Evaluation of different global navigation satellite tracking systems and analyses of movement patterns of cattle on alpine pastures

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Abstract: Global Positioning Systems (GPS) as one of the Global Navigation Satellite Systems (GNSS) have been applied in many studies especially focusing on wildlife but there are very few studies using GPS on domesticated animals under extensive conditions combined with extreme relief such as in the Alps. Therefore, the main aim of this study was to test, evaluate and support the development of new tracking systems based on GNSS- and GSM- technology. Furthermore, movement patterns of cattle and the workload of herdsman were analysed for a possible optimization of the management of grazing animals in mountainous areas. Two newly developed prototypes of companies GNSS_L and GNSS_M and two commercially available systems GNSS_H and GNSS_T were tested on several alpine farms (AF) over the pasture season of the year 2012 and 2013. The evaluation of GNSS devices focused on position accuracy, battery life, smartphone applications as well as availability of supportive functions and application of geo-fencing. Also a standardized dynamic accuracy test of a GPS data logger and four different tracking systems was conducted. Movement pattern analyses focused on distances walked by cattle from sequenced GNSS fixes and autocorrelation of recorded information. Parallel to the previous aims the workload management of different alpine farms was analysed to support the evaluation of advantages of using GNSS tracking systems in mountainous areas. Based on the results of a comparison of the tested tracking systems we can conclude that devices GNSS_M and GNSS_T performed better under the alpine conditions compared with GNSS_L and GNSS_H, when GSM (Global System for Mobile Communications) reception was available. The standardized dynamic accuracy test showed significant differences ($P \leqslant 0.001$) among most of the tested GNSS collars and the GPS data logger, except between the prototypes GNSS_L and GNSS_M ($P \geqslant 0.05$). On average 62% of information on the distance walked by cattle was lost when GNSS fix intervals increased from 5 to 20 min. Finally, based on analyses of the workload of herdsmen this study showed potential of using GNSS tracking systems to reduce labour time requirement and workload for farming in mountainous regions.

Keywords:alpine agriculture, cattle movement, GNSS cattle tracking, position accuracy

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1 Introduction

Animal tracking based on various techniques has been practiced since many decades. The study of Craighead (1982) using radiocollars on grizzly bears can be accounted as one of the pioneering studies in the area of animal tracking. Since GPS can be used for civilian purposes there have been numerous studies using GPS mounted in neck collars on wildlife such as European roe deer (Gottardi et al., 2010) and domesticated animals, mainly cattle (Ungar et al., 2005) and sheep (Rutter et al., 1997). However, studies focusing on using GPS to track the cattle under extensive pasture conditions combined with extreme mountainous relief (Thurner et al., 2011; Maxa et al., 2014) are rare.

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A decreasing number of livestock units grazed on the alpine pastures during the last decades resulted in abandoned land and succession processes in many regions of the Alps (Ellmauer, 2005). Gfeller (2010) mentioned high labour workload on AFs influenced by fencing and daily check-up rounds looking for the animals as one of the reason responsible for the mentioned situation. In the study of Handler et al. (1999) it was shown that on AFs with young cattle the labour input for livestock control varied between 0.4 to 21.7 h/livestock unit and season and that the total workload varied between 4.9 to 79.5 h/livestock unit and season. The number of livestock units on AFs had an influence on the total labour input, but only a weak influence on the labour input for livestock control (Handler et al., 1999). Nevertheless the relief of the farm and the area covered with trees might have a higher influence on the labour input for livestock control. Labour input needed for livestock control and searching for livestock in the Alps could be reduced via usage of modern technology such as GNSS tracking combined with GSM data transfer providing the actual location information of the animals to herdsman.

With increasing number of used GNSS tracking systems, the research on cattle behaviour is increasing as well (e.g. Turner et al., 2000; Spink et al., 2013). Furthermore, combinations of GNSS data with data from other sensors like accelerometer and magnetometer were used to develop cattle movement and behaviour models (Guo et al., 2009). Looking at the utilization of tracking systems by cattle grazed on AFs the information leading to early recognition of lameness and heat can be of advantage.

The main aim of this study was therefore to test, evaluate and support the development of new tracking systems based on GNSS- and GSM- technology. Furthermore, movement patterns analyses focusing on distances walked by cattle from sequenced GNSS fixes and autocorrelation of recorded information were analysed for further determination of cattle behaviour. This will result in optimizing of the management of grazing animals especially in the alpine areas of Europe. Finally, the workload of different AFs was analysed to access the evaluation of advantages of using GNSS tracking systems in mountainous areas.

2 Materials and methods

2.1 Study sites

The study sites were situated in the alpine areas of southern Germany (Bavaria) and western Austria (Tyrol) and were chosen in order to cover various management practices and differences in the environment and relief. The total size of an AF including pasture and sparse forest area varied between 250 and 1,130 ha. The average altitude ranged from 1,077 to 1,613 m. The pasture period in the studied areas usually covers the period from May till October with great differences among the AF (six weeks up to six months). The majority of the grazed cattle were young heifers of Simmental breed with a minimum number of heifers per AF of 37 and a maximum of 180. The young cattle were ranged freely on the pasture area without using stable facilities for the whole pasture season on all except one AF. Overall, fencing was very rare (close to dangerous places like rocks and roads) which increased the need of application of a cattle tracking system.

2.2 Workload analysis

Analysis of workload presented in this study was evaluated on six and five AF during the pasture season 2012 and 2013, respectively.The total workload of the herdsman was observed and daily manually registered for 32 activities divided into five main categories: organisation, work-farm, work-stable, work-animal and work-forest. The most important category work-animal consisted of five activities such as: control, driving, searching and recovering, treatment and other related work with animals. Furthermore, every herdsman carried one GPS data logger (type: Qstarz BT-Q1000XT, VarioTek) adjusted to a GPS-fix position interval of one minute in order to estimate daily and total distances and altitude meters walked by the herdsman to control and search the animals on the pasture and other related activities.

The collected data were validated and analysed using R software (version 2.15.2; http://www.R-project.org). Descriptive statistics were computed for the amount of observed and registered activities of the herdsmen as well as daily and total distances and altitude meters determined from GPS position data.The distance (*D*) in meters between two successive GPS coordinates was calculated according to the following Equation 1 (Kompf, 2014):

$$D = 6378.388 \times arccos(\sin(lat1) \times \sin(lat2) + \cos(lat1) \times \cos(lat2) \times \cos(lon2 - lon1))/1000 \quad (1)$$

Where: *lat1* equals latitudinal degree of the location 1, *lat2* equals latitudinal degree of the location 2, *lon1* equals longitudinal degree of the location 1 and *lon2* equals longitudinal degree of the location 2.

2.3 Evaluation of GNSS cattle tracking systems

The new tracking system prototypes of two companies GNSS_L and GNSS_M were tested together with two other commercially available GNSS systems of companies GNSS_H and GNSS_T on five and six AF over the pasture season of the year 2012 and 2013, respectively. The device's brand name can be obtained by requesting from the authors. Three of the tracking systems have been specially developed for animal tracking, while the fourth one has originally been used in telematics branch. Devices GNSS_H were provided with their own collars and housing which was located on the bottom of the animal's neck. The tracking system GNSS_M used collars and housing of the company Nedap without fixed position on the neck. For the other two tracking systems GNSS_L and GNSS_T commercially available collars with counterweight to secure the optimal position of the housing on the top of the cow's neck were used (Figure 1). Tracking systems GNSS_H and GNSS_L were rechargeable whereas devices GNSS_M and GNSS_T used non-rechargeable batteries to supply the energy for operation.

Figure 1 GNSS cattle tracking systems with different collars of the companies GNSS_L (above left), GNSS_M (above right), GNSS_H (down left) and GNSS_T (down right)

The involved cattle tracking systems were tested under field conditions with focus on position accuracy, battery life, user-friendly service, website and smartphone applications as well as availability of other supportive functions such as measurement of temperature of the animal, extreme behaviour and application of geo-fencing. Furthermore, device housing and collar type, way of data transfer, type of satellite system and final costs of the tracking system were compared.

The position accuracy measured as the standardized dynamic accuracy of four tracking systems and the GPS data logger mentioned in the previous chapter were determined in 2013, using a rotating dynamic test apparatus (Figure 2). The apparatus was built at the experimental farm Grub of the Bavarian State Research Center under open sky and level land. The data were collected within the total test duration of four days and the GPS collars were programmed to record positions every 5 min. Data collection of at least 8 h daily was considered in order to obtain at least one repetition of ephemeris data download and retention described by Augustine et al. (2011). Each of the tested tracking system was placed at a pre-defined position at the end of the apparatus's arm (Figure 2) with a resulting radius from 734 to 816 cm and 150 cm aboveground. The position of four tracking systems changed based on the test day but the GPS data logger was situated at the same, middle position during the whole test period. The distance between two tested tracking systems was at least 80 cm in order to minimize a possible influence of tracking systems on each other. The average speed of the rotational apparatus was approximately 5.65 km/h during the whole testing period. Distances between collected GNSS coordinates of all systems and the exactly measured GNSS coordinates (± 1.31 cm) at the middle point of the dynamic test apparatus were calculated using the equation presented in equation from chapter 2.2 related to workload analysis. Datasets sent from the tracking systems or saved by the GPS data logger contained different type of information but the x and y coordinates of the current position (coordinate system WGS1984) and a time stamp were part of each dataset. The accuracy of all systems was measured relative to the known radius circle of the system at a certain test day. The statistical differences in accuracy among the tested GNSS tracking systems and the data logger were tested with the Kruskal-Wallis-test and the Wilcoxon-rank-sum-test using R software (version 2.15.2; http://www.R-project.org).

Figure 2 Rotating dynamic test apparatus for testing the dynamic accuracy of GNSS receivers and a data logger

2.4 Analysis of cattle movement patterns based on GNSS data

Knowing the actual position of an animal on the mountain pasture is one of the aims of the tracking system based on GNSS and GSM technology. Furthermore, categorizing of animal movements and recognition of animal behavior such as lameness or heat based on GNSS data are important features supporting the utilization of such tracking systems.

In this study we focused on distance travelled by the cow calculated from GNSS data based on different GNSS time fix sampling intervals. Data for this analysis were collected from six Simmental heifers which were tracked every five minutes using GNSS_T collars during 18 days in June and July 2013. The heifers were ranged freely at least 14 hours per day on the AF situated in Tyrol, Austria. Only days with at least 95% of transmitted GNSS fix information without accuracy problems were selected for further analyses. These criteria were met by five out of 18 observation days and three out of six devices. The obtained datasets were further subsampled every 10, 20, 30, 60, 90, 120, 180, and 240 min. For each heifer, day and subsampled dataset, the distance between two successive GNSS fix positions were calculated. When subsequent positions were missing, mean coordinate values were calculated from the closest records in the dataset. After that, the mean distances travelled per hour in meters were calculated using the equation from chapter 2.2. Furthermore, correlation analyses were conducted for distances calculated between pairs of sequential locations using Spearman correlation in R software. The purpose of this calculation was to obtain information on autocorrelation of the data which is important for detailed animal movement analysis as described in the study of Perotto-Baldivieso et al. (2012).

3 Results and discussion

3.1 Workload on studied alpine farms

As presented in Table 1, the observations of workload on AFs pointed out that the category "work-animal" took into account the major part of the total workload per day at all, except for one AF. On the mentioned AF (AF 3), 58% of the total workload was used for the guest service and the pasture area was relatively easy to overlook. The activity "control of animals" on the pasture is one of the most important areas for herdsman where GNSS tracking systems could be applied. This activity accounted between 6% to 90% of the total daily workload as shown in Table 1. Compared to literature, Handler et al. (1999) reported values from 11.5% to 57.8% of the total workload on AF with young cattle for the activity "control of animals". The low amount of the activity "control of animals" on AF 4 can be explained by the different management system compared to other presented AFs. The heifers on AF 4 were driven every morning to the stable where they stayed during the day. This activity "driving animals" accounted for 63% of the total daily workload on AF 4 and moreover incorporated the activity "control of animals" as well.

Table 1 Total workload and category with activities related to work with animals per alpine farm (AF) as well as median of distance and height differences passed by herdsman on the alpine pasture

AF	Total workload	Category "work-animal"	Activity "control of animals"	Median of distance	Median of height differences
No.	h/d	% of total workload	% of total workload	km/d	m/d
AF 1	8.2	67	24	8.5	1,602
AF 2	8.6	62	43	6.6	1,105
AF 3	6.6	29	22	4.8	432
AF 4	5.0	66	6	2.7	426
AF 5	4.7	99	90	9.0	1,446
AF 6	3.9	94	82	6.8	1,152

As the next step of the workload analysis herdsman's daily and total distances and altitude meters needed to control the animals on the pasture and other related activities were estimated based on data from the GPS data logger. So far no similar investigations have been presented for the Alpine areas by other authors. As shown in Table 1, the median of daily distances passed by herdsman ranged from 2.7 to 9.0 km from AF4 to AF5, respectively. Median of daily height differences passed by herdsman are somewhat reflecting the topography of the AF with a minimum of 426 m for AF 4 and a maximum of 1,602 m for AF1 (Table 1). It was the topography of AF which had the highest influence (R2 = 0.74) on the average workload in the category "work-animal".

The main aim of this study – to support the development of new tracking systems based on GNSS- and GSM- technology is aiming on optimization of management of grazing animals in European Alpine areas. The results presented in this chapter showed high workload and long distances needed to control the animals by the herdsman. The main advantages when tracking system has been applied in our study were: reduction of time needed to control the animals on the pasture, elimination of time spent to search lost animals which can under special circumstances take the whole day into account and better planning of the daily work flow as a result of omission of unforeseeable tasks mainly related to time spent to control and search the animals on the pasture. Further described tracking system can be used together with geo-fencing application for pastures especially when fences are missing. Warning via e.g. Short Message Service can be send to the herdsman when animal with tracking system is entering an exclusion pasture zone or dangerous area such as rocks. This provides the herdsman advantage to briefly react and drive the animals into desired direction. Furthermore, if the movement data of the animals are stored in the web-database, there is a possibility for earlier recognition of un- or under grazed pasture areas based on visualisation of such data. This could help to prevent succession and degradation processes occurring in many regions of the Alps and provide potential for optimization of pasture management.

3.2 Performance and accuracy of GNSS cattle tracking systems

Two newly developed tracking system prototypes were compared with two other commercially available GNSS systems over two pasture seasons during the year 2012 and 2013. The results of the comparison of all tested tracking systems are summarized in Table 2.

Table 2 Comparison of four tested cattle tracking systems

Criteria	GNSS_L	GNSS_M	GNSS_H	GNSS_T
Battery life	+/o	+/o	-	o
User friendly service	o	+	o/-	+
Webpage	+	+	-	+/o
Smartphone-app	o	+	-	o
Supportive functions[1]	o	+/o	+	o
Housing/Collar	o	+	-	+
Housing-Weight (g)[2]	550	250	665 (with collar)	220
Price	Not known	Not known	-	+/o
Transfer of data	SMS	SMS-GPRS	SMS-GPRS	GPRS
Data saving[3]	yes	yes	yes	no
Satellite system	GPS	GPS-GLONASS	GPS	GPS
Accuracy information[4]	yes	yes	yes	no

Note: [1] Alarm functions (geo-fencing, extreme behaviour and temperature), measurement of temperature of the animal, battery status
[2] weight of housing including batteries
[3] Possibility to save the data in the tracking system in case of missing GSM/GPRS coverage
[4] Information about the accuracy of the last position of the tracking system (in m) visible directly on the map of the website/smartphone app
+ Positive, - negative, o neutral

Battery life is the most important criterion for using tracking systems during the summer pasture period in the Alps. Young cattle are usually grazed with a minimum use of fencing systems, without stable facilities and the possibility to fix the animal. Therefore, the tracking system in such areas should be able to function at least six months without the need of using a new set of batteries or recharging the batteries. This is theoretically fulfilled by most of the tested tracking systems except GNSS_T, but none of the tracking systems reached the full period of six months with GNSS position fixes every 20 min and sending the information via GSM or GPRS

(General Packet Radio Service) to the web-database under practical conditions. Another very important test criteria was the functionality. From the point of view of functionality and user-friendly service of the tracking systems, only two tracking systems, GNSS_M and GNSS_T, were able to function during the whole pasture period and give updated information about the position of the animals on the pasture to the herdsman. Overall, the receiver GNSS_T fulfilled best the criteria user-friendly service. We can conclude that from the point of robustness, weight and mounting of the housing on the collar the prototype GNSS_M and receiver GNSS_T performed better compared to other tested tracking systems. A customized website was available for all tested tracking systems but only prototype GNSS_M was equipped with a functioning smartphone application enabling the herdsman to see the actual position of the animal in the season 2013. Furthermore, supportive functions, such as measurement of temperature of the animal, extreme behaviour and application of geo-fencing were incorporated in the system GNSS_H. The functionality of this tracking system was negatively influenced by the difficult conditions in the mountains (GSM signal, canopy, terrain) which disabled appropriate usage of such applications.

The prototype GNSS_M received additionally to GPS also signals of the satellite system GLONASS (Global Navigation Satellite System; from Russia) which can be of advantage especially in the alpine areas with complex terrain and canopy. For the herdsman it is important to see the actual position of the animal on his smartphone or computer. The data transfer from the tracking system to the database and further to the customer (herdsman) is necessary and usually done via GSM or GPRS which causes problems in regions with weak GSM or GPRS coverage. Therefore, companies GNSS_H, GNSS_L and GNSS_M used the short message service (SMS) for transferring the information, which was supposed to work more efficiently in such regions. At the moment there is no favourable solution for the areas without GSM or GPRS coverage connected with difficult topographical conditions.

The standardized dynamic accuracy test was conducted for the data logger used by herdsmen and four different cattle tracking systems but no data were obtained from the receiver GNSS_H, caused by problems with data transfer. Significant differences in dynamic horizontal accuracy ($P \leq 0.001$) among most of the tested GNSS collars and the GPS data logger, except between the prototypes GNSS_L and GNSS_M ($P \geq 0.05$) were found. The median of the dynamic accuracy over the whole test period of four days was 1.02 m for the GPS data logger, 1.31 m for GNSS_T, 1.81 m for GNSS_L and 2.07 m for GNSS_M (Box-Whisker Plots in Figure 3). Furthermore, we found significant differences ($P \leq 0.05$) among most of the testing days for each tested GNSS receiver and GPS data logger. This was the influence of different satellite constellations at the certain time of the tested day. Although this study was planned to repeat over the four testing days within the same time span, weather influences such as thunderstorm and strong wind on the dynamic test apparatus resulted in interruption and postponing the test on days 1, 2 and 3. Nevertheless the planned total interval of eight hours per tested day was completed.

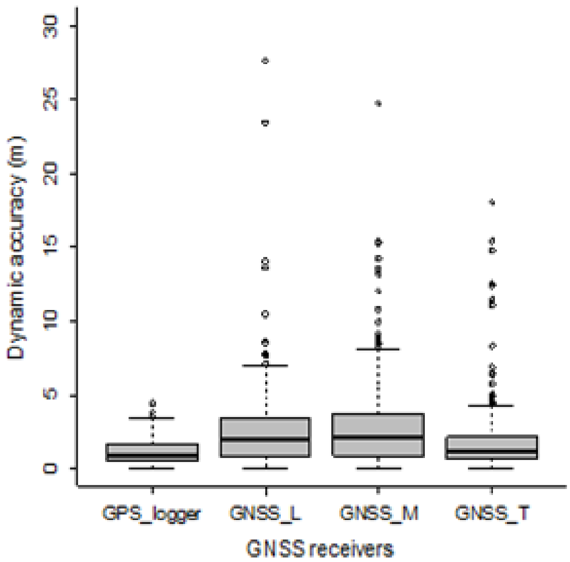

Figure 3 Dynamic accuracy (in m) of GNSS receivers and GPS data logger

The results of this study are comparable with a similar rotational apparatus of Stombaugh et al. (2002) who presented the dynamic accuracy (distance between all measured positions and the actual antenna location) of four different GPS receivers in the range from 0.06 to 2.03 m. Other authors such as Taylor et al. (2003) and Min et al. (2008) presented dynamic accuracies of various GPS receivers ranging on average from 0.17 to 1.35 m and 0.63 to 1.20 m, respectively. Nevertheless, these authors applied a different system of dynamic testing using railroad tracks or tractors as well as relief and canopy. Overall it is expectable to obtain much lower accuracy when GNSS cattle tracking systems will be used in areas with difficult topographical and canopy environment. On the other hand for the herdsman even the position fixes with low accuracy are helpful for his daily routine work with animals.

3.3 Livestock movement monitoring based on GNSS data

One of the aims of this study was to analyse the influence of different GNSS fix intervals (intervals of successive positions) on the mean distance travelled by cows on AFs. The mean distance travelled depending on GNSS fix interval is presented in Figure 4. There is a strong decrease of information with increasing GNSS fix interval between two successive observations (Figure 4). Increasing the interval even from 5 to 10 min resulted in a reduction rate of 38% of the travelled distance (from 305 m/h to 189 m/h). If we increased the interval from 5 to 60 minutes, only 16% of information on distance travelled was left (49 m/h). Similar results were presented in the study of Perotto-Baldivieso et al. (2012) where the highest reduction in rate of distance travelled by cows on free ranged pastures in Texas and New Mexico occurred between 5 and 60- min intervals.

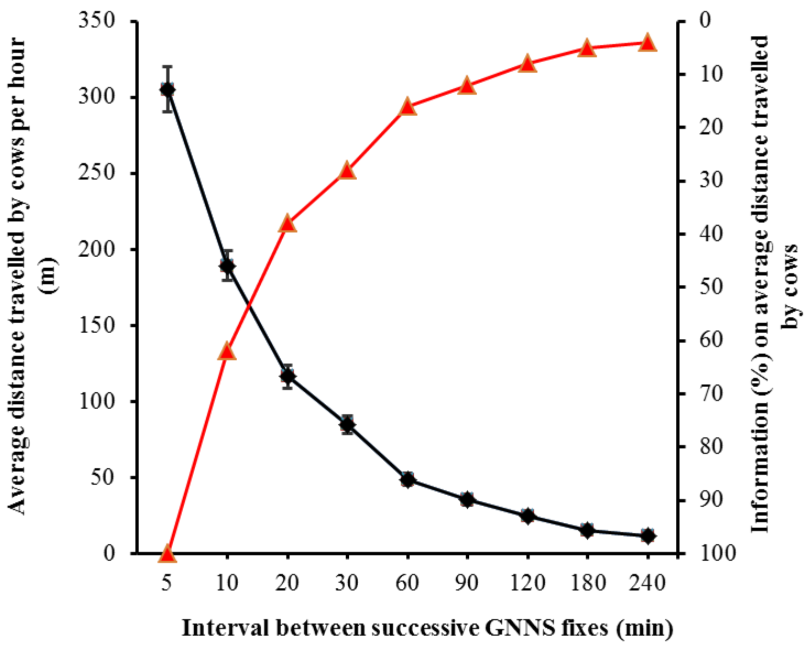

Figure 4 Means and standard error bars (black line) for average distance travelled by cows (in m/h) and the resulting amount of information in % (red line) for different time intervals between successive GNSS fixes-locations (in min)

Furthermore, analysis on autocorrelation problems of successive observations, described in several studies (Minta, 1992; Perotto-Baldivieso et al., 2012) was part of our study as well. For proper analyses of interactions between livestock and environment, autocorrelation should be removed from sequential sampling datasets (Swihart and Slade, 1985; Minta, 1992). In this study the successive distances between GNSS locations were significantly correlated when time interval was lower than 60 min (one heifer) and 120 min (two heifers). Similarly, Perotto-Baldivieso et al. (2012) presented significant correlations by the time intervals lower than 90 min (Texas locality) and 120 min (New Mexico locality) and suggested that in semiarid ecosystems of Southwestern United States the autocorrelation between successive observations can be minimized by intervals of at least 2 h. Nevertheless, the environmental and topographical conditions as well as number of animals used in our and the mentioned study were very different. Overall, the results concluded the antagonism among time intervals between successive locations needed to properly calculate distances travelled or to interpret cattle grazing patterns and interaction with environment. Perotto-Baldivieso et al. (2012) proposed to collect the data within small time intervals and if needed, subsample the data for specific statistical analyses. In this case there is still need in improvement of battery life management in order to reach the full pasture period on alpine pastures. The information collected would be helpful for further research and afterwards for development of supportive systems helping herdsman to early recognize misbalances in behaviour or healthy status of the grazing animals.

4 Conclusions

The main results of this study focusing on development and test of new tracking systems based on GNSS- and GSM- technology together with analyses of movement patterns of cattle and the workload of herdsman on alpine pastures showed that:

- The activity “control of animals” is most time consuming for the herdsmen on alpine farms with young cattle.
- Cattle tracking system has therefore potential for optimizing the workload of a herdsman and the pasture management by:
  - reduction of time needed to control the animals on the pasture;
  - elimination of time spent to search lost animals;
  - application of geo-fencing in unfenced areas;
  - earlier recognition of un- or under grazed pasture areas based on visualization of tracking data.
- On the other side, technical improvements especially in battery management of tracking systems are still necessary before final implementation.
- The analysis of livestock movement based on GNSS data pointed out the antagonisms among specific questions related to behaviour of grazing animals and time intervals of consecutive GNSS fixes needed for such analyses.
- Further research with focus on behavioural analyses using other sensors like accelerometers incorporated into GNSS tracking system will be performed.

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