



Scuola di Dottorato in Scienze Veterinarie
per la Salute Animale e la Sicurezza Alimentare

Università degli Studi di Milano

**GRADUATE SCHOOL OF VETERINARY SCIENCES
FOR ANIMAL HEALTH AND FOOD SAFETY**

Director: Prof. Valentino Bontempo

Doctoral Program in Animal Nutrition and Food Safety

Academic Year: 2011-2012

**Improving animal welfare, animal production
quality and food safety with advanced sensor
systems**

Gabriele Marchesi

Tutor:

Prof. Massimo Lazzari

Coordinator:

Prof. Giovanni Savoini

Index

1. Foreword	5
1.1. The concept of precision livestock management	9
1.2. Tools for precision livestock management	15
1.2.1 <i>Identification</i>	16
1.2.2 <i>Monitoring</i>	19
1.3. Precision Livestock Farming	21
1.3.1 <i>Technology, food safety and quality</i>	23
1.3.2 <i>Technology and animal welfare</i>	28
1.3.3 <i>Technology and animal environmental</i>	32
1.4. Proactive Herd Management: Herd Navigator®	34
1.4.1 <i>Sampler</i>	35
1.4.2 <i>Sampler intake</i>	36
1.4.3 <i>Analyser instrument</i>	36
1.4.4 <i>Biomodel</i>	36
1.4.5 <i>Consumables</i>	37
1.5. Calving monitoring system: Alarm birth control	37
2. Objectives	44
2.1. The Herd Navigator™	44
2.2. The calving monitor system	44
2.3. GPS Collars	44
3. Oestrus detection in dairy cattle with the Herd Navigator™: technical results in a dairy farm	48
3.1. Abstract	48
3.2. Introduction	48
3.3. Materials and methods	49
3.3.1 <i>Experimental site</i>	49
3.3.2 <i>The Herd Navigator™</i>	49
3.3.3 <i>Data Collection</i>	49
3.3.4 <i>Data Analysis</i>	50
3.4. Results and Discussion	51
3.5. Conclusions	51
3.6. References	51
4. Proactive herd management system in a small dairy farm in the northern Italy: technical and economic results	57
4.1. Abstract	57

4.2. Introduction	57
4.3. Materials and methods	59
4.4. Results and discussion	60
4.5. Conclusions	62
4.6. References	63
5. An electronic system for automatic calving detection: technical results in a dairy farm	67
5.1. Abstract	67
5.2. Introduction	67
5.3. Materials and methods	68
5.4. Results and discussion	70
5.5. Conclusions	71
5.6. References	72
6. Design, development and field test of a GPS/GSM based birth alarm for cattle at pasture	77
6.1. Abstract	77
6.2. Introduction	77
6.3. Materials and methods	79
6.4. Results and discussion	86
6.5. Conclusions	88
6.6. References	89
7. Design and testing of a low cost GPS/GSM collar to combat cattle rustling in grazing areas: preliminary results	93
7.1. Abstract	93
7.2. Introduction	93
7.3. Materials and methods	95
7.4. Results and discussion	99
7.5. Conclusions	105
7.6. References	105
8. The GPS / GPRS system for the transhumance flock: epidemiological monitoring	111
8.1. Abstract	111
8.2. Introduction	111

8.3. Materials and methods	112
8.4. Results and discussion	113
8.5. Conclusions	114
8.6. References	115
9. General discussion	119
10. Summary	129
11. Acknowledgements	135

CHAPTER 1

Foreword

1. Foreword

On the geological time scale, farming is a very recent phenomenon. Only some 10,000 years ago people gradually evolved from hunter-gatherers into farmers. The animal domestication (beginning with goats and then sheep) is occurred at *ca.* 10.000–9.500 B.P.†, 1.000 years after the domestication of crop plants in the southern Levant. Archaeological evidence suggests that pigs were first domesticated somewhere in south-eastern Anatolia by 10,500 B.P. than the cattle 10.000 B.P. (Zeder M.A., 2008). After that the agricultural and livestock concept were evolved in the rest of the Europe to put down roots for a modern farm.

Growing populations and other demographic factors such as age structure and urbanization determine food demand and have driven the intensification of agriculture for centuries. Growing economies and individual incomes have also contributed to growing demand and a shift in diets.

Agricultural modernization due to commercialization, land-saving and labour intensive production between 1870 and the 1920s doubled agricultural production per land area (Olmstead and Rhode, 2009).

These trends have accelerated a rapid increase in demand for animal products and other high value foodstuffs such as fish, vegetables and oils.

Agriculture not only made it possible to support larger populations, but also created the basis for specialisation. With the advancement of agricultural techniques, water management being one of the first, more and more people could devote larger portions of their time to other activities.

With the growth of the non-farming population and the subsequent increase in living standards, partly as a result of improved agricultural production, the role and function of agriculture has changed significantly.

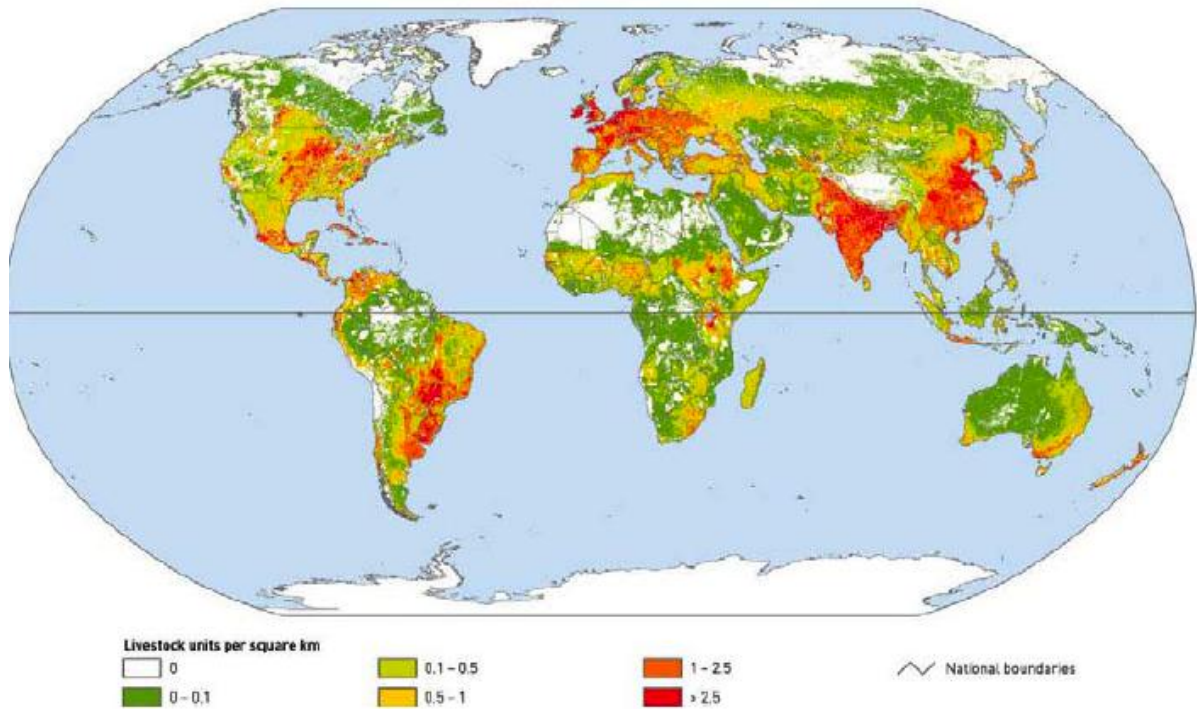


Figure 1: Livestock units per square km in the World (Source: FAO 2006g)

In order to satisfy an increasing global hunger for meat, dairy, and eggs, livestock production is increasingly becoming industrialized worldwide.

Between 1920 and 1970, the total inputs used in agriculture and livestock increased 20%, while total output increased 179%. It was already noted that the output increase was clearly not just an increase in the amount of inputs used but rather the technology knowhow for efficient agricultural inputs utilization (Duncan and Harshbarger, 1979). That was the first step for the farm changing, which was increasing between the end of the nineteen and twenty century.

The need to have more products for each animal raise the emergence of specialized farms: dairies, beef feedlots, pig operations, and chicken and turkey houses. Such productive activities use small land areas or are housed entirely inside buildings. Many animal units can be managed with small amounts of labour (Gordon, 1997).

Those changes help the use of the technology in a farm to support the farmer in daily operations.

Williams and Edge (2005) describe 'technology' as a social product, which is patterned by the conditions of not only its creation, but also its use. A similar perspective is provided by MacKenzie and Wajcman (1985) who describe technology in terms of three dimensions: physical objects and artefacts, activities or processes, what people know and do. These definitions emphasise an interaction between ideas, material objects, and humans in a system designed to accomplish a task.

The livestock sector has been affected by profound technological change on three different fronts:

- in livestock production, the widespread application of advanced breeding and feeding technology, has spurred impressive productivity growth in the most parts of the world;
- in crop agriculture, irrigation and fertilization techniques, combined with the use of improved varieties and mechanization, continue to translate into growing yields and improved nutrient composition in pasture and major crops used for feed;
- the application of modern information technology and other technical changes are improving post-harvest, distribution and marketing of animal products.

In animal production, technological development has been most rapid in those subsectors that have experienced the fastest growth: broiler and egg production, pork and dairy (FAO, 2006).

The advent of the computer, even though agriculture was far from its discovery, was one of the main innovations that radically changed the concept of farm management.

With the computer technology was developed a huge number of systems to control and collect data. There were different examples, to the computer using, divided by the farm type:

- Dairy farms: know the daily and annual milk output for every cow in the herd;
- Pig farms: know the weight gain and feed conversion efficiency of every sire used in their breeding operation;
- Cattle feedlot managers: know the weight gain and the carcass quality of every animal;
- Poultry producers: know the feed-to-meat ratio of their broilers and the egg production of each laying hen.

The potential benefits of the integrated monitoring system approach, for livestock production, arise from the opportunity to combine the strengths of the stockman and the computer system. The stockman is and will remain the primary monitor of livestock, but the amount of time available for observing and interaction with his stock has reduced dramatically in post war years and mechanisation has increased and the number of farm workers decreased. While it may be possible to ensure that there were sufficient staffs available to feed, inspect and care for all high value animals such as dairy cattle, on an individual basis, it has become impractical with sheep, goat and pig (Frost et al., 1997).

At the end of the twenty-century different research moved the attention to the integrated monitoring system development. Dijkhuizen and Huirne (1990) have

been developed an integrated monitoring system for pig production. Belyavin and Filmer (1990) describe a system for monitoring broiler production. However the dairy cows have received more attention than other animals. Was established a base system for record the quantity of milk provided by each cow, cow identity, health, fertility, milk quality and cow weight (Ordolff, 1989). In the last decades the technology changed rapidly the society and the agricultural world. Monitoring the animals becomes the responsibility for all aspects of the farmer. This responsibility was not only moral but was a commercial interest of the farmer to satisfy the basic needs of his livestock. The main purpose of the livestock production was to satisfy the customer requirements at a price that enables the producer to make a profit. This trend moved the farm concept to the new monitoring technology system to support their operation. This new idea of the farm takes the name of “Precision livestock management”.



Figure 2: The types of technologies most used in a modern farm

1.1. The concept of precision livestock management

A correct management system for livestock must be based on the concept of "information". The information is derived from the raw data. A raw data becomes information, when it finds a form of use in decision-making processes of the production system. The phases of the transformation of the data into information are shown schematically in Fig.1. There are four phases:

- Collection (raw data);
- Processing (processed data);
- Analysis and evaluation (evaluated or formatted data);
- Using (information).

The first stage involves the direct observation of the real system with data acquisition of potential interest to the observer. The acquired data can then take two alternative routes:

- be used - possibly through processing in real time - to make immediate decisions;
- provide for deferred use, passing through a necessary phase of storage, with possible integration and synthesis with other data from different eras.

The first path is the typical case of the operational control through automation processes. The second, indeed, covers all the normal management applications, with the objectives of managerial control that normally deal with problems that are not standardized and cannot be automated, with choices conditioned by reality models of individual decision-makers.

The cycle ends with the use of information. It provides, first, the taking of a decision that may relate to the following problems:

- control of business processes (in both the operational and managerial), in which case the decision follows action of intervention on processes;
- certification bodies to third parties (in accordance with the processes defined in the product specifications or quality standards of the products), in which case the decision is later in a documentary activities.

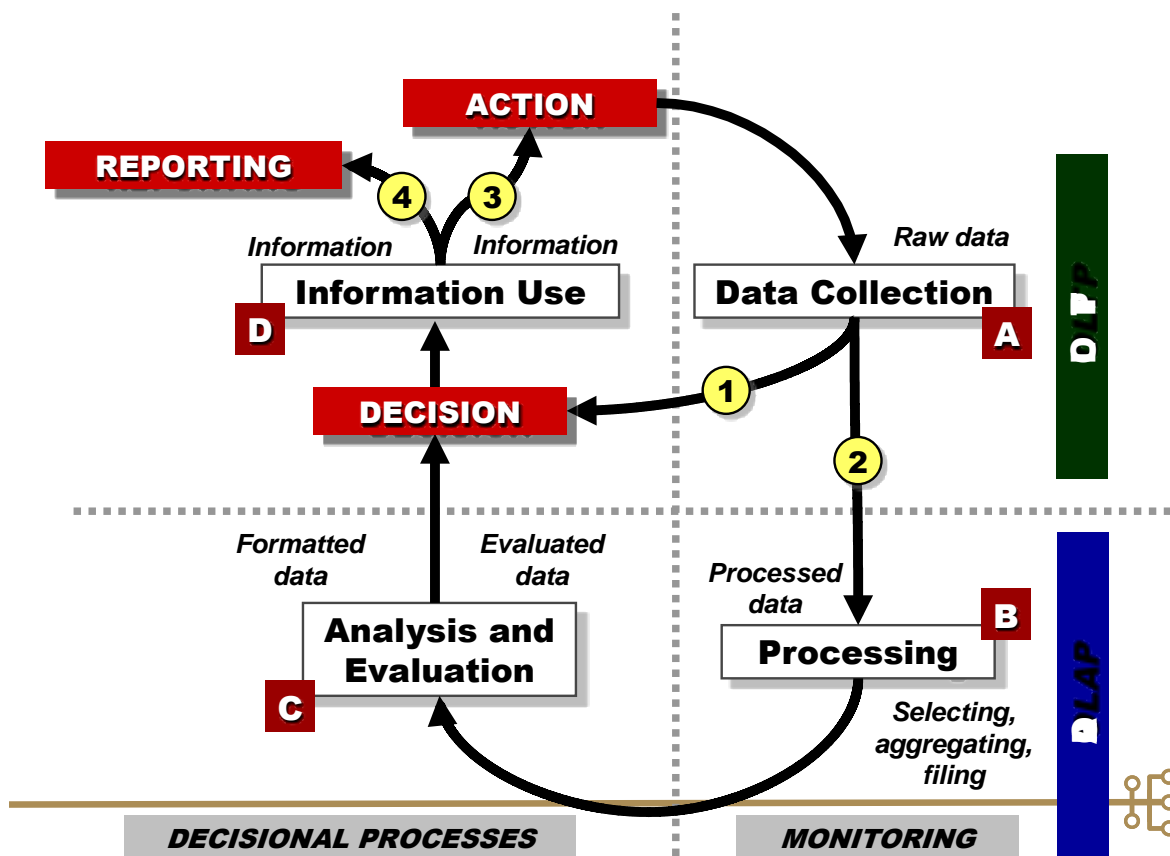


Figure 3 – Life cycle: From raw data to information

In conclusion, the information can also be considered a good role, at the same time, as a productive factor and the product of the business. Although physically immaterial, in fact, has a nature similar to any other material factors commonly employed in productive activities (fertilizers, pesticides, labour, energy, etc..). Because: i) involves the cost of supply (phase A), ii) requires storage systems (storage), possibly even after being subjected to the processes of transformation (phase B), iii) requires appropriate forms of management and use vary according to the purpose for which the information itself is used (phases C and D).

In addition, information is also an asset that may take the form: a) is re-used as a factor in the production process, when used in active regulation and control of processes (intra-company use, path 3 in Figure 3), b) and as a real product designed to fruition outside the company, when used in certification activities (off-farm use; route 4 in Fig.3).

Information systems are used, in fact, to manage information in a manufacturing system. In contrast to information (assets), an Farm Information System (FIS) is a set of components that interact to make the decision-maker in terms of managing all the phases (A to B) transformation of raw data ==> information. According to a methodology derived from the industrial sector, it is useful to

first predict the articulation of a FIS in two distinct interacting subsystems: the operational systems and informational systems.

The operational systems are the infrastructure that supports the work of the executive. Through them, the company carries out all its major functions: the management of operations, the sale of products or provision of services, including also any support for the administration and accounting. Help in the management of problems well structured, allowing the organization of the various flows of information in predefined charts, strong standardization of data to minimize the possibility of making mistakes and, at the same time, make operations smooth and rapid. The main functions of an operational system concerning the above activities: 1) monitoring, 2) documentation and 3) operational control.

The informational systems assist the user in decision-making related to issues of management of medium or medium to long term. In fact, as a rule are related to the scheduling of resources and corporate activities throughout the growing season, the need to use and to integrate, as mentioned, data of different nature and different temporal periods. As such, in general, these processes are not standardized nor related to automated (or semi-structured problems). In this sense, an informational system is designed precisely to support the decision-making process following the logical steps of the decision maker and offering at the same time, the ability to have visions differently organized data. There is, thus, essential tools that enhance the analytical capabilities of decision makers through: i) interactive analysis, ii) comparisons between different frames of comparative synthesis, iii) research tools correlations, uniqueness and data aggregation, iv) any simulations conducted operational data assuming future scenarios.

About the distinction between these systems, the information technology industry terminology distinguishes between two categories of technology components - in an FIS - to keep separate the elaboration of analytical those related to the management of individual production events (also called transaction). These families include:

OLTP (On Line Transaction Processing), which include components of operational systems used for the information processing relating to individual processes or corporate events (transactions, in fact), to ensure maximum efficiency in management - generally automated - operating processes; must ensure a high level of interactivity-system user during both monitoring (change or looking for specific information) as well as monitoring the progress of the processes;

OLAP systems (On Line Analytical Processing), which include the components of informational systems used for interactive analysis of the data by a small

number of managers, which are optimized for maximum efficiency in data synthesis and flexibility in queries.

Ultimately, in order to achieve a full application of Precision Farming (PF) there is: a) an operational system capable of recording data and manage the steps of automation of the operational control, b) a system in informational able to store historical data and consistent forms of aggregation and to assist decision-makers in the early stages of analysis, to arrive at the possible development of action plans through automated maps prescriptive.

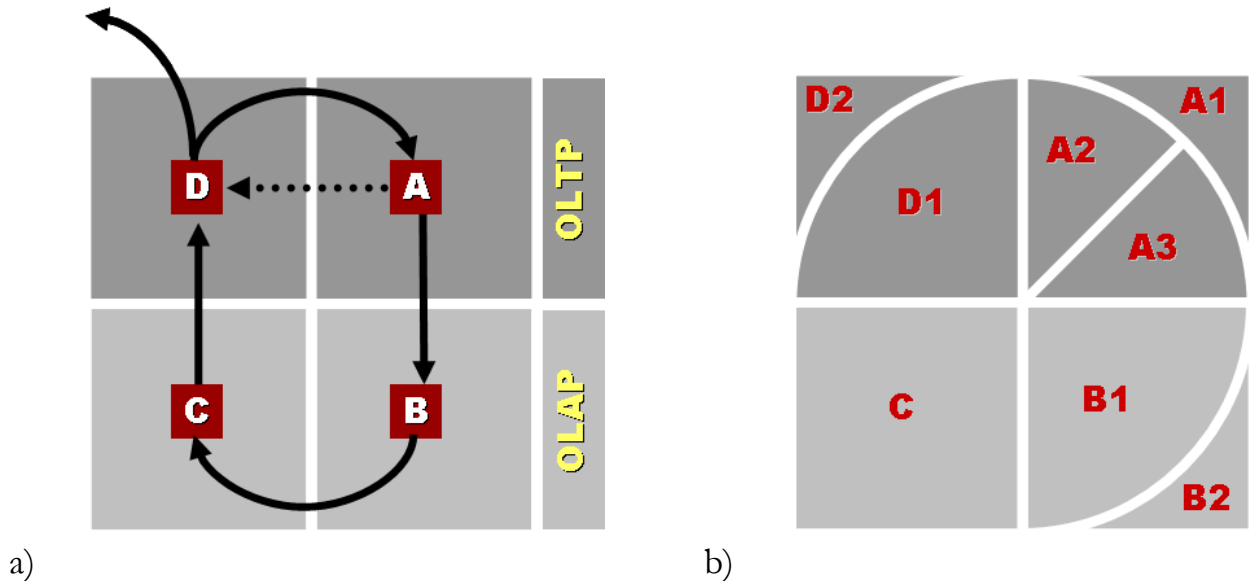


Figure 4 – Life cycles details: (a) phase and (b) sub phase.

The phases of the cycle data ==> information, at this point, may be used just for the purpose of a classification of the different technological application solutions provided by a system PF. For this purpose, it is proposed the scheme in a Fig.4 where the entire cycle is simplified through the four panes (Fig.4a) indicate that the cited phases of collection and monitoring (A), storage and processing unit (B), evaluation (C) and use of data (D). The arrows indicate the cyclical flow of data through the various phases (the dotted line refers to the automation process). Each step, then, is divided into further sub (Figure 4b), in order to put more emphasis on the functions of the different applications.

In this regard, it should be noted, first, that for a correct methodological approach to monitoring (phase A) in a farm is always useful to distinguish between the aforementioned phases:

A1) environmental monitoring, which provides for data acquisition systems one time, or in continuous. The first related to the findings, usually on the occasion of the first computerization of management (i.e., are put on the database with data on business configurations in place);

A2) animal monitoring, which may include surveys of animal behaviour (activity meters), and at the time of production;

A3) operational monitoring, providing for the acquisition of all the important data for the performance of productive enterprise (its aspects of human activity, organization and methods of work).

The data collected by the three forms of monitoring should integrate within the same OLAP system, physically independent from the solution adopted for the collection of data (manually or automatically).

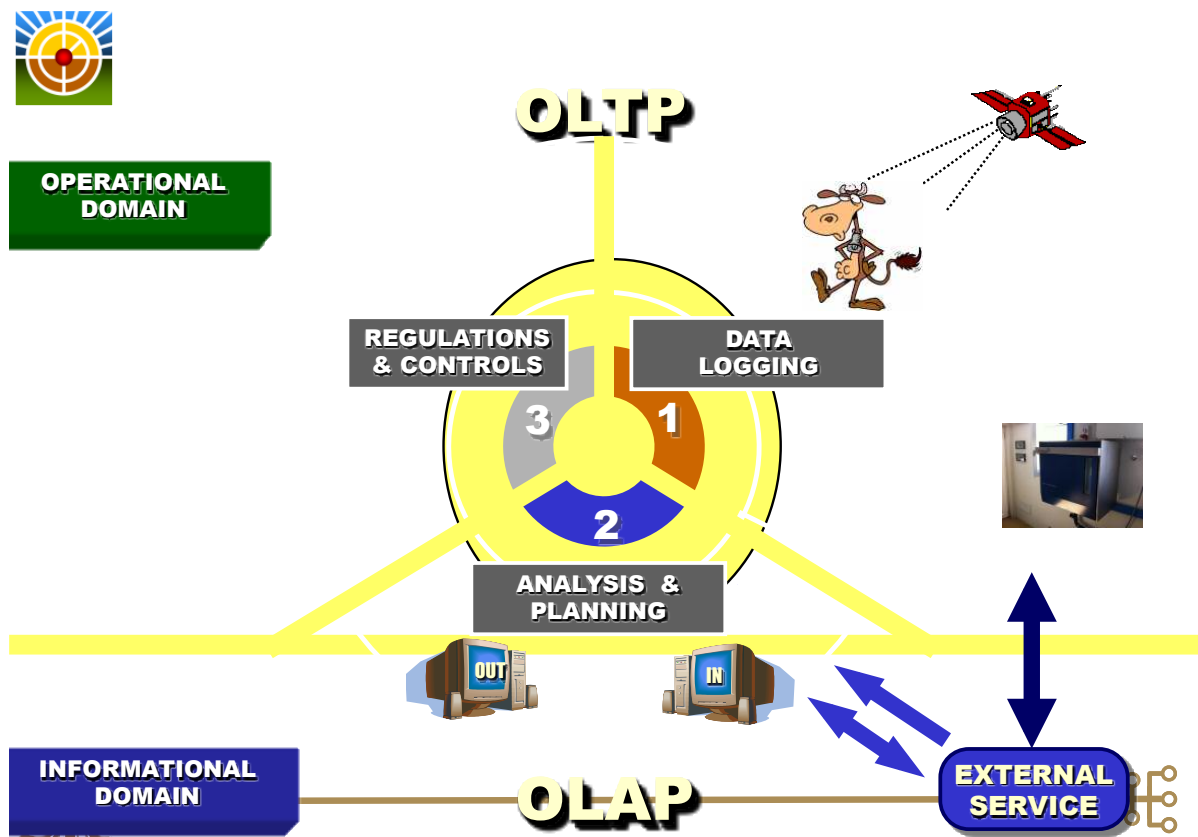


Figure 5: Towards integrated systems

In the next phase B, of storage and processing, differs between:

B1) office automation base, which covers the use of technologies essential for a first computerization of business processes, so beyond basic hardware (PCs, PDAs, any server, network connections, etc..) Includes the classic software packages needed for office automation (word processing, spread sheets, graphics programs, email, etc..), in this context, the use of the database through DBMS, it is essential for digital archiving and targeted consultation information;

B2) Advanced Office Automation, which provides for the use of software tools for medium and high complexity, usually dedicated to cartographic processing interfaced to database (GIS). Their use is typically intended for advanced users

(knowledge workers), which assist on a permanent basis to the management company.

Further, the phase C of analysis and evaluation of data involves a scope of the most complex use, dealing generally medium to highly unstructured problems, whose solution is still strongly influenced by cognitive abilities of the decision maker. The computer technologies usable in this phase are software and consist of a series of highly specialized applications, different depending on the specific problem to treat and evaluate (tools for the analysis of production costs, predictive models for the generation of scenarios, alternative diagnostic tools for assessing health status of the animals, programs for the formulation of food plans...). Even in this case, their use is typically designed for users with highly specialized experts often need to find at external centres of technical assistance.

For stage D data usage, it should be - finally - to distinguish between:

D1) intra-company use of information regarding the domain to be put into productive activities, providing for the use of all components of different nature (basically the actuators controlled by microprocessor technologies) that allow the use of information in business processes run more or less automated;

D2) use non-corporate information, which covers all devices that can make the company capable of producing the necessary documentation to certify, according to various purposes, methods of conducting business processes; involves mainly the use of software applications suitable for this purpose, however, it remains subject to the prior formal activity is being monitored (phase A) and computerization of management (especially in stage B1).

From a technological point of view, the hardware and software components that are used to make computer systems can be classified as:

- Basic electronic technologies: monitoring, operational control and automation (sensors & actuators, identification system);
- Position technologies: as above, but required when the information content must be geo-referenced within a spatial reference system;
- Hardware IT: Physical treatment of information;
- Software IT: Semantic treatment of information.

In particular, according to these technologies can assume a greater or lesser importance in various fields described above (Fig.6)

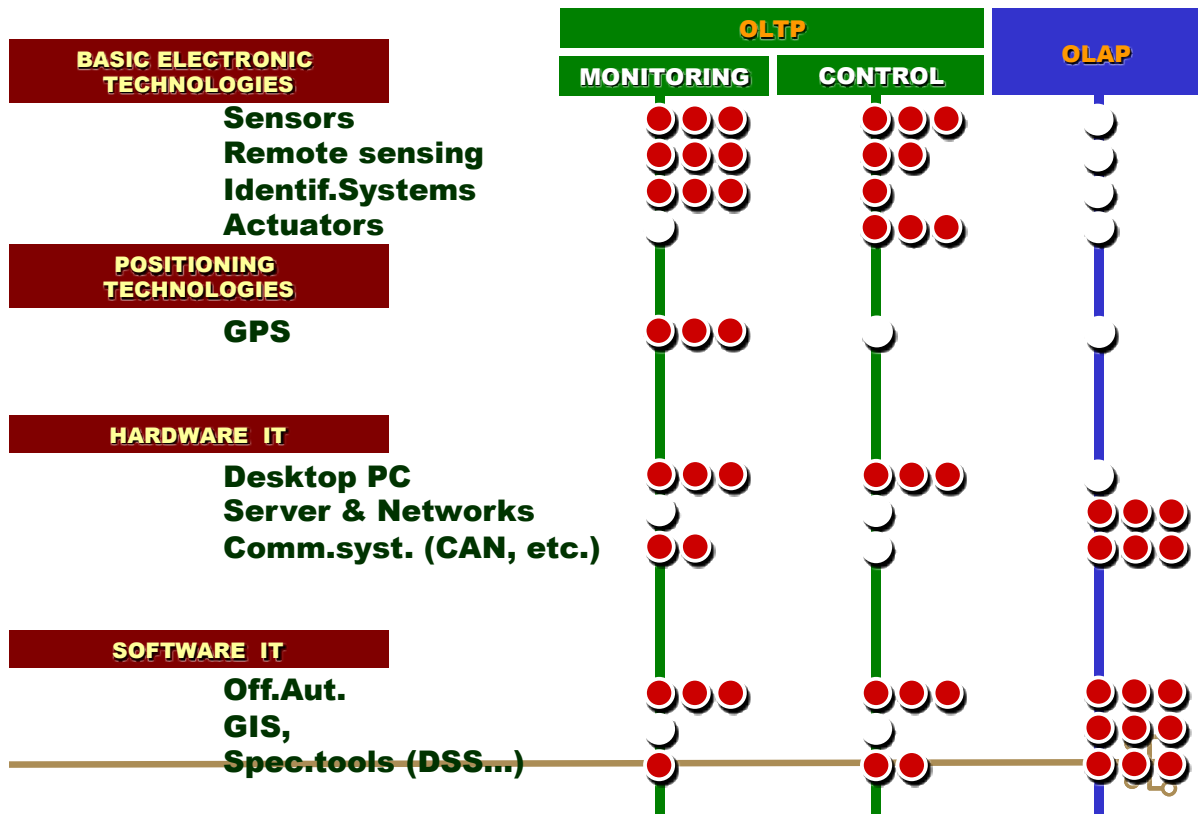


Figure 6: The technologies used in the SIA. The pertaining of the tool in the field is showed with different number of red circle. Otherwise there is a white circle.

1.2. Tools for precision livestock management

In the twenty-one century the most of the dairies farms, pig farms and poultry producers, have at least one tool to support the farmer job. Many precision farming technologies, including animal identification, milking system, Global Positioning system (GPS) and automatic oestrus detection are already being utilized by the farmer. There are many types of sensors that are either in current use, or are likely to become available in the future.

There are two big fields where the tools are uptake:

- Identification:
 - o Animal identification.
- Monitoring:
 - o Animal Monitoring;
 - o Environmental monitoring;
 - o Operational monitoring.

DATA COLLECTION

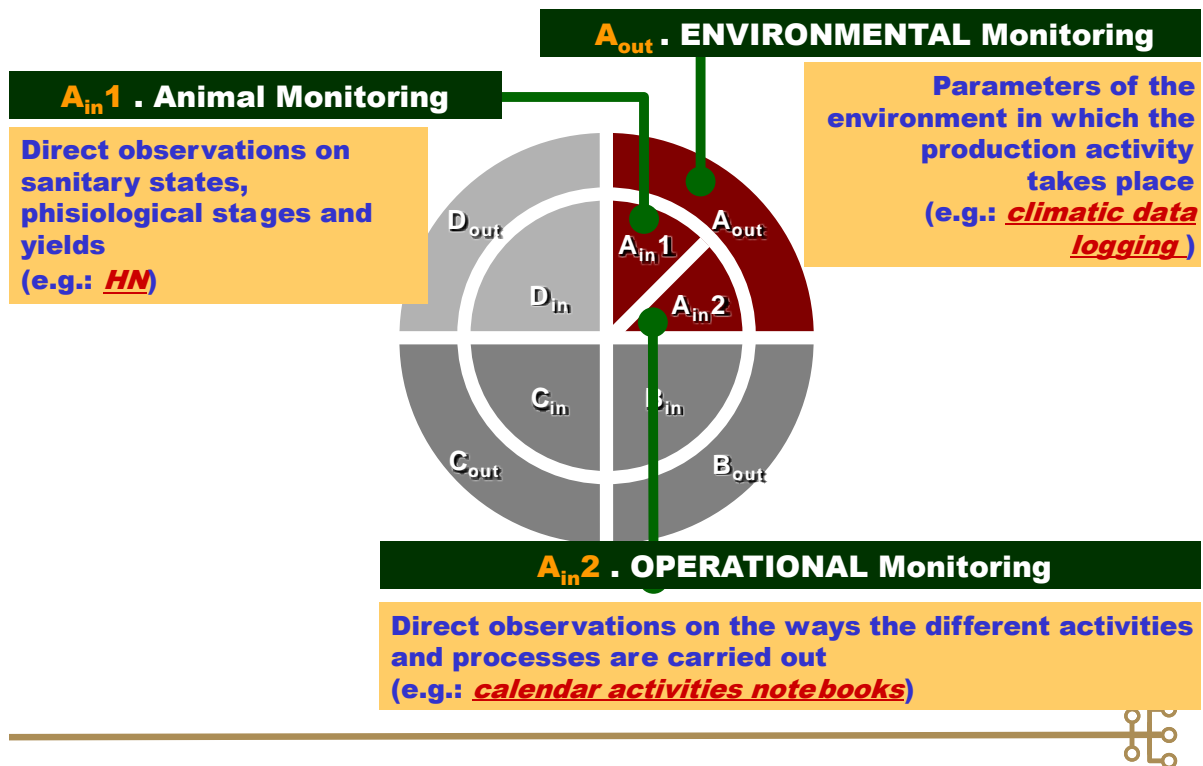


Figure 7: Data collection sectors towards the integrated system

1.2.1 Identification

Animal identification

Since animals were unable to express their own identity, the problem of farmers has always been to provide the same symbols or codes that could be uniquely and indelibly recognized and identified after time. So in the past the branding has been the practice becoming predominant for ensuring a secure identification. It, as well as with hot iron, was also made by incising the skin of the animal with sharp knives to injure, so that with healing could be recognized (Nava, 2010). It was created areal culture around the branding operation and marks remarkably sophisticated have been developed, in many cases made with great aesthetic taste.

The features that the animal identification device must:

- Had univocal code per each animal;
- Guarantee the traceability;
- Easily to apply;

- Readable;
- Not be easily lost or broken;
- Not be easy to replace, edit or manipulate.

However the crisis generated by the outbreak of Bovine Spongiform Encephalopathy (BSE) and the difficult of tracing the routes of the infected meat made a radical changed in the animal identification field. Was defined that the traceability will be the most useful tool in the management of food emergencies. In this context the EC Regulation178/2002 sets out general principles and requirements of food law, establishing the European authorities responsible for food safety and set clear procedures in matters of food safety. This decision smooth the way to the electronic identification development livestock trade.



Figure 8. Different type of reader and RFID tag position (Nava, 2010).

RFID

The electronic identification is based on the radio frequency, named: Radio Frequency Identification (RFID). The RFID systems are composed by two elements: Antenna and Transponder (or Tag). The tag is read when get across the antenna range. After that the antenna receive the tag's alphanumeric code, which re-edit and send to the management software. There are different types of

antenna and tag, which are different in shape and size in accordance to the radio frequency range. The RFID for animal is 134.2kHz, this is a standard defined by the International Standardization Organization (ISO).

Otherwise the RFID technology can be detect the animals in a maximum range of 20 - 50 cm. In a huge grazing area detect the animals could be more difficult only with the RFID. Therefore to tracking the grazing animals can be used the Global Positioning System (GPS).

GPS

The Global Positioning System (GPS) is a space-based satellite navigation system that provides location and time information in all weather, anywhere on or near the Earth, where there is an unobstructed line of sight to four or more GPS satellites. It is maintained by the United States government and is freely accessible to anyone with a GPS receiver. The GPS technologies based on the latitude, longitude and altitude triangulation of radio signals transmitted by a system of 24satellitesgeo-orbiting.

Each GPS satellite transmits data that indicates its location and the current time. All GPS satellites synchronize operations so that these repeating signals are transmitted at the same instant. The signals, moving at the speed of light, arrive at a GPS receiver at slightly different times because some satellites are farther away than others. The distance to the GPS satellites can be determined by estimating the amount of time it takes for their signals to reach the receiver. When the receiver estimates the distance to at least four GPS satellites, it can calculate its position in three dimensions. Many authors were described the GPS technology detailed (Rempel and Rodgers, 1997, Hulbert et al., 1999, Turner et al., 2000). The use of GPS-collar receivers for tracking animal movement is common in wildlife studies (Moen et al., 1996; Sibbald and Gordon, 2001). The most important using were for find the animals location and, therefore, replace the continuous activity of control over grazing farmer.

The applications of GPS today cover a wide range of scientific fields, such as topography, geodesy, transportation and logistics, and animal tracking (Xiaohong et al., 2010). In the field of animal husbandry, the GPS had found applications in studies relating to ethologists and pasture management (Turner et al., 2000; Bailey, 2001; Ganskopp, 2001; Agouridis et al., 2004; Barbari et al., 2007; Nadimi et al., 2009). Same researchers were concentrated for detecting and logging the spatial distribution of urine patches of grazing female sheep and cattle (Betteridge et al., 2010). Anderson (2000) developed a virtual fence through the use of GPS collars reduce labour costs associated with fence construction in rotational grazing.

1.2.2 Monitoring

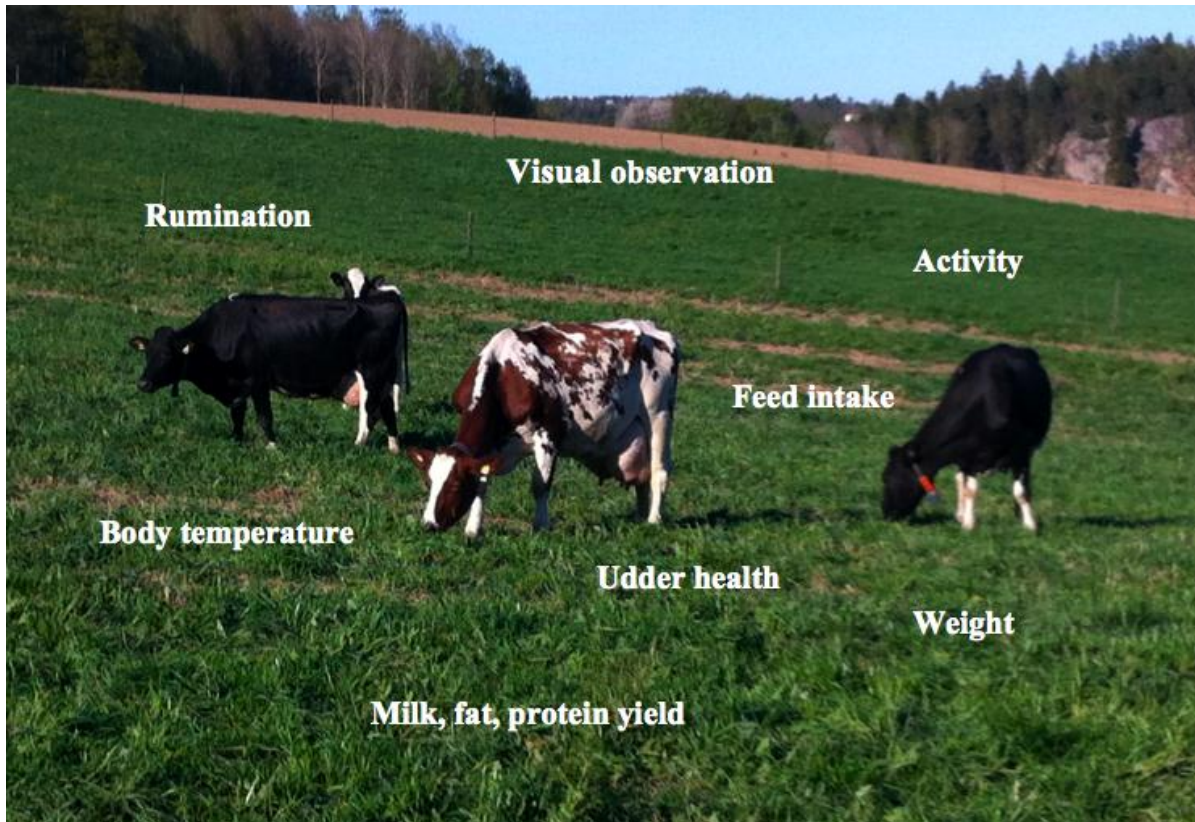


Figure 9: The cows' monitoring issues

Animal monitoring

The dairy industry is the industry with the most use of sensors. The milking system is the most important instrument to detect milk. The oldest sensor in the dairy industry is probably the “jar” milk meter that measured the individual cow milk production but records had to be done manually. Electronic milk meters did not change this situation until individual cow identification (ID) was developed, more or less, in parallel and opened the age of on-line performance recording. The electronic milk meter soon became, in addition to its individual cow performance capabilities. This unit uses infrared technology, which ensures no direct contact with the milk. It senses the milk flow and displays the estimated yield, giving a good indication of each cow's milk yield.

The older system used to the farmer to understand the animal health was the visual observation. The number of animals within many dairy herds is increasing while the time for surveillance of each cow is decreasing. In consequence disease symptoms will be often not detected. As the level of automation increases, time that the cattle keeper uses for monitoring animals often decreases. This has

created a need for systems for automatically monitoring the health for farm animals.

A diseased animal may be more, or less, active than a healthy one; an animal's activity level may be linked to its stage in the reproduction cycle (Frost et al., 1997).

The activity (as measured by pedometers) of dairy cows during oestrus was studied for the first time in 1950 (Farris, 1954). Farris has shown that the period of oestrus in dairy cows is characterized by a substantial increase in the number of steps.

The pedometers establish a base line of normal activity, and using that base line, a formula calculates an increase or a decrease in activity. A decrease in activity could be a sign of illness or lameness.

The new activity meters generation (accelerometers) give more efficiency and sensitivity than the older one. Accelerometers measure three different movements: side-to-side, up and down, and front to back.

Rumination is an important constituent of the digestive function in ruminant animals (Murphy *et al.*, 1983). Different sensors have been used:

- Accelerometers: the rumination function is related to the jaw movements;
- Jaw balloons and pressure transducers: A balloon on plastic tubing, passed into the reticulum via a rumen cannula, connected to the pressure transducer for the pressure measuring variation during the rumination;
- Microphone: It is an instrument for the sound of rumination recording.

Other systems to detect the animal status are based on the hormonal enzyme and metabolic substance changes in the milk. The most studied were:

- Progesterone: reproduction management. Is a sexual hormone, produced in the corpus luteum in the ovaries, formed after the expulsion of an egg (oocytes). Progesterone has the ability to prepare and maintain a pregnancy. If there is no pregnancy established, the corpus luteum will regress at around 18 days after the heat, and a new heat will occur.
- Beta Hydroxyl Butyrate (BHB): ketosis management. Is one of three metabolic intermediate substances produced when the breakdown of body fat for milk production is not fully degraded, example due to inadequate supply of carbohydrates.
- Lactate Dehydrogenase (LDH): Mastitis management. Is an endothelial enzyme, released to milk when cells in the udder are destroyed during an inflammation (mastitis).
- Urea: Feeding management. Is a residual product from protein degradation in the liver.

Also a diagnostic tool for health and reproduction solitarily, or with other sensors, which came into practice like milk conductivity for udder health detection.

Environmental monitoring

The use of sensors to manage the environment has changed the farming systems. The possibility of having rearing systems in every part of the world has been possible thanks to the use of specific sensors. Environmental monitoring is a very important factor. By controlling the environmental status of the herds you can maintain the right operating conditions.

The use of sensors for environmental monitoring of temperature and humidity is widely used in many herds. In particular, the pigs and poultry that require special attention. The sensors most commonly used are:

- Thermometers: measuring the temperature change in the environments of rearing;
- Humidistats: identifying the environment status variation;
- Light Measurement: detecting the light variations.

Operational monitoring

The herd management operations are changed with the introduction of the sensors. The introduction of the sensors systems helped the herd management practices.

In the past, and some companies even now, there was only the farm's agenda as a tool for data logging. Now more farm are recording all work related to monitoring of the herd (heat, lameness, sales, deaths, etc. ..) through computer support. With the herd management systems (DBMS) is allows connecting all the sensors in the farm. In that way the farmer can manage the herd directly from the PC.

The first step is the data collecting. The second step is the single animal control. The ability to locate the animal's position allows improving and speeding the management of the herd. The operation of the system in this case is governed by two instruments, RFID and gate detector (antenna). One of the more concrete examples is the use of these two sensors at the entrance of the milking parlour. In the moment when the animal passes near the antenna, is identified. This allows the farmer to associate the animal in the parlour position. The presence of milk meters can directly bind to the individual milk production.

1.3. Precision Livestock Farming

An article search, using the words 'automation' or 'automatic' and 'animal welfare' reveals that the number of scientific articles using these words increased from 5 in 1997 to 80 in 2010. It is clear that the implications of farm automation

for animal welfare are being recognised, including the potential of automation to monitor animal welfare.

At its simplest, automated assessment of animal welfare involves using automation to take measures on some aspect of an animal, which a human then interprets in terms relevant to animal welfare; for example, using machines to measure the activity of an animal, which a person then uses to decide whether the animal is lame. In addition, computer algorithms are being developed to make higher order inferences from data collected automatically, e.g. judging whether an animal is lame or not (Rushen et al., 2012).

The increasing use of computers and the dramatic increase in the use of the internet, have to some degree improved and eased the task of handling and processing of internal information, as well as acquiring external information. However, the acquisition and analysis of information still proves a demanding task, since information is produced from many sources and may be located over many sites and is not necessarily interrelated and collaborated (Sørensen et al., 2010). The potential of using these data will reach its full extent when suitable information systems are developed to achieve beneficial management practices (Blackmore et al., 2006). However, such systems still have to be enhanced in terms of collaboration with automated acquisition of operational farm data and integration with the overall Farm Information System (FIS).

FARM INFORMATION SYSTEMS: FIS

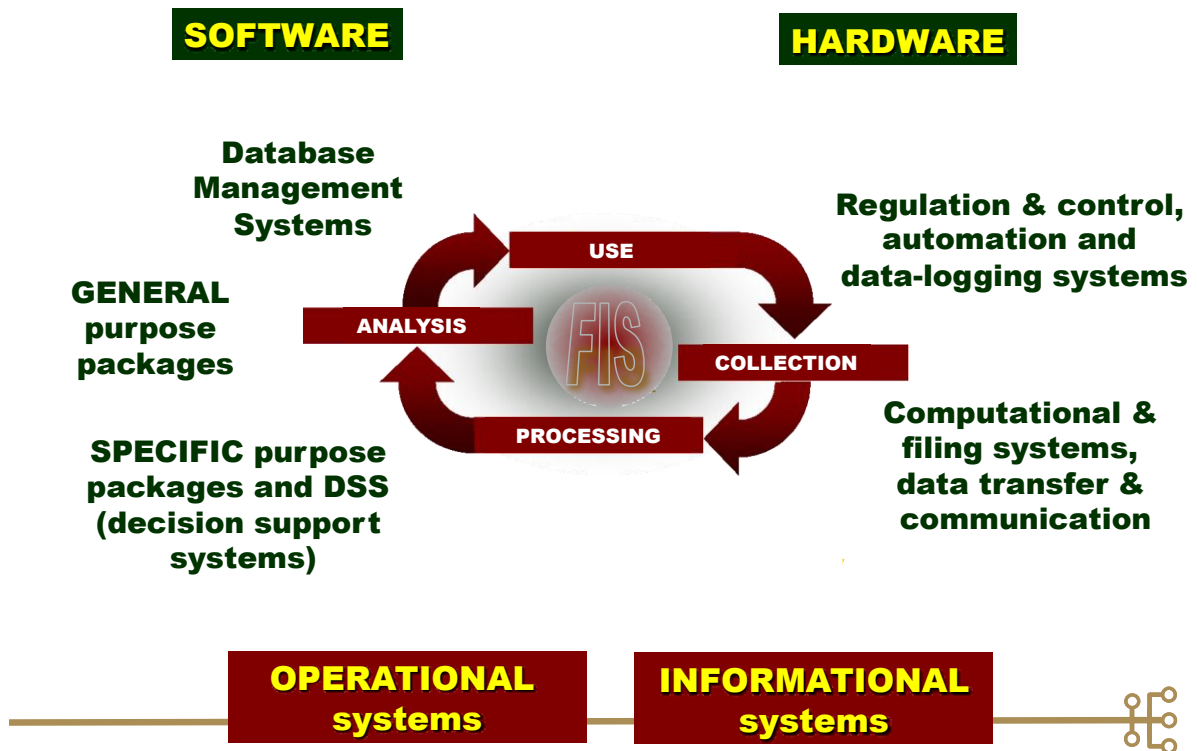


Figure 10: Farm information system Hardware and Software processing data

There are three important filed into the precision livestock:

- Technology, food safety and quality;
- Technology and animal welfare;
- Technology and animal environmental.

1.3.1 Technology, food safety and quality

The enormous changes that have affected the food system community, characterized by a close relationship between producer and consumer, pose new problems and critical points to be solved to ensure food safety and product quality. The enlargement of the European Union and the intensification of international trade relations have helped to further increase the spread of livestock products in Europe and beyond on the market. This scenario has caused, in some cases, public health emergencies in the food. This is demonstrated by what happened, for example, as a result of the alarm generated by avian influenza that caused a dramatic drop in the consumption of poultry meat and incalculable damage to an entire supply chain. The quality products must always be supported and demonstrated by objective indices that are based on processes of communication with consumers. In fact, consumers are now far away from the manufacturer and they cannot use their experiential knowledge when choosing the food, but must resort to more complex procedures based on a more detailed knowledge of the products. In other words, the quality of the products must be guaranteed through marketing operations based on traceability and this must be based on the collection of objective data, which can become the basis for providing information to consumers. In the last decade Europe, first with the White Paper on Food Safety in 2000 and Regulation 178/2002, then with vertical regulations (pigs, hens, broilers, cattle up to seven months of life) and horizontal (transport and slaughter animal), has established the need to regulate food safety in the respect for life and normal growth of livestock. At the same time is attaching great importance to define the minimum quality of the food, which must apply within a single member State. As widely supported by the European Union, the animals and humans welfare interact each other to form an unbreakable bond. A good animal health is related to the healthy and quality production (milk, meat, eggs), and greater security and protection for the consumers' health. An effective food safety policy requires an assessment and continuous monitoring of risks to consumer health. The risks may arise from raw materials, farming practices and food processing activities. At present it is therefore essential to ensure the traceability of products through technological systems to highly automate, eliminating potential fraud and / or error.

Traceability in agro-food sector can be defined as "possibility of carrying out the tracking throughout the production, transformation and distribution stages of a food, feed or animals or substances used for food production" (Perez Aloe et al., 2007).

The European Union General Food Law Regulation defines traceability as "The ability to trace and follow a food, feed, food producing animal or substance through all stages of production and distribution".

There are many technologies that can be used to improve traceability in the food supply chain (Smith and Furness, 2006). Radio Frequency Identification (RFID) is one such technology that assists in monitoring the physical location and quality of products as they move through the different stages of supply chain.

RFID is a rapidly emerging technology that facilitates automatic identification using tags and readers. In recent years, RFID systems have seen a proliferation in the number of applications and have been successfully applied to different areas. RFID systems may be employed for automatic identification, monitoring, authentication and alerting through this exchange of data between the tag and the reader. The process is automatic and functions well even when the tag and the reader are not in direct view of each other. Advances in technology have resulted manufacturing costs for RFID tags dropping precipitously, thus enabling companies to move forward with RFID implementations of traceability systems.

TRACEABILITY FOR SAFETY AND QUALITY

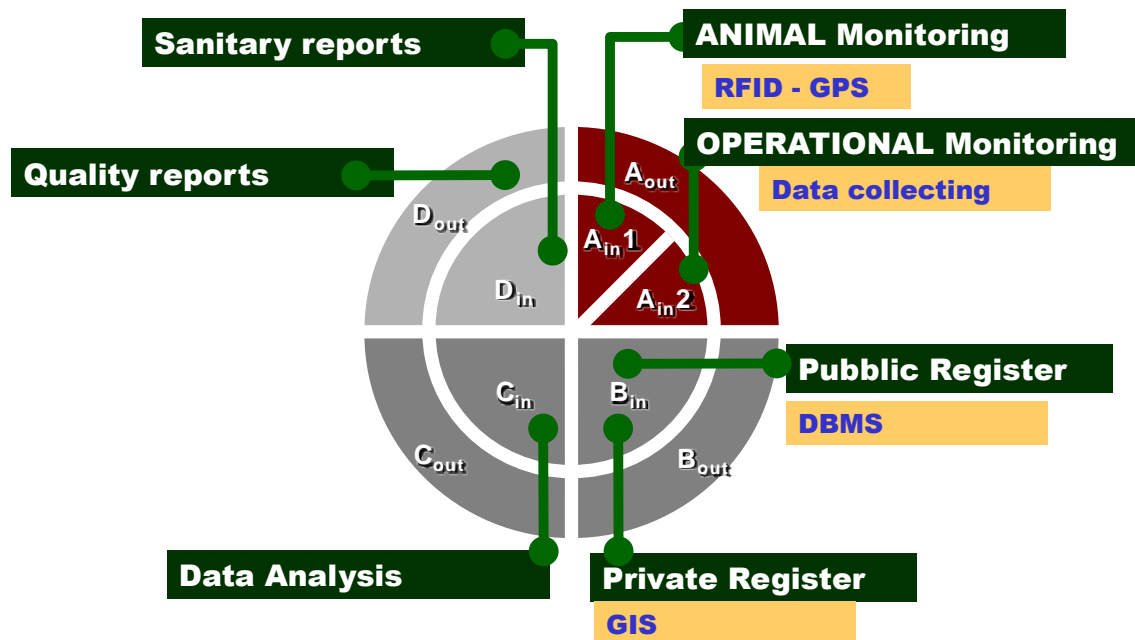


Figure 11: Traceability for safety and quality into an integrated system

The first actor in the food cycle is the farm and in particular the animals. Electronic identification devices have been available since 1990 in the dairy industry. A recent study by Nava et al. (2010) shows the use of RFID for an integrated traceability system, in a cattle industry, from the farm to the slaughter, dissection houses and the store.

The bovine meat production chain has been developed in different steps:

- automatic data flow management of the production cycle (control and certification);
- guarantee of the origin and quality of the food products (link with the territory);
- reliability of food product information (food safety, prevention of food adulteration); - responding to consumer's desires for high quality products;
- increasing the value of food products and new market positioning.

Otherwise those steps could increase the customer market impact, in particular for:

- food safety and quality;
- guarantee the origin of the food products;

- additional information related to food products: production cycle, geographical, and historical data (smart labeling).

Other system that can become a new traceability instruments is the Global Positioning System (GPS). The GPS has become the most developed high-tech in food logistics recently. This technology has the potential to change the way that all companies do business, as well as to push companies into higher productivity. As more and more companies adopting GPS to create a competitive advantage, it will become a standard for the rest to follow.

GPS is a system with the functions of navigation, positioning, timing and speed measurement. It will not only allow companies to provide better customer service to their consumers via real-time tracking, but also to complete tasks more efficiently. What's more, it can offer important and long-awaited features, which are valuable to the commercial sector. These features will help companies increase their growth and create a higher profit margin through the use of more efficient logistics.

The adoption of GPS systems in farming equipment to implement precision farming technique sand automatic driving machine has been for years the focus of researcher sand practitioners (Lazzari, 2006). Parallel to these studies there are different research for the GPS system application in the animals filed.



Figure 12 : Cow with GPS/GSM collar in a grazing area

Is quite recent the proposal to use the same to support the management of pasture in an automatic way through the technique of virtual fence (virtual fencing), thus avoiding having to install traditional or electric fences (Bishop-Hurley et al., 2007). Other recent research was made to develop a low cost GPS/GSM collar to track animal's movement within a grazing area and get alert from animals trespassing virtual fences.

Recent research (Luvisi et al., 2011) has used the RFID and GPS technology together for combined the data stored in the agricultural sector. That is a combination of data and geographical position, which could create an addition value to the food traceability. For each product e.g. meat, wine, honey, is possible create a historical life cycle about where, who and what the product was made. For example when the costumer buy a beef can know all the cattle life and where the cattle was grazing, in which type of pasture and so on.

A recently collaboration between the Department of animal health and food safety (VESPA) and Royal Tags (Lugano, CH) have create a GPS/GPRS collar. A number of 35 GPS/GPRS collars were mounted a on a herd of 40 Highland cows. There was a cartographic processing interfaced to collect and manage the data from the collars. In this case the GPS collar number identifies each animal.

This project was carried out with the highland cattle society (Switzerland). That society had created a new concept of commerce. The idea was the association between the cow and the customer. The customer pays every month a fixed price to support the animal's life. With the GPS/GPRS collar the consumer can know the pasture location of own cow from a PC, tablet or smartphone (Fig.13). At the end of the animal's life cycle it will be possible know historical animal life. This project could open a new idea of the traceability, because every consumer can know everything of the animal's life: When was born; where and when was grazing; where is going and so on.

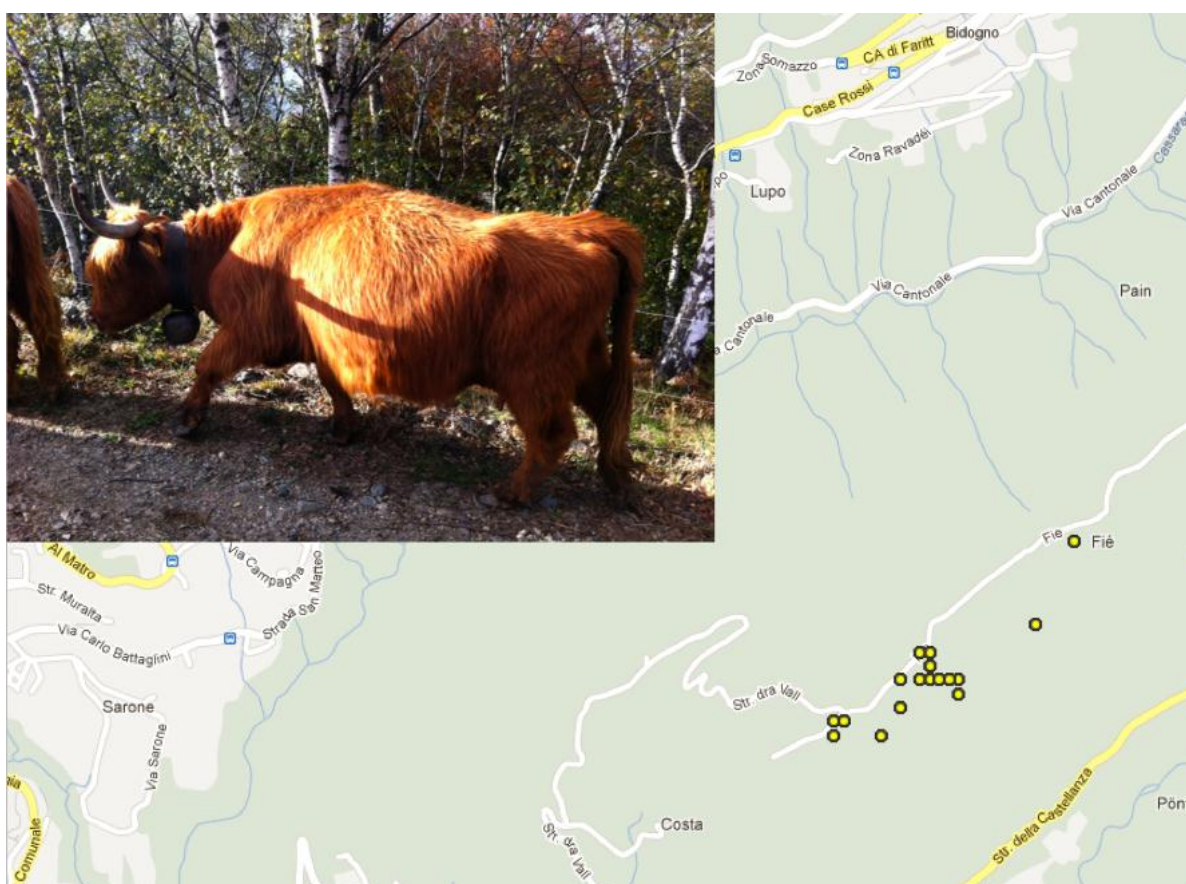


Figure 13: Animal tracking on the web-App map

1.3.2 Technology and animal welfare

In the last years there were a decreasing of the dairy farms number but on the same time the herd sizes, per each farm, was increasing (Eurostat, 2011). Bigger herds imply that the farmer spends less time to individual cow monitor its health and productive status. Intensive farming systems could sometimes have side effects, particularly concerning the animal welfare.

A happy and healthy animal is a productive animal. An animal with problem can reduce the production of milk or eggs and made some reproduction disease that can affect on the animal life. However the health problems are related to the veterinary and medicine costs, which can inflict the farm economical sustainability.

The association between the animal welfare and the technology is an important argument that increasing in the last ten years. There are different scientific papers, academic program and European meeting that are interesting about the animal health.

TECHNOLOGY AND ANIMAL WELFARE

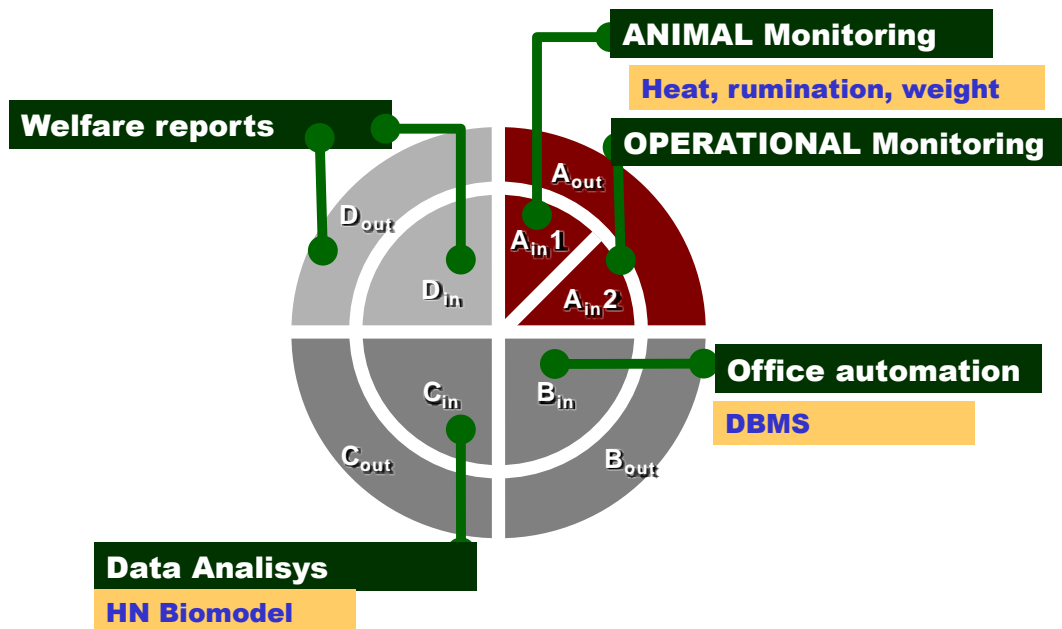


Figure 14: Technology and animal welfare into an integrated system

In the context of Precision Livestock Farming, the use of electronic devices and sensors, has create the possibility to collect objectively and evaluate the animal behaviour and its changes, so they can serve as indicators and decision support in the management process. An automatic cow tracking system can be a solution, which can find the animals with welfare problems or oestrus. The most commercially method used to measuring any aspect of behaviour is the activity meters system, which is used to detecting oestrus in a dairy cows. The activity

meters are divided in pedometer and neck collar, but more or less the function is the same. Oestrus is associated with an increase in activity and therefore significant changes of movements over a precise period especially if associated with a specific algorithm (At-taraset al., 2001, de Mol et al., 2001, Firk et al., 2002, Roelofs et al. 2005).

Otherwise the data are collected to the management software that filters out different variable (milk yield, cow parity, number of calving etc..) and show the results. Accurate and quick detection of oestrus, which depends on the reproduction and subsequent milk production, is a factor that has a significant effect on the economy of the farm (Jonsson et al., 2011).

A recent research has considered the most useful results, for use on-farm, a combining observation by neck collar and the farm staff visual observation with 75% of sensitivity and 91.7% positive predictive value (Holman et al., 2011).

Other various study show different device used to monitor the animal health, related to the different animal behaviour. The first one system was related to the rumination status and the consequent animal behaviour.

As an option to visual observations, several sensors have been developed to monitor the jaw movements of grazing ruminants. *E.g.* jaw and mercury switches (Stobbs & Cowper, 1972), accelerometers and displacement transducers (Chambers *et al.*, 1981), jaw balloons (Derrick *et al.*, 1993) and pressure transducers (Ruckebusch & Bueno, 1978), and systems developed for stall-fed animals (Beauchemin & Iwaasa, 1993).

The Heatime HRTM (SCR Ltd Engineers, Netanya, Israel), is a microphone-based system that measure rumination time. The microphone is incorporated in a plastic gadget, which is attached to the left side dorsally on the head collar. To maintain the gadget, or “tag”, in its right position, a lead weight is attached to the collar ventrally. Through a combination of activity measurements and rumination surveillance it is marketed as a good herd management tool for early detection of metabolic disorders, heat and calving.

The data are analysed through a complex algorithm inside the tag. The tag is claimed to detect rumen activity with 97% of accuracy through the following parameters:

- Minutes of rumination in 2h intervals with a resolution of 2 minutes;
- Average interval between boluses in last 24h;
- Average interval between chewing actions in last 24h.

The tag is able to store the data for maximum 24h. The information contained in the tag is unloaded via infrared (IR) communication to an antenna placed by the milking parlour, the water trough or located inside the barn. The Rumination data are collected and elaborated in a software management, where an algorithm with various variables gets the results (Schirrmann et al., 2009). The goal of this

system is related to the complete automation of the heat and rumination detection. With two “touch” the farmer can know the cows in heat and the cows with rumination problems.

The best way to understand the animals’ problems is rise directly from the animal blood, but in a daily farm routine is impossible to do. Otherwise for the dairy cows is easier get the results from the milk than form the blood. There were different research about the milk analyses of Progesterone, Beta Hydroxyl Butyrate (BHB), Lactate Dehydrogenase (LDH) and urea (Grohn et al., 1999; Lopez et al., 2004; Kenneth et al., 2004; Friggens et al., 2005).

The milk progesterone analyses are very accurate to pinpoint the time of heat. In the literature, concentrations below 3 ng/ml were considered indicative of an oestrus (Lamming and Bulman 1976). Recently Friggens et al. (2006) has verified, during the test in Danish dairy herds, an oestrus breakpoint level of 5 ng/ml.



Figure 15: The Herd Navigator’s Analyser Instrument unit

Recently has been developed a system that collected the milk sample every milking. The system mentioned is the Herd Navigator™ (DeLaval and Foss). The Herd Navigator™ (Fig. 15) in line milk testing system provides some very powerful information. The system automatically samples selected cows at each milking and analysis the milk sample for Progesterone, LDH (Lactate

Dehydrogenase), BHB (Beta-hydroxybuterate) and Urea. The measured values are fed into the biological models (BIOMODEL). The BIOMODEL processes all data available and provides risk values of several physiological and pathological statuses. Different levels of progesterone analysed by the BIOMODEL can show oestrus, follicular and luteal cysts, anoestrus and pregnancy status. The model assumes the cow to be in one of the three states:

- Status 0- Post partum anoestrus. During this period and until the first ovulation, progesterone values are very low;
- Status 1- Progesterone values are increasing, indicating that the cow is now cycling;
- Status 2- Potentially pregnant. This state will start at every heat alarm, where progesterone values are again below 5ng/ml.

Test results are summarized and reported through the herd management software, which also defines and applies the testing schedule to provide the best possible information (Blom and Ridder, 2010).

1.3.3 Technology and animal environmental

During the last few decades' increasingly sophisticated interest in the welfare of farm animals has developed. At the same time there has been a move towards more welfare-friendly housing systems.

Examples of this are loose housing systems and stables with deep litter for dairy cows, group housing for pregnant pigs, and large floor systems with access to outdoor facilities for laying hens. These so-called welfare-friendly housing systems provide generous space and other conditions, which encourage animals to express their natural behaviour. Potentially the animals can experience a high level of welfare as a result. In some countries, government subsidies for farmers are linked to guarantees of high welfare standards on the farm. Typically, meat and other animal products coming out of welfare-friendly housing systems are labelled and sold at a higher price than alternatives, which have been 'conventionally' produced. But if consumer and government trust is to be secured, some control of the level of welfare is necessary. Consequently, there is a need to develop methods that can be used to assess the level of welfare in farm animals (Johnsen et al., 2001).

Livestock housing in temperate climates falls into two types, controlled environment and climatic buildings in which the physical environment mirrors that outdoors. This distinction is based on the desirability of control or modification of the physical environment (Frost et al., 1997). The control of the environment is very important in order to satisfy the animal request. The used of technologies in the farms can helps the farmer. Every data are collected by the

computer, which develops a correct climate value for the animals. The environmental control and the climatic buildings are two aspects very important for all animal and farmer in the world. That farming system can help a dairy farmer in Russia such as dairy farmer in Spain.

Animal ambient and welfare are not always compatible with the physiological needs, resulting in increased susceptibility to various stressors, including heat stress.

Heat-stressed poultry can suffer high mortality rates when air velocity in the microenvironment around the chickens falls below a minimum threshold level.

Animal ambient and welfare are not always compatible with the physiological needs of birds, resulting in increased susceptibility to various stressors, including heat stress (Furlan, 2005). The ideal temperature for egg production is 21 - 26°C for adult hens (Silva, 2000). Regarding the effect of ambient temperature on layers, numerous studies mention the existence of a thermal comfort zone. Nevertheless, determining such comfort zone implies the knowledge of the interactions of several variables that can impact this process, including moisture, management, ventilation, facilities, etc. (Gomes et al., 2011).



Figure 16: The different type of tools used in a poultry farm for the environmental control.

Heat stress generates a significant economic impact for the dairy industry in arid and semi-arid regions of the world, so that heat abatement is an important issue for dairy producers. One of the ways to reduce effects of heat stress is use of artificial cooling systems such as wetting the skin with sprinklers or sprays and refreshing it with air from fans (Collier et al. 2006). Cooling systems based on spray and fans have a positive impact in productivity of lactation Holstein cows in arid regions by reducing body temperature through evaporation.

In sheep the efficacy of thermoregulatory mechanisms largely depends on sheep breeds and individual animal genetics. The effects of heat stress on sheep milk production have been deeply investigated, and differences of the severity of heat stress on milk yield have been ascribed to genetics (Finocchiaro et al., 2005).

1.4. Proactive Herd Management: Herd Navigator®

In some ways, the technologies that have made it possible to milk 100 cows per hour and feed 400 cows per hour, have also robbed us of the opportunity to manage them individually. But new technologies are now providing new opportunities to “watch” cows using automation. Perhaps it is easiest to illustrate this potential with a very practical system that is being field-tested in European dairy herds: the Herd Navigator (HN).

The HN is composed by:

- Sampler: sample the milk of the individual animal (**S**);
- Sampler intake: manage the milk samples collected during milking (**SI**);
- Analyser instrument: carry out the analysis (**AI**);
- Biomodel: acquisition and processing of data;
- Consumables: stick, diluent, detergent and desiccant.

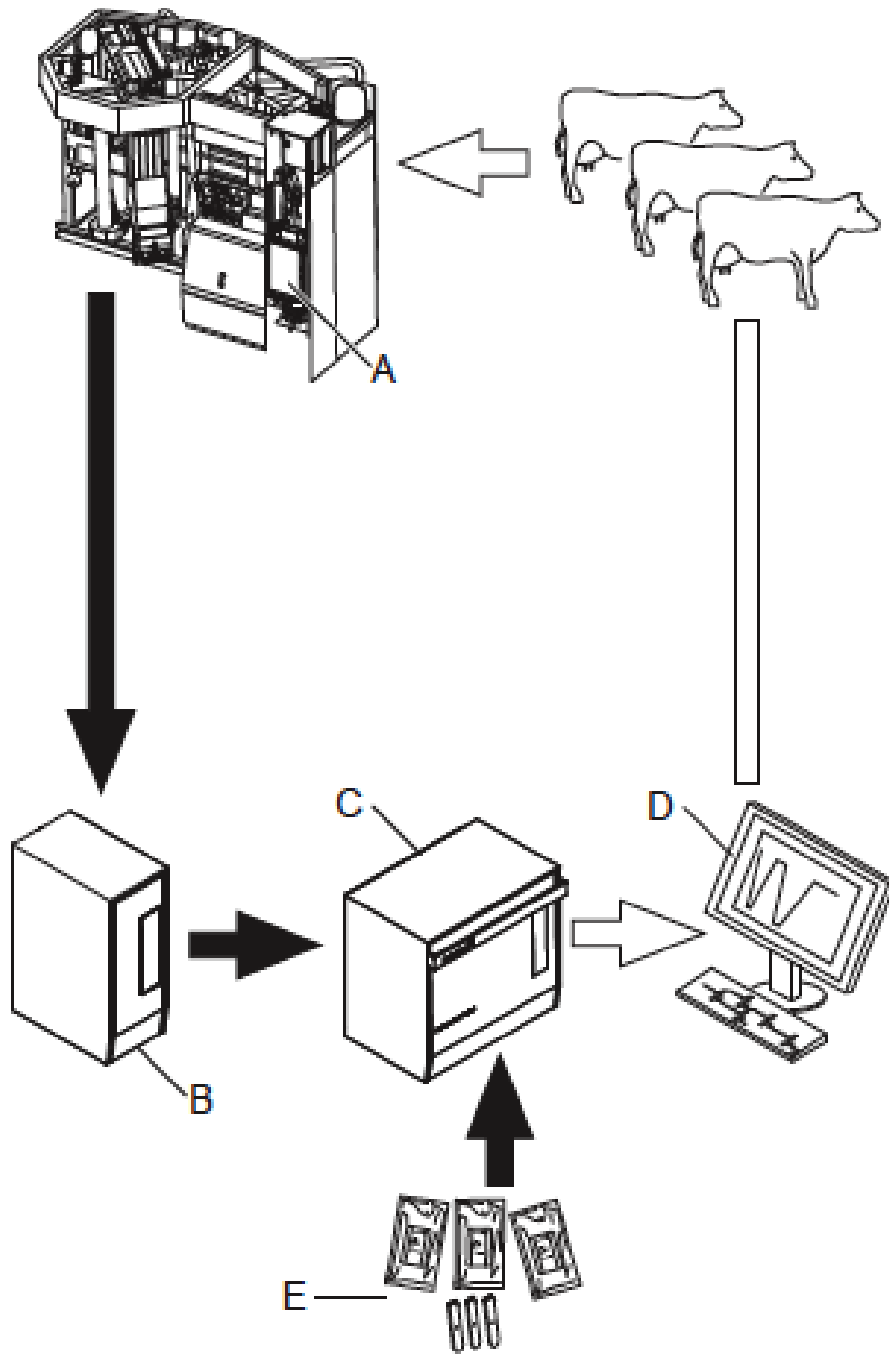


Figure 17: The Herd Navigator system: Overview

1.4.1 *Sampler*

The sampler gets the milk after each milking session. Could be installed into the Voluntary milking system (VMS) or in a parlour. Into the sampler there is a container where the milk is stocked.

If the milk yield is more than 25 kg (max volume of the VMS receiver is 28 kg) the sample container is filled twice and two samples from the same cow are taken. On the contrary, if the milk yield is below 5 kg no sample is taken. After that the milk is mixed to homogenize the sample by letting air into the container through the waste tube. After mixing the milk is transferred by air pressure:

- Fat sample to fat sample unit, if required;
- Milk surplus is returned;
- HN milk sample (max 80 ml) to SI;

After sample transfer to SI, the transfer tube is flushed with water.

1.4.2 Sampler intake

The HN transfer tube from each HN sampler is connected to a pinch valve and to a nipple of the multivalve. Milk samples are stopped at the pinch valve. By following the principle of first-in, first out, the multivalve sorts them out. The first part of the sample is diverted to the drain. The remaining part, 30 ml, is collected by a swivelling arm moving to the appropriate nipple. The sample is then pumped to the AI. The SI unit includes a cleaning module that cleans the multivalve every fourth hours and the milk tube between the SI unit and the needle in the AI.

1.4.3 Analyser instrument

The subsystem that characterizes the HN is the last of the three the AI. The AI measures the concentration of the analytical parameters of milk, by optical jet sticks containing a reagent specific, for each parameter to be measured. When an analysis process is about to begin, the cartridge is selected for the specific parameter to be measured and a needle releases inside a drop of milk. This causes a chemical reaction that determines the colour of the stick. An optical reader detects the intensity of the colour after a short incubation period, and then the data is sent to the application "Biomodel".

1.4.4 Biomodel

The biomodel is based on a series of mathematical algorithms. The data are collected from the values of the analytical parameters of milk (progesterone levels, lactate dehydrogenase, beta-hydroxybutyrate and urea) and crossing with some characteristic data of individual animals (days of lactation, number of birth, last fertilization, last delivery, etc.). The data are sent to the herd management software a list of animals for which it is necessary to intervene in the present physiological states classified as "abnormal".

Interestingly, these physiological states (heat, pregnancy, ketosis, mastitis, etc. ..) are detected by the system 2 - 3 days in advance, which allows the breeder to adopt a proactive approach.

1.4.5 Consumables

The consumables are vital parts to perform the daily milk analysis and to operate the Herd Navigator system correctly.

Detergent: HN detergent for VMS is a concentrated liquid for cleaning of the SI unit, the milk transfer tube and the AI;

Diluent: Diluent is a liquid solution used during analysis in the AI. It is mixed with milk to perform the progesterone analysis and to rinse the dosage module in the AI;

Desiccant: Desiccant bags contain calcium bentonite and are used to maintain a low relative humidity in the storage module of the AI;

Cartridges: The cartridges contain dry sticks which are analytical elements intended for measurement of Progesterone, LDH, BHB or Urea.

The cartridges are kept in aluminium foil bags.

The labels on the foil bags are coloured coded:

Pink: Progesterone;

Green: Urea;

Purple: LDH;

Blue: BHB.

1.5. Calving monitoring system: Alarm birth control

In dairy cattle farm the stage of labour has always been considered a sensitive time. This event focuses on the two core capital breeder: the cow and the calf. The dystocia is the common problem in dairy cattle and especially those at first calving (Roughsedge T. and C. Dwyer, 2006). The calving assistance and the calving prediction should be considered as the elements that allow operator to get an action to reduce possible injures to the calf, caused by the cow or the environment (Mee, 2004).

Calving monitoring is especially important for cows suffering from poor health along with primary labour insufficiencies, as well as for cows with very valuable offspring (e.g. calves produced by embryo transfer) (Streylet *al.*, 2011).

Recently an electronic system for calving monitoring (C6 birth control®), Sistecks.r.l., Italy) in dairy cows has been put on the market.

The C6 birth control® is composed by:

- Transceiver;
- Receiver-transmitter.

Transceiver

The transceiver (Fig.18) is a device composed by two parts: Internal and external. The internal part is an electrical circuit powered by one Li-Ion battery. The external part is hard and watertight plastic-shell (4.9 x 2.1 x1cm). The plastic shell is characterized by four holes, two at the top and two at the bottom, necessary for attached the device with the catgut.

In a lateral side of the device there is a magnetic connection with the mobile part. The mobile part is a cylinder magnetic, covered with plastic, connected by catgut. When the cylinder branched by plastic shell, the electrical circuit is closed and the transceiver transmitted frequency wave (433 MHz) to receiver-transceiver.



Figure 18: The C6 birth control transceiver

Receiver-transceiver

The receiver–transceiver (Fig.19) is a box (25 x 20 x 5 cm) composed by an electrical circuit powered by a rechargeable Li-Ion buffer battery (3.7 V, 0.85 Ah).

Two modules compose the electrical circuit:

Radio wave (433MHz): receive the data from the transceivers;

Global system for mobile communication (GSM) (850/900/1800/1900 MHz): sent to farmer's phone the alarm.

An integrated SIM card reader is connected to the GSM module, essential to send the message to the phones.



Figure 19: The transceiver is attached at vulva lips in pregnant cows and when it is activated by fetal membranes expulsion a radio wave signal is sent to a receiver-transmitter. Through the use of the Global System for Mobile communication (GSM) technology the receiver sends a short text message (SMS) to the farmer's mobile phone warning him of the coming delivery.

CHAPTER 2

Objectives

2. Objectives

The aim of this thesis was to evaluate the use of different type of technologies in the livestock farming. In particular were studied:

- The Herd Navigator™;
- The calving monitor system;
- The GPS collars.

2.1. The Herd Navigator™

The aim of these studies was to evaluate the use of the Herd Navigator on dairy commercial farms. The studied were done in two different farms:

- In the northern Sweden were individuated the efficiency for the oestrous identification (Sensitivity and Positive Predictive Value) in a commercial dairy farm with the Herd Navigator™ system,;
- In the northern Italy were detected the reproductive performance before and one year after the Herd Navigator™ installation. To evaluate the potential economic benefits of the introduction of this technology a model was developed using literature and commercial data.

2.2. The calving monitor system

The calving monitor system study is divided in two trials:

- C6 birth control®: the aim of this trial was to estimate the Sensitivity (S) and Positive Predictive Value (PPV) of the C6 birth control® in a commercial dairy farm;
- GPS-CAL (GPS- CALving alarm device): the aim of the trial were the design, development and test a GPS/GSM birth alarm for cattle grazing.

2.3. GPS Collars

Has been developed two different GPS collars:

- GPS-ACT (Anti Cattle rustling): The goals of this research were to create a low-cost GPS/GSM collar, using commercial hardware and through the implementation of a specific software, for limiting the cattle rustling;
- OVItrace (ovine traceability): The aims of the trial were study and evaluate a new system for the epidemiological monitoring in a flock.

CHAPTER 3

Oestrus detection in dairy cattle with the Herd Navigator™: technical results in a dairy farm

3. Oestrus detection in dairy cattle with the Herd Navigator™: technical results in a dairy farm

3.1. Abstract

The Herd Navigator™ is a system that automatically programs the analysis of milk progesterone samples from selected specific cows of the herd. In a commercial dairy farm, the same 156 cows were monitored with the Herd Navigator™. Sensitivity and positive predictive was calculated as 100% and 96% for the oestrus detection with the Herd Navigator™.

3.2. Introduction

The failure in the detection of oestrus is the biggest contributor to the lowering of fertility (Lopez et al., 2004) and it is a factor that has a significant effect on the farm economy (Jonsson et al., 2011).

Numerous oestrus detection aids are used in attempt to improve conception rates, ranging from simple systems, such as visual observation, to more specific systems, such as automated controls with collars or pedometers (Holman et al., 2011).

The activity (as measured by pedometers) of dairy cows during oestrus was studied for the first time in 1950 (Farris, 1954). Farris has shown that the oestrus period in dairy cows is characterized by a substantial increase in the number of steps. Subsequent studies have confirmed that the measurement of the increase in the number of steps is a useful tool for the detection of oestrus especially if associated with a specific algorithm (Moore and Spahr 1991, Lehrer et al 1992, Liu and Spahr 1993, At-taraset al., 2001, de Mol et al., 2001, Firk et al., 2002, Roelofs et al. 2005).

Another system for oestrus detection is the analysis of progesterone in milk. There were different studies about the milk progesterone measurement (Bulmanand Lamming, 1978; O'Conner, 1993; Royal et al., 2000; Friggens and Chagunda, 2005).

In the literature, concentrations below 3 ng/ml were considered indicative of an oestrus (Lamming and Bulman 1976). Recently Friggens et al. (2006) has verified, during the test in Danish dairy herds, an oestrus breakpoint level of 5 ng/ml.

The Herd Navigator™ (HN) system - recently introduced on the market by Delaval and FOSS - is the expression of the Proactive Herd Management Model. It automatically programs the analysis of representative milk samples from

selected specific cows of the herd. These analyses regard different parameters – not only progesterone –and help farmers in monitoring reproduction, mastitis, and energy and protein balance of the animals (Mazeris F. 2010). Nevertheless progesterone is the only parameter analysed to be used for oestrus detection. The aim of this study was to individuate the Sensitivity (S) and Positive Predictive Value (PPV) with the Herd Navigator™ system, in a commercial dairy farm.

3.3. Materials and methods

3.3.1 Experimental site

The test was carried out in a commercial dairy farm in the Central Sweden during the period from 1 April 2011 to 8 March 2012.

For each milking cow was made a milk sampling with the Herd Navigator™.

The herd was formed by 63 primiparous and 93 multiparous dairy cows both Holstein Friesian and Swedish Red and White.

The cows were milked in a three voluntary milking systems (DeLaval VMS) with free flow (mean no. visits / day = 2.3). Mean annual milk sales per cow were 10'000 l with an average peak yield of 50 l/day.

3.3.2 The Herd Navigator™

The Herd Navigator™ system automatically creates a cow sampling list. After each milking session and based on the cow sampling list, the VMS sampler takes a representative sample (80 ml). From the VMS sampler, the representative milk sample is delivered to the Sample intake unit (SI). The SI holds the samples and delivers them one by one to the Analyser Instrument (AI), which is placed close to the SI. The temperature and humidity in the AI is automatically controlled to 25°C, 20 RH and a dry stick technology is used to perform the analysis. The sticks are stored in cartridges inside the AI. The progesterone determination was based on an immunoassay. The measured values from the AI are fed into the biological models (BIOMODEL). The BIOMODEL processes all data available and provides risk values of several physiological and pathological status. Different levels of progesterone analysed by the BIOMODEL can show oestrus, follicular and luteal cysts, anoestrus and pregnancy status.

3.3.3 Data Collection

For each cow, the milk samples were collected for a period starting 20 days before the voluntary waiting period (VWP) and ending 55 days after successful insemination. All data were stored into the database of the herd management software DelPro 3.5 (DeLaval) and used to show in a graph for each cow:

- the milk progesterone raw level (PR). In accordance with Friggens et al. (2008), PR was considered the gold standard: a true oestrus was defined as a period with the level of progesterone less than 5 ng/ml in one or two samples followed by a period of progesterone above 5 ng/ml.
- an index called progesterone smoothed (PS). The PS is an indicator calculated by the BIOMODEL mainly using the PR values smoothed with data like lactation number, calving date, insemination date, pregnancy check result and more, in order to better identify the oestrus time.

3.3.4 Data Analysis

The initial dataset stored consisted of every oestrus events identified as positive by:

- HN;
- when PR was less than 5 ng/ml.

On this basis, a number of 1494 events were totally recorded.

Obviously this initial dataset potentially included data regarding false-positive identification not depending to the main effect linked to the two systems in comparison. To be confident to eliminate the majority of these false-positive events, the dataset was filtered out for cows:

- with Days in Milk (DIM) less than 60 days,
- in the pregnancy period (from 30 days after insemination and positive pregnancy diagnostic),
- in period with Follicular and Luteal cysts HN alarms;
- culled or with an abortion event during the lactation.

After the filtering, a total of 496 oestrus events were used for the study.

The HN oestrus alarms registered were compared with the PR gold standard and only when this last confirmed them the measure was considered a true oestrus.

The efficiency of the system was based on the following two performances indexes:

- Sensitivity (S) as the number of oestrus periods observed divided by the total number of true oestrus identified;
- Positive Predictive Value (PPV) as the number of true oestrus divided by the number of the true oestrus and false oestrus periods.

3.4. Results and Discussion

A total of 207 true oestrus events were finally identified considering PR analysis. The HN signaled only 198 events of the 207 failing in identifying 9 cows with secure oestrus and for this reason the sensitivity of the HN alarm was calculated as 96% and the PPV was 100%. Those values were higher in comparison to the values found by Friggens et al. (2008) using a HN prototype (Sensitivity of 93.3% and PPV of 72.2%). The main reason for these differences was probably related to the methodology used to filter the data for the elimination of events related to reproduction problems.

As previously found by Friggens et al. (2008), the HN sensitivity is very high if compared with the results reported for other methods of oestrus detection. Holman et al., (2011) using different methods of oestrus detection and calculating for them S and PPV had the following results: neck collar (58.9 % and 93.5%), pedometer (63.3% and 73.5%), visual observation (56.5% and 92.9%). The most useful results obtained by Holman et al., (2011) were a combination of visual observation and neck collars with a 75% of S and 91.7% of PPV. The best result of sensitivity found in literature (94%) was reported by de Mol et al. (1999) using a combination of activity, milk yield, milk temperature and conductivity of vaginal mucus. In any case, these data were less than the results found in this study with the HN.

3.5. Conclusions

This study retrospectively evaluated the performances of HN system in detecting oestrus events. The results as shown a high performance for the oestrus detection with high level of S and PPV. In addition, the results obtained for HN, when compared to the ones obtained for other activity tools reported in literature, show the best performances never reported.

3.6. References

- At-Taras, E.E., Spahr, S.L.** (2001). Detection and characterization of heat in dairy cattle with an electronic heatmount detector and an electronic activity tag. *J. Dairy Sci.* 84, 792–798.
- Brehme U., Stollberg U., Holz R., Schleusener T.** (2008). ALT pedometer—New sensor-aided measurement system for improvement in oestrus detection. *Computers and electronics in agriculture* 62:73–80

Bulman D.C., Lamming G.E. (1978). Milk progesterone levels in relation to conception, repeat breeding and factors influencing acyclicity in dairy cows. *Journal Reproduction Fertility* 54, 447–458.

deMol R.M., Keen A., Kroeze G.H., Achten J.M.F.H. (1999). Description of a detection model for oestrus and diseases in dairy cattle based on time series analysis combined with a Kalman filter. *Computer and Electronic Agricultural* 22, 171–185.

deMol R.M., Ouweltjes W., Kroeze G.H., Hendriks M.M.W.B. (2001). Detection of estrus and mastitis: field performance of a model. *Applied Engineering Agricultural* 17, 399–407.

Farris E.J. (1954) Activity of dairy cows during estrus. *Journal American Veterinary Medicine Association*. 125:117–20.

Firk R., Stamer E., Junge W., Krieter J.(2002).Automation of oestrus detection in dairy cows: a review. *Livestock Production Science*. 75:219–32.

Friggens N.C., Chagunda M.G.G. (2005).Prediction of the reproductive status of cattle on the basis of milk progesterone measures: model description. *Theriogenology*. 64, 155–190.

Friggens N.C., Bjerring M., Ridder C., Højsgaard S. and Larsen T. (2008). Improved Detection of Reproductive Status in Dairy Cows Using Milk Progesterone Measurements. *Reproduction Domestic Animal* 43 (Suppl. 2), 113–121.

Jonsson R., Blanke M., Poulsen N.K., Caponetti F., Højsgaard S.(2011). Oestrus detection in dairy cows from activity and lying data using on-line individual models. *Computers and Electronics in Agriculture* 76:6–15.

Kamphuis C., DelaRue B., Burke C. R., and Jago J.(2012). Field evaluation of 2 collar-mounted activity meters for detecting cows in oestrus on a large pasture-grazed dairy farm. *Journal of Dairy Science*. 95 :3045–3056.

Holman A., Thompson J., Routly J. E., Cameron J., Jones D. N., Grove-White D., Smith R. F., Dobson H. (2011). Comparison of oestrus detection methods in dairy cattle. *Veterinary Record* 2011 169: 47.

Lamming G.E., Bulman D.C. (1976). Use of milk progesterone radioimmunoassay in diagnosis and treatment of subfertility in dairy cows. *Br Vet J* 132, 507–517.

Lehrer A.R., Lewis G.S., Aizinbud E. (1992). Oestrus detection in cattle: recent developments. *Animal Reproduction Science*. 28:355–61.

Liu, X., Spahr, S.L., (1993). Automated electronic activity measurement for detection of estrus in dairy cattle. *Journal of Dairy Science* 76 (10), 2906–2912.

Lopez H., Satter L.D., Wiltbank M.C. (2004). Relationship between level of milk production and estrous behaviour of lactating dairy cows. *Animal Reproduction Science* 81:209-223.

Mazeris F. (2010). DeLaval Herd Navigator® Proactive Herd Management. The First North American Conference on Precision Dairy Management.

Moore A.S., Spahr S.L. (1991). Activity monitoring and an enzyme immunoassay for milk progesterone to aid in the detection of estrus. *Journal of Dairy Science* 74 (11), 3857–3862.

O'Connor M.L. (1993). Heat detection and timing of insemination for cattle. Penn State University College of Agricultural Sciences. *Extension Circular* 402, 19

Roelofs J.B., van Eerdenburg F.J.C.M., Soede N.M., Kemp B. (2005). Pedometer readings for estrous detection and as predictor for time of ovulation in dairy cattle. *Theriogenology* 64 (8), 1690–1703.

Royal M.D., Darwash A.O., Flint A.P.F., Webb R., Woolliams J.A., Lamming G.E. (2000). Declining fertility in dairy cattle: changes in traditional and endocrine parameters of fertility. *Animal Science* 70, 487–501.

CHAPTER 4

Proactive herd management system in a small dairy farm in northern Italy: technical and economic results

4. Proactive herd management system in a small dairy farm in the northern Italy: technical and economic results

4.1. Abstract

Reproductive and economic data were recorded before and one year after the Herd Navigator™ installation in a commercial dairy farm - with automatic milking system - located in mountain areas. The number of days open (DO) was reduced from 166 to 103 days. The same reduction has been identified in the number of days between the first and the second insemination that was passed from 45 days before the Herd Navigator™ introduction, to 28 days. Another important value was the 80% reduction in the number of days required to identify an abortion (from 31 to 6 days). The preliminary results obtained confirm the usefulness of the system for the reproduction management. A model was developed using literature and commercial data to evaluate the potential economic benefits of the introduction of this technology. The model considers the benefits deriving from the decrease of reproduction problems and the reduction of days open. Considering the effects related to the above aspects, in a case study involving 70 dairy cows a 5 year time of investment return has been calculated.

4.2. Introduction

The reproductive management is one of the most important point in a dairy farm.

In particular an easy and accurate oestrus identification can influence farm's economy (Jonsson et al., 2011), because is strictly linked to reproduction and milk production.

A bad oestrus identification can reduce the herd fertility (Lopez et al., 2004). This is the initial point of the substantial economic inefficiencies.

Many oestrus detection system in the herd management were developed: easy systems, as the visual observation and more specific systems such as automated controls with pedometers based on the cows' activity measurement were applied (Holman et al., 2011).

The activity oestrus detection was studied firstly in 1954 by Farris. In this study Farris showed that the cows' activity was directly related to the oestrus period.

Later studies confirmed the usefulness of this index (Moore and Spahr 1991, Lehrer et al 1992, Liu and Spahr 1993, At-Taras et al. 2001, de Mol 2001, Firk et al. 2002, Roelofs et al. 2005).

However different studies were conducted in order to develop a new technology for the oestrus activity system. The only use of the activity system for the oestrus detection for each animal was not so sensitive (as the cows number detected related to the real oestrus cows).

This was related to the silent heat and to the presence of cows without any evident activity changed.

The mathematical algorithm makes the difference in the operation and sensitivity of the activity systems. The algorithm collects biological data from devices and reworks depending on the physiological state of the individual cow (Brehme al., 2008). Therefore, from a technological point of view, companies, maintaining the physico-mechanical devices, were evolving towards the development of systems that gave incremental innovations regarding essentially algorithms that increase sophistication and specificity.

DeLaval (world leader in milking systems) was moving to a radical innovation that, since 2008, in collaboration with FOSS (world leader in systems for the food products analyser), has on the market an innovative system for the reproduction management and animal health in dairy farm: the Herd Navigator™ (HN). This instrument, through analysis of some chemical parameters of milk carried out on samples collected properly during milking, is able to highlight different physiological states that are showed by the system such as: ketosis, mastitis, urea, detection of oestrus and reproductive problems connected. Among these, the one that is primarily explored in the present work is related to the detection of oestrus.

On this subject, tests carried out in Denmark between 2008 and 2009 on three farms, with more than 150 animals in lactation, using the HN, showed a detection rate of heat (Heat Detection Rate: HDR) between 95% and 97%, and a conception rate (Conception Rate: CR), ranging from 40% to 63%. The HN introduction, moreover, has reduced the number of days open on an average of 22 days (Blom and Ridder, 2010). Further tests carried out in 2009 on three farms in Denmark and two in Holland, with an average of about 180 heads of Holstein Frisian, however, had showed an HDR between 97% and 100% and an improvement in the rate of pregnancy (Pregnancy Rate: PR) from a minimum of 7.7% to a maximum of 44.4% (Vreeburg, 2010).

This study aims to verify the HN potential benefits on reproduction management in dairy Italian farm located in mountain areas with robotic milking.

4.3. Materials and methods

In a technical point of view the HN is composed by:

- Sampler (S): is located inside the VMS or close to the parlour. It takes 80ml of milk samples per each cow, if required;
- Sample intake (SI): The SI is a queuing unit where milk samples are sorted out (first-in, first-out) and are transferred to the AI;
- Analyser intake (AI): The AI is where the substance analysis takes place. It must be located in a hygienic area, for instance, the milk room. The AI is connected to

the SI through a milk transfer tube;

- Bio-model: The Biomodel can be described as the brain of the HN. It includes mathematical and biological algorithms which process the analysis results from the AI unit together with the cow specific data.

Delpro (DeLaval management software) is the HN interface for the farmer. The farmer get into Delpro the data (veterinarian check, breeding, dry-off etc...) and the HN receive and manage it.

The HN system was installed in September 2011 in a farm in the Northern Italy. There were 70 dairy cows, Holstein Frisian and Brown Swiss, before the HN installation. During the first year the cows number drop to 60. The cows were milking with an Voluntary milking system (VMS, DeLaval). The test was carried out from September 2011 to September 2012.

Before the HN installation were recorded the data farm in two sessions:

- General aspects, asked to the farmer (table 1);
- Reproductive aspects; asked to the veterinarian (Table2).

In addition more data were collected with the Italian breeder association (AIA) DeLaval Delpro management software was used to look into the farm backup. In particular was recorded and stored the reproduction data (heat identification, pregnancy rate,...) found by the HN. The reproduction data were individuated with the progesterone analysis. When the HN sent the alarm for the reproduction status (heat, pregnancy, abortion...) was called the veterinarian to check the situation.

Moreover were individuated the PR, HDR and CR without the standard calculation of the 21 days but with the real heat observation per each cow.

The economic model

An economic model of the potential benefits was used according to the technique of partial budgets. The cash flows changes were identified at the HN

introduction, and were evaluated the costs and benefits over a period of 8 years from the HN installation.

4.4. Results and discussion

The results shown that was a typical farm located in the mountain, with few cows in lactation in a small building. Eventhough the level of milk production and the Difference in milk yield between older cow and heifer registered were remarkable for the area considered (table 1).

Table 1- Farm overview

Milking Cows (included the dry cows) [n]	70
Average milking production [kg/lactation]	110.000
Difference in milk yield between older cow and heifer [kg]	1.300
Days per year with reduced attention to heats (harvest, holidays etc.) [gg]	90
Annual culling rate [%]	30%
Salary [€/h]	€ 20,00
Milk price [€/kg]	€ 0,40
Price of a heifer 24 months [€/manza]	€ 2.000,00
Slaughter price per cow culled due to reproduction problems [€/vacca]	€ 500,00
Price per insemination (semen + labor) [€]	€ 23,00
Cost per pregnancy check [€/diagnosi]	€ 4,00
Cost days open [€/giorno]	€ 2,00
Voluntary waiting period (VWP) [gg]	60

Table 2 – Reproduction data before the HN installation

No. of pregnancy check per cow per lactation [n]	3,0
Veterinarian cost [€]	40
Surveillance of pregnancy check [h/check]	0,04
Time spent to heat detection [h/days]	1,0
Avg. of Days In Milk (DIM) at the first insemination [days]	85
Days after latest heat for identify luteal cysts (before typically by the time of pregnancy check) [days]	40
% cystic cows culled [%]	35,0%
Days after abortion / 1st heat [days]	31
HDR [%]	45,0%
CR [%]	40,0%

PR [%]	18,0%
Days from 1st to 2nd insemination [days]	45
Average days open [days]	166

The HDR level (45%), showed in table 2, was very low. That number was related to the absence of the electronic oestrus identification before the HN installation. Another very important point was the PR level (18%). Moreover the average of days open (166 days) were at the same level of the farm located in the “Po Valley” (150-160 days).

After the HN installation, showed in table 3, the parameters compared were considerably changed. In particular were recorded a reduction of:

- 80% of days spent for the abortion identification, from 31 to 6 days;
- 38% of days from 1st to 2nd insemination, from 45 to 28 days;
- 38% of average days open, from 166 to 103 days.

Those values were affected to the level of HDR,CR and PR that were increased. In particular the PR level was changed from 18% to 61.4%.

Table 3 - Reproduction data after the HN installation

No. of pregnancy check per cow per lactation [n]	1,0
Surveillance of pregnancy check [h/check]	0,04
Time spent to heat detection [h/days]	1,0
Avg. of Days In Milk (DIM) at the first insemination [days]	65
Days after latest heat for identify luteal cysts (before typically by the time of pregnancy check) [days]	20
% cystic cows culled [%]	5,0%
Days after abortion / 1st heat [days]	6
HDR [%]	96,0%
CR [%]	64,0%
PR [%]	61,4%
Days from 1st to 2nd insemination [days]	28
Average days open [days]	103

Were showed in table 4 the results about the economic model after the HN installation.

Table 4 – Economic model results

Benefits

increase in average cows and less feed due to reduced days open.	[euro/year]	7560
Reduced labour	[euro/year]	7300
Reduced veterinarian costs	[euro/year]	4800
Reduced insemination costs	[euro/year]	2760
Reduced cull cows	[euro/year]	2092,5
total	[euro/year]	24512,5

Costs

Service and sticks (130 €/year*cow)	[euro/year]	7800
Electrical power	[euro/year]	547,5
other	[euro/year]	182,5
total	[euro/year]	8530

An initial investment of 70,000€ for the HN, with a real interest of 1.5% (net inflation), 8 years of shelf life estimated, a 10% of the initial recovery value and considered an emergency maintenance after 4 years as 10% of the investment value, was calculated :

- Return investment period of 5 years;
- An annual net value of 48.500€;
- Internal rate of return of 15%.

The level of Beta Hydroxyl Butyrate (BHB) for the ketosis management, lactate Dehydrogenase (LDH) for the mastitis management and the urea for the feeding management were not used in the economic calculation. That was an author's choice related to the good level of those aspect before the HN installation.

4.5. Conclusions

The trial was conducted in a mountain area in a typical farm of those place, with low number of cows, good production level and reproductive performance not so good.

In that situation the HN has showed a good results in terms of reproductive performances and economic data. For the reproduction point of view the HN can helps the farmer to know and act in relation of the condition of each cow. Moreover the economic data showed a substantial benefit for the farmer investment.

For the nutritional and mastitis management the HN didn't show considerable benefits in terms of data, probably this situation was related to the good farm level before the HN installation.

4.6. References

At-Taras, E.E., Spahr, S.L. (2001). Detection and characterization of heat in dairy cattle with an electronic heatmount detector and an electronic activity tag. *J. Dairy Sci.* 84, 792–798.

Blom J, Ridder C. (2010). Reproductive Management and Performance Can be Improved by Use of DeLaval Herd Navigator®. *The First North American Conference on Precision Dairy Management.*

Brehme U., Stollberg U., Holz R., Schleusener T. (2008). ALT pedometer—New sensor-aided measurement system for improvement in oestrus detection. *Computers and electronics in agriculture* 62:73–80

deMol R.M., Ouweltjes W., Kroeze G.H., Hendriks M.M.W.B. (2001). Detection of estrus and mastitis: field performance of a model. *Applied Engineering Agricultural* 17, 399–407.

Farris E.J. (1954) Activity of dairy cows during estrus. *Journal American Veterinary Medicine Association.* 125:117–20.

Firk R., Stamer E., Junge W., Krieter J.(2002).Automation of oestrus detection in dairy cows: a review. *Livestock Production Science.* 75:219–32.

Jonsson R., Blanke M., Poulsen N.K., Caponetti F., Højsgaard S.(2011). Oestrus detection in dairy cows from activity and lying data using on-line individual models. *Computers and Electronics in Agriculture* 76:6–15.

Holman A., Thompson J., Routly J. E., Cameron J., Jones D. N., Grove-White D., Smith R. F., Dobson H. (2011). Comparison of oestrus detection methods in dairy cattle. *Veterinary Record* 2011 169: 47.

Lehrer A.R., Lewis G.S., Aizinbud E. (1992). Oestrus detection in cattle: recent developments. *Animal Reproduction Science.* 28:355–61.

Liu, X., Spahr, S.L., (1993). Automated electronic activity measurement for detection of estrus in dairy cattle. *Journal of Dairy Science* 76 (10), 2906–2912.

Lopez H., Satter L.D., Wiltbank M.C. (2004). Relationship between level of milk production and estrous behaviour of lactating dairy cows. *Animal Reproduction Science* 81:209-223.

Moore A.S., Spahr S.L. (1991). Activity monitoring and an enzyme immunoassay for milk progesterone to aid in the detection of estrus. *Journal of Dairy Science* 74 (11), 3857–3862.

O'Connor M.L. (1993). Heat detection and timing of insemination for cattle. Penn State University College of Agricultural Sciences. *Extension Circular* 402, 19

Roelofs J.B., van Eerdenburg F.J.C.M., Soede N.M., Kemp B. (2005). Pedometer readings for estrous detection and as predictor for time of ovulation in dairy cattle. *Theriogenology* 64 (8), 1690–1703.

Trinderup P. (2010). Development of monitors for digestive and metabolic disorders. *Report from Agrotch A/S Udkarsvej 15, DK-8200 Arhus N., Denmark, 22p.*

Vreeburg N. (2010). Precision Management On Two Dutch Dairy Farms By Use Of Herd Navigator®. *The First North American Conference on Precision Dairy Management.*

CHAPTER 5

An electronic system for automatic calving detection: technical results in a dairy farm

Published in:

Australian Journal of Animal Production Science, Just accepted 12 January 2013

5. An electronic system for automatic calving detection: technical results in a dairy farm

G. Marchesi¹, S. Leonardi¹, F.M. Tangorra¹, A. Calcante², E. Beretta¹, E. Pofquer³ and M. Lazzari¹

¹Department of Health, Animal Science and Food Safety, Università degli Studi di Milano, Via Celoria 10, 20133 Milan, Italy

²Department of Agricultural and Environmental Sciences, Università degli Studi di Milano, Via Celoria 2, 20133 Milan, Italy

³Zootecnia II (Bovinos y Equinos), Facultad de Ciencias Veterinarias, Universidad Nacional de La Plata, Calle 60 y 118 S/N, CC 296, 1900 La Plata, Argentina

5.1. Abstract

Precise calving monitoring is important for reducing the effects of dystocia in cows and calves. C6 birth control system® is an electronic device that detects the time of the expulsion phase during the calving. A number of 53 Holstein were fitted on the day 280 ± 5 of gestation with the C6 birth control system®, which was left in place until confirmation of calving. Sensitivity and positive predictive value of the system were calculated as 100% and 95%, respectively. The partum events occurring at the group fitted with the system were compared with the analogous occurred at 59 animals without device. When alarmed by the system the farm staffs were in the calving barn during the expulsion phase in the 100% of the cases. On the contrary the cows without the device were assisted only in 17% of the cases ($P < 0.001$).

5.2. Introduction

The calving time has been considered the most crucial moment on a dairy farm. A difficult birth can cause trauma for the cow and the calf (Johanson and Berger, 2003). The cow may experience reduced milk production or uterine infection, resulting in additional veterinary costs and decreased fertility, which may lead to premature culling (Dematawewa and Berger, 1997).

The calving assistance and the calving prediction should be considered as the elements that allow operator to get an action to reduce possible injuries to the calf, caused by the cow or the environment (Mee, 2004).

Calving monitoring is particularly important for cows suffering from poor health along with primary labour insufficiencies as well as for cows with very valuable offspring (e.g. calves produced by embryo transfer) (Streyll *et al.*, 2011).

The variability of the pregnancy period and the uncertainty to identify the precise moment of birth reduce the probability to have a quickly act (Hodge *et al.*, 1982; Bleul *et al.*, 2006). Many protocols have been implemented to predict the exact moment of birth through the analysis of changes in body temperature (Fujimoto *et al.*, 1988; Aoki *et al.*, 2005), observation of ultrasound findings (Wright *et al.*, 1988), analysis of blood levels of estrone sulphate and of 17- β -estradiol (Shah *et al.*, 2007) or progesterone blood level (Matsas *et al.*, 1992; Streyl *et al.*, 2011), progressive relaxation of the ligaments of the pelvis (Dufty, 1971), and electrolyte concentrations in mammary secretions (Bleul *et al.*, 2006). High costs, difficulties of execution or demand of quality staff have limited the use of the above mentioned systems in practice.

Recently an electronic system for calving monitoring (C6 birth control[®], Sisteck s.r.l., Italy) in dairy cows has been introduced on the market. This device is sutured at vulva lips in pregnant cows close to calving time and when it is activated by fetal membranes expulsion a radio wave signal is sent to a receiver installed in the calving barn. Through the use of the Global System for Mobile communication (GSM) technology, the receiver sends a short text message to the farmer's mobile phone warning him of the coming delivery. Preliminary observations of this system, for predicting time of parturition in dairy cows, were carried out by Paolucci *et al.* (2008). More recently a study was performed to test the reliability of this system as a tool for reducing perinatal mortality and preventing the majority of post-partum reproductive pathologies (Paolucci *et al.*, 2010).

The aim of the present study was to estimate the sensitivity (S) and positive predictive value (PPV) of the C6 birth control[®] in a commercial dairy farm.

5.3. Materials and methods

The C6 birth control[®] (Sisteck s.r.l., Italy) consists of a transceiver and a receiver apparatus equipped with a GSM modem. The transceiver, powered by two internal lithium 1.5 V 0.26 Ah batteries, is composed by two distinct parts: a rectangular water-resistant plastic shell (4.9 x 2.1 x 1 cm), sutured on the vulva left side; a cylindrical mobile part, sutured on the right side. The mechanical separation of the transceiver mobile part activates a radio wave transmission to the receiver-transmitter apparatus. The receiver-transmitter is a rectangular box 25 x 20 x 5 cm powered by a rechargeable Li-Ion buffer battery (3.7 V, 0.85 Ah). It receives the signal from each miniaturized transmitter, by wave transceiver 433 MHz, in a range of 100 m. The receiver-transmitter process the signal and, through a GSM quad-band module (850/900/1800/1900 MHz), sends an alarm

text message (Short Message Service) with event date and time up to 8 different mobile phones.

The C6 birth control® tests were carried out one year (September 2010 – September 2011) in a Holstein Friesian dairy farm located in Northern Italy.

A total of 112 cows were involved in the study: 53 animals (22 primiparous and 31 multiparous) were monitored using the electronic system for birth control (Group A), and 59 animals (22 primiparous and 37 multiparous) constituted the control group (Group B) without electronic birth control assistance. The cows were randomly assigned to each group.

On day 280 ± 5 of gestation the farm staff checked the animals. If one or more cows showed the premonitory signs of early calving (discharge of the liquefied mucous plug sealing the uterus, enlargement of the udder, relaxation of the pelvic ligaments), they were moved to the calving barns (CB) named CB1 and CB2, located in two different farm area. The calving barns were consisted of a box (10x10 m) with a rough concrete floor covered with straw. The transceiver was applied by the veterinary farm just upon the ventral commissure of the vulva of the cows belonging to Group A, in the CB1. The transceiver was sutured after washing the vulva with iodopovidone (IP) 10%, using a needle-thread ASSUNYL (Assut Europe, Italy) polyamide monofilament, non-absorbable, with high tensile strength. The cows of the Group B, without the device, were visually controlled, in the CB2 calving area, for ten minutes at 6 a.m. and 6 p.m. (before each milking session), conversely the cows in the CB1 (Group A) were observed only after the C6 birth control alarm.

Data collection and statistical analysis

The following data were recorded for the animals of Group A: installation time of the transceiver [min]; time of alarm activation [hh:mm]; arrival time of the farm staff in the calving barn after the alarm [hh:mm]; end time of delivery [hh:mm]; length of parturition time from alarm to complete the fetus expulsion [min].

The sensitivity (S) and the positive predictive value (PPV) of the electronic system were calculated. Sensitivity was calculated as the number of true calving observed divided by the total of calving events. The PPV was defined as the number of true calving divided by the number of the true calving and false calving.

For the animals of the Group B were recorded: the farm staffs were in the calving barn during the calving [Yes/No]; the arrival time of the farm staff at the moment of the calving [hh:mm].

Statistical analysis were carried out using SAS ® 9.2 for Windows (SAS Institute Inc., Cary, NC, USA). Fischer's exact test was performed for testing the

relationship between calving detection methods (automatic and visual detection) and calving observation (positive and negative).

5.4. Results and discussion

The average time needed to apply the transceiver was 5.2 ± 0.5 and 4.6 ± 0.5 min., respectively for primiparous and multiparous cows, but there were no significant differences. These values are comparable with those obtained by Paolucci *et al.* (2008).

On average calving occurred 5 ± 3 days after the application of the transceiver and 2 ± 1 days earlier than the herd management software prediction. Calving was observed mainly in the evening and in the night both for primiparous and multiparous cows, respectively with about 58 % and 60 % of the total calving events recorded between 6 p.m. and 6 a.m., that usually is the period of the day quieter and with fewer people in the barn.

During the experimental period, 3 false calving alarms were recorded on a total of 56 calving. The false alarms were caused by the friction of the animal against the fence of the barn, with the consequently accidental separation of the two parts of the transceiver.

On average 22.0 ± 6.0 min. was the time required by the farm staff to reach the calving barn after the alarm activation. During the visit 96.0 % of the cows showed an anterior longitudinal calf presentation while the remaining 4.0 % showed a posterior longitudinal position of the calf. This factor did not affect the health of the calves.

The length of parturition was 50.0 ± 23.0 min. and 48.0 ± 28.0 min., respectively for primiparous and multiparous cows, even if no statistically significant differences were observed between the two categories of animals. The values found for multiparous cows are comparable with those obtained by Paolucci *et al.* (2008), but for primiparous cows are much lower (- 40 %). The difference could be explained considering that in the study carried out by Paolucci *et al.* (2008) 41.2 % of heifers have required pulling assistance and 17.7% of them presented dystocia due to calves' postural defects.

The C6 birth control® showed an S of 100 % and a PPV of 95 %. These values are higher if compared with other methods and physiological indicators used for predicting parturition times. The changes in body temperature, measured rectally as well as vaginally, were investigated by many authors (Aoki *et al.*, 2005; Birgel *et al.*, 1994; Dufty, 1971) and there is conflicting information in the literature about the predictive value of these parameter. Different authors described a drop of at least 0.4°C within 22 h before parturition (Birgel *et al.*, 1994; Dufty, 1971; Lammoglia *et al.*, 1997). In contrast, another study (Rexha and Grunert, 1993) found that observed changes in body temperature within the last 36 to 24 h

before parturition have no significant predictive value. Streyl et al. (2011) found that the change in body temperature before calving appears to be of little value for predicting calving within 24 h. However, body temperature must be monitored for at least 3 days before parturition, and it is not possible to give a predictive answer about parturition from a single examination. Additionally, it is unclear if the described decline in body temperature occurs equally in animals suffering from fever.

Attempts have also been made to predict calving time based on individual external signs including relaxation of the pelvic ligaments (Berglund *et al.*, 1987; Birgel *et al.*, 1994), swelling of the vulva, and udder distension showing that the presence of very relaxed ligaments indicates that parturition will probably occur within 24 to 72 hours.

About the progesterone profiles it has been shown that a reduction in progesterone concentrations below 1.2 ng/mL is currently the most accurate way to predict calving time within 24-12 h (Birgel *et al.*, 1994; Matsas *et al.*, 1992; Streyl *et al.*, 2011). Depending on the type of test used and if the blood samples were frozen or not, the sensitivity and the PPV were between 80-93% and 75-89% respectively.

Streyl et al. (2011), by combining parturition score of different clinical signs (broad pelvic ligaments relaxations, filling of the teats, hyperplasia of the udder) and a progesterone rapid blood test, found S between 89-91% and a PPV between 53-66% to predict the calving within 12 hours. Moreover, it should be considered that calving signals and body temperature in a dairy cow are influenced by many factors (Chikamune *et al.*, 1986; Mosher *et al.*, 1990).

All the above mentioned methods can predict the parturition time in a range between 12 and 24 hours but not at the exactly moment of the expulsion phase.

Using C6 birth control®, excluding the early false alarms, the calving observation by the farm staffs in the CB1 was 100%. Without device, during the calving the farm staffs were nearby in the CB2 only in the 17% of the cases: in the 83% when staffs arrived in the barn when the calf was already born. The presence of the farm staff during the calving with the two methods differs significantly ($P < 0.001$).

5.5. Conclusions

The transceiver application doesn't require a lot of time and the normal livestock working routine require minimal modification to include it. The professional work requirements to make the surgical application can be supported weekly by the veterinary.

The C6 birth control® proved to be a useful and reliable tool to detect the incoming of the fetus expulsion allowing the farm staff to be present at the

moment of the calving and assist the animals if necessary, preventing, therefore, possible problems for the cow and the calf. This is of great interest particularly with heifers and with cows suffering from poor health.

Despite this, it is important underline that the device just sends an alarm and excellent results can be obtained only if there is a responsible and ready to act farm staff and then a good management of the calving barn. The possibility of applying the device without suture, using for example a sticking plaster, could in the future simplify its use, avoiding the necessity of the veterinary during the application, and increasing its diffusion.

5.6. References

Aoki M., Kimura K., Suzuki O. (2005) Predicting time of parturition from changing vaginal temperature measured by data-logging apparatus in beef cows with twin fetuses. *Animal Reproduction Science* 86, 1-12.

Berglund B., Philipsson J., Danell Ö. (1987) External Signs of Preparation for Calving and Course of Parturition in Swedish Dairy Cattle Breeds. *Animal Reproduction Science* 15, 61-79.

Birgel E.H.Jr., Grunert E., Soares J.A. (1994) The preliminary stage of labor in cattle in relation to the clinical signs of labor and the course of progesterone secretion for the prediction of the calving time. *Deutsche Tierärztliche Wochenschrift* 101, 355- 359.

Bleul U., Spirig S., Hässig M., Kähn W. (2006) Electrolytes in bovine prepartum mammary secretions and their usefulness for predicting parturition. *Journal of Dairy Science* 89, 3059-3065.

Chikamune T., Kanai Y., Shimizu H. (1986) Comparison of effects of seasonal-climatic changes on thermoregulatory responses and plasma concentrations of thyroid hormones in swamp buffaloes and cattle. *Japanese Journal of Zootechnical Science* 57, 778-784.

Dematawewa C.M.B., Berger P.J. (1997) Effect of Dystocia on Yield, Fertility, and Cow Losses and an Economic Evaluation of Dystocia Scores for Holsteins. *Journal of Dairy Science* 80, 754-761.

Dufty J.H. (1971) Determination of the onset of parturition in Hereford cattle. *Australian Veterinary Journal* 47, 77-82.

- Fujimoto Y., Kimura E., Sawada T., Ishikawa M., Matsunaga H., Mori J.** (1988) Change in rectal temperature, and heart and respiration rate of dairy cows before parturition. *Japanese Journal of Zootechnical Science* 59, 301-305.
- Hodge P.B., Wood S.J., Newman R.D., Shepherd R.K.** (1982) Effect of calving supervision upon calving performance of Hereford heifers. *Australian Veterinary Journal* 58, 97-100.
- Johanson J.M., Berger P.J.** (2003) Birth Weight as a Predictor of Calving Ease and Perinatal Mortality in Holstein Cattle. *Journal of Dairy Science* 86, 3745-3755.
- Lammoglia M.A., Bellows R.A., Short R.E., Bellows S.E., Bighorn E.G., Stevenson J.S., Randel R.D.** (1997) Body temperature and endocrine interactions before and after calving in beef cows. *Journal of Animal Science* 75, 2526-2534.
- Matsas D.J., Nebel R.L., Pelzer K.D.** (1992) Evaluation of an on-farm blood progesterone test for predicting the day of parturition in cattle. *Theriogenology* 37(4), 859-868.
- Mee J.F.** (2004) Managing the dairy cow at calving time. The Veterinary clinics of North America. Food animal practice 20, 521-546.
- Mosher M.D., Ottobre J.S., Haibel G.K., Zartman D.L.** (1990) Estrual rise in body temperature in the bovine II. The temporal relationship with ovulation. *Animal Reproduction Science* 23, 99-107.
- Paolucci M., Di Giambattista A., Sylla L., Menichelli M., Banchio A., Monaci M.** (2008) Predicting time of parturition in Holstein Friesian cows by using C6 Birth Control®. *Reproduction in Domestic Animals* 43, 57-58.
- Paolucci M., Sylla L., Di Giambattista A., Palombi C., Elad A., Stradaioli G., Pascolo P., Monaci M.** (2010) Improving calving management to further enhance reproductive performance in dairy cattle. *Veterinary Research Communications* 34, 37-40.
- Rexha S., Grunert E.** (1993) The forecasting of the time of calving using a rapid progesterone test. *Tierärztliche Praxis* 21, 197-200.

Shah K.D., Nakao T., Kubota H., Maeda T. (2007) Peripartum changes in plasma estrone sulphate and estradiol-17beta profiles associated with and without the retention of fetal membranes in holstein-friesian cattle. *Journal of Reproduction and Development* 53(2), 279-288.

Streyl D, Sauter-Louis C., Braunert A., Lange D., Weber F., Zerbe H. (2011) Establishment of a standard operating procedure for predicting the time of calving in cattle. *Journal of Veterinary science* 12(2), 177-185.

Wright I.A., White I.R., Russel A.J., Whyte T.K., McBean A.J. (1998) Prediction of calving date in beef cows by real-time ultrasonic scanning. *Veterinary Record* 123(9), 228-229.

Publications:

Marchesi G., Tangorra F.M., Pofcher E., Beretta E. (2011) Use of an electronic system for automatic calving detection in dairy cattle: technical and economic preliminary results. *Book of abstracts of the 62nd annual meeting of the European federation of Animal Science.*

CHAPTER 6

**Design, development and field
test of a GPS/GSM based birth
alarm for cattle at pasture**

6. Design, development and field test of a GPS/GSM based birth alarm for cattle at pasture

6.1. Abstract

At the expulsion phase, during the calving, the system sent a Short message Service (SMS) to the farmer's phone. In the SMS there were indicated the GPS coordinates where the cow was calving. Three tests were done: a) laboratory test to evaluate the battery life and the GPS's accuracy; b) field test in a commercial dairy farm with small pasture; c) field test in a commercial cattle farm in the Apennines. The laboratory tests showed a battery life of one month. The GPS accuracy was 1,237 m. In field "b" were tested 18 calving. In field "c" were tested 8 calving. In the total of 26 calving the GPS-CAL sent the SMS with the correct cow calving position.

6.2. Introduction

Always the birth symbolizes a crucial factor in the zootechnical sector. The assistance of man to the animal and the unborn during this event is fundamental to ensure the health and then, to preserve the corporate capital that, in the same, sees one of this core components.

So, in herd management, being able to predict effectively the moment of birth must be considered as a fundamental management element since it allows the operator to intervene promptly in order to reduce possible lesions to the calf, which could be caused by the mother or the surrounding environment (Mee 2004).

This prevision is very important in particular for animals that are confined in wide pasture areas where, because of the extension, it is more difficult to intervene promptly in case of necessity.

Obviously, the variability of the gestation period and the uncertainty in identifying the exact moment of the birth reduces the chances to act in time and to limit possible complications arising (Hodge et al., 1982, Bleul et al., 2006).

Many protocols have been implemented to predict exact moment of the birth through the analysis of changes in body temperature, (Fujimoto et al., 1988, Aoki et al., 2005) observation of ultrasound findings (Wright et al., 1988), analysis of blood levels of oestrone sulphate and of 17- β -estradiol (Shah et al., 2007) or progesterone blood level (Matsas et al., 1992, Streyll et al., 2011), progressive

relaxation of the ligaments of the pelvis (Dufty,1971), and electrolyte concentrations in mammary secretions (Bleu et al.,2006).

High cost , difficulty execution or demand of quality staff have limited the use of the above mentioned systems in practice.

All of these methods are in fact probabilistic ; in other words they allow the breeder to be able to predict, with some degree of uncertainty, the moment of birth.

Recently an electronic system for calving monitoring (C6 birth control®, Systeck S.r.l., Italy)in dairy cows has been put on the market.

This device is attached at vulva lips in pregnant cows close to calving time and when it is activated by fetal membranes expulsion a radio wave signal is sent to a receiver installed in the calving born.

Through the use of the Global System for Mobile communications (GSM) technology, the receiver sends a short text message to the breeder's mobile phone warning him of the coming delivery.

Contrary to the systems previously described, the C6 birth control points out and notifies the breeder of the exact moment when the labor begins with a very high level of reliability.

In fact, Marchesi et al (2013)has shown accuracy (100%)and Positive predictive Value(95%)of the C6 birth control® in a dairy commercial farm in Italy.

The application and operation features of the described devices constrains use exclusively for extensive breeding; however they are realities easily manageable as the birth takes usually place in special boxes.

Currently nothing like this has been proposed or studied or animal grazing, despite this type of breeding is very important: just think that at European level the number of grazing animals in the cow-calf exceeds 12000000 of animal raised on over 54000 ha of surface.

Particularly in Italy cattle at pasture is limited to small but significant local realities like pastures on the alpine chain where some dairy cows by Bruna Alpina are raised in the wild and some beef cattle particularly fine(for example Chianina in Tuscany, Pezzata Rossa in central Italy, Podolica in Calabria).

The device described in this work is a birth alarm specially designed for animal raised at pasture named GPS-CAL(GPS Calving Alarm Device).

In summary, the device is able to detect with precision the time at wich the birth begins and to alert the breeder through a SMS(short message service)containing, in addition to the date and time of the event, the identification of the animal and the GPS coordinates of the point at which the moment of the expulsive phase is started.

The system was designed, developed, tested and patented by the Authors with the collaboration of “Università degli studi di Milano” and of a private company (Sisteck, Sassuolo-MO, Italy).

The coordinates transmitted by the device are expressed in geographical size compatible with Google Maps. Thereby it is possible to visualize on the digital map the point at which the birth is being carried out.

Moreover, using simple applications for mobile phones of last generation, it is possible to adopt the coordinates and to reach, following the instructions on screen, the point in question.

Obviously, this last application is useful especially for extensive breeding.

Generally, however this system can be interesting also for breeders with traditional pastures, who can effectively monitor risk situations (for example following the birth of primiparas) as well as intervene only and exclusively when the event has begun, avoiding unnecessary vigils and waiting, especially at night.

6.3. Materials and methods

Project overview

A Phase I study was conducted from February 2011 to January 2012 in order to design and to develop the GPS/GSM birth alarm system (GPS-CAL, Birth Alarm Device).

A Phase II study was conducted from February 2012 to October 2012 to test the GPS-CAL prototype under real operating conditions. In this phase, the device was tested in two farms with grazing area.

Phase I study

GPS/GSM birth alarm system: hardware components and operating logic.

The developed device, from a technological point of view, is composed of a sensor (a radio transmitting apparatus operating in radiofrequency) to fix, through a small and bloodless operation of external surgery, to outer lips of the vagina of the animal and of a small receiving system fixed to the neck of the animal with a normal collar for zoo-technical use.

The vulvar sensor is composed of two distinct parts (Figure 1) which separate once the vaginal dilatation has begun (upon the occurrence of labor).

The mechanical separation of the two parts has as result the activation of a transmitter module that sends the device fixed on the collar of the animal a RF alarm signal.

The force required to separate the two parts is about 4-5N.

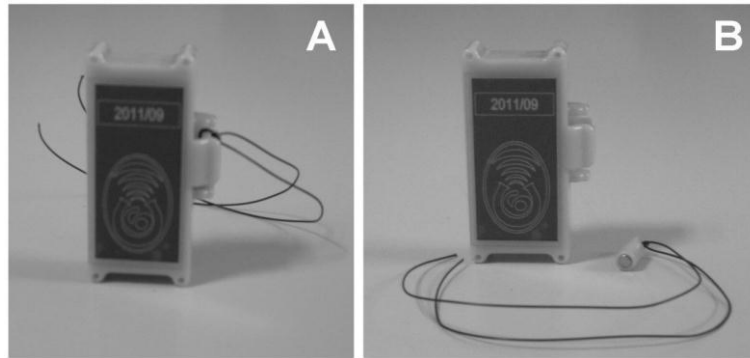


FIGURE 1: A)The vulvar sensor with the two parts in contact
 B)The sensor with the two parts separated.

It is during this phase that the sensor transmits the birth alarm signal to the device fixed on the collar.

This value allows to reduce the chances of accidental unhooking (and so of unjustified alarm sending) and, at the same time, to avoid lesions to the genital apparatus of the animal during the birth.

Once the births ends the parts can be assembled again and the sensor is ready for a next use .

The alarm signal is modulated in FSK and it is transmitted on the free frequency of 33 MHZ.

Ultimately it is composed of: 1 byte for the sensor ID,1 byte for the recipient address and 1 byte for the sensor dedicated to the alarm message.

The vulvar sensor is equipped with internal battery and has been designed to transmit, in the course of its life, about 250 birth alarm.

The transmitter circuit is incorporated in the resin inside a container of plastic material in order to ensure mechanical robustness and water-proof.

The RF antenna is placed inside the container.

The intervention for the application of the vulvar sensor involves the fixing of the same to the animal's vulva big lips with some points suture.(FIGURE 2B).

Obviously the sensor is placed in order not to limit the natural phisiological needs of the animal.

The intervention, directly used by the staff of the stable, needs about 5 minutes for each animal.



Figure 2: Close up of the vulvar sensor applied to a cow. Totally it can be seen 3 points suture for the fixing of the two parts of the sensor to the animal's big lips.

As mentioned, when the birth begins, the two parts of the vulvar sensor separate and the alarm signal is transmitted.

It is received by the device fixed to the neck of the animal (Figure 2).

The device is composed of a mother board on which are placed:

- 1) A RF receiver specially designed, which is able to receive and demodulate the message coming from the vulvar sensor.
 - 2) A GPS L1 receiver, 48 channels that enforce the SIRF-Star IV board(Sirf Technology, San José California)with external antenna.
- The receiver is able to use the differential correction SBAS/EGNOS
- 3) A radio modem GSM/GPRS, equipped with external antenna
 - 4) A microprocessor

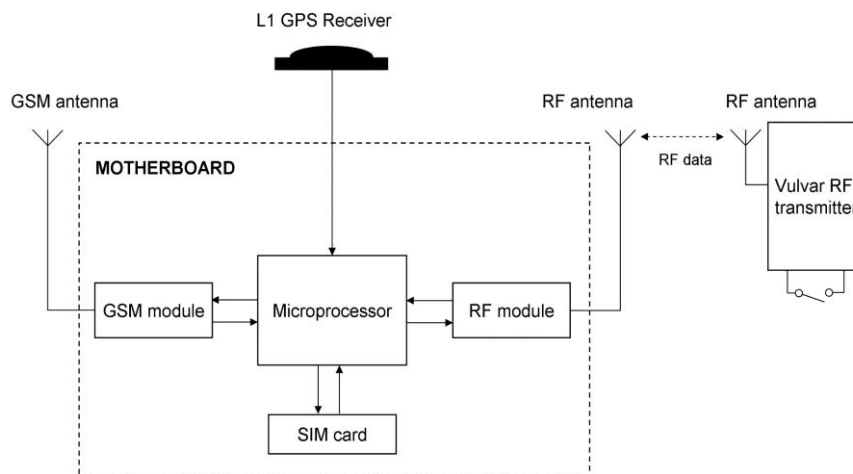


Figure 3: Block diagram of birth alarm system.

The device is powered by a rechargeable 3.6V-2200mAh lithium-ion battery whose life is estimated, at the project level, in 30-40 days.

The entire circuit has been assembled inside a heavy plastic material having degree of protection IP68 on whose surface there is a watertight mini-USB connector to allow the charging of the battery through a common universal charger for mobile phones.

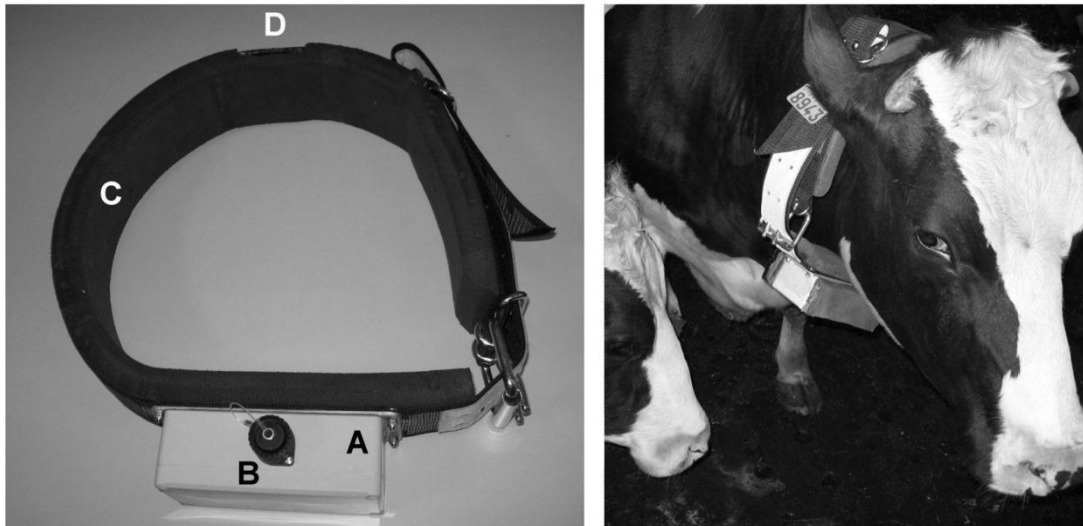


Figure 4: On the left, the GPS/GSM collar made

- A) plastic IP68 container
- B) waterproof connector for battery charging
- C) Neoprene band
- D) Gps/GSM antenna

On the right, cow with collar

The container has been solidly attached to a collar for cattle where it has been pasted neoprene padding in order to minimize the effects of rubbing the collar on the skin of the animal.

In the opposite position to the container (that is on the top of the animal's neck) is the GPS/GSM antenna.

The latter has been positioned between the collar and the neoprene band to ensure the integrity once the collar is fixed on the neck of the animal.

The operation logic of the entire system is shown in Figure 5.

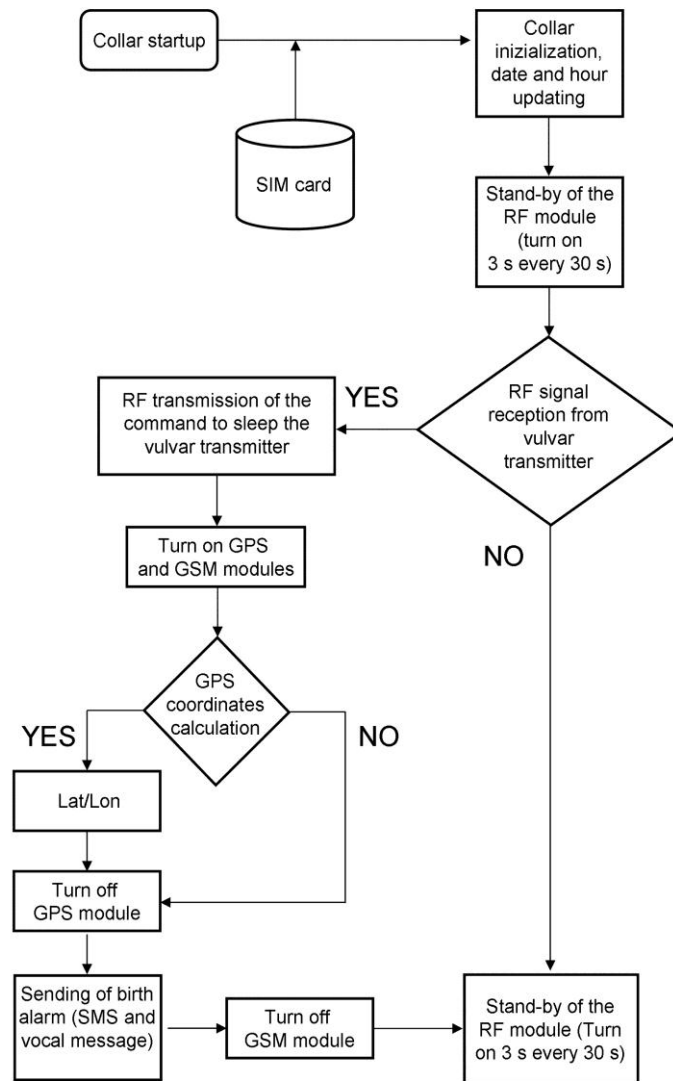


Figure 5: the operation logic of the designed system

In summary once the device is powered on the collar and date and time are updated, the system initialization ends with the reading of further data previously stored on a common SIM card. These are: a) the GSM band on which the transmission takes place (it depends on the town you are) ; b) the activation or not of a working test in daily frequency followed by the sending of a birth alarm SMS to the user.; c) the hierarchical list of phone numbers to which must be sent the birth alarm SMS (up to 8 different phone numbers); d) the chance to send the breeder, at the same time of the alarm SMS sending, a further bitonal vocal message.; e) time offset from Greenwich.

It can be seen, therefore, that all of the settings which can be managed by the user are on the SIM card and are modifiable by acting directly on it.

When the initialization phase ends, the device goes into standby.

Essentially the GPS and GSM modules are turned off, while the only RF module

is in waiting line for 3 seconds every 30 seconds.

Accordingly, in case of birth beginning with relative alarm message sent from the sensor vulvar, the system will receive the RF signal with a maximum delay of 27 seconds.

Once the alarm signal is received, the device sends first a sleeping command to the vulvar sensor through the RF module.

In this way its battery can be preserved and the reactivation on the device can be avoided once the SMS is sent the breeder.

Then, the microprocessor switches on the GSM and GPS module, the latter updates time and date of the device and calculates the coordinates (in a format compatible with Google maps).

In case it is not possible to make the correct triangulation (for example if the animal is indoors or under cover crop), the system is still able to send the breeder a SMS even if it is devoid of coordinates: in this way the communication of the birth event is not lost.

After that the GPS receiver turns off and the message is sent (SMS and/or vocal message) to the phone numbers stored (Figure 6).

To note that the SMS indicates, in addition to the time and the date of the event, the identifier of the device, the coordinates and the state of charge of the battery, expressed in percentage.

Finally the GSM module turns off too and the entire system returns to standby.

The duration of the whole reception cycle alarm-SMS sending is about 100-110 s.



Figure 6: birth alarm message received on the breeder's mobile phone.

In the case in which, once the alarm message is transmitted, the cow has changed its position, it is possible from the breeder sending an appropriate command via SMS to the collar. The latter will answer sending a further SMS with current animal's coordinates.

Anyhow, Marchesi et al. (2013) and Paolucci et al. (2010) have verified that between the beginning of the expulsive phase of the calf and its birth spend 45-50 minutes.

Further, after calving the calf, it is the cow's first priority.

During the first hour after calving the cow licks her calf intensively and this behaviour declines gradually during the next few hours.(Edwards and Brooms, 1982, Illman and Spinka, 1993; Lidfors and Jensen, 1988).

All this allows the breeder to find the animal in labor following the instructions of the GPS coordinates indicated during the beginning of the expulsive phase.

As mentioned, the coordinates transmitted by GPS-CAL are expressed in a geographical size compatible with Google Maps (latitude/longitude expressed on decimal degree, WGS84 datum).

This allows both to project the point directly on the photo of the geo-referenced area provided by Google Maps (in case it is enough, for the breeder, to find the area where the animal has given birth) and to import the coordinates in any portable receiver in order to guide the breeder to the exact point where the birth has taken place (useful in the case of extensive grazing). If the animals to monitor are a lot, and so more collars are necessary, it is possible to set a one-to-one correspondence between the vulvar sensor and the collar itself.

Essentially, as the sensor can transmit its ID, it can be done in such a way that the collar is active only if the alarm signal comes from a vulvar sensor default.

Thus established, between the collars and the various sensors installed, a 1 to 1 relationship.

GPS-CAL Application in real conditions

To verify the birth alarm system in real conditions we have tested the GPS-CAL in two different contexts: in an intensive grazing from Lombardia of dairy cows by Holstein Frisian equipped with external reserved paddock (2,9 ha), for the trial period, to the cows to give birth, and in a herd of Chianina beef cows raised on pasture in Tuscany.

With regard to the first production reality we applied three GPS-CAL system to 18 cows in sequence (6 cows and 12 heifers), that is by moving each device (collar and vulvar sensor) on an animal only when the previous one had given birth.

In this way, each system monitored 6 parts.

We chose to favor heifers as, being primiparas, are the cattle considered most at risk and require more attention by the breeder.

Being the paddock small, the test aims more to the reliability assessment of the system than to the identification of the point where the birth took place.

Anyhow, all the points received via SMS have been projected on Google Maps in order to verify if the birth took place actually inside the enclosure or not.

The test which involved the Chianine cows raised on pasture took place in a lot of about 20 ha on the Tuscan Apennines.

The pasture is at an altitude of 900 meters above sea level and included both a part of permanent meadow and a large portion of broad-leaved forest.

The business center is from the pasture around 1500 meters far.

In this context we applied two alarm devices monitoring in 8 beef cattle (3 cows and 5 heifers).

6.4. Results and discussion

GPS-CAL in an intensive dairy commercial farm

In table 1 were summarized the farm tests. In the table were showed: data, calving time, cow's age and the cow's number, calving difficulties and note. The last two points were imported from the farm management software (Cincinnati, Italservice, Cremona, Italy) where the farmer put the information after each calving.

The GPS-CAL had recorded 100% of the calving events (18 cows monitored, 18 calving alarm). Was required the farmer helps during fifteen calving and only in five events the calving was without specific problems (23/02/2012, 28/02/2012, 17/03/2012, 15/04/2012, 17/04/2012).

One calving event had required the veterinarian operation (09/03/2012), while in the 22/03/2012 one calf stillbirth. Was observed the most of the calving problems in the heifers (six events recorded).

Was not registered any operational problems during the trials: The GPS-CAL sent the SMS with all the information and in less time. The three GPS-CAL collars were charged only one time after 25 operation days (anyway were registered a residual battery of 15-20%).

Table 1. Farm tests results

Birth alarm		Animal		Difficult calving	Note
Data	Time	Number	Age		
23/02/2012	05:27	509	Heifer	low	-
28/02/2012	22:22	323	cow	low	-
01/03/2012	06:31	524	Heifer	middle	Farmer help
03/03/2012	19:39	538	Heifer	high	Farmer help
08/03/2012	07:40	528	Heifer	high	Farmer help
09/03/2012	07:47	503	Heifer	high	Caesarean

11/03/2012	23:53	510	Heifer	low	-
16/03/2012	01:15	520	Heifer	middle	Farmer help
17/03/2012	23:01	523	Heifer	high	Farmer help
21/03/2012	22:04	518	Heifer	middle	Farmer help
22/03/2012	16:54	517	Heifer	high	unborn
25/03/2012	17:07	287	cow	middle	Farmer help
01/04/2012	11:15	521	Heifer	high	Calving with problem
06/04/2012	06:52	300	cow	middle	Farmer help
07/04/2012	18:24	402	cow	middle	Farmer help
10/05/2012	21:57	515	Heifer	middle	Farmer help
15/04/2012	02:30	414	cow	low	-
17/04/2012	16:15	357	cow	low	-

GPS-CAL in a cattle farm a grazing area

In the table 2 were showed the grazing tests.

Table 2: Grazing tests results with the geographical data.

Birth alarm	Animal	Lat	Lon	Difficult calving
Data	Time	Number	age	
10/08/2012	19:37	817	Heifer	44.05467 11.18383 Media
18/08/2012	23:12	403	Heifer	44.05479 11.18424 Alta
01/09/2012	05:44	840	Heifer	44.05470 11.18385 Alta
15/09/2012	17:32	705	Heifer	- - -
17/09/2012	00:23	593	cow	44.05442 11.18362 Media
28/09/2012	04:57	675	Heifer	44.05447 11.18378 Media
13/09/2012	09:42	792	Vacca	44.05468 11.18386 Media
25/10/2012	23:07	392	Vacca	44.05459 11.18495 Bassa

Only in one calving event (cow n°705) the GPS-CAL has sent the SMS without the geographical data. That was happened because the cow was calving in the middle of the wood (indicated by the farmer). The many numbers of tree had covered the system signal. Otherwise for the other 7 cows the system was worked right and the geographical data were sent in the SMS. With the geographical data and the GPS receiver the farmer was found all the calving cows without problems.

In the Figure 7 has showed the calving place on the digital map. In the most of the situation the calving was done in a marginal area.

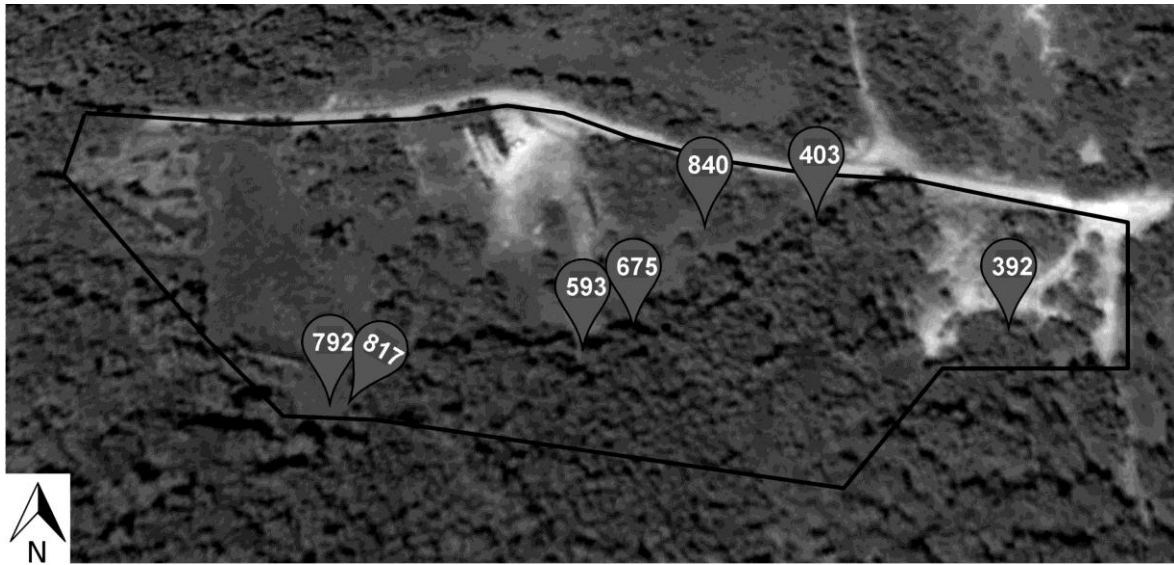


Figure 7: GPS-CAL geographical data. The white row was indicated the marginal grazing. Every tag shown the cow's number during the calving.

6.5. Conclusions

The aims of the present study were to develop and test a new birth alarm system for the cows located in the grazing area. Was not observed a problems the used of the GPS-CAL on the cows. The GPS-CAL collars had not created graze or excoriation on the cow's neck. The transceiver installation on the vulva had required not so much time (5 min/cow) and particular complications. Otherwise new solution for the transceiver application, with medical sticking plaster and not surgical suture, are still in progress.

The field tests results done in an intensive and extensive farms had confirmed the project prestige.

The only limitation found was related to the dense forest, which cover the GPS signals and the GSM air cover. On the other hand the GPS-CAL could be a new tool for the calving grazing management for the cows and other species (sheep, goat, horse, buffalo..). The GPS-CAL could be used in the extensive farm like Argentina, Australia, New Zeland and for the high value cows located in a marginal area like Chianina or Romagnola in Italy.

In conclusion, the originality and the efficiency of the GPS-CAL, confirmed by the considerable interest of the workers, had given the Authors, the Università degli Studi di Milano and the Sisteck company of Sassuolo, Modena, Italy to patent the system in Italy and in Europe.

6.6. References

- Mee J.F.** (2004) Managing the dairy cow at calving time. *The Veterinary clinics of North America. Food animal practice* 20, 521-546.
- Hodge P.B., Wood S.J., Newman R.D., Shepherd R.K.** (1982) Effect of calving supervision upon calving performance of Hereford heifers. *Australian Veterinary Journal* 58, 97-100.
- Bleul U., Spirig S., Hässig M., Kähn W.** (2006) Electrolytes in bovine prepartum mammary secretions and their usefulness for predicting parturition. *Journal of Dairy Science* 89, 3059-3065.
- Fujimoto Y., Kimura E., Sawada T., Ishikawa M., Matsunaga H., Mori J.** (1988) Change in rectal temperature, and heart and respiration rate of dairy cows before parturition. *Japanese Journal of Zootechnical Science* 59, 301-305.
- Aoki M., Kimura K., Suzuki O.** (2005) Predicting time of parturition from changing vaginal temperature measured by data-logging apparatus in beef cows with twin fetuses. *Animal Reproduction Science* 86, 1-12.
- Wright I.A., White I.R., Russel A.J., Whyte T.K., McBean A.J.** (1998) Prediction of calving date in beef cows by real-time ultrasonic scanning. *Veterinary Record* 123(9), 228-229.
- Matsas D.J., Nebel R.L., Pelzer K.D.** (1992) Evaluation of an on-farm blood progesterone test for predicting the day of parturition in cattle. *Theriogenology* 37(4), 859-868.
- Shah K.D., Nakao T., Kubota H., Maeda T.** (2007) Peripartum changes in plasma estrone sulphate and estradiol-17beta profiles associated with and without the retention of fetal membranes in holstein-friesian cattle. *Journal of Reproduction and Development* 53(2), 279-288.
- Streyl D., Sauter-Louis C., Braunert A., Lange D., Weber F., Zerbe H.** (2011) Establishment of a standard operating procedure for predicting the time of calving in cattle. *Journal of Veterinary science* 12(2), 177-185.

Dufty J.H. (1971) Determination of the onset of parturition in Hereford cattle. *Australian Veterinary Journal* 47, 77-82.

Marchesi G. , Leonardi S., Tangorra F.M., Calcante A., Beretta E., Pofcher E. and Lazzari M. (2013) An electronic system for automatic calving detection: technical results in a dairy farm. *Australian Journal of Animal Production Science (Just Accepted)*

Paolucci M., Sylla L., Di Giambattista A., Palombi C., Elad A., Stradaioli G., Pascolo P., Monaci M. (2010) Improving calving management to further enhance reproductive performance in dairycattle. *Veterinary Research Communications* 34, 37-40.

Edwards, S.A. and Broom, D.M. (1982) Behavioural interactions of dairy cows with their newborn calves and the effects of parity. *Animal Behavior* 30, 325–35.

Illmann, G.; Špinko, M. (1993) Maternal behaviour of dairy heifers and suckling of their newborn calves in group housing. *Applied Animal Behaviour Science* 36, 91-98.

Lidfors L., Jensen P. (1988) Behaviour of free-ranging beef cows and calves. *Applied Behaviour Science* 20, 3, 237-247

Patent:

22 November 2012. n.: MI2012A001989

Title: “Sistema elettronico di generazione di un segnale di allarme parto per un animale e relativo metodo” – “ Electronic system for automatic calving detection with an alarm monitor system”

Holder: Università degli Studi di Milano, Sisteck

Inventors: Lazzari, Calcante, Marchesi, Fontana, Romagnoli, Banchio

CHAPTER 7

**Design and testing of a low cost
GPS/GSM collar to combat cattle
rustling in grazing areas:
preliminary results**

7. Design and testing of a low cost GPS/GSM collar to combat cattle rustling in grazing areas: preliminary results

7.1. Abstract

Rustling is an age-old practice extensively widespread in Italy until the first half of the 20th century in traditional grazing areas. After a gradual decline occurred in the last decades due to the reduction of herds pastured, today the cattle rustling is again a problem, but not only for Italy. It is becoming a plague for the US ranchers and it is still rampant in East Africa.

Usually in Italy the cattle rustling phenomena have been limited to the territorial surveillance that is, however, not always feasible, especially in grazing areas often characterized by difficulty of access and far from the farm center.

Global Positioning System (GPS) and Geographic Information System (GIS) combined technologies are increasingly applied for livestock tracking and monitoring with greater spatial and temporal resolution, while case-studies on the use of GPS technology to combat cattle rustling are not still reported into literature.

Aim of the research was to develop a low-cost GPS/GSM collar, using commercial hardware and implementing a specific software, to track animals movements within a grazing area and get alert from animal trespassing of virtual fences.

A Phase I study was conducted from September 2008 to June 2009 to build the GPS/GSM collar, while a Phase II study was conducted in July 2009 to test the GPS collar under real operating conditions.

Production costs of the GPS/GSM collar did not exceeded € 1.000, including software and labor required for its construction. Field tests highlighted the potentiality of the GPS/GSM collar as anti-theft system.

Battery life was the most limiting factor of the system due to the high power consumption of the GPS receiver and the high frequency GPS sampling (30-s intervals) required by anti-theft monitoring.

7.2. Introduction

Rustling refers to the act of stealing livestock, especially cattle and sheep, from a farm or a pasture. Rustling is an age-old practice, and already in Roman law was severely punished because of the damage caused to farmers for the typical

connotation of the herd or flock as capital goods of their activity. The rustling, extensively widespread in Italy until the first half of the 20th century in traditional grazing areas, gradually declined in recent decades following the change of farming techniques which led to the reduction in the number of herds pastured (Bassignana, 2005). In the last years, however, the theft of livestock is become again a problem on the whole of Italian territory and it was estimated by the national law enforcement agency that thousands head of cattle were stolen and addressed to illegal slaughterhouses during 2008. Therefore, it is an offense that goes beyond the direct interests of the agriculture sector and affects the whole community and, more specifically, the product quality and the public health.

But cattle theft is an international problem that is growing as the recession bites. Cattle rustling is becoming a plague for the US ranchers as reported more and more frequently by media and cattle raisers associations. In the course of 2005 cattle and calves theft in USA totaled respectively 0,6% and 0,5% of the total cattle and calves losses from non-predator causes (NASS, 2006). Cattle theft is still rampant in some parts of East Africa, among the cross border communities between Kenya and adjoining areas of Uganda, Sudan, Ethiopia and Somalia (Siror et al., 2009).

Usually in Italy the solutions adopted till now for trying to contrast cattle rustling have been limited to the territorial surveillance that is, however, not always feasible, especially in grazing areas often characterized by difficulty of access and far from the farm center. Global Positioning System (GPS) and Geographic Information System (GIS) combined technologies provide new opportunities for very large scale livestock monitoring, such as in alpine pasture farming. Moreover, downloading data via satellite communications, even if still expensive, or global system for mobile communications (GSM), even if limited in some regions of the world, enable remote data-download, reducing the need to frequently recapture collar animals for data retrieval.

The use of GPS-collar receiver for tracking animal movement is common in wildlife studies (Moen et al., 1996; Rempel and Rodgers, 1997; Sibbald and Gordon, 2001) and recently GPS and GIS technologies have been used to assess livestock grazing behavior and management with greater spatial and temporal resolution (Turner et al., 2000; Ganskopp, 2001; Agouridis et al., 2004; Barbari et al., 2005; Clark et al., 2006; Pandey et al., 2009). Anderson (2000) developed a virtual fence through the use of GPS collars to reduce labor costs associated with fence construction in rotational grazing.

Case-studies on the use of GPS technology to combat cattle rustling are not reported into literature. Siror et al. (2009) proposed a solution based mainly on the use of Radio Frequency Identification (RFID) to address the problem of cattle rustling in the East Africa.

The goals of this research were to develop a low-cost GPS/GSM collar, using commercial hardware and through the implementation of a specific software, for limiting the cattle rustling menace in grazing areas.

7.3. Materials and methods

A Phase I study was conducted from September 2008 to June 2009 to build the low-cost GPS/GSM collar to combat cattle rustling (GPS-Shepherd). This phase entailed the following steps: choice of hardware components and their assembly; implementation of a software for managing cartography and data recorded by a GPS receiver; implementation of a short message service (SMS) interface for sending and receiving SMS between the GPS collar and the cattle farmer; static tests to determine the accuracy and precision of the GPS receiver; power consumption tests to estimate the maximum batteries operation life of the GPS receiver.

A Phase II study was conducted in July 2009 to test the GPS-Shepherd under real operating conditions. This phase entailed geo-referencing of grazing areas and fitting the GPS-Shepherd on a cow of a grazing herd to track its location over the pasture and assess the potentiality of the collar as anti-theft system.

Phase I

GPS/GSM collar design: hardware and software components

Major hardware components of the GPS-Shepherd included a Car Securer 4.00 device (Media Systems Ltd., Bulgaria), a combined active GPS and quad-band GSM antenna (FAL-ANT-5, FALCOM GmbH, Germany), and an external sealed rechargeable backup lead-acid battery (12 V, 7Ah).

Car Securer (CS) is a commercial device originally designed for AVL (auto-vehicle locator), fleet management and telemetry market. The hardware backbone contains: quad-band (850/900/1800/1900 MHz) GSM/GPRS engine; L1 C/A code 20-channel GPS receiver with SiRF Star III GSC3f/LP chip set and ARM7/TDMI CPU core; rechargeable Li-Ion buffer battery (3.7 V, 0.85 Ah) and external backup battery connection (Li-Ion, Li-Pol, Lead Acid); integrated 3D motion sensor; integrated SIM card reader; embedded micro SD card reader. Two analogue and four digital inputs, four digital outputs, RS232 serial port, USB and audio interfaces defines the connectivity capabilities of the device. The hardware layer components are supported by standard configurable embedded firmware layer. Using easy script like command framework all relevant operation parameters of the CS device (firmware update, data logging, alarm and tracking conditions and reports, communication channel parameters, geo-fencing conditions, etc.) can be defined.

The CS device was inserted in a metal box to protect it from accidental bumps and the GPS/GSM antenna was applied on the top of the box. The metal box containing the CS device and the GPS/GSM antenna were then applied to a leather collar support (length 120 cm, width 10 cm), which allowed them to be fixed to neck of the animals, and coated with heat-sealing rubber to have a smooth surface, free of protrusions that could interfere with shrubs and trees typical of the Apennines pastures. The rubber coating also ensured adequate protection from atmospheric elements. The inner surface of the collar was lined with a closed cell cross-linked polyethylene foam (Plastazote®, ZOTEF OAMS, UK), suitably shaped to have a correct gripping to the animal neck and to ensure a greater comfort. The choice of this material was dictated by its outstanding properties (lightweight and durable, water repellent, excellent chemical resistance, wide range of densities and stiffness, non-toxic and safe, easy to work and shape, etc.), that made it a material used extensively in a wide variety of medical and health care applications, many of which involve direct skin contact. A metal box IP65 (16x7,5x10,5 cm) was applied at the bottom of the collar to place an external backup battery (12 V, 7.2 Ah), for charging the internal Li-Ion battery and powering the CS device, and the USB port for downloading GPS-fix data from the GPS receiver. The external battery and the CS device were connected so that as a result of unfastening or tampering the collar, as could happen in case of cattle theft, the electric circuit was interrupted and a warning message (SMS) was sent to the cattle farmer.

The GPS-Shepherd collected and stored GPS-fix (NMEA 0183 Format, RMC sentence), differentially corrected in real-time using the European geostationary navigation overlay system (EGNOS), on a removable memory card (2 Gb micro SD) contained within the CS device.

A software for managing cartography and data recorded by GPS-Shepherd, and a short message service (SMS) interface for sending/receiving SMS to/from the GPS-Shepherd were developed in collaboration with ARVAtec S.r.l. (Italy).

The software tool (ARVA Shepherd) was developed in Delphi 7 language (Borland, USA), and was structured into three main parts.

A first section was implemented for:

- importing shape files (land parcels), ECW files (aerial photographs), and raster graphic images from an external storage memory (USB pen drive or portable hard drive) without the need for an Internet connection;
- drawing polygonal and circular virtual fences, and displaying their area, perimeter and number of vertices (for polygons) or area, circumference and radius (for circles);
- calculating the real distance between points;

- importing NMEA files;

Main features of the second section were:

- displaying virtual fences with their characteristics such as shape (polygons or circles) and location (latitude and longitude of each vertex for polygons and the center for circles);
- erasing virtual fences erroneously drawn;
- sending warning messages to a minimum of three mobile phone numbers when the cow wearing the GPS-Shepherd got out/into the virtual fences or the GPS-Shepherd was tampered with;
- setting pre-alert zones, external to the virtual fence, where no warning SMS are sent. This function enable to compensate for position errors of the GPS-Shepherd when trespassing from virtual fences are limited in distance.

The third section was implemented for the serial port setting when the GPS-Shepherd is connected to PC for downloading GPS-fix data.

The SMS interface was developed to ensure the interaction between the cattle farmer and the GPS collar, through the sending and receiving of SMS, when:

- cow wearing the GPS-Shepherd exited/entered the virtual fences;
- GPS-Shepherd was unfastened or tampered;
- external battery charge level was less than 11 V;
- cattle farmer called for the position of the GPS-Shepherd.

Whenever a SMS was sent by the GPS-Shepherd date, time, grazing area, latitude, longitude, altitude and internal and external battery charge levels were displayed on the cattle farmer's mobile phone.

Static testing

A long term static test of the GPS-Shepherd was conducted during May 2009 at the Department of Agricultural Engineering of the University of Milan located in Northern Italy. The static test was performed to determine accuracy and precision of the device before the field test. The GPS-Shepherd was placed next to an active geodetic antenna of a base station belongs to Faculty of Agriculture of Milan (ellipsoidal coordinates: latitude $45^{\circ}28'34.828061''$, longitude $9^{\circ}13'36.911848$, altitude 174.10 m) equipped with a Ashtech GPS Receiver XII Z-12, Ashtech, CA, USA. The geodetic antenna is powered at 5V and is able to receive the L1 (1575.42 MHz) and L2 (1227.60 MHz) frequencies. The GPS-Shepherd was set to collected GPS data at 30 s intervals during a test carried out from May 26 to May 28, 2009.

The accuracy of the GPS-Shepherd during the static test was examined using the guidelines established by the Institute of Navigation as outlined in ION STD 101: Recommended Test Procedures for GPS Receivers (ION, 1997). This

manual is mainly based on US Department of Defense GPS specification documents and is the recommended protocol for performing static GPS accuracy tests (Stombaugh et al., 2002).

The precision of the GPS-Shepherd during the static test was calculated using the following statistics: mean, CEP (circular error probable) or 50 %, 1 sigma (one standard deviation, 68 %), and R95 (horizontal 95 % accuracy). Moreover, data received from the satellites were used for the calculation of the DOP (dilution of precision) average value.

Power consumption testing

Power consumption tests were run, as static tests, at the Department of Agricultural Engineering of the University of Milan to estimate the maximum batteries run-time of the GPS-Shepherd.

In June 2009, two 1-h tests were carried out to measure the power absorbed by the system respectively when only the GSM signal was active (test 1) and when both GSM and GPS signals were active and SMS were sent at intervals of 15 minutes (test 2). The instantaneous voltage and current values absorbed by the system were recorded using a datalogger (dataTaker DT50, dataTaker, Australia) and a data acquisition software (DeLogger Plus ver. 3.0, dataTaker, Australia). The average power absorbed by GPS-Shepherd during tests was calculated as follows:

$$\bar{P} = \frac{E_{tot}}{\Delta t_{tot}} = \frac{\sum_{n=1}^{3600} P_n}{\Delta t_{tot}}$$

where:

P_n = power acquired at 1-s interval (W)

$\Delta t_{tot} = 1$ h

The batteries run-time (h) was calculated as:

$$Brt = \frac{Ebatt}{\bar{P}}$$

where:

E_{batt} = energy supplied from the two batteries (buffer battery + lead battery) (Wh)

Phase II
Field testing

A field test of the GPS-Shepherd was conducted during July 2009 in a private farm of Romagnola cows, located on the Northern Apennines (latitude 43.810316, longitude 12.061403). The farm owns four contiguous grazing areas, at altitudes of between 1000 and 1200 m a.s.l., for a total surface of about 10 ha and the cows are bred according to the cow-calf line that allows the exploitation of the natural grazing resources during summer, approximately from June through September depending on the meteorological conditions.

The vertices of the pastures were determined by using the Differential Global Positioning System (DGPS) technology with post processing correction to create virtual fences. DGPS system consisted of two Topcon dual frequency GPS receivers (Topcon Corporation, Japan), one (Topcon Hiper Pro) used as base station at the pasture border, and the other (Topcon GB 500) as a rover station. Due to topography of the land, a dwelling time of 2 minutes was set up for each point. Post processing of GPS data was carried out using Grafnav Lite software, ver. 6.03 (Waypoint Software, NovAtel Inc., Canada). Corrected GPS data points were imported into ARVAshepherd (ARVAtec S.r.l., Italy) to rebuild the polygons of the grazing areas and to project them on a satellite digital map georeferenced according to WGS84 (World Geodetic System 1984) reference system.

The GPS-Shepherd was applied to a multiparous dry cow of a grazing herd composed of 40 subjects (30 cows and 10 calves) to assess the GPS receiver's ability to provide accurate position of the animal and to limit cattle rustling through sending warning messages to the farmer whenever the cow exited the virtual fence or the GPS-Shepherd was unfastened or broken as happens in case of theft.

GPS-Shepherd was applied to the cow on July 24th, 2009 and powered up just prior to application. The GPS receiver was programmed to provide a GPS fix every 30 s. Data were collected from July 24 to July 29, 2009 and saved on a 2 Gb micro SD card contained within the CS device. The GPS data were processed using ArcView 3.2 (Esri, USA).

7.4. Results and discussion

At this writing the cost for the GPS-Shepherd was about € 1.000, including software and labor required for its construction. As reported by Clark et al. (2006) and Davis et al. (2011) several manufacturers market GPS collars for tracking animal movement patterns (i.e. Lotek Inc., BlueSky Telemetry, Telonics Inc., etc.), but commercial GPS tracking collars with remote data-access

capabilities and large enough for beef cattle cost approximately \$ 3.000/unit plus the cost of software and any peripherals. Clark et al. (2006) developed an experimental low-cost (\$ 840 plus 2-h in labor) GPS-based animal tracking system and, more recently, an experimental low cost (\$ 500 plus 6-h in labor) GPS herd activity and well-being kit (GPS HAWK) was developed by Davis et al. (2011) to monitor locomotion behavior of cattle at high sampling frequency (20 s).



Figure 1. The GPS-ACT collar with the components

The GPS-Shepherd was solid and sturdy, and weighted a total of 3,2 kg, including the external backup battery, leather harness and padding foam (Figure 1). The high-frequency sampling (30 s) for anti-theft monitoring required a larger battery for the GPS-Shepherd making it heavier than the commercial collars, but comparable to other experimental devices developed for monitoring the animal behavior at high sampling frequency as the GPS HAWK (Davis et al., 2011). However for a 600 kg animal this would only be 0,5 % of the body weight. Table 1 compares the GPS-Shepherd to other commercial and experimental devices to be used with beef cattle.

The inner lining of the GPS-Shepherd with a closed cell cross-linked polyethylene foam ensured a good fit of the collar and no lesions were observed on the skin of the animal equipped with the collar during the field test. Moreover, no restrictions on the behavioral activities of the animal (grazing, lying, standing, walking) were observed. However, a longer field test for the entire grazing season from June through September is needed to confirm these preliminary observations.

Table 1. Comparison of the GPS-Shepherd with some commercial and experimental available GPS systems

Device classification	Company/Institution	Product name	Approx. weight [g]	Differential Correction
Experimental	University of Milan - ARVAtec S.r.l. (Italy)	GPS-Shepherd	3200	EGNOS
	Iowa State University (USA)	GPS HAWK	3371	WAAS
	US Department of Agriculture – Oregon State University (USA)	Clark ATS	990	WAAS
Commercial	Lotek Wireless Inc. (Canada)	GPS Livestock 3300	950 ¹	As option
	BlueSky Telemetry (Scotland)	AGTRAX L6-l18 (livestock tracking)	470-720 ²	Post processing
	Telonics Inc. (USA)	TGW 4601 (cattle)	1100-1200 ³	Post processing

¹ with light duty belt; ² excluding harness and depending on batteries power pack; ³ with collar

In the long term static test over 49 hours of data, totaling approximately 5.900 positions, were collected. Figure 5 [Horizontal scatter plot for long term static positioning test. Verificare quale scatter plot è più indicato] shows the horizontal scatter plot of the position error as regards to an active geodetic antenna of a base station with coordinates: x (easting) = 517735.95 and y (northing) = 5035893.19 (UMT-WGS84 Zone 32). With an average calculated accuracy of 2,176 m and a DOP of 1,4 the positional measurements can be considered accurate enough to meet all the most sensitive applications.

Within the designated time period, the static GPS positioning error achieved a mean, CEP (50 %), 1 sigma (68 %), and R95 (95 %) respectively of 1,965 m, 1,460 m, 1,645 m, and 4,582 m. These values are comparable with those obtained by Agouridis et al. (2004) in open field static tests of a commercial GPS collar for grazing studies.

Results of the power consumption tests are shown in Figure 6 (da rifare in Times New Roman). The average power absorbed by the system with the only active GSM signal was equal to 0.55 W, while the average power absorbed by the system with both active signals (GPS + GSM) almost tripled (1.63 W). On both the time series, two sets of power peaks can be highlighted at intervals of about 15 minutes with a phase displacement of about 7 minutes. These peaks were due respectively to the GSM network connection and to the attempt to GPRS network connection operated by the GPS-Shepherd. Sending SMS messages caused an instantaneous power absorption equal to 2.01 W. Anyway, not being changes in voltage as a consequence of sending SMS messages, the power absorption can be considered insignificant compared to the available energy in the battery.

Based on the power consumption of the system when the GSM and GPS signals were active (1,63 W) and the total energy (89,5 Wh) supplied by the batteries powering the GPS receiver, a theoretical battery life of about 55 h was calculated.

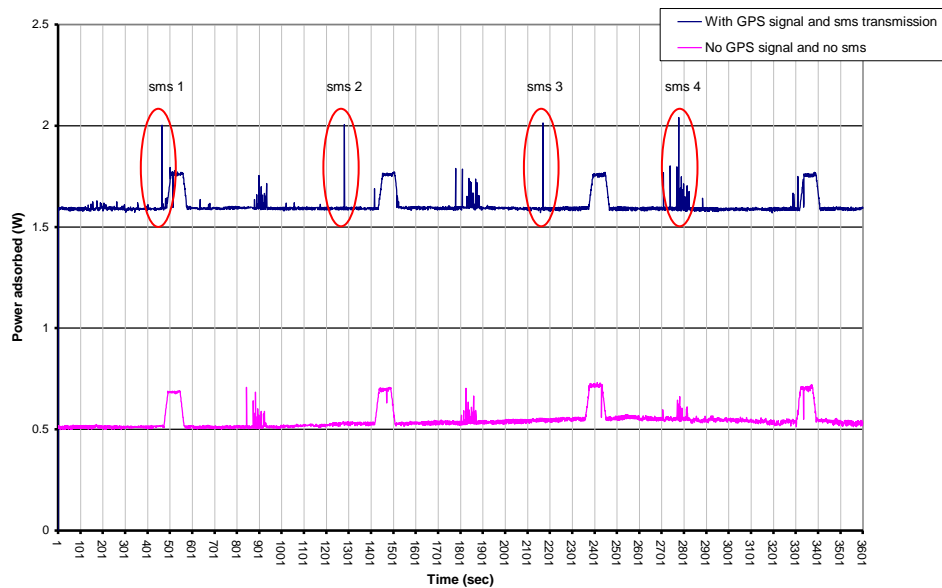


Figure 2. Power adsorbed by GPS-Shepherd when only the GSM signal was active (in purple) and when both GSM and GPS signals were active and SMS were sent at intervals of 15 minutes (in blue)

Figure 3 shows the virtual fences drawn for delimiting the grazing areas of the farm and the GPS-fixing recorded over the field test. Surfaces and perimeters of these areas, identified with the numbers from 1 through 4, are summarized in Table 2. In the same table the farm area is identified with the number 5.

Table 2. Surface and perimeter of the grazing areas

ID	Use	Surface (ha)	Perimeter (m)
1	Grazing	3.48	770.1
2	Grazing	1.77	558.4
3	Grazing	3.77	879.1
4	Grazing	0.81	389.7
5	Farm	0.097	108.7

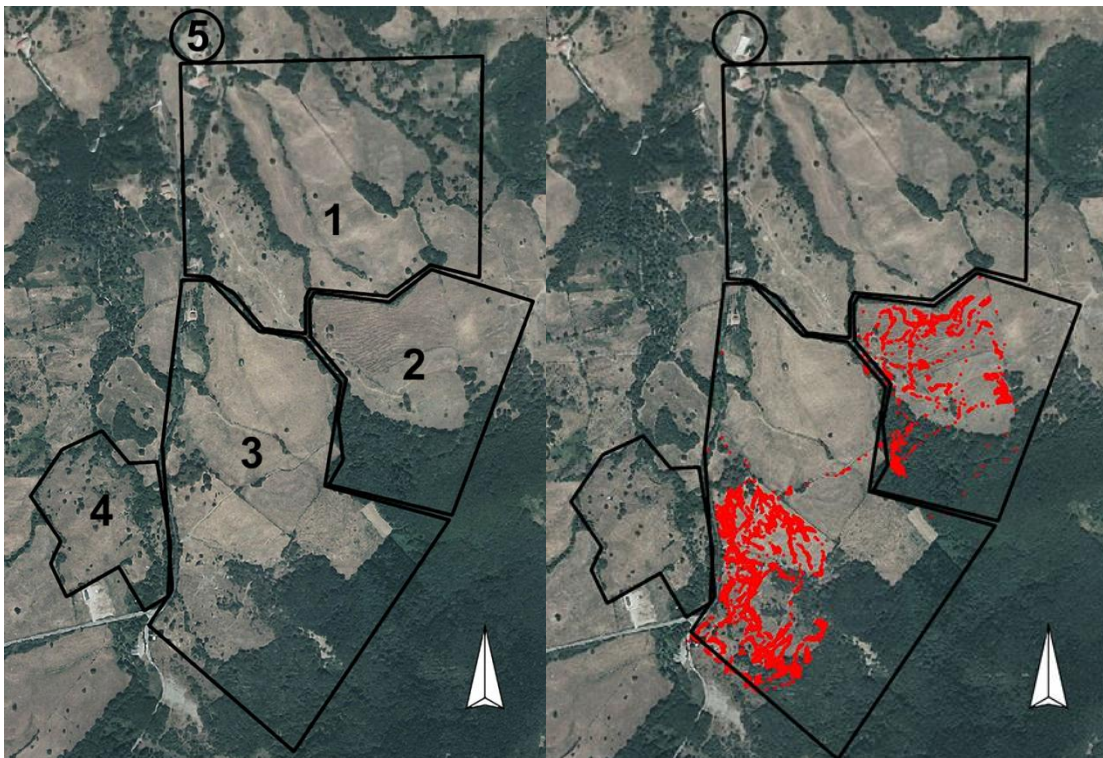


Figure 3. On the left: virtual fences of the pastures of the farm where the GPS-Shepherd was tested. On the right: GPS positions recorded by the GPS-Shepherd during the field test. Scale 1:12000

Out of the four geo-referenced pastures, only the areas 2 and 3 were used for the field test, and in the first instance considering that the R95 value of the GPS positioning error, calculated during the static test of the GPS-Shepherd, was 4,582 m a buffer of 5 m around the virtual fences was set up in order to limit the number of erroneous warning messages from the collar. These grazing areas are characterized by the alternation of open field areas with areas covered by shrubs and trees not always accessible for the cattle.

The memory card data storage used in the GPS-Shepherd was capable of storing over 26,5 millions of GPS locations or the equivalent of about 1 year of data collected at 30-s intervals, providing a large increase in capacity over commercially available GPS-tracking collar. However, these values are comparable with the results obtained by other researchers (Clark et al. 2006; Davis et al., 2006 and 2011) with experimental GPS collar developed for livestock monitoring.

A total of 8.941 GPS-fixing were recorded by the GPS collar at 30-s frequency sampling. Out of the total GPS positions, 6535 fixing were recorded into the pasture 3 between 24 and 27 July 2009 and the others 2406 fixing were recorded into the pasture 2 between 28 and 29 July 2009 (Figure 3). About 55 % (1334) of the GPS-fixing recorded into the grazing area 2 were subjected to EGNOS differential correction in real-time. This aspect could be explained by considering that within the grazing area 2 the cow equipped with the GPS-Shepherd spent more time underneath trees with full foliage in comparison with the grazing area 1 where less than 0,5 % of the GPS-fixing were EGNOS differentially corrected.

The 99,7 % (8.916) of the total GPS-fixing were within the virtual fences of the grazing areas 2 and 3, while the remaining 0,3 % (25) were out of them and produced warning messages (SMS) on the cattle farmer's mobile phone. Each message displayed date, time, grazing area, latitude, longitude, altitude, internal and external battery charge levels enabling the farmer to check the cow position, warding off a potential danger or theft, and the GPS collar functionality. A warning message was sent to the farmer also when the GPS-Shepherd was unfastened for simulating a cattle theft. Despite the GSM cellular coverage in the Northern Apennines is limited, no problem was encountered for sending/receiving SMS to/from the GPS collar.

The GPS-Shepherd exhausted the useable capacity of the batteries powering the CS device after 54,4 hours (from 24 July to 26 July, 2009 on grazing area 3) with a mean overall power consumption of 88.7 W, as expected by the power consumption test. A warning message was sent by the GPS collar to the farmer that recovered the grazing cow and substituted the external backup battery on 27 July 2009. The field test restarted on the afternoon of 28 July 2009 and

continued for about 20 hours on grazing area 2 with a mean overall power consumption of 32.6 W.

Due to the higher power consumption of the GPS receiver we used in comparison with the GPS receivers usually used for livestock tracking and monitoring systems, and the higher frequency GPS sampling (30-s intervals) required by anti-theft monitoring, battery life is the most limiting factor for using the GPS-Shepherd as anti-theft system in grazing areas.

7.5. Conclusions

The objective of this research to develop a low-cost GPS/GSM collar for combatting cattle rustling in extensive grazing areas was successfully met.

Production costs of the GPS-Shepherd did not exceeded € 1.000, including software and labor required for its construction. Field tests highlighted the potentiality of the GPS-Shepherd as anti-theft system. When the cow wearing the GPS collar exited the virtual fences delimiting the grazing areas or when the GPS collar was unfastened for simulating a cattle theft, a SMS displaying the main GPS data (date, time, grazing area, latitude, longitude, and altitude) was sent to the farmer, enabling him to check the cow position and ward off a potential danger or theft.

Battery life was the most limiting factor of the GPS-Shepherd due to the high power consumption of the GPS receiver and the high frequency GPS sampling (30-s intervals) required by anti-theft monitoring.

Further actions have to be oriented in limiting the energy requirements, increasing battery life (for example with the adoption of Li-Ion battery, which provide most amperage respect the lead battery, for the same physical dimensions) , and integrating the device with photovoltaic cells.

7.6. References

Anderson, D.M. (2000). The cyber cow whisperer and his virtual fence. *Agricultural research*. 48(11), 4-7.

Barbari, M., Conti, L., Koostra, B.K., Masi, G., Sorbetti Guerri, F., Workman, S.R. (2006). The use of global positioning and geographical information systems in the management of extensive cattle grazing. *Biosystems Engineering*. 95(2), 271-280.

Bassignana, M., (2005). Politiche agricole e alpeggi. *Environnment*. 30, 39-42.

Clark, P.E., Douglas, E.J., Kniep, M.A., Jermann, P., Huttash, B., Wood, A., Johnson, M., McGillivan, C., Titus, K. (2006). An advanced, low cost, GPS based animal tracking system. *Rangeland Ecology and Management*. 59(3), 334-340.

Davis, J.D., Darr, M.J., Xin, H., Harmon, J.D., Brown-Brandl, T.M. (2005). Development of a low-cost GPS herd activity and welfare kit (HAWK) for livestock monitoring. *Livestock Environment VII, Proceedings of the Seventh International Symposium, 18-20 May 2005, Beijing, China. ASAE Publication Number 701P0205*.

Davis, J.D., Darr, M.J., Xin, H., Harmon, J.D., Russell, J.R. (2005). 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. *Applied Engineering in Agriculture*. 27(1), 143-150.

Ganskopp, D. (2001). Manipulating cattle distribution with salt and water in large arid land pastures: a GPS/GIS assessment. *Appl. Anim. Behavior Sci.* 73(4), 251-262.

ION, 1997. ION STD 101: Recommended Test Procedures for GPS Receivers. Alexandria, VA. Institute of Navigation Standards.

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

National Agricultural Statistics Service (NASS). Cattle death loss. Agricultural Statistics Board, U.S. Department of Agriculture. *Washington D.C., USA*.

Pandey, V., Kiker, G.A., Campbell, K.L., Williams, M.J., Coleman, S.W. (2009). GPS monitoring of cattle location near water features in South Florida. *Applied Engineering in Agriculture*. 25(4), 551-562.

Rempel, R.S., Rodgers, A.R. (1997). Effects of differential correction on accuracy of a GPS in animal location system. *J. Wildl. Manage.* 61(2), 525-530.

Sibbald, A.M., Gordon, I.J. (Eds.) (2001). Tracking animals with GPS. Proceedings of an International Conference, Macaulay Land Use Research Institute, Aberdeen, 12-13 March 2001. ISBN 0708406432.

Siror, K.J., Sheng, H., Wang, D., Wu, J. (2009). Use of RFID technologies to combat cattle rustling in the East Africa. *Fifth International Joint Conference on INC, IMS and IDC, August 25-27, 2009, Seoul, Korea.*

Stombaugh, T.S., Shearer, S.A., Fulton J. (2002). Elements of a dynamic GPS test standard. *ASAE Annual International Meeting. ASAE Paper N.021150. St. Joseph, Mich. ASAE.*

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

Publications:

Tangorra F.M., Marchesi G., Nava S. and Lazzari M. (2011) Study, development and testing of a low cost GPS-GSM collar to control cattle rustling. *Book of abstracts of the 62nd annual meeting of the European federation of Animal Science.*

CHAPTER 8

The GPS / GPRS system for the transhumance flock: epidemiological monitoring

8. The GPS / GPRS system for the transhumance flock: epidemiological monitoring

8.1. Abstract

The OVItrace collar was a GPS / GPRS device connected to the management software. The system tracks and traces the path of the flock in real time. An OVItrace collar was placed onto a donkey in a flock. During the test stability and functionality of the system were verified. In particular, a number of 1563 location data has been recorded, with the exact definition of the location and the flock identification. Position requests were sent either via software (web-app) or via smartphone. In both cases the collar has promptly sent the position, ensuring a quick test for the field epidemiological analysis. However the OVItrace gives a number of further information in real time of the flock's path. The OVItrace collar use can be considered a good system for the epidemiological monitoring.

8.2. Introduction

The transhumance of flocks has a public health management problem (MIPAF, 2010). Is essential a management system for the control of the diseases and the flocks' position.

Until few years ago the transhumance was still based on the "book of transhumance" or "booklet pasture" (DPR. 320/1954). The shepherds was written over the book the land where he had authorized for the grazing, should be noted the outcome diagnostic and treatment, which had been subjected the sheep.

The minister of health at 13/11/2010, have moved from the booklet pasture to the veterinarian local health authorities (ASL) management. Periodically, the ASL requires to the shepherd the path planned for the next 4/5 months. All the movements were recorded in electronic form. If the flock change the path planned, during the way, the shepherd must communicate it to the ASL with the new route.

In addition to this, if required, the shepherd must inform the city with a notice of 7-15 days (depending on the municipality). In general, the shepherd does not feel the importance of these acts. In addition this procedure was increased the economic management cost caused by the high number of veterinary control.

The aim of this study was to create and using an innovative management system based on the technology of GIS (Geographic Information Systems) and GPS (Global Position System). The use of GPS technology in the livestock field is

common: many authors had described (Moen et al., 1997, Rempel and Rodgers, 1997; Rutter et al., 1997; Hulbert et al., 1998; Turner et al., 2000, Lazzari et al., 2011).

The system, created through a collaboration between the Department VESPA Università degli Studi di Milano and the private company GuardOne Italy Srl, has been used on an experimental basis by USL Monza / Brianza to monitor in real time the flock's transhumant movement in Lombardy and applying, on the basis of this, innovative procedures of epidemiological importance. The test began in August 2010 and is still ongoing. In this paper were mentioned the mainly technical aspects of operating collar, pointing only to veterinary aspects of the test.

8.3. Materials and methods

The OVItrace (OVIne traceability) collar was made with a GPS/GSM system, the KT CHASE ME® (GuardOne Italia S.r.l.). The system is composed by an integrated GPS/GSM antenna, a GPS module and a GSM/GPRS quadri-band module. The electrical circuit is powered by a LIon battery 13 Ah/3.6V. The KT CHASE ME ® was closed into a box 70x70x48mm, IP67.

After that the box was connected to the nylon collar. The OVItrace collar weight was <2kg, small and easy to put on the sheep's neck.

The OVItrace was connected to the WEB application (Figure 1) with the GPRS module. Was used a commercial web server to saw:

- The real time flock position on map;
- Automatic report (flock tracking);
- Historical tracking on map;
- Latitude, longitude, data, time, place (route and City) and distance.

The flock monitored was composed by 2000 sheep, 20 goats, 3 donkeys and 3 dogs. During all the year the flock was moving between the mountain and the "Po Valley".

Epidemiological issues

The aim of the veterinary group was to monitoring the: Q Fever, Chlamydia infection and the Lyme disease.

For the Q Fever and Chlamydia infection, were done a draw blood before the mountain pasture (spring 2011):

- Randomly in the flock (primiparous, multiparous and lambs > 6 months);

- All the rams in the flock;
- All the goats.

During the pasture in the “Po Valley” (December 2011) was controlled the lambs born in the 2011.

During the study has been registered the ticks found on the animals and in the ground, for check the Lyme disease.

The OVItrace collar was used to:

1. Found the flock and made a sample taking in a short time;
2. Recorded and follow the flock tracking to identify the ticks on the ground;

However the animals were controlled by the shepherd during all the study and he was looking for a ticks in them.

8.4. Results and discussion

The OVItrace collar was monitored for 18 months. During the trial was recorded 1563 position data with the follow set up, GPS starting every 4 hours and the GSM/GPRS every hour. Were send 24 SMS to the system and were load new position in the WEB-app by the veterinarian group.

The data position were managed to the server application, which:

- Sent the SMS position to the phone;
- Registered the flock tracking in a table, recorded on the web-server.

For a both situation the response were done in a few minute. In all cases the veterinarian group had found the flock position in the grazing area.

During the trial the OVItrace collar had not created a problem for the sheep. The battery life, considering all the data and the parameters changing, was a medium of 6 months. In addition was not registered collar or box damaged, during the trial.

The veterinarian’s results needs more data to create more discussion, even so it was possible made some qualitative preliminary results:

- Was showed an high prevalence of the disease considered. Most of all the Chlamydia infection was registered in 1/3 of the animals;
- The Q fever level was very important. The 15% of the animals were infected but could be influential in the future analysis on the flock. That because some animals should be infected but not negative during the test yet;
- Were showed a very high prevalence for all the disease in the goat. That result need more consideration in relation to the animals number and the animal species;

- Were registered a number of new lambs infected less than 5%. That results shown an infection way for the animals;
- There were any results for the Lyme disease because were not found any ticks.

Economic analysis

The OVItrace collar with the WEB-app have had an initial costs of 700 € (Table 1). Was calculated the operating costs as the classical sector method (Lazzari et al, 2005). Was considered 5 years as a shelf life, 3.5% as the interest rate and a residual value = 0. Overall, the annual fixed costs amount to € 162.75 / year

The SIM card recharge and the batteries' changing were considered as a variable costs. Those points were depends by the GPS settings and the time to send the position data (FIX). In This trial was used 6 daily FIX. The costs were 0.057€/FIX , whereof 0.017€ for the batteries and the roaming data.

At the end the total operating costs was 0.131 €/FIX, as a 50% of variable costs and 50% of fixed costs. It will be possible change the FIX/days and have a reduction of the operating costs around 30-40%.

However it will be possible reduce the fixed costs. A system with 50 collars have a 60€/year as the reducing costs.

After that it was considered 100-120 €/flock as an operating cost per year.

The using of the OVItrace collar has reducing the veterinarian labour costs. If considered 50-55 €/hour for a veterinarian, the OVItrace costs has reached only with two hours/year.

There were other benefits indicated in the table 1.

Table 1: OVItrace Economical points

	Price	Costs	Pay frequency
GPS Collar	200 €	Fixed	One-time
WEB-app	500 €	Fixed	in 5 years
Battery	0,017 €/FIX	Variable	Change the battery 1-4/year
SMS	0,04 €/FIX	Variable	SIM 3-5/year*

*depends of the phone contract

8.5. Conclusions

This trial has showed an interesting results for future OVItrace using, in particular for the sanitary issues.

The OVItrace could be considered as a good alternative for the real time flock monitoring. Using that system can help the veterinarian for an immediately

operation with few people. In addition in the future the system can reduce the bureaucratic labour costs for the veterinarian.

Otherwise the system need more features as:

- Engineering of the collar;
- Upgrading of the WEB-app with the attributes of the diseases associated with the flock, and check the evolution epidemiological time;
- Completion of the database with the introduction of a cartography. The introduction of an index of health risk for each type of disease, allows to divide the territory into risk bands and notify the veterinary service of the events passing the flock in hazardous areas and, therefore, to take appropriate requirements.

8.6. References

Guffari A., Garbanino C. (1999) - Piano di controllo ed eradicazione della *Brucella ovis* in Lombardia - *L'osservatorio ASL*

Hulbert, I.A.R., Wyllie, J.T.B., Waterhouse A., French, J., and McNulty, D. (1998) - A note on the circadian rhythm and feeding behaviour of sheep fitted with a lightweight GPS collar. *Applied Animal Behaviour Science* 60 (4): 359-364

Lazzari M., Mazzetto F. (2005) – Prontuario di meccanica agraria e meccanizzazione - *Reda Edizioni Torino*, 1-222

Lazzari M., Nava S., Tangorra F.M., Beretta E. (2011) - Nuove tecnologie elettroniche e informatiche al servizio della zootecnia. *I Georgofili. Quaderni* 8 (2011).

Ministero delle politiche agricole e forestali (2010) - *Comunicato stampa* <http://www.politicheagricole.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/1716>

Moen r., Pastor j., Coehn Y. (1997) - Accuracy of GPS telemetry collar locations with differential correction. *J. Wildl. Manage* 61, 530-539

Rempel R.S., Rodgers A.R. (1997) - Effects of differential correction on accuracy of a GPS in animal location system. *J. Wildl. Manage* 61, 525-530

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

Publications:

Marchesi G., Beretta E., Lazzari M. (2013). Possibilità di controllo epidemiologico di greggi transumanti con sistemi informativi a base GPS. *Informatore Agrario*.

CHAPTER 9

General Discussion

9. General discussion

Eastwood et al. (2004) defined precision farming technology as “the use of information technologies for assessment of fine-scale animal and physical resource variability aimed at improved management strategies for optimizing economic, social, and environmental farm performance.” Spilke and Fahr (2003) stated that precision farming, with specific emphasis on technologies for individual animal monitoring, “aims for an ecologically and economically sustainable production of milk with secured quality, as well as a high degree of consumer and animal protection.”

The main objectives of farm technologies were maximizing individual animal potential, early detection of disease, and minimizing the use of medication through preventive health measures.

Precision dairy systems used state-of-the-art devices to collect information for farm managers to use in decision-making. Farmers used this information to exert greater control over the inherent variation and risk in their farm environment. However it was apparent that a farmer switching to a ‘precision’ dairying system faces challenges in adaptation of management practices and maximising use of the new information gathered. Farmers need to adapt to a data-rich management style, a change from more common tacit-style management systems. They also must adapt to greater use of information and communication technologies, which were the cornerstone of precision dairy systems.

Researchers and retailers, of precision dairying tools, have taken a techno-centric approach to precision dairying where concerted effort was placed into development of devices, without sufficient consideration of issues around farmer adaptation and learning post-installation. While precision farming systems were obviously based on technological devices, the role of farmers who use the devices and information must not be understated or ignored. Precision farming development often represents technology-push, with farmers as end users receiving little attention.

In this techno-centric mind-set there was a focus on creation of devices, rather than development of a system involving learning and knowledge development among users.

References

Zeder M.A. (2008) Domestication and early agriculture in the Mediterranean Basin: Origins, diffusion and impact. *University of Pennsylvania Museum Of Archaeology and Anthropology, Philadelphia, PA.*

Olmstead L., Rhode P. (2009). Conceptual issues for the comparative study of agricultural development. In: Lains, P., Pinilla, V. (Eds.), *Agriculture and Economic Development in Europe since 1870*. Routledge, London, pp. 27–52.

Food and Agriculture Organizations for the United States (FAO) (2006) Livestock's long shadow. Environmental issues and options. www.fao.org.

Duncan, M., Harshbarger, E. (1979). Agricultural productivity: trends and implications for the future economic. *Econ. Rev. (September)*, 1–12.

Conway G. (1997) *The Doubly Green Revolution: Food for All in the Twenty-first Century*. Ithaca, N.Y.: Comstock Publishing

Williams, R., and Edge, D. (2005) 'The social shaping of technology', in David Preece, Ian McLoughlin, Patrick Dawson (eds.) *Technology, Organizations and Innovation: Critical Perspectives on Business and Management*, Routledge, USA.

MacKenzie, D. and Wajcman, J. (1985) *The social shaping of technology: how the refrigerator got its hum*, eds. D MacKenzie and J Wajcman, Open University Press, Philadelphia, USA.

Martin-Retortillo, M., Pinilla, V. (2012) Why did agricultural labor productivity not converge in Europe from 1950 to 2006? In: Proceedings of the 2012 Economic History Society Annual Conference, University of Oxford, Friday 30 March- Sunday 1 April. UK.

Frost A.R., Schofield C.P., Beulah S.A., Mottram T.T., Lines J.A., Wathes C.M. (1997) A review of livestock monitoring and the need for integrated systems. *Computer and Electronics in Agriculture*. 17 139-159.

Dijkhuizen A.A. and Huirne R.B.M. (1990) CHESS – An integrated decision support and expert system to analyse individual sow-herd performance. *Integrated decision support system in Agriculture – Successful Practical Applications. Proc. 3rd Int. Congr. Computer Technology, Frankfurt*. Pp221-227 .

Belyavin C. and Filmer D.G. (1990) Computer assisted control of growth in poultry houses. *Prv. VIII European Poultry Conference, Barcelona, 25-28 June*.

Ordolff D. (1989) Investigations on the design of floats to control milk meters. *J. Agric. Eng. Res.* 43 113-123

Eastwood, C., Chapman D., and Paine M. (2004) Precision dairy farming-taking the microscope to dairy farm management.

Spilke, J. and Fahr R. (2003) Decision support under the conditions of automatic milking systems using mixed linear models as part of a precision dairy farming concept. *in EFITA 2003 Conference, Debrecen, Hungary.* 780-785

Eastwood C.R., Chapman D.F., Paine M.S. (2009) Farmers as co-developers of innovative precision farming systems. *EFITA conference '09.*

Eastwood C. R., Chapman D. F. and Paine M. S. (2005). Information management within Australian precision dairy systems. *Paper presented at the European Conference of Precision Livestock Farming. Uppsala, Sweden.*

Nava S., Tangorra F. M., Beretta E., Lazzari M. (2009). Study and development of an integrated automatic traceability system for the bovine meat chain. *WCAA 2009 7th World Congress on Computers in Agriculture – June 2009 – Reno, Nevada (United States).*

Rempel R.S., Rodgers A.R. (1997) Effects of differential correction on accuracy of a GPS in animal location system. *J. Wildl. Manage, 61: 525-530.*

Hulbert I.A.R., Wyllie, J.T.B., Waterhouse A., French J., McNulty D. (1998) A note on the circadian rhythm and feeding behaviour of sheep fitted with a lightweight GPS collar. *Applied Animal Behaviour Science, 60 (4): 359-364.*

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

Moen R., Pastor J., Coehn Y. (1997) Accuracy of GPS telemetry collar locations with differential correction. *J. Wildl. Manage, 61: 530-539.*

Sibbald, A.M., Gordon, I.J. (Eds.) (2001). Tracking animals with GPS. Proceedings of an International Conference, Macaulay Land Use Research Institute, Aberdeen, 12-13 March 2001. ISBN 0708406432.

Xiaohong K., Jun W., Lei L., Bing X., Huazhi X. (2010) Applications of intelligent information technology in food logistics. *International conference on Computer and Communication Technologies in Agriculture Engineering.* 978-1-4244-6947-5

Bailey D.W. (2001). Evaluating new approaches to improve livestock grazing

distribution using GPS and GIS technology. In: *Proceedings of the First National Conference on Grazing Lands*, Las Vegas, NV, December 5–8, 2000, 91–99

Ganskopp, D. (2001). Manipulating cattle distribution with salt and water in large aridland pastures: a GPS/GIS assessment. *Appl. Anim. Behav. Sci.* 73, 251–262.

Agouridis, C. T., Stombaugh, T. S., Workman, S. R. Koostra, B. K., Edwards D. R., E. S., Vanzant (2004) Suitability of a GPS collar for grazing studies. *Transactions of the ASAE, 2004 (VOL. 47) (NO.4) 1321-1329.*

Barbari M., Conti L., Simonini S. (2007). Stato dell'arte e ambiti applicativi potenziali delle tecniche di monitoraggio animale: simulazioni in ambienti reali. In *L'e- nell'ingegneria agraria, forestale e dell'industria agro-alimentare AIIA*, Firenze.

Nadimi E. S., Jørgensen R. N., Blanes-Vidal V., Christensen S. (2009). Monitoring and classifying the behavior of a herd of sheep using ad hoc wireless sensor networks and artificial intelligence. *7th World Congress on Computers in Agriculture and Natural Resources Conference Proceedings 22-24 June 2009 (Reno, Nevada USA)*

Betteridge K., Hoogendoorn c., Costall D., Carter M., Griffiths W. (2010). Sensors for detecting and logging spatial distribution of urine patches of grazing female sheep and cattle. *Computers and Electronics in Agriculture.* 73 66–73

Anderson, D.M. (2000). The cyber cow whisperer and his virtual fence. *Agricultural research.* 48(11), 4-7.

Farris EJ. (1954) Activity of dairy cows during estrus. *J Am Vet Med Assoc;*125:117–20.

Rushen J., Chapinal N. and AM de Passillé (2012). Automated monitoring of behavioural-based animal welfare indicators. *Animal Welfare,* 21: 339-350

Sørensen, C.G., Fountas, S., Nash, E., Pesonen, L., Bochtis, D., Pedersen, S.M., Basso, B., Blackmore, S.B., (2010). Conceptual model of a future farm management information system. *Comput. Electron. Agric.* 72 (1), 37–47.

Blackmore, B.S., Griepentrog, H.W., Pedersen, M.S., Fountas, S., (2006). Precision farming in Europe. In: Srinivasan, A. (Ed.), *Handbook of Precision*

Farming: Principles and Applications. The Haworth Press, Inc., Binghamton, NY, USA, p. 684.

Perez-Aloe R., Valverde J. M., Lara ACarrillo., J. M., Roa I. and Gonzalez J. (2007) Application of rfidtags for the overall traceability of products in cheeseindustries. *In IEEE RFID Eurasia, Istanbul, Turkey, pages 1 – 5.*

Smith I. and Furness A. (2006) Improving traceability in food processing and distribution. *CRC Press, Boca Raton, FL,*

Lazzari M. (2006). Il controllo della macchine agricole mediante GPS. *Quaderni dei Georgofili 2005-X, pp69-147;*

Bishop-Hurley G.J., Swain D.L., Anderson D.M., Sikka P., Crossman C., Corke P. (2007) Virtual fencing applications: Implementing and testing an automated cattle control system. *Computers and Electronics in Agriculture 56 14–22*

Luvisi, A., Pagano, M., Bandinelli, R., Rinaldelli, E., Gini, B., Scarton, M., Manzoni, G., (2011) Virtual vineyard for grapevine management purposes: A RFID/GPS application. *Computer and Electronics in Agriculture 75 368-371*

Eurostat (2011) <http://epp.eurostat.ec.europa.eu/>

At-Taras, E.E., Spahr, S.L., (2001). Detection and characterization of oestrus in dairy cattle with an electronic heatmount detector and an electronic activity tag. *J. Dairy Sci. 84, 792– 798.*

de Mol, A.S., (2001). Automated detection of oestrus and mastitis in dairy cows. *Tijdschr. Diergeneesk. 126 (4), 99– 103.*

Firk R, Stamer E, Junge W, Krieter J. (2002).Automation of oestrus detection in dairy cows: review. *Livest Prod Sci;75:219–32.*

Roelofs, J.B., van Eerdenburg, F.J.C.M., Soede, N.M., Kemp, B., (2005). Pedometer readings for estrous detection and as predictor for time of ovulation in dairy cattle. *Theriogenology 64 (8), 1690–1703.*

Jonsson R., M. Blanke, N.K. Poulsen, F. Caponetti, S. Højsgaard (2011). Oestrus detection in dairy cows from activity and lying data using on-line individual models *Computers and Electronics in Agriculture 76:6–15*

Schirmann K., von Keyserlingk M. A. G., Weary D. M., Veira D. M.; Heuwieser, W. (2009): Technical note: Validation of a system for monitoring rumination in dairy cows. *Journal of Dairy Science* 92, 6052-6055

Klaas, I.C., Rousing, T., Fossing, C., Hindhede, J., Sørensen, J.T., (2003). Is lameness a welfare problem in dairy farms with automatic milking systems? *Anim. Welf.* 12 (4), 599–603.

Juarez, S.T., Robinson, P.H., DePeters, E.J., Price, E.O., (2003). Impact of lameness on behaviour and productivity of lactating Holstein cows. *Appl. Anim. Behav. Sci.* 83, 1–14.

Van Hertmen T., Alchanatis V. Antler A., Maltz E., Halachmi I., Schlageter Tello A., Lokhorst C., Voros A., Romanini Bites E., Bahr C. and Berckmans D. (2011). Experimental setup for the study of a computer vision based automatic lameness detection system for dairy cows. *Precision Livestock farming* (3) 113-123

Rajkondawar, P.G., Tasch, U., Lefcourt, A.M., Erez, B., Dyer, R.M., Varner, M.A., (2002) A system for identifying lameness in dairy cattle. *Appl. Eng. Agric.* 18 (1), 87–96.

Dyer, R.M., N.K. Neerchal, U. Tasch, Y. Wu, P. Dyer, and P.G. Rajkondawar. (2007) Objective determination of claw pain and its relationship to limb locomotion score in dairy cattle. *J Dairy Sci.* 90: 4592-4602.

Gröhn, Y. T., J. J. McDermott, Y. H. Schukken, J. A. Hertl & S. W. Eicker (1999). Analysis of correlated continuous repeated observations: Modelling the effect of ketosis on milk yield in dairy cows. *Preventive Veterinary Medicine*, 39, 137–153.

Lopez et al., 2004; Lopez H., LD Satter, MC Wiltbank. (2004). Relationship between level of milk production and estrous behaviour of lactating dairy cows. *Animal Reproduction Science* 81:209-223.

Kenneth V. Nordlund, DVM., Nigel B. Cook, BVSc, MRCVS (2004) Using herd records to monitor transition cow survival, productivity, and health. *Vet Clin Food Anim* 20 (2004) 627–649

Friggens N.C. and Chagunda M.G.G. (2005) Prediction of the reproductive status of cattle on the basis of milk progesterone measures: model description. *Theriogenology* 64,155–190.

Lamming G.E. and Bulman D.C. (1976) Use of milk progesterone radioimmunoassay in diagnosis and treatment of subfertility in dairy cows. *Br Vet J* 132, 507–517.

Friggens N.C., M Bjerring, C Ridder, S Højsgaard and T Larsen (2008) Improved Detection of Reproductive Status in Dairy Cows Using Milk Progesterone Measurements. *Reprod Dom Anim* 43 (Suppl. 2), 113–121

Blom J, Ridder C., (2010). Reproductive Management and Performance Can be Improved by Use of DeLaval Herd Navigator®. *The First North American Conference on Precision Dairy Management*.

Johnsen, T.S.; Zuk, M.; Fessler, E.A. (2001) Social dominance, male behaviour and mating in mixed-sex flocks of red jungle fowl. *Behaviour*, 138, 1-18.

Furlan RL. (2005) Influencia do calor na fisiologia de poedeiras. Junior AB, GAMA NMSQ Junqueira OM, Jaboticabal, Funep 96-118.

Silva RG. (2000) Introducao a bioclimatologia animal. *Sao Paulo: Nobel*. 286p

Gomes F.A, Figueiredo ALV., Oliveira EL., Souza LP. (2011) Influence of the environment on the physiological responses of is a brown layers under various production systems in hot/humid weather. *XXII Latin American Poultry Congress 2011*.

Collier RJ., Dahl GE. And Van Baale MJ. (2006) Major advances associated with environmental effects on dairy cattle. *J. Dairy Science*. 89: 1244-1253.

Finocchiaro, R., van Kaam, J.B.C.H.M., Portolano, B., Misztal, I., (2005). Effect of heat stress on production of Mediterranean dairy sheep. *J. Dairy Sci.* 88, 1855–1864.

CHAPTER 10

Summary

10. Summary

The objective of the researches described in this thesis is to study and evaluate different type of technologies used in the “Precision farming technology” (PFT). In this context, the research work within the PhD was divided on study and develop of three different automation systems in the livestock industry:

- Herd Navigator™: Study of the reproduction benefits for the use of the proactive herd management system ;
- Calving control systems: Study and develop a new system for the automatic calving detection;
- GPS/GPRS collars: Study and develop GPS/GPRS collars prototype in order to monitor and manage the cows herd and a sheep flock.

To achieve those objectives, six different trials were done; in the first trial, it was evaluated the use of an electronic system for automatic calving detection; in the second trial, it was designed, developed and tested a GPS/GSM birth alarm for cattle-grazing; in the third trial, it was evaluated the oestrus detection in a dairy cattle farm with the Herd Navigator™; in the fourth trial, it was analysed the reproduction and economical performances in a dairy cattle farm with the Herd Navigator™; in the fifth trial, it was designed and tested a low cost GPS/GPRS collar to combat cattle rustling; in the sixth trial, it was studied a GPS collar to trace the epidemiological issues in a flock.

In the first study, the technical performance of the C6 birth control system® was analysed. The C6 birth control system® is an electronic device that detects the time of the expulsion phase during the calving. A number of 53 Holstein was fitted on the day 280 ± 5 of gestation with the C6 birth control system®, which was left in place until confirmation of calving. Sensitivity and positive predictive value of the system were calculated as 100% and 95%, respectively. The partum events occurring at the group fitted with the system were compared with the analogous occurred at 59 animals without device. When alarmed by the system the farm staffs were in the calving barn during the expulsion phase in the 100% of the cases. On the contrary the cows without the device were assisted only in 17% of the cases ($P < 0.001$).

The aim of the second trial was the development of a GPS/GSM birth alarm for cattle-grazing (GPS-CAL). At the expulsion phase, during the calving, the system sent a Short message Service (SMS) to the farmer’s phone. In the SMS there were indicated the GPS coordinates where the cow was calving. Three tests were done: a) laboratory test to evaluate the battery life and the GPS’s accuracy; b) field test in a commercial dairy farm with small pasture; c) field test in a

commercial cattle farm in the Apennines. The laboratory tests showed a battery life of one month. The GPS accuracy was 1,237 m. In field “b” were tested 18 calving. In field “c” were tested 8 calving. In the total of 26 calving the GPS-CAL sent the SMS with the correct cow calving position.

The third study was related to the Herd Navigator™ monitoring of cows reproduction performances. The Herd Navigator™ is a system that automatically programs the analysis of milk progesterone samples from selected specific cows of the herd. In a commercial dairy farm, the same 156 cows were monitored with both a Herd Navigator™ and a DeLaval® activity system. Sensitivity and positive predictive value of the systems were calculated as 100% and 96% for Herd Navigator™, and as 49% and 70% for activity meter. The test definitely, demonstrates a significant difference ($P < 0.001$) between the two oestrus detection systems both for sensitivity and positive predictive value, with higher performances for the Herd Navigator™ system.

The aim of the fourth trial was verify the Herd Navigator™ benefits on the reproduction management in a commercial dairy farm - with automatic milking system - located in mountain areas. Reproductive and economical data were recorded before and one year after the Herd Navigator™ installation. The number of days open (DO) was reduced from 166 to 103 days. The same reduction has been identified in the number of days between the first and the second insemination that was passed from 45 days before the Herd Navigator™ introduction, to 28 days.. Another important value was the 80% reduction in the number of days required to identify an abortion (from 31 to 6 days). The preliminary results obtained confirm the usefulness of the system for the reproduction management. A model was developed using literature and commercial data to evaluate the potential economic benefits of the introduction of this technology. The model considers the benefits deriving from the decrease of reproduction problems and the reduction of days open. Considering the effects related to the above aspects, in a case study involving 70 dairy cows a 5 year time of investment return has been calculated.

In the fifth trial, it was developed a low-cost GPS/GSM collar, using commercial hardware and implementing specific software, to track animals' movements within a grazing area and get alert from animals' trespassing of virtual fences. A Phase I study was conducted from September 2008 to June 2009 to build the GPS/GSM collar, while a Phase II study was conducted in July 2009 to test the GPS collar under real operating conditions. The GPS/GSM collar production costs did not exceed € 1.000, including software and labour required for its construction. Field tests highlighted the potentiality of the GPS/GSM collar as anti-theft system. Battery life was the most limiting factor of the system due to the high power consumption of the GPS receiver and the high frequency GPS sampling (30-s intervals) required by anti-theft monitoring.

The aims of the last trial were study and evaluate a new system for the epidemiological monitoring in a flock. The OVItrace collar was a GPS / GPRS device connected to the management software. The system tracks and traces the path of the flock in real time. An OVItrace collar was placed onto a donkey in a flock. During the test stability and functionality of the system were verified. In particular, a number of 1563 location data has been recorded, with the exact definition of the location and the flock identification. Position requests were sent either via software (web-app) or via smartphone. In both cases the collar has promptly sent the position, ensuring a quick test for the field epidemiological analysis. However the OVItrace gives a number of further information in real time of the flock's path. The OVItrace collar use can be considered a good system for the epidemiological monitoring.

CHAPTER 11

Acknowledgements

11. Acknowledgements

I would like to express my deep and sincere gratitude to my supervisors, Professor Massimo Lazzari and Professor Antoniotto Guidobono Cavalchini, Department of Health, Animal Science and Food Safety, VESPA, Università degli Studi di Milano. Their wide knowledge and Their logical way of thinking have been of great value for me. Their understanding, encouraging and personal guidance have provided a good basis for the present thesis.

I wish to express my warm and sincere thanks to the all people in the Department of Bio-Engineering , Department of Health, Animal Science and Food Safety, VESPA, Università degli Studi di Milano. Their ideas and concepts have had a remarkable influence on my entire career as a PhD student.

I owe my most sincere gratitude to Dott. Fernando Mazeris and Dott. Goran Roxstrom, DeLaval international AB, for their support and help during my external period in DeLaval International AB, Tumba, Sweden.

During this work I have collaborated with many colleagues for whom I have great regard, and I wish to extend my warmest thanks to all those who have helped me with my work.

I owe my loving thanks to my wife Sefora, my son Matteo. They have lost a lot due to my research abroad. Without their encouragement and understanding it would have been impossible for me to finish this work. My special gratitude is due to my brother and parents for their loving support.