried out on the data acquired through the LP-GPS device as shown in Table 1. In detail, it is possible to highlight that, by considering the data collection period (i.e., 21 days) and the data sending time-interval of 20 minutes (i.e., thus 4 acquisition per hour), the expected acquisitions for each individual device during the entire observation period should have been 2,016 instead of, at least, less than 1,800, as reported in Table 1. By analysing the recorded data, it was found that, all devices documented signal losses ranged between 233 to 729 lost samples per cow, with an average of 443 equals to about 22%. Furthermore, as reported in Table 1, the devices that have lost the highest percentage of points are those ones referred to the *case I*_cow 1 and *case I*_cow 9, with 32.39% (i.e., 653 samples) and 36,16% (i.e., 729 samples) of lost data, respectively. Since the losses were evenly recorded for all the cows it could be due to the low signal power and coverage in the study area. Therefore, by installing a repeater, it could be possible to increase the signal coverage of the telecommunication network and consequently reducing the data loss.

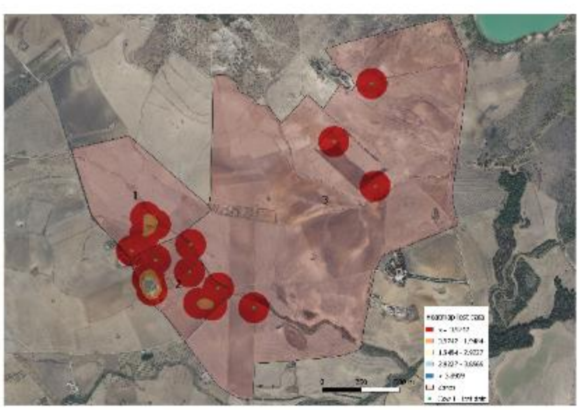
Table 1: Data obtained by the LP-GPS device during the whole observation period.

Cow ID	**Num. lost samples**	**Num. obtained samples**	**Num. expected samples**	**% Num. lost samples**
*case I*_cow 1	653	1363	2016	32.39
*case I*_cow 2	296	1720	2016	14.68
*case I*_cow 3	276	1740	2016	13.69
*case I*_cow 4	233	1783	2016	11.56
*case I*_cow 6	448	1568	2016	22.22
*case I*_cow 7	422	1594	2016	20.93
*case I*_cow 8	445	1571	2016	22.07
*case I*_cow 9	729	1287	2016	36.16
*case I*_cow 10	481	1535	2016	23.86
Total	3983	14,161	20,160	19.76

3.2. Case II

As well as for Case I, by using KDE tool, available in QGIS software tailored maps for each cow were obtained reporting their most preferred areas among the three considered different ones. It emerged that all the considered cows remain for longer time into area 2 (Figure 1). This latter was most preferred by the animals as it was the richest in forage in particular *Trifolium alexandrinum*, and because this kind of forage is considered by cows more palatable than others.

The heatmaps, representing the territorial area of whole grazing area where the signal coverage most frequently could be lost, were carried out, through KDE tool, for each considered cow (Figure 2). As shown in Figure 2 and reported in Table 2, the lost data, considering the increase of the signal coverage by Sigfox repeater installation, were around 6% of the total recorded data, with a minimum of 23 and maximum of 1103 lost samples.



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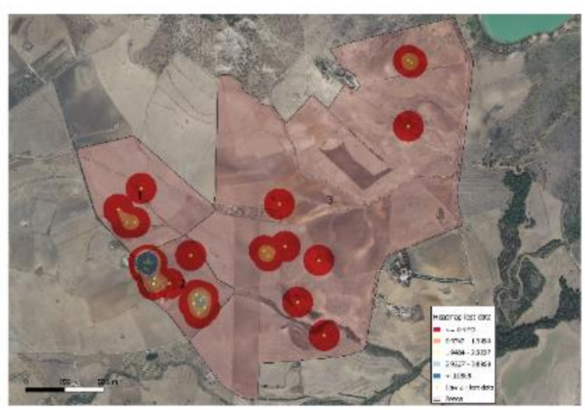
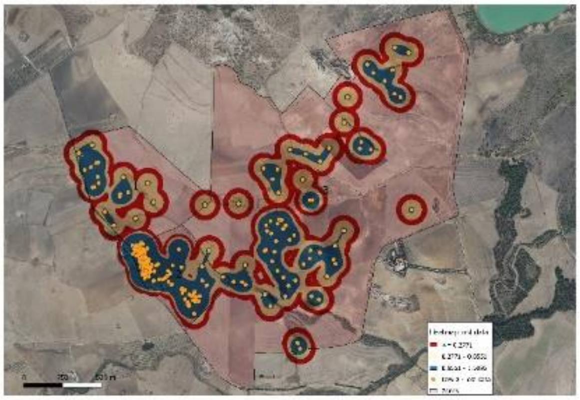
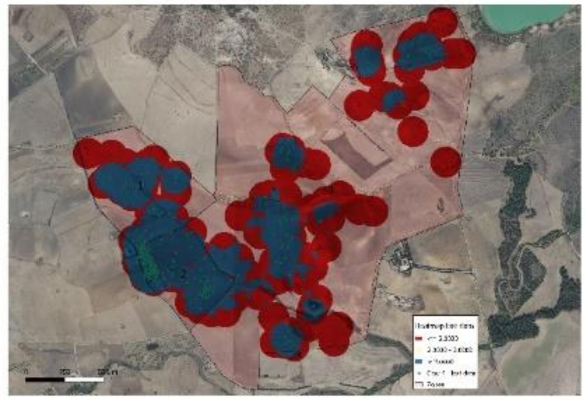


*case II*_cow 2

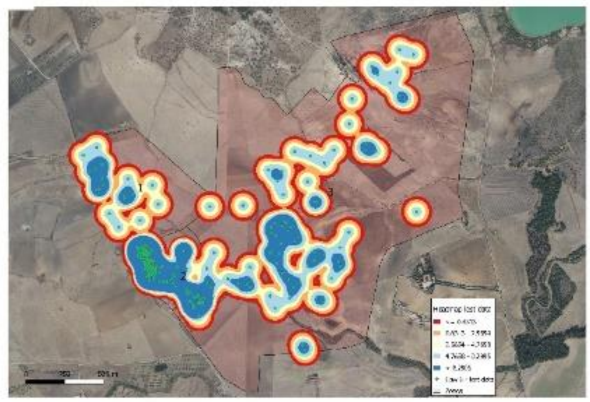


*case II*_cow 3



*case II*_cow 4

*case II*_cow 5



*case II*_cow 6

Figure 2: KDE analyses for each cow representing the area of the territory where the signal coverage most frequently could be lost in CASE II

Moreover, by observing Figure 2, the heatmaps carried out for *case II*_cow 4, *case II*_cow 3, and *case II*_cow 6, showed the highest concentration of lost data, as confirmed in Table 2. By excluding these three selected cows (i.e., *case II*_cow 3, *case II*_cow 4, and *case II*_cow 6), the percentage of lost data was drastically reduced to less than 1%, thanks to the installed Sigfox repeater.

These latter demonstrated that the losses data should be attributed to the wearable devices not to the low signal coverage, also because the losses resulted evenly distributed within the whole grazing area, by highlighting the highest number of losses in area 2, exactly where the Sigfox repeater was placed.

Table 2: Data obtained by the LP-GPS device during the whole observation period within Case II

Cow ID	Num. lost samples	Num. obtained samples	Num. expected samples	% Num. lost samples
*case II*_cow 1	23	6361	6384	0.36
*case II*_cow 2	41	6343	6384	0.64
*case II*_cow 3	679	5705	6384	10.63
*case II*_cow 4	1103	5281	6384	17.27
*case II*_cow 5	56	6328	6384	0.88
*case II*_cow 6	217	6167	6384	3.39

Total	2119	36185	38304	5.53

As reported in Table 2, considering the devices embedded to the collars belonging to the *case II*_cow 3 and *case II*_cow 4, the recorded losses were 10.63% and 17.27%, respectively.

Finally, by comparing the two analysed case studies, i.e., Case I and Case II, it is possible to notice that the installation of the Sigfox repeater contributed to reduce losses of position-related samples. In detail, from a total loss of about 22%, recorded for Case I, a total percentage of lost samples equal to about 5.53% was reached in Case II.

In order to improve the performance of the developed system by strongly reducing the number of lost samples, it is important to analyse the behavioural activities of the cows, by combining motion sensors (i.e., accelerometers) and GPS data to reach the most accurate way for measuring animal activity on extensive farm. In this regard, in literature only few research works that combine GPS data with accelerometers were found, compared to those ones that instead of use single types of data (Brennan et al., 2021). Among them, most studies focused on the use of GPS collars combined with accelerometers in small pastures and over short time periods (Riaboff et al., 2020), therefore, as also demonstrated by the achieved results, checking this technology in bigger pastures and, above all, for longer observation periods is urgently needed.

Another important issue highlighted by the achieved results and needed of further improvements is how to increase both battery life and network performance in combined GPS and accelerometer systems. In this regard, it is important to highlight that the long battery life reached in both the analysed case studies, especially in Case II (i.e., more than 4 months) was reached by using a 10-minutes data monitoring. Indeed, as stated by Raizman et al. (2013), due to the limited battery life of the devices, in some research studies, the animal's position was detected only one time per hour, but by reducing the number of detections it is impossible to achieve an efficient monitoring of grazing animals.

4. Conclusions

As reported by several studies, knowing the position of the animal related to a defined area allows to obtain key information about the feeding, soil consumption and, in some cases, the habits of the considered animals. Obviously, the position data alone is not always exhaustive, therefore the subsequent elaborations via GIS allow the creation of maps which can be crucial in the management of herd. Real-time monitoring of herd in extensive livestock systems represents a challenging task to monitor those variables that can warn farmers with timely alerts. Furthermore, as it is well known, in extensive farms it is not always easy to monitor the animals as the telecommunications networks may not be present or have poor signal and coverage.

In this regard, the achieved results demonstrated that the use of Low-Power networks (i.e., Sigfox) allows continuous monitoring of the herd while preserving the battery life of the devices, unlike non-low-power networks. Furthermore, the installation of a Sigfox repeater has made it possible to significantly reduce data losses.

In detail, the loss of the samples in a system aimed at detecting the position is a crucial data because, considering that most of the systems proposed in literature send the positions in an order of magnitude referable to minutes, in some cases even to hour, the loss of a sample or more samples certainly involve a monitoring of little use for both breeders and researchers.

Further developments of the proposed system should consider the combination of GPS and accelerometers, with related behaviour detection systems, by allowing even more precise monitoring of the herd and avoiding loss data.

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Declaration of interests

☒The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

CRediT author statement

D. Mancuso contributes to Data curation, Investigation, and Writing - original draft. **G. Castagnolo** contributes to Formal analysis, Software, Validation, and Writing - original draft. **M.C.M. Parlato** contributes to Visualization. **F. Valenti** contributes to Conceptualization, Methodology, Writing - review & editing, and Supervision. **S.M.C. Porto** contributes to Funding acquisition.