Development of a GPS Herd Activity and Well-being Kit (GPS HAWK) to Monitor Cattle Behavior and the Effect of Sample Interval on Travel Distance

J. D. Davis, M. J. Darr, H. Xin, J. D. Harmon, J. R. Russell

Abstract. *As an alternative to commercial GPS tracking collars, a low-cost GPS Herd Activity and Well-being Kit (GPS HAWK) was developed to monitor locomotion behavior of cattle at a high sampling frequency (20 s). The operational goal of the GPS HAWK was to collect GPS location data at a user-specified frequency and store the data in a secure format (compact flash media) for retrieval and optimize power consumption to extend the sampling period. The GPS HAWK uses a Garmin 12-channel low-power GPS receiver powered by a sealed-lead acid battery housed in an aluminum enclosure on a shoulder-mounted harness. Data gathered by the GPS HAWKs were used to determine individual daily travel distance (DTD) and the effect of sample interval (SI) on this measurement. Differences (P < 0.0001) were shown in DTD across four days using animals with available data. The Angus cows (*Bos Tarus *L.) averaged 4.05 ± 0.14 km/d (2.52 ± 0.09 mi/d) during the four days. Sample interval (SI) had an effect on DTD. Differences in DTD were detected for all SIs (P < 0.0001) except between the 60- and 120-s intervals. By changing the SI from 20 s to 20 min, the mean DTD decreased by 1.68 km or 44%. Significant errors in estimates of cattle energetics from GPS monitoring can be introduced by increasing sampling interval. Therefore, researchers must account for increasing error in DTD due to undersampling as SI is increased to save battery power and to increase the interval between animal handling periods. Holding the GPS system in place consistently with a shoulder mounted harness proved to be somewhat challenging.*

Keywords. *Livestock tracking, GPS, Animal behavior.*

Global positioning systems (GPS) have been used together with geographical information systems (GIS) to monitor both wildlife and domestic animal movement and behavioral activities (Moen et al., 1996; Rutter et al., 1997; Udal, 1998; Turner et al., 2000; Schlecht et al., 2004; Agouridis et al., 2005; Ungar et al., 2005). Within livestock production applications, GPS loggers have been utilized to monitor grazing, lying, or standing behavior of domestic sheep (Rutter et al., 1997); to track beef cattle in intensively managed grazing systems (Udal, 1998; Turner et al., 2000); and to study the effectiveness of using travel distance to distinguish among grazing, traveling, and resting activities of beef cattle (Ungar et al., 2005). Agouridis et al. (2005) monitored beef cattle locomotion under several grazing systems to determine the treatment effects on streambank erosion in the humid region of the United States.

Moen et al. (1996) stated that the concern of the investigator regarding GPS data collection was whether to take fewer locations with high precision or more locations with low precision. The limiting factor in determining the length of sampling interval and quality of readings in a portable GPS tracking unit is power management. Higher sampling frequency and higher accuracy (differentially corrected – DGPS) readings require longer satellite monitoring and calculation intervals, resulting in greater power consumption. Thus power requirement determines the minimum physical enclosure size and the length of time a researcher can monitor an animal before the GPS logger has to be removed and batteries changed or charged.

Some researchers have used the smallest sampling interval available in commercial units (5 min) in previous studies (Udal, 1998; Turner et al., 2000; Agouridis et al., 2005; Ungar et al. 2005). However, even the smallest 5-min interval may not be sufficient to capture the dynamic behavior of beef cattle, under certain circumstances such as limited-area rotational grazing systems.

Monitoring multiple animals over multiple plots becomes very cost prohibitive. Several manufacturers market GPS collar-mounted loggers (Advanced Telemetry Systems, Lotek, and Telemetry Solutions, for example) for tracking animal movement patterns. GPS collars that are large enough for beef cattle cost approximately $3000/unit plus the cost of software and any peripherals.

The objectives of this study were: 1) to develop a low-cost GPS Herd Activity and Well-being Kit (GPS HAWK)

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capable of collecting high frequency GPS data; 2) to demonstrate use of the GPS HAWK by monitoring daily travel distance (DTD) of multiple cows on pasture; 3) to determine the effect of sampling interval (SI) on DTD.

Materials and Methods

GPS HAWK Design

In response to the relatively high costs and limited capabilities of commercial GPS collars, this study was initiated to develop an alternative data aquition platform to minimize cost and improve sampling capabilities. The operational goal for the GPS HAWK was to collect animal location and optional sensor data at a user-selectable sampling frequency (higher frequency than commercially available), store the data in a secure format, and optimize power consumption to extend logging period.

GPS Receiver

The quality of location data gathered is dependent upon the GPS receiver utilized. When choosing the GPS receiver, several characteristics including accuracy, weight, power use, complexity, methods of differential correction, and cost were considered. Stombaugh et al. (2005) provide an extensive summary of the GPS system, sources of error, and methods of correction for different classifications of receivers.

Many of the GPS receivers (Trimble, Starfire, etc.) currently used in precision row-crop agriculture, while highly accurate (sub inch accuracy for row-crop applications using RTK), were eliminated due to their bulky size, excessive weight, and high power consumption. Furthermore, most of these systems are quite expensive ($10,000 to $50,000), making it cost prohibitive to monitor multiple animals simultaneously. To reduce the time of post-processing, the GPS HAWK design used a self-contained GPS receiver with an embedded antenna. The relatively inexpensive, weatherproof 12-channel receiver selected for this application (GPS 18 LVC, Garmin International, Inc., Olathe, Kans.) is disk-shaped and measures 61.0 mm diameter × 19.5 mm height (2.4 × 0.8 in., respectively), and weighs only 115.6 grams (0.25 lb, fig. 1). The low-power receiver had a published Wide Area Augmentation System (WAAS) accuracy of less than 3 m (9.8 ft) and acquisition times of 15 s (Garmin International, Inc., 2004).

Figure 1. An Angus cow fitted with a GPS HAWK. The black dome centered above the grey enclosure is the GPS receiver.

The GPS 18LVC used NMEA (National Marine Electronics Association) 0183 v. 2.0 (2002) protocol to transmit data over serial communication. The receiver could be programmed to transmit only the needed NMEA sentences. The following parameters were collected and stored as space delimited text file with the following information: latitude, longitude, number of satellites in view, and differential correction status. The World Geodetic System 1984 earth datum was used to calculate location. In addition, the receiver output the date and time in Coordinated Universal Time (UTC). The receiver was tested to determine the minimum time required to initialize and acquire a differentially-corrected signal. Data sampled at intervals greater than this minimum time would allow the GPS receiver to be powered down between samples, thus ensuring more efficient power management and increasing duration between battery adjustments.

Data Collection and Storage

Compact flash cards (CF) were chosen as the data storage media. CFs have a secure storage format and are fast and easy to swap when changing batteries. Initially, upon acquisition of a GPS fix, the information was transferred directly to a space delimited text file on a CF (32MB, Sandisk, Milpitas, Calif.) using a compact flash writer (FlashCore-B with real-time clock and battery, Tern, Inc., Davis, Calif.). Testing of this method was successful, but power consumption became problematic as the CF storage technique required 750 mW of power, nearly twice the power needed for the GPS receiver (390 mW). A secondary solution was implemented in which the sampling information was stored to an electrically erasable programmable read-only memory (EEPROM) serial device and downloaded to the same CF device when the EEPROM was full (intervals determined by storage size and sampling frequency).

Microprocessor

A microcontroller-based system (PIC18LF258, Microchip, Chandler, Ariz.) was chosen to serve as the main computing unit for the GPS HAWK. The selection was based on power management and input and output (I/O) capabilities of the microcontroller. The microcontroller was equipped with six analog to digital (A/D) conversion channels (0-5V single-ended, 10-bit resolution) as well as 16 general purpose I/O pins that could be configured for digital operations or serial communication. The unused I/O lines provided future expandability as they could interface with various other digital sensors or peripheral devices. A printed circuit board was designed to house the PIC microcontroller and all necessary peripheral components. The circuit board also allowed for external connection to the GPS receiver, power supply and test ports.

The microcontroller code was compiled using the PIC Basic Pro compiler and transferred to the microcontroller via an EPIC flash programmer both from Micro Engineering Labs, Inc. (Colorado Springs, Colo.). The program code was developed to enable the microcontroller to record GPS information as well as data from analog sensors at predetermined intervals (fig. 2). On connection of a power source, the microcontroller initialized the GPS receiver to acquire satellite almanac information and calculated a differentially-corrected GPS signal. The microcontroller synchronized the sampling interval to the UTC obtained from the satellites. Upon capturing a DGPS reading, the value was stored to an EEPROM device. The microcontroller powered down the GPS receiver for the difference in time between the sample interval and the minimum time needed to initialize the GPS receiver with a differential correction. Subsequently, the microcontroller initialized the GPS receiver the determined minimum time before the next reading. The sample interval was again synchronized with the satellite UTC and data stored to the EEPROM. After a predetermined number of readings based on sample interval and EEPROM storage size, the microcontroller would download the data from the EEPROM to the CF. Finally, the microcontroller powered down the GPS receiver and repeated the sampling algorithm (fig. 2). A schematic representation of wiring circuitry for the GPS HAWK is presented in figure 3.

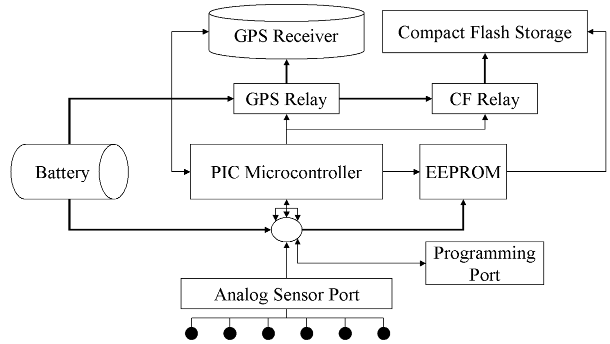

Figure 3. GPS HAWK hardware schematic.

Power Management

Many battery types (alkaline, lithium ion, sealed lead acid, etc.), shapes, and power ratings were examined. Sealed lead-acid (SLA) batteries had the highest power density of sealed rechargeable batteries. The battery chosen to power the GPS HAWK was an SLA0926 Interstate Battery (6V, 7.2Ah). The battery had dimensions of 151 × 34 × 98 mm (5.9 × 1.3 × 3.9 in.) and weighed 0.82 kg (1.8 lb).

In an attempt to decrease the size and weight of the battery, a 7-day trial was conducted to determine the power output of thin film solar panels (PowerFilm WeatherPro P7.2-75, PowerFilm, Inc., Boone, Iowa). The thin film solar panel had a dimension of 270 × 100 mm (10.6 × 3.9 in.) and operating current and voltage of 100 mA and 7.2V, respectively. Three solar panels were mounted 1 m above the ground with no obstructions to the sky and voltage monitored across a 10-Ω resistor with a 4-channel datalogger (Hobo H8, Onset Computer Corp., Bourne, Mass.) at 1-min intervals. Solar radiation (W/m^2) was measured with a silicon pyranometer (S-LIB-M003, Onset Computer Corp., Bourne, Mass.) mounted on a weatherstation (H21-001, Onset Computer Corp., Bourne, Mass.) at 1-min intervals as well.

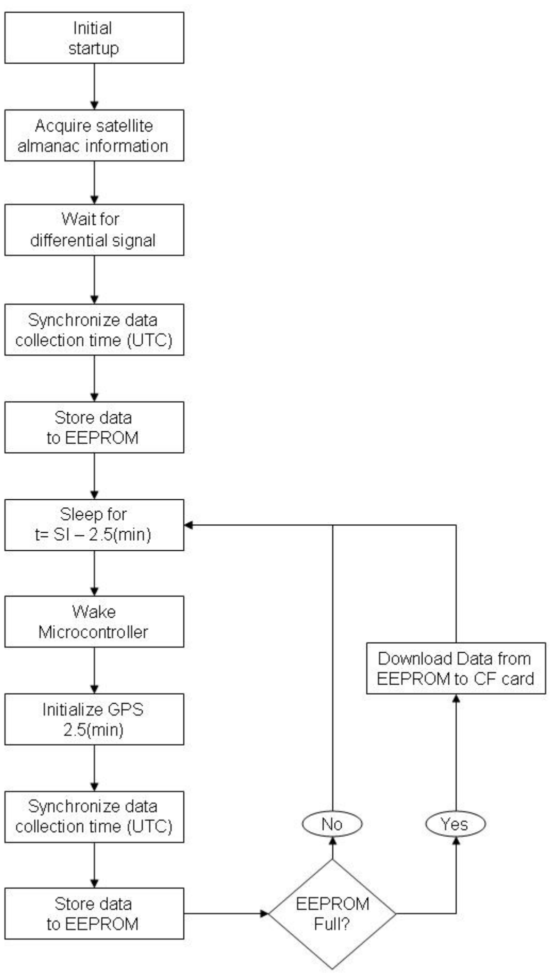

Figure 2. Flowchart of the GPS HAWK operation.

Housing and Harness

Several methods of securing the unit on the animal were considered: halter, collar, and shoulder mounted. The GPS HAWK was arranged into a shoulder-mounted harness largely due to the battery weight. The battery and circuitry were housed in a 16- × 16- × 7-cm (6.3- × 6.3- × 2.8-in.) weather-proof aluminum enclosure (HMD604-ND, Digikey Corp., Thief River Falls, Minn.). The enclosure was fastened to a 0.64- × 12.7- × 43.2-cm (0.25- × 5.0- × 17.0-in.) leather blank. Two 0.64- × 3.8-cm (0.25- × 1.5-in.) slots were cut at both ends to securely attach straps. A custom foam pad was constructed of two 6-mm (0.24-in.) layers of black neoprene glued on top and bottom of a 1.27-cm (0.5-in.) polyethylene foam blank. An adjustable 5.1- × 143.3-cm (2.0- × 56.4-in.) nylon webbing strap attached to an 11- × 91-cm (4.3- × 35.8-in.) felt cinch encircled the animal's girth while 3.8-cm (1.5-in.) elastic webbing was placed down both sides of the neck and attached to the cinch strap between the legs to provide stability to the GPS HAWK. The unit was positioned on the back of the animal just behind the shoulders (fig. 1). Each shoulder-webbing was attached between the front leg and the brisket using two D-rings. The GPS HAWK weighed 3.37 kg (7.4 lb) including all straps and padding.

Experimental Pasture and Animals

A 2.02-ha (5-acre) Bromegrass pasture was located along Willow Creek at the Iowa State University Rhodes Research Farm (lat. 42° 00' N, long. 93° 25' W). The pasture ran North and South with approximately 133 m (436 ft) of stream access. Drinking water was provided to the animals through open access to Willow Creek and supplemental water tanks. Environmental parameters were recorded with an onsite weatherstation (H21-001, Onset Computer Corp., Bourne, Mass.). Black-globe humidity index (BGHI) was calculated using the equation developed by Buffington et al. (1981) and included to demonstrate variations in environmental conditions.

Fifteen fall-calving Angus cows [*Bos taurus* L.; initial body weight 577 ± 53 kg (1272 ± 117 lb)] were fitted with a GPS HAWK unit. The GPS HAWKs were set to intensively monitor each animal's location at 20-s intervals for two 4-day periods during June and July of 2006. The animals were returned to the pasture and allowed to acclimate on day 1.

Concurrent visual observations of the animals were conducted at 1-min intervals for 11 consecutive (daytime) hours on days 2 and 3 of each period. The observer followed the herd of animals maintaining a distance of no less than 20 m to minimize effects of observers. Large identification numbers (01 through 15) painted on each GPS HAWK unit were used to track each cow. The cattle were monitored for grazing, resting (standing and lying), and traveling behaviors. A complete analysis of the activities will be presented in a separate article. GPS HAWKs were removed to retrieve data cards and replace batteries on day 4.

Data Analysis

The GPS data were viewed and processed using a GIS software package (ArcMap, ESRI, Redlands, Calif.). The location data were converted from latitude and longitude coordinates (WGS 1984) to the Universal Transverse Mercator (UTM) coordinate system (NAD 1983 UTM zone 15N). Aerial photos with 1-m resolution were downloaded from the USDA National Agriculture Imagery Program through the Iowa State University Geographic Information Systems Support Facility. The animal-location data, fencing, and other attributes were overlaid upon the aerial photos for further analysis.

The DTD from 0:00h to 23:59h on 25 June, 26 June, 24 July, and 25 July were calculated using the Euclidean distance between consecutive GPS locations. Data collected at 20-s intervals for each cow were parsed to create six separate datasets at sampling intervals of 20, 60, 120, 300, 600, and 1200 s. These datasets were formed to evaluate the effects of SI on the DTD. Data were analyzed with an ANOVA and means were separated using Fisher's LSD. Analyses were performed with PROC MIXED (SAS Institute, 2004) to determine differences in 1) mean DTD among cows, and 2) mean DTD for sample interval. Statistical significance was established at $P \leq 0.05$.

Results and Discussion

GPS HAWK Design and Refinement

The programmable GPS HAWK was designed and constructed to mount behind the shoulders of a beef animal and monitor location and locomotion at intervals as short as 20 s for less than $500 in materials and approximately 6 h in labor each. Major components of the GPS HAWK included a harness system enclosing a 12-channel, WAAS corrected GPS receiver, CF memory storage and writer, battery, and microcontroller connected on a circuit board.

The GPS receiver was tested to determine the minimum time required to initialize and acquire a differentially-corrected GPS signal. An initial study using 1.0-, 2.0-, 2.5-, or 3.0-min warm up intervals determined that 2.5 min was the shortest warm up interval to achieve a differentially-corrected signal before taking a measurement. Once initialized, a 20-s interval was used rather than the 15-s minimum by Garmin International to allow for any time discrepancies in the microcontroller and circuit and to maintain an even sample rate of 3 readings per minute. No structural or electronic issues were experienced during this study with the 18LVC GPS receiver or the PIC18LF258 microcontroller.

As with all portable GPS systems, power consumption was the limiting factor when determining sampling frequency and length of operation. Based on the power consumption by the microcontroller (40 mW) and GPS receiver (390 mW) and sampling frequency, the required battery size was calculated (table 1). Any sample interval shorter than 2.5-min would require the receiver to continuously operate at 9.4 Wh/d. The battery would last approximately 4.5-d sampling at 20-s intervals. As the sample interval is increased, the amount of time the receiver is operational decreases thus decreasing the energy requirement. A 6-h or longer sample interval would stabilize the power consumption at a minimum of 1 Wh/d.

In an effort to extend the capacity of the battery, thin film solar panels were mounted stationary 1 m above the ground and tested in a 7-d trial to determine power output. The total solar radiation (W/m^2) and average total energy output (mW*h) for the solar panels are shown for each day in table 2. The largest power output (1010 mW*h) occurred on 11 February under clear skies. On 13 and 15 February, cloudy skies resulted in nearly zero power output. Under clear skies, the thin film panels have the potential to fully recharge the GPS HAWK taking samples equal to or greater than 6 h. However, our goal was to monitor the animals at higher frequencies and the thin film panels could only recharge the batteries by 10% under clear skies. Though these daily power outputs may increase due to longer days in summer, this 7-d trial showed the potential variability in the power output. This trial did not consider the reduced output due to animals standing in the shade or the thin film solar panel getting soiled due to dust. The panels were not included in the final design due to these limitations and the extra area needed for attachment.

Table 1. Calculated power consumption for a given sample interval.

Sample Interval (Min)	Receiver Operation Time (%)	Power Consumption (Wh/d)
≤ 2.5	100	9.4
5	50	5.2
10	25	3.1
30	8.3	1.7
60	4.2	1.3
360	0.7	1
720	0.3	1
1440	0.2	1

Table 2. PowerFilm solar panel power output for 7-d period.

Day	Daily Solar Radiation (W/m^2)	Daily Panel Output (mWh)	SEM (mWh)
11 Feb	3674	1010	40
12 Feb	2312	280	10
13 Feb	305	2	0.1
14 Feb	3241	670	30
15 Feb	954	11	0.4
16 Feb	3809	760	30
17 Feb	3592	610	20

Due to the weight of the sealed lead-acid batteries, the GPS enclosure was limited to a shoulder mounted system. An initial design used an ABS plastic enclosure to house the unit. After the first day of testing, several of the logger enclosures were found underneath a low tree where the cows sheared the enclosures from the harnesses. Initially the padding design was covered with a synthetic vinyl but the animals sweated making the vinyl slick. The pad design was changed to a neoprene covered pad with fabric facing. Though sweating was still present on hotter days, it was observed to be less than the vinyl.

The most difficult design parameter in the shoulder-mounted units was keeping the top heavy units centered on the back. During the initial day of placement the GPS units would remain centered behind the animal's shoulders. Once the animals laid down for the night, many of the units would shift to one side of the body as the animals stood up. Plastic blocks at 2.54-cm (1-in.) diameter were bolted on each corner of the enclosure above the padding to create a cavity for the ridge of the animal's back (fig. 1). Placing lead shot in the lower girth strap to offset the enclosure weight was tried but the belt tension and hair resistance would not allow the weight to slide the enclosure back to center. The best solution to keep the unit in place was to move the D-ring attachments of the shoulder-webbing between the front leg and the brisket 12.7 cm (5 in.) off center of the cinch strap. Two animals with more narrow shoulders than the rest of the herd learned to push their body backward while laying their head forward allowing the weight of the unit and tension of the should straps to pull the unit off over their heads and step out of the girth belt.

Table 3 compares the GPS HAWK to five commercially available GPS collars large enough to fit cattle. The Televilt GPS-Budget collar was the least expensive of the five commercial units but the data could not be differentially corrected to decrease location errors**.** Uncorrected GPS data have errors in the range of 15 m (49 ft) or 11% of the stream width of the study area. The four remaining collars can be differentially corrected to accuracies in the range of 3 m (3 ft) or less but cost at least six times that of the GPS HAWK. The high-frequency sampling for this study required a larger battery for the GPS HAWK making the unit heavier than the commercial collars. Since the completion of this study, many of the commercial GPS collars have reduced their minimum sampling interval down to one minute though costs have maintained or increased. In addition to this study, Clark et al. (2006) developed a collar mounted low-cost ($840 plus 2-h labor) GPS animal tracking system with similar capabilities to the GPS HAWK.

For the 15 cows used in this study, seven animals were available for further analysis with a maximum of six animals on 24 July (table 4). Only three cows had complete data for the four days in the measurement period. The other animals either detached their GPS HAWK unit or data were lost or partially lost to equipment failure and thus removed from the analysis. The 24-h diurnal locomotion paths (20-s sampling intervals) of three cows (2375, 8374, and 2280) on 26 June are illustrated in figure 4. The animals began the day lying at the south end of the pasture, transitioned to grazing, then traveled to the north end of pasture before returning south. Visually, the density of the sampling points illustrates the differences in resting (stacked points), grazing (close points of varying direction), and traveling (spaced points along linear path) at the high sampling frequency. Upon closer inspection of the three locomotion paths in figure 5, the cows started the morning lying just south-east of the water tank (illustrated with three large circles). The animals began grazing south of the maintenance road (light shaded line running East from the water tank) before grazing north, eventually traveling to the stream. The 20-s sampling interval allowed for recording of the meandering paths as the animals grazed over a relatively small area. These meandering grazing paths would not have been as apparent with larger (e.g., 10-min) sampling intervals given the small study area.

Table 4. Mean daily travel distance (DTD) for animals with full 24-h data sets.

Cow No.	25 June (km/d)[a]	26 June (km/d)	24 July (km/d)	25 July (km/d)
63	–	–	3.69	4.00
118	–	–	3.23	–
1136	4.18	4.24	–	–
1330	–	–	3.23	–
2280	5.15	4.39	3.42	4.22
2375	5.34	4.40	3.68	3.93
8374	4.16	4.36	3.43	3.83
Mean[b]	4.71^{a}	4.35^{ab}	3.45^{c}	4.00^{b}
SEM	0.31	0.04	0.08	0.08

[a] a,b,c Denotes significant difference ($P < 0.0001$).
[b] Means were separated with pooled standard error (SEM = 0.16).

Table 3. Comparison of GPS HAWK with commercially available GPS systems.

Company/Institution	Product Name	Weight (g)	Differential Correction	Unit Price (US$)	Software
Iowa State University *(USA)*	GPS HAWK	3371	WAAS	$500	None
Advanced Telemetry Systems *(USA)*	ATS GPS	1250	Post-Process	$3,000	Included
BlueSky Telemetry *(Scotland)*	AgTraX-L6	470	Post-Process	$3,000	Included
Lotek Wireless, Inc. *(Canada)*	GPS 3300	870	Post-Process	$3,600	$2,500
Telonics *(USA)*	TGW-3570	850	Post-Process	$3,000	$350
Televilt *(Sweden)*	GPS-Budget	650	GPS	$1,100	$60

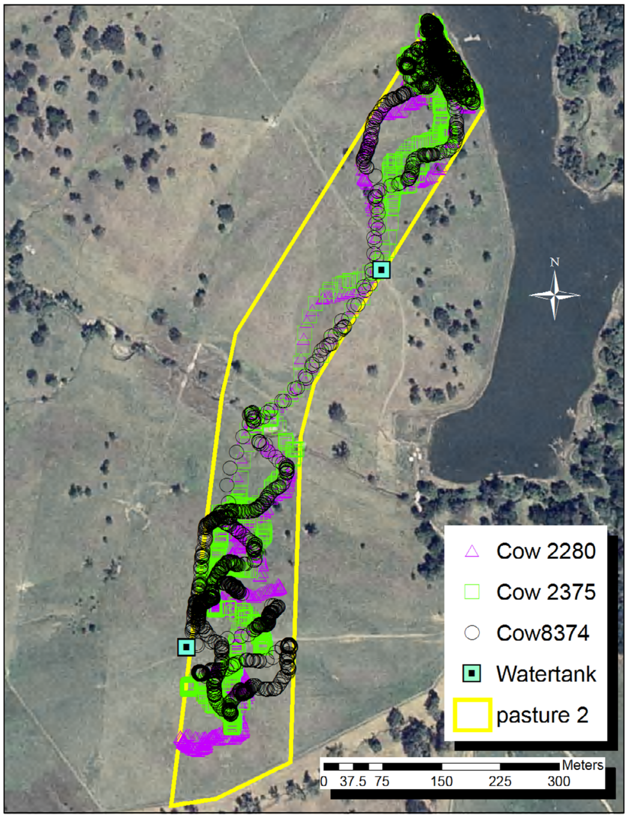

Figure 4. Location profiles of three cows over a 24-h period on 26 June as measured with the GPS HAWK.

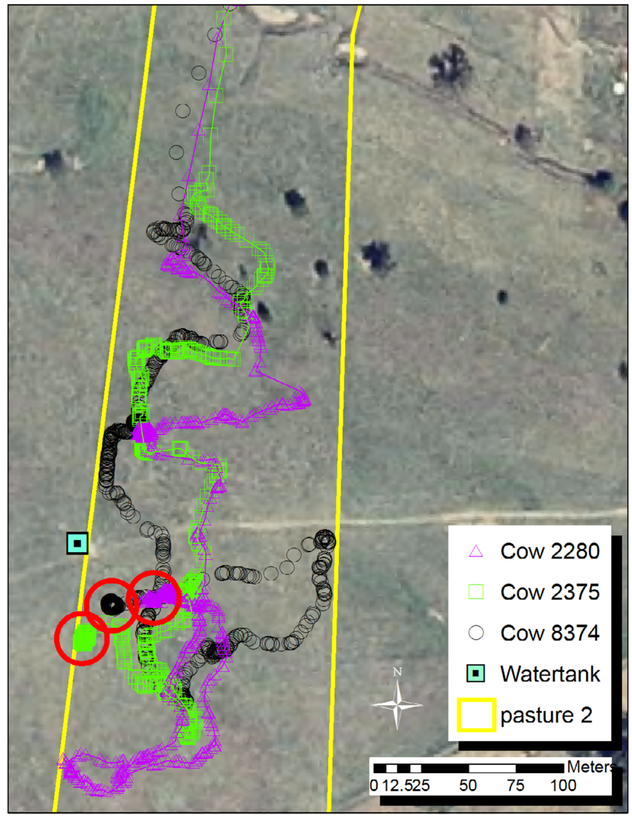

Figure 5. Location profiles during the morning of 26 June. The large circles indicate where the three cows were lying at the beginning of the day.

If the goal is to determine animal behaviors (grazing, resting, traveling) without visual observations or secondary equipment, the need for high-frequency GPS sampling to distinguish activity rather than general location is apparent in figure 5. Because of the meandering paths during grazing, a large interval (e.g., 10 min) could alias locomotion data within that interval if the animal returns near the previous sample location. Recently, Guo et al. (2009) monitored six cows at 10-s intervals for four days in a 7-ha (17-acre) pasture. The high frequency GPS data were coupled with other sensors to determine linear and angular motion. These data were used to determine resting, grazing, and traveling behavior. Other researchers (Schwager et al., 2007) are using high frequency sampling to determine adaptive sampling to conserve power for periods of no activity.

Many grazing studies using GPS technologies attempt to give estimates of time spent at certain activities (i.e. resting, grazing or traveling) or distance from specified aspects within defined areas over a period. However, one gets little sense of the distances covered during the period of a day. Figure 6 depicts the DTD for six cows on 24 July. Periods of rest display slopes in DTD approaching zero, while periods of travel covering larger distances display increased slopes over a short time period. Periods of grazing have variations in slope of DTD due to the transitions in active grazing, chewing, and changing directions.

The DTD of seven available cows averaged 4.05 ± 0.14 km/d (2.52 ± 0.09 mi/d) with a minimum of 3.23 km (2.01 mi, cows 118 and 1330) on 24 July to a maximum of 5.15 km (3.20 mi, cow 2280) on 25 June. Differences ($P <$ 0.0001) in mean DTD were shown across the four days (table 4).

Effect of Sample Interval

Using the previous DTD data (table 4), six subsets were created by parsing the 20-s data at sample intervals (SI) of 60, 120, 300, 600, or 1200 s. Figure 7 illustrates differences in the DTD profile due to SI for cow 8374 on 25 June. As the SI increased, the DTD decreased. In viewing the visually observed activity (0 = resting, 1 = grazing, and 2 = traveling; fig. 7), cumulative distance in periods of traveling and grazing were most affected by SI. The mean DTD for each SI is presented in table 5. Sample interval had an effect on DTD. Differences in DTD were detected for all SIs ($P < 0.0001$) except between the 60- and 120-s intervals. The mean DTD for each SI and percent difference of each SI to the reference SI (20 s) were illustrated in figure 8. Changing the SI from 20 s to 20 min led to a reduction of DTD by 1.68 km (1.04 mi) or 44%. Significant errors in estimates of cattle energetics from GPS monitoring can be introduced by increasing sampling interval. Therefore, researchers must account for increasing error in DTD due to undersampling as SI is increased to save battery power and to increase the interval between animal handling periods.

Summary and Conclusions

A low-cost data acquisition platform was developed to monitor locomotion behavior of cattle at high frequency

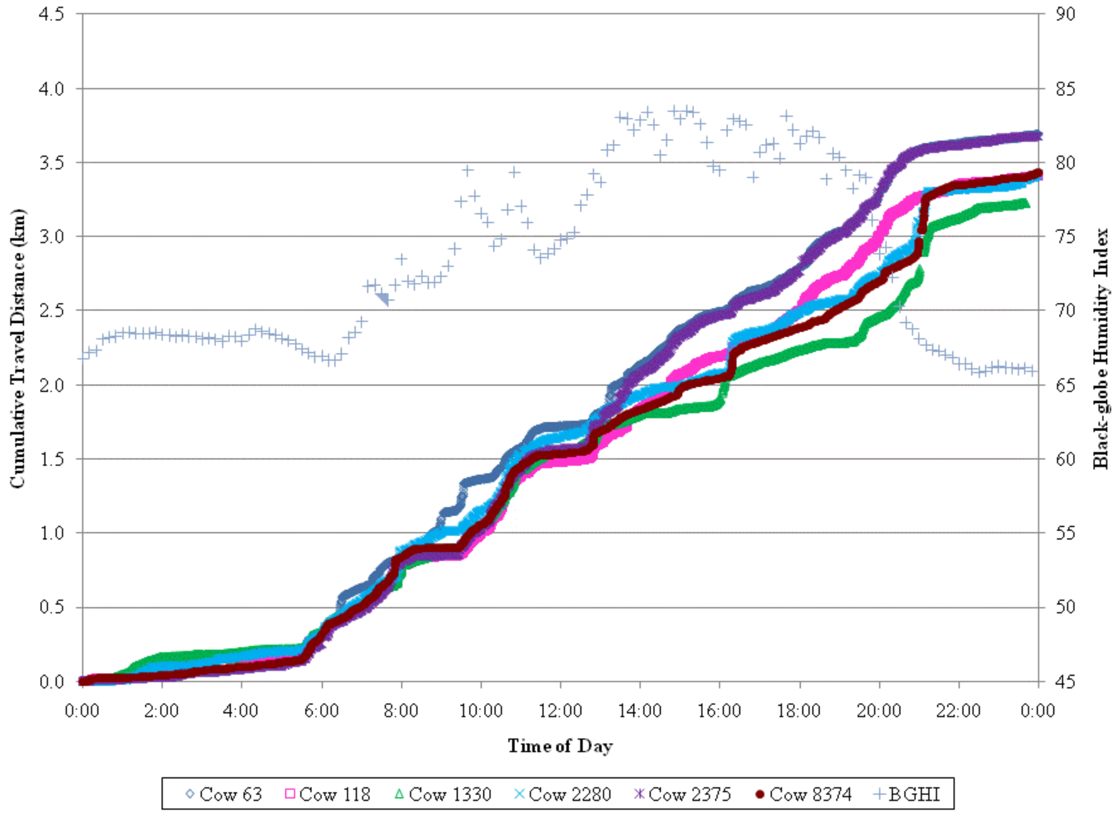

Figure 6. Daily travel distance (DTD) for six cows on 24 July. Black-globe humidity index (BGHI) is included on the secondary axis to illustrate environmental conditions.

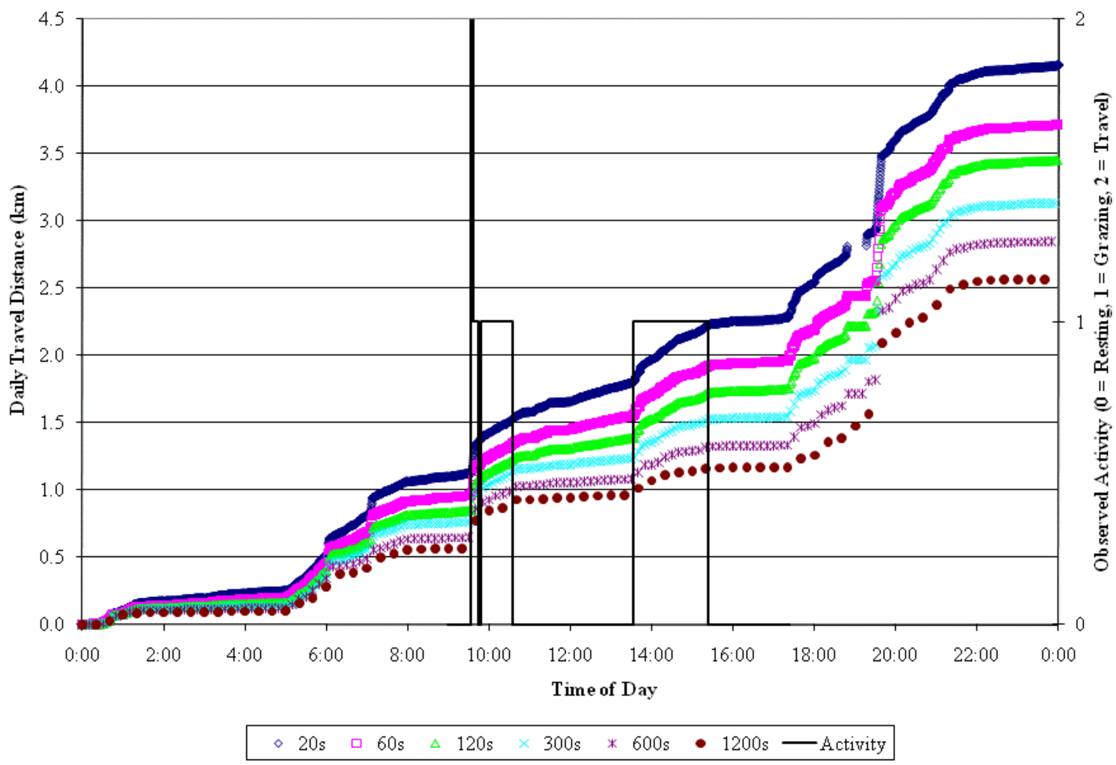

Figure 7. Daily travel distance (DTD) for cow 8374 on 25 June as affected by sample interval. Grazing activity is shown on the secondary axis.

(20-s sample interval). GPS data collected with the GPS HAWKs were used to determine individual cow DTD. The cows averaged 4.05 ± 0.14 km/d (2.52 ± 0.09 mi/d) during the four days. Differences ($P < 0.0001$) were shown in DTD

Table 5. Mean daily travel distance (DTD) for each sample interval (SI).

Sample Interval (s)	Mean DTD (km)[a]	SEM (km)	Mean DTD (mi)	SEM (mi)[b]
20	3.91[a]	0.14	2.43	0.09
60	3.45[b]	0.12	2.14	0.07
120	3.20[b]	0.11	1.99	0.07
300	2.86[c]	0.11	1.78	0.07
600	2.53[d]	0.09	1.57	0.06
1200	2.18[e]	0.10	1.35	0.06

[a] a,b,c Denotes significant difference ($P < 0.0001$).
[b] Means were separated with pooled standard error (SEM = 0.10).

across four days using animals with full data over the 24-h monitoring periods. Differences in DTD were detected for all SIs ($P < 0.0001$) except between the 60- and 120-s intervals. By changing the SI from 20 s to 20 min, the mean DTD decreased by 1.68 km (1.04 mi) or 44%. Significant errors in estimates of cattle energetics from GPS monitoring can be introduced by increasing sampling interval. Therefore, researchers must account for increasing error in DTD due to undersampling as SI is increased to save battery power and to increase the interval between animal handling periods. Holding the GPS system in place consistently with a shoulder mounted harness proved to be somewhat challenging

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References

Agouridis, C. T., D. R. Edwards, S. R. Workman, J. R. Bicudo, B. K. Koostra, E. S. Vanzant, and J. L. Taraba. 2005. Streambank erosion associated with grazing practices in the humid region. *Trans. ASABE* 48(1): 181-190.

Buffington, D. E., A. Collazo-Arocho, G. H. Canton, and D. Pitt. 1981. Black globe humidity index (BGHI) as comfort equation for dairy cows. *Trans. ASAE* 24(3): 711-714.

Clark, P. E., D. E. Johnson, M. A. Kniep, P. Jermann, B. Huttash, A. Wood, M. Johnson, C. McGillivan, and K. Titus. 2006. An advanced, low-cost, GPS-based animal tracking system. *Range. Ecol. Manage.* 59(3): 334-340.

Garmin International, Inc. 2004. GPS 18 Technical Specifications. Olathe, Kans.: Garmin International, Inc. Available at: www.garmin.com/manuals/GPS18_TechnicalSpecification.pdf. Accessed 15 November 2004.

Guo, Y., G. Poulton, P. Corke, G. J. Bishop-Hurley, T. Wark, and D. L. Swain. 2009. Using accelerometer, high sample rate GPS and magnetometer data to develop a cattle movement and behaviour model. *Ecological Modelling* 220: 2068-2075.

Moen, R., J. Pastor, Y. Cohen, and C. C. Schwartz. 1996. Effects of moose movement and habitat use on GPS collar performance. J. *Wildl. Manage.* 60(3): 659-668.

Rutter, S. M., N. A. Beresford, and G. Roberts. 1997. Use of GPS to identify the grazing areas of hill sheep. *Computers and Electronics in Agric.* 17: 177-188.

SAS Institute. 2004. SAS User's Guide: Statistics. Version 9.1. Cary, N.C.: SAS Institute Inc.

Schlecht, E., C. Hulsebusch, F. Mahler, and K. Becker. 2004. The use of differentially corrected global positioning system to monitor activities of cattle at pasture. *J. Applied Animal Behaviour Sci.* 85: 185-202.

Schwager, M., D. M. Anderson, Z. Butler, and D. Rus. 2007. Robust classification of animal tracking data. *Comput. and Electron. in Agric.* 56: 46-59.

Stombaugh, T., D. McLaren, and B. Koostra. 2005. The Global Positioning System. AEN-88. Lexington, Ky.: Cooperative Extension Service, University of Kentucky.

Turner, L. W., M. C. Udal, B. T. Larson, and S. A. Shearer. 2000. Monitoring cattle behavior and pasture use with GPS and GIS. *Can. J. Anim. Sci.* 80(3): 405-413.

Udal, M. C. 1998. GPS tracking of cattle on pasture. M.S. thesis. Lexington, Ky.: University of Kentucky.

Ungar, E. D., Z. Henkin, M. Gutman, A. Dolev, A. Genizi, and D. Ganskopp. 2005. Inference of animal activity from GPS collar data on free-ranging cattle. *J. Rangeland Ecol. Manage.* 58(3): 256-266.

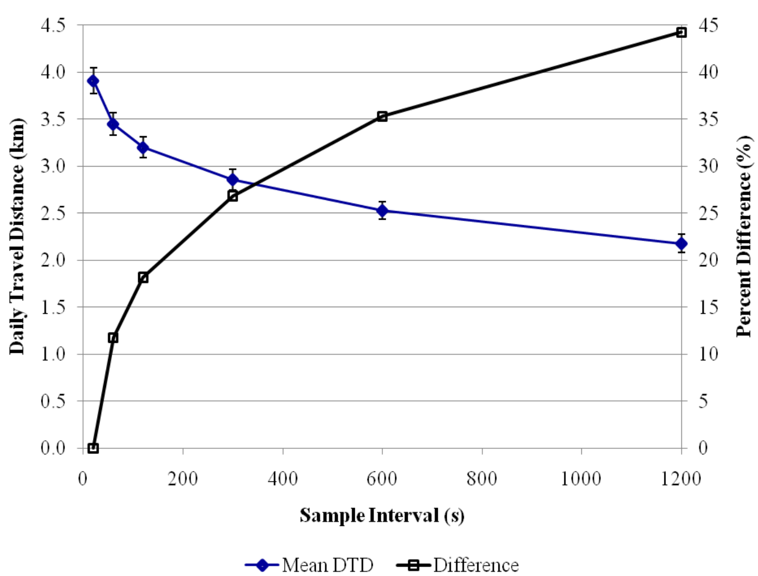

Figure 8. Mean daily travel distance with standard errors of cows on pasture as affected by sample interval (SI) of GPS location recording. Difference in 20 s and subsequent DTD measurements is shown on the secondary axis.