Resource use and proximity technology in extensive systems - getting useful information on livestock at lower costs?

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Abstract

Comprehensive livestock tracking and behavioral characterization in extensive systems is technically challenging and expensive. Some technologies and data strategies based around proximity information may be more affordable. This paper brings together experiences from two major PLF projects involving cattle in extensive U.S. rangelands and sheep in extensive UK mountains and considers proximity technology for two resources, water in dry rangelands, and supplementary feed in pregnancy, respectively. Opportunities to characterize useful livestock variables include presence/absence, diurnal patterns, use of resources and changing use patterns. Results covering supplementary feed, used fixed Bluetooth Low Energy (BLE) readers arrayed around feeding points, 48 Blackface and 50 Lleyn ewes on 33ha of grazing that wore small (c14 g) BLE beacons. Beacons on ewes communicated identity and RSSI (Received Signal Strength Indicator) via receiving readers, pushing data in near-real time via LPWAN to an ArCGIS Online database. Differences in proximity at feeding areas were found for breed and age and patterns of activity over 24-hour periods, supporting the view that BLE technology covering only proportions of grazing areas could be useful for management purposes. For water access in arid rangelands, 11 cows in a 480ha paddock wore NoFence virtual fencing collars with GNSS real-time tracking using cellphone communications. Daily patterns of proximity to the only water source derived from GNSS data support the view that useful information could be provided by BLE proximity systems at lower cost than GNSS collars. Proximity approaches alone provides less information than GNSS systems.

Keywords: proximity, Bluetooth, GNSS, extensive systems, cost/benefit

Introduction

Technologies to monitor livestock have become increasingly more widespread and accessible in both research and commercial intensive livestock systems. The rate of progress of PLF technology suited to extensive livestock systems, and those associated with small ruminants and beef cattle, has been slower, but increasing (Fogarty et al., 2018). New prototypes and technologies are coming forward (Aquilani et al., 2022,Caja et al., 2020) with advances in the capability of these technologies. The central theme behind this paper is that although scientists and producers can find increasingly diverse and multiple means to capture single or multiple sensor data in real-time from extensive livestock, it does not mean that they must use high, and expensive, levels of data capture to obtain useful information.

Wearable GNSS systems, with real-time communication and user dashboards, are the current 'gold standard' for livestock monitoring, with data transferred by LPWAN (Low Power Wide Area Network) or cell phone technology. However, alternative technologies can collect and transfer information using less expensive and complex systems. The technical focus of this paper is the use of BLE beacons worn by individual animals to readers communicating to end-users in near real-time. This technology also illustrates the principle that simpler, less complex systems may have a role. BLE readers may be fixed within the grazing environment or worn by some individuals in the group. We have communicated some early results of this technology (Walker et al., 2022, Waterhouse et al., 2019) and at least one commercial company is commercializing a similar version of the technology for extensive sheep (RealtimeID®, https://realtimeid.no/en/). Hardware characteristics involve animals wearing beacons of <20 g weight, with many months of battery life, costing c.$10 covering a range of up to, or beyond, 50 meters.

This paper will focus upon illustrating how BLE beacon-wearing livestock, along with fixed readers linked to feed or water resources, relate to the following questions: Are the livestock there? Are they using the resource? Can whole flock/herd or individual stock status be monitored, and behavioural change be identified?

Finally, a different GNSS dataset will provide a scenario testing whether proximity technology can provide cost-effective livestock surveillance capabilities.

Materials and methods

Sheep and proximity study

The study was carried out on SRUC's hill sheep farm in western Scotland using two paddocks with highly diverse topography, with low quality semi-natural grazing, of limited availability and quality. Further details are provided in Figure 1. Water availability was from natural streams passing through each paddock at multiple points.

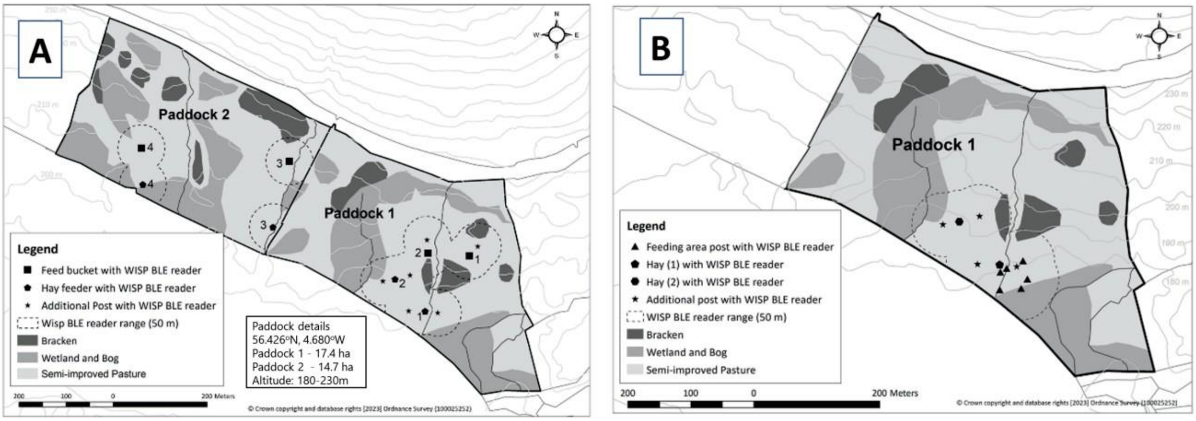

Figure 1: Maps with locations of BLE readers A: Phase 1 with self-fed buckets and hay B: Phase 2 with twin bearing ewes with pelletized feed fed once per day and hay

Ninety-eight ewes of two contrasting breeds (Scottish Blackface and Lleyn) in the 3rd month of pregnancy (February) were split between the two paddocks and offered self-fed *ad libitum* feed buckets (Crystalyx Extra High Energy, 12% protein). In each paddock these were placed at two locations, Buckets 1 and 2 in Paddock 1 and Buckets 3 and 4 in Paddock 2. There were large hay bales fed in ring feeders (Hay 1 and Hay 2 in Paddock 1, and Hay 3 and Hay 4 in Paddock 2). Each bucket and hay location had a proximal BLE reader. In Paddock 1 only, additional readers were on fenceposts a short distance (5-10m) away from each feed locations (see Figure 1). In a second phase, in the 4th month of pregnancy (March), the number of fetuses per ewe was assessed by ultrasound pregnancy scanning. Thirty-nine twin-bearing ewes (13 Blackface and 26 Lleyn) now occupied Paddock 1. They were transitioned to a higher level of feeding over a few days by introducing a pelletized feed product containing 18% crude protein. The ewes were fed once a day, between

9.30a.m. and 11.15a.m., with a daily allowance of 450g/ewe. Six BLE readers, on tripods (1m high) were positioned around a feeding area about the size of a tennis court. Hay in feeders was offered, with BLE readers, as in the earlier phase.

The purpose built Wearable Integrated Sensor Platform (WISP) system was commissioned from and built by Scotland's Innovation Centre for Sensor and Imaging Systems (CENSIS). Each WISP reader consisted of multiple sensors including GNSS receiver, accelerometer, and BLE reader. Each WISP recorded and reported data on a 5-minute duty cycle, both in real-time via LPWAN and to an 8 MB Flash Drive.

The BLE reader (BLE 4.2) within each WISP unit reported the identity and RSSI (Received Signal Strength Indicator) of 16 'closest' beacons seen within its 5-minute duty cycle. Receivers would scan for 30 seconds, then idle for 30 seconds. During each scanning window of 5 minutes, the RSSI of any beacon seen was added to that of any previous adverts and sorted based on average RSSI and a maximum of 16 beacons with highest average RSSI included in data packet reported. BLE 5.1 beacons (Mini beacon, Shenzhen Feasycom Technology Co., Ltd) were used. Our other studies found that ranges of transmission/reception were typically c. 50 meters in these field study contexts. In this study each ewe wore a BLE beacon on a string necklace, together with a large cattle ID tag with number readable at distance for ground-truthing. Data were communicated via LPWAN, through gateways and The Things Network to an ArcGIS Online database in near real-time but were also written to an on-board flashcard memory. For this study, flashcard data was used as primary data source because it was the most complete. However, four of the flash drives failed and for these only LPWAN data was used.

Rangeland cattle study

This study was carried out at a pasture of 480 ha at the New Mexico State University's Chihuahuan Desert Rangeland Research Center (32.5461°N 106.82560°W). The pasture had a single water trough at the south end. The topography is relatively flat, with sparse vegetation representing the sandy ecological site within the Chihuahuan Desert ecosystem. Eleven matured nursing Brangus cows (~690 kg) were fitted with deactivated C2 NoFence ® (Batnfjordsøra, Norway) virtual fence collars weighing 1.3 kg. The collars operated on solar and battery energy with 4G global system for mobile to communicate real-time positions and activity at 15-minute and 30-minute intervals respectively.

GNSS coordinates for two-week deployment period were imported and projected to NAD 1983 UTM Zone 13N using ArcGIS software (ESRI 2018, ArcMap Desktop v.10.6). Distance to water trough location of each GPS coordinate was calculated using Euclidean distance method. The number of GNSS positions per collar/day within 50m radius of the water trough location was computed and the sum of the 50m radius GPS count was used to represent water trough visitation of individual cows. Ethical approvals were covered by SHE AE 22-2021 and IACUC Protocol 2021–010 for SRUC and NMSU respectively.

Results and discussion

Sheep study phase 1 self-feeding period

Data was successfully collected from all BLE readers on Day 1 from all 49 beacons in Paddock 1 with Figure 2 showing the average number of these contacts per reader per day for all ewe beacons for full 12 days of this phase. The final columns show averages per reader and shows 1,697 records per day, and 16,970 by all 10 readers/day, averaging at 346 contacts per ewe beacon per day. There can only be one contact per reader and a maximum of 16 contacts per reader within any 5-minute duty cycle. However, contacts between one beacon and different readers can occur multiple times within the same 5-minute window of time due to overlapping ranges as shown in Figure 1. The area covered by the range of 50 m per reader gives a combined estimated coverage of 4.3 ha, comprising 24.7% of the Paddock area, and visual observations confirmed that sheep spent considerable parts of their daily time budget at, close by and lying in areas around the feed sources, all of which corresponds to the high numbers of contacts per beacon.

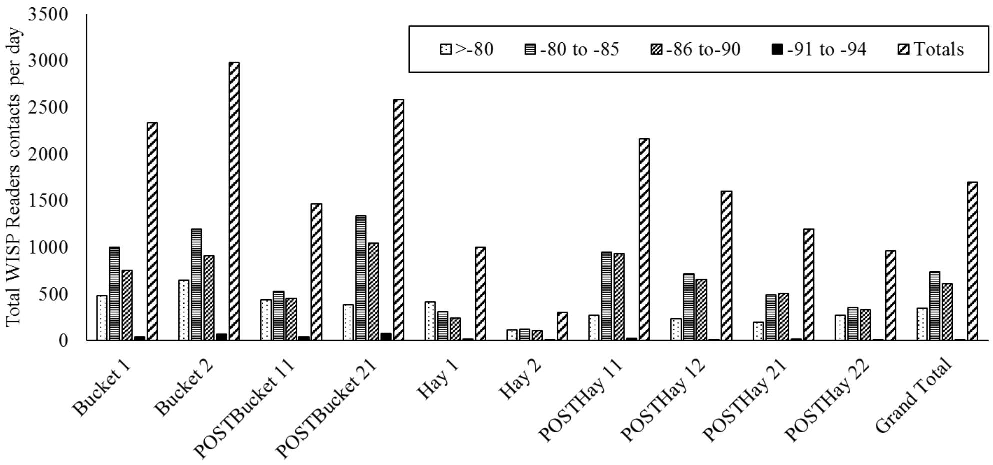

Figure 2: Beacon/ reader contacts for each reader, in RSSI bands and overall (NB strongest signal bar is '>-80'). The final column set of Grand Total shows averages/reader

Given high data volumes, there is scope to analyze patterns of locational behaviour between different classes of stock. Table 1 shows breed means and statistical significance for all main factors from an ANOVA. This uses data from both paddocks but using reader/beacon data for directly analogous readers only (the four equivalent Bucket and Hay readers in Paddock 1 to match the four readers in Paddock 2). Performance differences for the two contrasting breeds are not unexpected with literature support for differences in foraging behaviour between these breeds (McCloskey et al., 2009).

Table 2: Performance and WISP/beacon contacts for each breed across both Paddocks for each of two Bucket or Hay readers in Paddock 2 and the equivalent central Bucket and Hay BLE readers only in Paddock 1.

	Blackface	Lleyn	Significance (ANOVA & Chi^2)
n (excluding incomplete data)	37	50	
Bodyweight at Phase start (kg)	51.5	62.0	Breed **, Age **, Breed x Age **
Bodyweight Loss over phase (kg)	-0.77	-2.40	Breed ***
BCS	2.82	3.07	Breed *
BCS Change	0.11	0.05	NS
Mean ultrasound Foetal No/ewe	1.22	1.54	Breed and *P*<0.01 Chi ^{2},1 vs 2-3
Bucket Contact Count (per ewe/per day/Reader)	44.18	24.84	Breed***, Paddock*** Breed x Paddock*
Hay Contact Count (per ewe/per day/Reader)	13.63	17.54	Breed x Paddock**

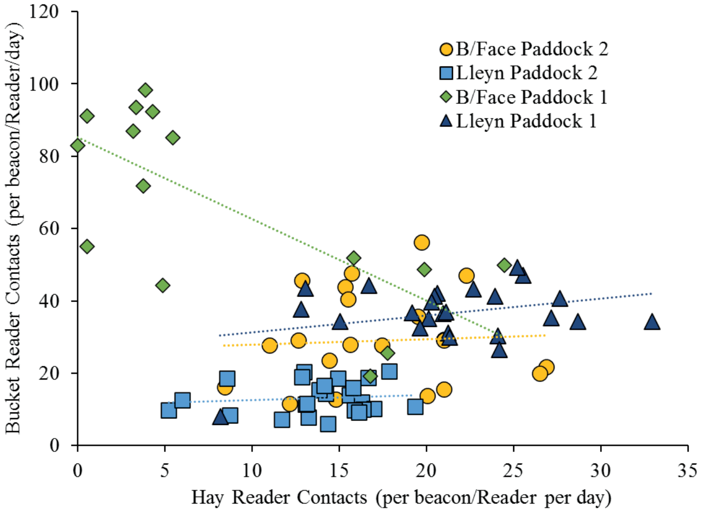

Figure 3: Relationship between Daily Contacts between ewe beacons and Bucket and Hay BLE readers for ewes of each breed in each paddock. Trendlines are illustrative only.

Differences between breeds for use of the two feed resource types is shown in Figure 3. Regression analysis of this data confirms breed, age, paddock and breed x paddock interaction effects for Contact counts for different feed location types. The cluster of Blackface ewes with high Bucket and low Hay contacts were all older ewes above parity 1 and this has strong influences on data distribution patterns. There were no correlative relationships between any of the feed reader/beacon counts and the simple, though short-term, bodyweight or condition parameters. This was also true when this outlier cluster of Blackface ewes were removed, and the central cluster alone was analyzed. This remaining largest cluster of ewes had a significant correlation between Hay and Bucket contacts (R^2=0.492, p<0.001). Presence attribution per day by each sheep required data from multiple BLE readers, with individual readers obtaining data for only some individual sheep on any one day. Despite large numbers of beacon/reader contacts per day, only on the first two days were all 49 beacons logged as 'present'. Some sheep escaped to the next paddock where their presence was logged by resident readers there, but other sheep had very low numbers of contacts and some days of complete absence. A small section of Table 3 based around a 'Red, Amber, Green (RAG)' system illustrates how alerts might function at individual and flock levels, with potential alerts for full absences, and low numbers of daily contacts, for absence, health and welfare issues.

Table 3: Extract from a Red, Amber, Green (RAG) table of counts of total contacts per ewe beacon per day, 'color-coded' for low and zero presence.

Date/ID	4085	4088	4089	4093	4095	4096	4097
19-Feb	474	351	358	402	213	318	205
20-Feb	313	311	342	437	204	164	244
21-Feb	333	396	357	258	218	149	281
22-Feb	348	311	279	395	344	420	191
23-Feb	265	314	243	413	240	121	154
24-Feb	322	213	178	325	367	255	176
27-Feb	284	438	314	371		473	440

'Green' >201	
'Amber'100-200	
'Red' 0-99	

Sheep Study – Twins fed supplementary pellets phase

A similar 'RAG' table produced for this phase also shows sheep with varying patterns of absence and low levels of attendance in the reduced area of feeding. In this case, the readers (with 50m of range) were estimated to cover 17% of the Paddock area.

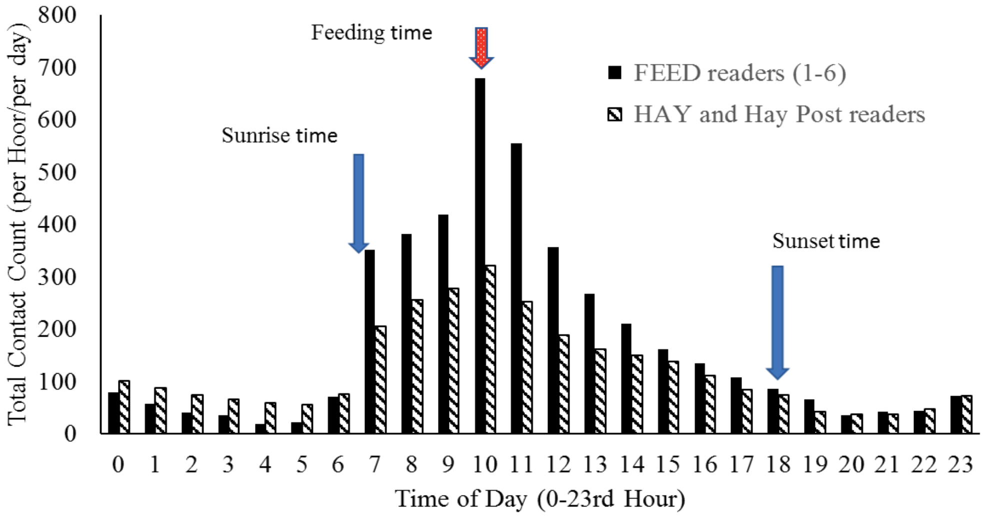

Figure 4: Ewe beacon and reader contacts in one-hour segments for reader at Feeding and Hay feeder BLE readers.

The 24-hour pattern of proximity to the feed areas is shown in Figure 4. Mean sunrise and sunset times for study period are shown, along with mean time of pelletized feeding provision. Records of each of the six Feed readers all showed a clear step up in contacts closely synchronized with time of arrival and feeding by the shepherd and then slow dispersal after 10-30 minutes. The daily patterns shown here and also in the earlier first phase linked to sunrise and sunset are virtually identical to that reported by Nunes et al., (2018) who estimated activity patterns from accelerometer data only with an earlier generation of Blackface ewes in the same paddock over the same winter date range.

Rangeland cattle study

Data in Figure 5 shows the proximal position of cows near the water trough, confirming the typical patterns expected of multiple visits per day by cattle in these systems (Nyamuryekung'e et al., 2021). Both Cow and Day are highly significant ($P<0.001$) factors in ANOVA. Given the large time gap between GNSS locations (30 mins) it was feasible that cattle accessed water without GNSS tracking being logged within 50 m of water trough. However, this data (in either graphical or a RAG system as earlier), shows the potential to highlight to the rancher when there are days of concern (D 8-9), days of return to normality (D 10-12) and concern for individuals (e.g. Cow 86017 at D 13).

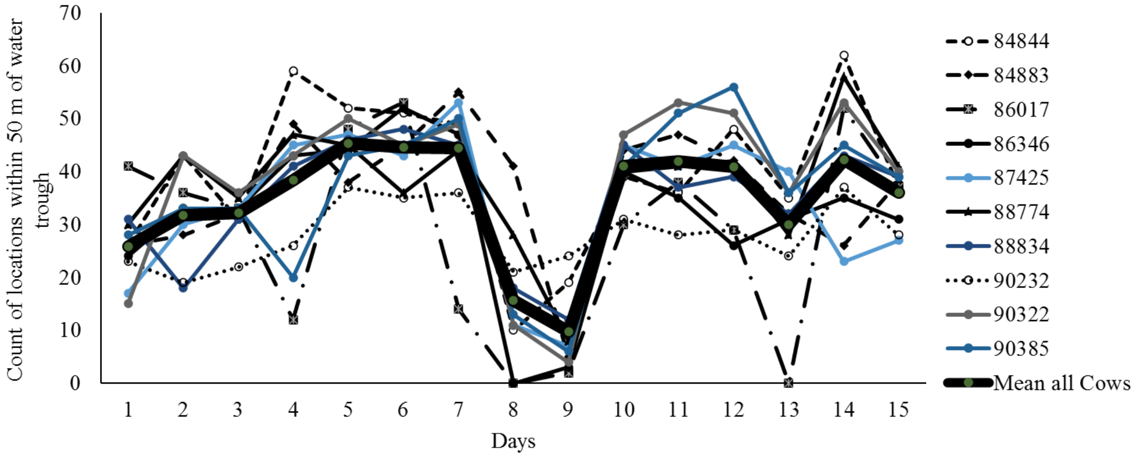

Figure 5: 'Contacts' count (GNSS fixes/cow/day) within 50m of water trough location.

Whilst a full GNSS based system, potentially with on-board accelerometers, could provide the same information and potentially much more, including the important role in finding any 'alert' cow in very large paddocks, a proximity system at a water trough or gateway could provide useful information at lower cost. Proximity systems would likely involve equipment scenarios using ear tags and could involve calves too. Adding in local water level meters could provide a further level of complementary surveillance.

Table 4: The field studies scaled to 100 head and costed and a third option of cattle system with BLE proximity system added. Main assumptions are in footnotes.

System	Wearable costs	Fixed readers	Data transfers	Totals	Cost per head
Scottish Sheep – proximity[1]	100 beacons = $1,000	4 readers[4] = $600	$1,000	$2,600	$26
US Rangeland Cattle – current[2]	100 GNSS collars @ $100	-	$2,000[6]	$14,000	$140
US Cattle – using proximity[3]	200 beacons =$2,000	1-2 readers[5] $300	$1,000	$3,300	$33[7]

[1] 100 ewes, all wearing BLE beacons
[2] 100 cows wearing collars, 100 calves have no sensors as GNSS collars too large/heavy
[3] Both 100 cows and 100 calves have BLE beacons
[4] Multiple readers at multiple locations to cover feeding
[5] Minimum of 2 readers to create some overlap and back-up
[6] To cover full range area perhaps need multiple reception/communication towers
[7] Covers 100 cows and their calves, rather than only the 100 cows in current system

Table 4 shows the two 'study' scenarios scaled up to 100 adult head and with some likely infrastructure needs and some generalised hardware costings (with no costs for network and subscriptions). A proximity system might cost less than a third of that of a full GNSS system, and might be more attractive on cost criteria alone. The fourth, missing, scenario is the Scottish sheep system using GNSS-based collars, with similar costs per head to the cattle system. At around $140 per head, this is more than the value of the sheep, emphasising affordability issues for extensive systems.

Conclusions

Where limited proximity capability can be focused around a key resource such as supplementary feed, water sources or potentially field gateways or passages then useful information on presence/absence can be gained from proximity data. Daily patterns of behaviour were elicited in scenarios where coverage of the grazing area was c 25% or less than the full area providing potential to use partial coverage especially where there are locational attractions to site readers. Affordability is highlighted in the previous section and the need for precision farming solutions for extensive systems that meet with challenges of communication coverage and cost/benefit are vital.

Acknowledgments

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