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SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS, NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

Internet of things and smart cities and communities – Frameworks, architectures and protocols

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Requirements and framework for smart livestock farming based on the Internet of things

Recommendation ITU-T Y.4482

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Recommendation ITU-T Y.4482

Requirements and framework for smart livestock farming based on the Internet of things

Summary

Smart livestock farming (SLF) is a convergence service in which information and communication technologies (ICTs) are applied to livestock value chains. It has the potential to deliver more productive and sustainable production by integrating processes of smart farming, management information systems (MISs), stockbreeding automation and robotics to provide better decision-making or more effective exploitation operations and management of livestock value chains.

The use of Internet of things (IoT) technologies in SLF aims at providing full coverage of processes by collecting and transmitting data from the entire agroecosystem. That means SLF can establish contact with each participant of a livestock chain, providing and collecting information about their processes and increasing the possibilities for control and improvement on the efficiency of their tasks.

Recommendation ITU-T Y.4482 provides an overview of SLF based on IoT, high-level requirements for SLF and a reference model which represents a generic sequence for livestock value chains and is applicable to these chains as a whole, regardless of species or rearing techniques.

History

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Agro-ecosystems, ICT, IoT, livestock value chain, management information systems, smart livestock farming, sustainability, traceability.

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1 Scope

This Recommendation provides an overview of smart livestock farming (SLF) based on IoT, high-level requirements for SLF and a reference model which represents a generic sequence for livestock value chains.

SLF is a convergence service in which information and communication technologies (ICTs) are applied to the livestock value chains. It has the potential to deliver more productive and sustainable production by integrating processes of smart farming, management information systems (MISs), stockbreeding automation and robotics to provide better decision-making or more effective exploitation operations and management of livestock value chains.

The scope of this Recommendation includes:

– an overview of SLF;

– an SLF conceptual model;

– high-level requirements of SLF;

– a reference model for SLF from the perspective of the IoT; and

– security considerations.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T L.1504] Recommendation ITU-T L.1504 (2016), *ICT and adaptation of agriculture to the effects of climate change*.

[ITU-T Y.3041] Recommendation ITU-T Y.3041 (2013), *Smart ubiquitous networks – Overview*.

[ITU-T Y.3500] Recommendation ITU-T Y.3500 (2014) | ISO/IEC 17788:2014, *Information technology – Cloud computing – Overview and vocabulary*.

[ITU-T Y.4000] Recommendation ITU-T Y.4000/Y.2060 (2012), *Overview of the Internet of things*.

[ITU-T Y.4100] Recommendation ITU-T Y.4100/2066 (2014), *Common requirements of the Internet of things*.

[ITU-T Y.4113] Recommendation ITU-T Y.4113 (2016), *Requirements of the network for the Internet of things*.

[ITU-T Y.4208] Recommendation ITU-T Y.4208 (2020), *Internet of things requirements for support of edge computing*.

[ITU-T Y.4401] Recommendation ITU-T Y.4401/2068 (2015), *Functional framework and capabilities of the Internet of things*.

[ITU-T Y.4450] Recommendation ITU-T Y.4450 (2015), *Overview of smart farming based on networks*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 access network [b-ITU-T Q.1742.1]: A network that connects access technologies (such as a radio access network) to the core network.

3.1.2 application [b-ITU-T Y.2091]: A structured set of capabilities, which provide value-added functionality supported by one or more services, which may be supported by an API interface.

3.1.3 context [b-ITU-T Y.2002]: The information that can be used to characterize the environment of a user.

3.1.4 core network [b-ITU-T Y.101]: A portion of the delivery system composed of networks, systems equipment and infrastructures, connecting the service providers to the access network.

3.1.5 device [ITU-T Y.4000]: With regard to the Internet of Things, this is a piece of equipment with the mandatory capabilities of communication and the optional capabilities of sensing, actuation, date capture, data storage and data processing.

3.1.6 gateway [b-ITU-T Y.4101]: A unit in the Internet of Things which interconnects the devices with the communication networks. It performs the necessary translation between the protocols used in the communication networks and those used by devices.

3.1.7 Internet of things [ITU-T Y.4000]: A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.

NOTE 1 – Through the exploitation of identification, data capture, processing and communication capabilities, the IoT makes full use of things to offer services to all kinds of applications, whilst ensuring that security and privacy requirements are fulfilled.

NOTE 2 – From a broader perspective, the IoT can be perceived as a vision with technological and societal implications.

3.1.8 IoT area network [ITU-T Y.4113]: A network of devices for the IoT and gateways interconnected through local connections.

3.1.9 object [b-ITU-T Y.2002]: An intrinsic representation of an entity that is described at an appropriate level of abstraction in terms of its attributes and functions.

3.1.10 sensor [ITU-T Y.4113]: An electronic device that senses a physical condition or chemical compound and delivers an electronic signal proportional to the observed characteristic.

3.1.11 sensor node [b-ITU-T Y.4105]: A device consisting of sensor(s) and optional actuator(s) with capabilities of sensed data processing and networking.

3.1.12 smart farming based on networks [ITU-T Y.4450]: A service that uses networks to actualize a convergence service in the agricultural field to attain more efficiency and quality improvement and to cope with various problems.

3.1.13 thing [ITU-T Y.4000]: In the Internet of things, this is an object of the physical world (physical things) or the information world (virtual things), which is capable of being identified and integrated into the communication networks.

3.1.14 ubiquitous networking [ITU-T Y.4450]: The ability for persons and/or devices to access services and communicate while minimizing technical restrictions regarding where, when and how these services are accessed, in the context of the service(s) subscribed to.

NOTE – Although technical restrictions to access services and communicate may be minimized, other constraints such as regulatory, national, provider and environmental constraints may impose further restrictions.

3.2 Terms defined in this Recommendation

This Recommendation defines the following term:

3.2.1 smart livestock farming: A convergence service which applies information and communication technologies (ICTs) to livestock value chains, with the potential to deliver more productive and sustainable production.

NOTE 1 – By integrating processes of smart farming, management information systems, stockbreeding automation and robotics, smart livestock farming helps decision-making for more effective and efficient exploitation, operations and management of livestock value chains.

NOTE 2 – Examples of products from domesticated animals (excluding pets) are meat, eggs, milk, honey, fur, leather and wool.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

EC Edge Computing

ICT Information and Communication Technology

IoT Internet of Things

LBS Location-Based Services

MIS Management Information Systems

NGN Next Generation Network

RFID Radio Frequency Identification

SLF Smart Livestock Farming

5 Conventions

The following conventions are used in this Recommendation:

- The keywords "is required to" and "must" indicate a requirement which must be strictly followed and from which no deviation is permitted, if conformance to this Recommendation is to be claimed.
- The keywords "is recommended" indicate a requirement which is recommended but which is not absolutely required. Thus, this requirement need not be present to claim conformance.
- The keywords "can optionally" and "may" indicate an optional requirement that is permissible, without implying any sense of being recommended. This term is not intended to imply that the vendor's implementation must provide the option and the feature can be optionally enabled by the network operator/service provider. Rather, it means the vendor may optionally provide the feature and still claim conformance with the specification.

6 Overview of SLF

Smart livestock farming (SLF) is a concept that refers to modern ICT applied to livestock value chains. It has the potential to deliver more productive and sustainable production by integrating processes of smart farming, MIS, agricultural automation and robotics to provide better decision making or more effective exploitation operations and management of livestock value chains.

The term livestock is used to refer to domesticated animals raised for labour and to produce commodities such as meat, eggs, milk, honey, fur, leather and wool, including their by-products. It can be used for extensive or intensive space usage animal husbandry and can refer to several animal species, such as horses, cattle, swine, poultry, rabbit, sheep, goat, fish and bees, among others, and including the various breeds and variations of the ones mentioned.

The use of Internet of things (IoT) technologies [ITU-T Y.4000] in SLF aims at providing a full coverage of the processes related in a livestock value chain. This is done by collecting and transmitting data from the entire agroecosystem, for example, register and control of inputs, purchases and consumption throughout the production processes – reproduction, growing and finishing, slaughtering and meat processing – until the products reach the trade market and the customer.

IoT aspects are vital to the SLF concept. By using IoT, SLF is able to run the workflow between the farmer, service provider, logistic, market and end consumer simultaneously (Figure 1Figure).

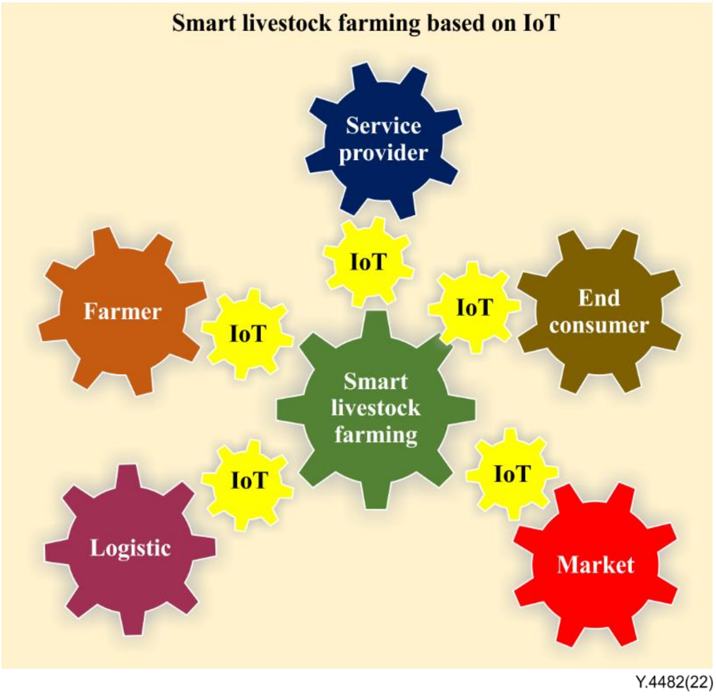

Figure 1 – Concept of smart livestock farming based on IoT

On the other hand, without applying IoT, livestock farming will continue, but will not be able to achieve higher performance levels and mitigate problems in a timely manner. Using IoT means SLF can establish contact with each participant of a livestock chain, providing and collecting information about related processes and increasing the possibilities for control and improvement on the efficiency of the related tasks [ITU-T L.1504].

7 SLF conceptual model

Livestock commodities can be marketed for domestic (national intra- or inter-state) or international markets involving a complex series of stakeholders and logistic products. Figure 2 shows a three-tier conceptual model of SLF.

In the upper tier is a community view, which represents the main stakeholders (suppliers, farmers, processors, traders and retailers, and consumers). They can respond to ICT infrastructure changes at the same time that they are subjected to local, national and international laws and requirements.

Additionally, it is possible to comply with food-quality standards and sustainability labels to achieve differentiated markets, increasing the value of their products.

In the middle tier is a list of services that support community operations. Each service has different processes, linked to achieving outcomes for the use of one or more stakeholders.

In the lower tier is the ICT infrastructure, which allows the functioning of IoT engines, attaining the objectives of monitoring and control along the livestock value chain.

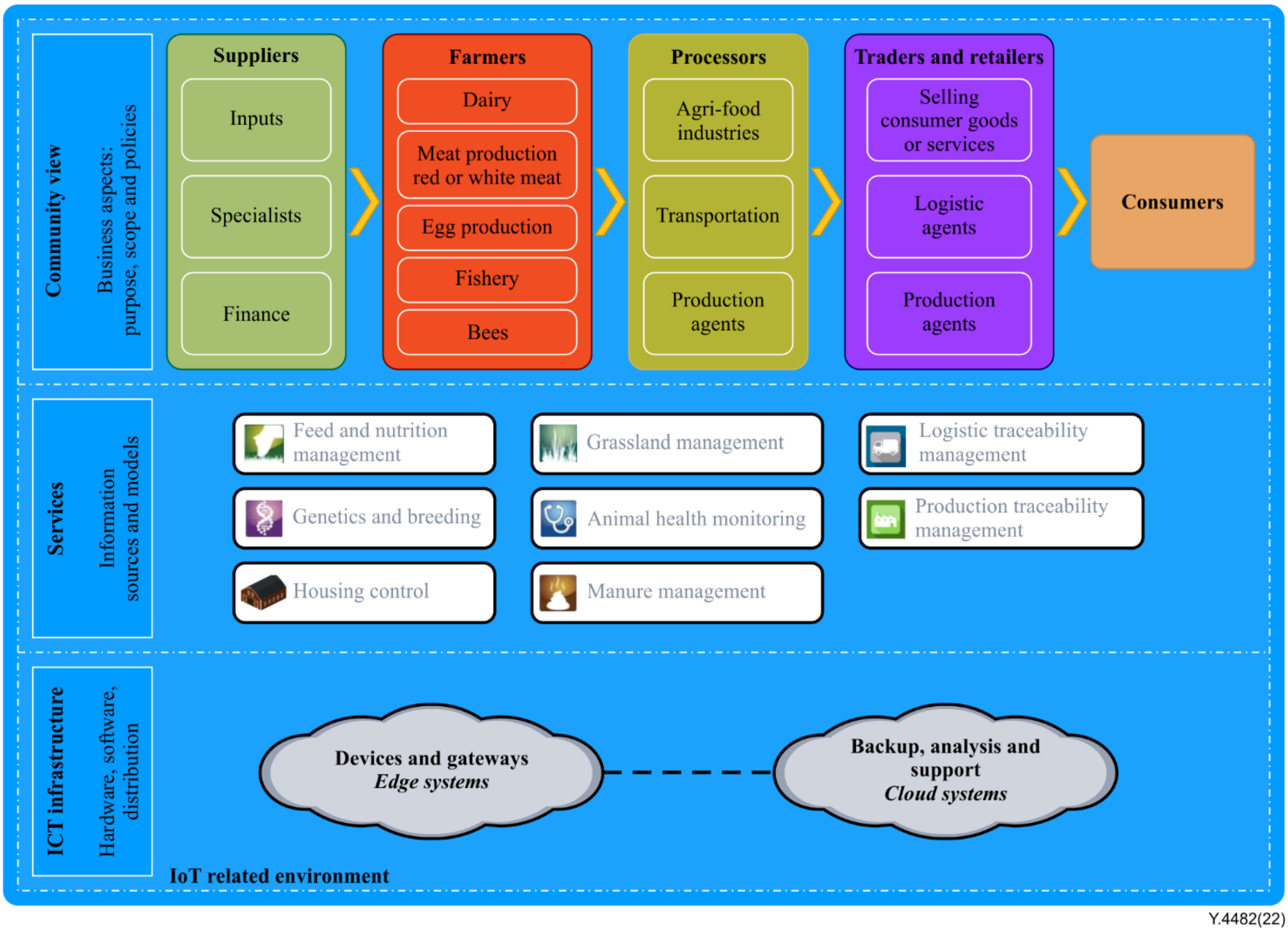

Figure 2 – Three-tier conceptual model for SLF

7.1 Community view

The first tier presented in Figure 2 is the community view, which represents the main actors present in the livestock value chain, as described in clauses 7.1.1-7.1.5.

7.1.1 Suppliers

Suppliers are responsible for providing any kind of tool, equipment, products, raw material or logistics, as well as tangible services, necessary for the development of farming activities. Examples of suppliers include:

– Input suppliers, who supply feed, medicine, fertilizers, herbicides, insecticides, seeds, water, machines and equipment, as well as work and electricity.

– Specialists, who act as technical consultants to analyse processes and provide necessary knowledge and specialized services to the farmer or producer. They can be related to animal health, nutrition, breeding and agriculture, such as veterinary surgeons, zoo technicians, artificial inseminators and agronomists.

– Finance suppliers, who supply asset allocation or financial investments, which include a broad range of businesses that manage money, such as providers of loans, insurance, accountancy, finance planning and financial trades.

7.1.2 Farmers

Farmers are responsible for the production process, including every aspect related to the production units and facilities. They spend most of the time close to the animals and their related issues throughout the production process. Livestock production farmers' main activities include:

– Dairy farming, that is, work related to the production of milk or milk products, such as cheese, yogurt and butter.

– Meat production farming, that is, work related to the husbandry of animals in order to obtain their meat. Examples of animals include cows, pigs, turkeys and chickens.

– Fishery farming, that is, work related to saltwater or freshwater, wild or farmed organisms, usually for food. Examples of such organisms include finfish, molluscs, crustaceans and echinoderms;

– Egg production farming, that is, work related to the husbandry of poultry in order to obtain eggs. An example of poultry is chickens.

– Bee farming, that is, work related to bees and their products. Examples of bee products include honey, beeswax, propolis, pollen and royal jelly.

7.1.3 Processors

Processors are responsible for the processing and preparation of products after the farm stage. Processors consist of meat processors and other processors; meat processors are usually represented by slaughterhouses, whereas other processors are represented by food related industries that receive inputs coming from the farms and employ any kind of manipulation or processing in order to transform them into the final product.

In addition, processors act as important players for the traceability of the final product, since they may receive information about how and when it was produced on the farm and then aggregate information about its processing steps. Examples of processors include:

– Agri-food industries that receive production from the farmers and employ industrial processing methods to transform it into final products. They are also responsible for packaging and storage.

– Transportation of living animals or finished products.

– Production agents that manage records and information about origins, inputs, quality, issues and destination of products, and enable the tracking of the distribution of goods from production to final consumption or disposal.

7.1.4 Traders and retailers

Traders and retailers are responsible for the logistics and sale of the products in order to supply the markets. Examples of traders and retailers include:

– Sellers of consumer goods or services;

– Logistic agents that are responsible for tracing multistage tracking of finished products from processing to distribution;

– Production agents, also acting as processors to ensure the complete tracking of products.

7.1.5 Consumers

Consumers are the final point in the chain and should be the most concerned in issues such as product quality, traceability and cost.

7.2 Services

Services are used by owners of various processes; responsibilities for single activities are indicated within the detailed process descriptions.

Clause 7.2.1-7.2.8 describe the services presented in Figure 2 and identify IoT service functions that serve as a basis for the requirements identified in clause 8.

7.2.1 Feed and nutrition management

An animal's optimal weight gain is based on the feed conversion ratio and energy expenditure. For this purpose, the integration of IoT devices and/or systems should be able to associate parameters such as individual animal ID, weight, food consumption ratio (in order to obtain feed conversion ratio), water ingestion and movement (to estimate energy expenditure). One of the key pieces of information along the entire value chain is the identification of the animals, since this register that accompanies the animal throughout its life inside the farm and remains attached to all the products derived from it, if possible. Any kind of electronic identification (internal, external or subcutaneous) that permits an easy and instantaneous identification of the animal with a proper device or antenna can be used.

7.2.2 Genetics and breeding

Animal genetics and breeding is the branch of science concerned with maximizing desirable genetic traits, such as producing animals that have leaner meat. Therefore, an animal genetics and breeding service is important to ensure the continuous improvement of farm animals, generation after generation.

An animal genetics and breeding service is responsible for increasing concentration, controllability and uniformity of animal production while decreasing negative environmental impacts.

For that, an animal genetics and breeding service uses various IoT sensors to identify cattle and associated growth and health information; examples of such information include feed, weight, disease and immunizations recieved.

7.2.3 Housing control

An important issue during the production stage is the ambient conditions that the animal is subjected to. They can directly affect productivity, since energy expenditure will rise together with the animal's metabolism, to regulate its temperature or to survive (in extreme cases). In addition, ambient conditions are very crucial during transportation and in waiting rooms in slaughtering houses.

For that, the housing control system monitors the environmental temperature, relative humidity, radiation and light with the use of IoT devices and then adjusts the environmental conditions accordingly with the use of actuators, controlling their effects on the animals.

7.2.4 Grassland management

A grassland management service is responsible for providing appropriate lands to raise domestic animals. Grasslands around the world can have drastically different grazing management systems depending on the political, social, economic and cultural settings.

For that, the grassland management system monitors the atmosphere and soil conditions with the help of sensors and drones and then adjusts the environmental conditions accordingly with the use of actuators such as an irrigator, controlling their effects on the animals.

7.2.5 Animal health monitoring

An animal health monitoring service is responsible to prevent productivity losses or even possible threats to human health. For this purpose, animal health monitoring systems are applied, which can be enhanced with the use of internal and external sensors capable of sensing and communicating important parameters to the server or a cloud at an appropriate time interval. Besides crucial information such as vaccinations received, exams, pests, diseases, bruises and other health related records should be registered on the management system and, also to the animal's electronic identification device, for safety.

NOTE – Various types of sensors can be implanted in or installed on animals. Examples of internal sensors include a mobile sensor box – thermometer, PH sensor – swallowed or implanted to a cow's stomach. Examples of external sensors include a mobile sensor box – accelerometer, pedometer, vibration sensor – attached to a cow's neck or ankle.

Animal welfare is also an important issue related to animal health and productivity. It is mainly related to respect for animal life, based on the belief that non-human animals are sentient and that consideration should be given to their well-being or suffering, especially when they are under the care of humans. However, another aspect is that it is closely related to production indexes; when the animal is considered to suffer for any reason, its efficiency decreases, leading to direct losses for the producer. This issue is interrelated to climate control and health monitoring and if possible, one should adopt systems capable of detecting abnormal behaviour through GPS monitoring (for extensive farming) or image recognition (for confinements or intensive animal farming).

7.2.6 Manure management

A manure management service is responsible for capturing, storing, treating and utilizing animal manures in a sustainable manner. It can be used in various types of storage. Animal manure can occur in liquid, slurry or solid form. It is distributed on fields in amounts that enrich soils without causing water pollution or unacceptably high levels of nutrient enrichment. Manure management is a component of nutrient management.

Livestock manure produces several gases including four main toxic gases: hydrogen sulphide, methane, ammonia and carbon dioxide. The highest concentrations of these gases are noted during manure agitation, that is, stirring manure to homogenize the manure for pumping out of the storage.

For that, manure management systems monitor animal manures with IoT devices, and treat them with the use of actuators, controlling their threats to the environment.

7.2.7 Logistic traceability management

Logistics traceability refers to the possibility of identifying the origin and different stages that a product goes through, as well as its subsequent logistics distribution before reaching the final consumer. Therefore, a well-defined logistic traceability management service is responsible for providing qualified information about the location of animal or product to service users in real time. For that, IoT devices with location-based service (LBS) capabilities are used to monitor the animal or product transportation. Additionally, the transportation of animals or perishable goods should consider recording climate variables to maintain traceability.

NOTE – In this Recommendation, logistic traceability management is considered to be different from production traceability management depending on whether transport is involved or not.

7.2.8 Production traceability management

In addition to the importance of providing the right amount of inputs with correct timing throughout the whole value chain, in order to maintain its optimal workflow, it should be made possible to follow the path of any unit of product through the value chain, as it moves between organizations, in order to enable a fast and effective recall. In this sense, recording can be done through means of barcodes, QR codes, RFID tags and other tracking media.

7.3 ICT infrastructure

7.3.1 Edge systems

In terms of IoT edge computing (EC), some of the capabilities offered by the IoT, e.g., computing, storage and analytics, are evolving in close proximity to IoT data sources. IoT devices or gateways may need to have computing, storage and intelligence support from IoT platform(s) or IoT application server(s).

IoT requirements to support EC [ITU-T Y.4208] may differ depending on the context (e.g., applications and network technologies). EC is intended to offer flexibility (e.g., related to performance, deployment models and applications) with respect to the identified needs. It is important to assess which service and functional requirements are needed in a given context. For example, not all IoT technical components may require capabilities related to support of EC.

In SLF, an edge system enables various services, such as feed and nutrition management and housing controls.

7.3.2 Cloud systems

Cloud computing, which is a base technology of cloud systems, is a paradigm for enabling network access to a scalable and elastic pool of shareable physical or virtual resources with self-service provisioning and administration on demand. The cloud computing paradigm is composed of key characteristics, cloud computing roles and activities, cloud capabilities types and cloud service categories, cloud deployment models and cloud computing cross cutting aspects [ITU-T Y.3500].

8 High-level requirements of SLF

The high-level requirements of the IoT are provided by [ITU-T Y.4000], [ITU-T Y.4100] and [ITU-T Y.4113].

Clauses 8.1 and 8.2 provide high-level requirements of SLF, in terms of common requirements of SLF and service-specific requirements of SLF.

8.1 Common requirements of SLF

Clauses 8.1.1-8.1.4 present common requirements of SLF.

8.1.1 Identification

In SLF, it is important to identify animals and products individually for breeding, processing and tracing. The following are requirements for identification:

– It is required to identify each individual animal or a group of animals;

– It is required to identify the inputs;

– It is required to identify the places the animal was raised;

– It is required to identify the animal products;

– It is required to manage the identification information of each animal or group of animals;

– It is required to provide the identification information on proper request.

8.1.2 Sensing data

To assess data along the different phases and processes of SLF value chains, the establishment of an information flow using IoT is necessary. Table 1 contains the different types of data to be measured or recorded along the livestock chains [ITU-T Y.4000], [ITU-T Y.4450].

Table 1 – Types of sensing data for IoT in the livestock chains

Nature of monitoring	Measuring object	Sensing parameter
Transportation monitoring	Vehicle and product/load	Temperature Relative humidity Wind speed Vibration Balance Inflation pressure Weight (load capacity)
	Surrounding environment	Temperature Relative humidity Light Noise
Product traceability	Product	Identification number Facility identification numbers
Animal tracking	Animal (individual or group)	Identification number Position Counting (for colonies or groups of small animals)
Animal health	Animal (individual or group)	Physiological parameters (inner and body surface temperature, heart rate, respiratory rate, movement, blood pressure, cortisol level, blood and rumen pH, etc.) Image and sound recognition (to detect abnormal behaviour, diseases, fights, death and activity) Registration of vaccines and examinations Identification of breed or variety Oestrus identification Insemination record
Productivity	Animal (individual or group)	Weight Feed intake Water intake Movement
Climate control	Facilities	Temperature Relative humidity Ventilation rate Radiation Light Gas concentration Dust
Pollution control	Environment	Air quality (gas and dust emissions) Water quality Soil pollution Noise production

The following are requirements for the sensing data:

– It is required to measure vehicle and product/load data to monitor transportation conditions;

– It is required to measure surrounding environment data to monitor transportation conditions;

– It is required to measure product data for tracking purposes;

– It is required to measure animal data individually or in groups to monitor animal health;

– It is required to measure animal data individually or in groups to monitor animal productivity;

– It is required to measure the facility conditions to monitor climate;

– It is required to measure the facility conditions to monitor pollution.

8.1.3 Network infrastructure

a) Ubiquity

The network infrastructure must be capable of being always connected and keeping data up to date during any instance of operation. The following are requirements for ubiquity of SLF:

– It is required that the devices are always reachable, and able to interact with other devices;

– It is recommended to enable reliable, real-time and flexible access to devices.

b) Connections

The network infrastructure must be capable to support the different ubiquitous networking communication types [ITU-T Y.4450]. The following are requirements for all connections:

– It is required to provide person-to-person communication, person-to-device communication and device-to-device communication;

– It is required to include the support of tag-based devices (e.g., RFID) and sensor devices;

– It is required to provide identification, naming and addressing capabilities for the devices.

c) Open web-based service environment

The service environment must be capable of providing rich user experiences and new business opportunities for the provision of ubiquitous networking services and applications by using interactive, collaborative and customizable features [ITU-T Y.4450]. The following are requirements for the open web-based service environment:

– It is required for emerging ubiquitous services/applications to be compatible with legacy telecommunication and broadcasting services;

– It is recommended for emerging ubiquitous services/applications to be provided based upon an open web-based service environment;

– It is recommended to support application programming interfaces (APIs) and web services with dynamics and interactivity.

d) Context awareness and seamlessness

Context awareness means the ability to detect changes in the status of devices. When associated with intelligence systems, the environmental and user status can be recognized, and the best service can be provided, according to the situation. Seamlessness means that applications should interact smoothly and transparently with the system and with other applications [ITU-T Y.4450]. The following are requirements for context awareness and seamlessness:

– It is required to support context awareness;

– It is required to support seamless application interaction.

e) Multinetworking

The transport layer needs multinetworking capabilities to simultaneously support unicast/multicast, multihoming and multipath. Because of high traffic volume and the number of receivers, ubiquitous networking requires multicast transport capability for resource efficiency. Multihoming enables the device to be always best connected using multiple network interfaces including different fixed/mobile access technologies. [ITU-T Y.4450]. The following are requirements for the multinetworking:

– It is required to support multinetworking in order to guarantee continuous connectivity;
– It is recommended to support network reliability through redundancy and fault tolerance;
– It is recommended to support desirable quality of service (QoS).

f) End-to-end connectivity over interconnected networks

All devices must be accessible over interconnected heterogeneous networks, such as next generation networks (NGNs), other IP-based networks, broadcasting networks, mobile/wireless networks and public switched telephone network/integrated services digital networks (PSTN/ISDNs). Internet Protocol version 6 (IPv6), with its large address space, can be considered a good candidate for providing globally unique addresses to devices [ITU-T Y.3041], [ITU-T Y.4450]. The following are requirements for end-to-end connectivity over interconnected networks:

– It is required to provide end-to-end connectivity over heterogeneous networks;
– It is required to assign a globally unique address to each device.

g) Easy maintenance

Network maintenance covers all questions and proceedings necessary to keep a network up and running; these can be considered either structured tasks or interrupt-driven tasks. The following are requirements for easy maintenance:

– It is required to provide fast and accessible troubleshooting of network problems;
– It is required to assistant hardware and software installation/configuration;
– It is recommended to provide self-monitoring for network performance and QoS improvement;
– It is required to provide a secure network in order to prevent threats.

8.1.4 Cloud infrastructure

a) Storage and computing

Cloud storage is the process of storing digital data in an online space that spans multiple servers and locations; such a space is usually maintained by a hosting company or entity. The following are requirements for the cloud infrastructure:

– It is required to enable authorized parties to access the data that is stored on the cloud (as shown in Figure 2) from multiple devices;
– It is recommended to use cloud computing to offer flexibility, data recovery, limited maintenance, easy access and high level of security;
– It is recommended to provide EC capabilities to guarantee always connected conditions;
– It is required for the data to be processed in the cloud and the data processing results to be sent back to the edge (as shown in Figure 2).

b) Advanced data analytics

Advanced SLF should use machine learning and artificial intelligence techniques to cope with predictive and behavioural analysis functionalities through the employment of an advanced decision support system and real-time assessments. The following are requirements for advanced data analytics:

– It is recommended to apply big data analytics to extract insights from large volumes of data that are generated at high speed with heterogeneous formats.

c) Data quality

Data analytics needs the integration of data from different sources. In this process, data quality issues are likely to arise due to errors and duplications. The following are requirements for data quality:

– It is recommended to enable a series of operations on the raw data to ensure the quality of data as shown in Figure 3;

– It is required to guarantee data quality which is a key issue in farm management information systems;

– It is recommended to treat big and real-time data.

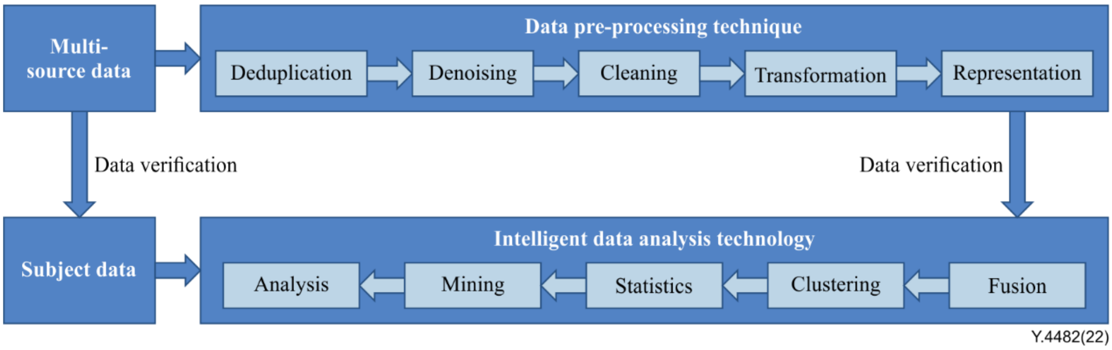

Figure 3 – The flow chart of intelligent processing of agricultural big data [b-Li]

8.2 Service-specific requirements of SLF

Clauses 8.2.1-8.2.8 define service-specific requirements to provide services as presented in Figure 2.

8.2.1 Feed and nutrition management

In order to obtain the animals' optimal weight gain, the integration of IoT devices and feed and nutrition managing systems are needed. The following are requirements for feed and nutrition management:

– It is required to monitor each animal's feed and water ingestion;

– It is required to monitor each animal's nutrient intake;

– It is required to record each animal's related (regular and unexpected) events and the associated information.

NOTE – An example of an animal's related regular events is daily feeding, with the animal's feed amounts and feeding time as the associated information.

8.2.2 Cattle genetics and breeding

In order to ensure the continuous improvement of cattle, it is required to provide their associated growth and health information. The following are requirements for genetics and breeding:

– It is required for devices to be capable of sensing physiological parameters, such as inner and surface temperature, heart rate, respiratory rate, movement, blood pressure, cortisol level, blood and rumen pH;

– It is recommended to use systems that are capable of recognizing animals' image and sound to detect abnormal behaviour, diseases, fights, death and activity;

– It is required to register vaccines and examinations;

– It is required to identify breed and variety;
– It is required to sense oestrus;
– It is required to record the insemination history.

8.2.3 Housing control

In order to have optimal animal productivity and welfare, a good and effective housing control by monitoring the environmental conditions and adjusting them appropriately and in a timely manner is necessary. The following are requirements for housing control:

– It is required to sense a livestock barn's internal as well as external atmosphere;
– It is recommended to artificially control a livestock barn's atmosphere;
– It is required to manage manure to minimize environmental pollution.

NOTE – Examples of livestock barn atmosphere parameters include temperature, humidity and ammonia, which cause difficulties in breathing.

8.2.4 Grassland management

In order to manage the atmosphere and soil conditions of grassland, IoT devices such as sensors, drones and irrigators can be used. The following are requirements for grassland management:

– It is recommended to monitor outdoor atmosphere;
– It is recommended to control soil conditions such as humidity and nutrition;
– It is recommended to control grass development through images;
– It is recommended to control grass conditions thorough the use of sensors and irrigators.

8.2.5 Animal health monitoring and welfare

In order to prevent productivity losses, livestock diseases or even possible threats to human health, it is necessary to continuously monitor an animal's health with IoT devices such as internal or external sensors. The following are requirements for the animal health monitoring and welfare:

– It is required to record each animal's health occurrences;
– It is required to monitor and manage each animal's health conditions;
– It is required to monitor and manage the conditions under which each animal was raised;
– It is required to monitor and manage each animal's nutrient intake;
– It is required to manage each animal's pedigree;
– It is required to provide animals' health related records on proper requests;
– It is recommended to provide an optimal climate environment for animals;
– It is required to detect animal's abnormal behaviours;
– It is required to provide information on an animal's growth;
– It is required that all information regarding animal health be accessible in real time to the farmer or service provider;
– It is required to record all important events and make records readily available to the authorities.

NOTE 1 – Examples of animal health occurrences include diseases, bruises, pests and other related occurrences.

NOTE 2 – Examples of animal health conditions include temperature measuring, movement monitoring, rumination monitoring and other related conditions.

8.2.6 Manure management

In order to avoid the dangerous effects caused by untreated animal manure, such as several toxic gases emitted by liquids, slurry or soil, it is needed to monitor animal manures with IoT devices and treat them, controlling manure effects over the environment. The following are requirements for manure management:

– It is required to use systems that are capable of monitoring the quality of air (gas and dust emissions), water and soil in real time;

– It is recommended to monitor noise production from the livestock barn.

8.2.7 Logistic traceability management

In order to provide means of traceability to follow the path of any unit of product through the value chain, IoT devices with LBS capabilities are used to monitor animal or product transportation. The following are requirements for logistic traceability management:

– It is required to handle records of origin and quality of cargo;

– It is required to monitor animal transportation conditions;

– It is required to control the transportation environment;

– It is required to provide multistage tracking for production, processing and distribution;

– It is required to record market and distribution information.

8.2.8 Production traceability management

In order to identify the origin of a product, IoT devices for identification are applied to follow the path of any unit of product through the value chain. The following are requirements for the production traceability management:

– It is required to uniquely identify livestock products during their life cycle;

– It is required to uniquely identify facilities;

– It is required to provide a means of product anti-counterfeiting.

9 Reference model for SLF

This clause presents a reference model for SLF based on the IoT precepts [ITU-T Y.4401], [ITU-T Y.4450].

This reference model defines a generic sequence for the value chain (Figure 4), contemplating the interconnection between production, processing and transportation steps and the informational flow that can relate to any kind of livestock production.

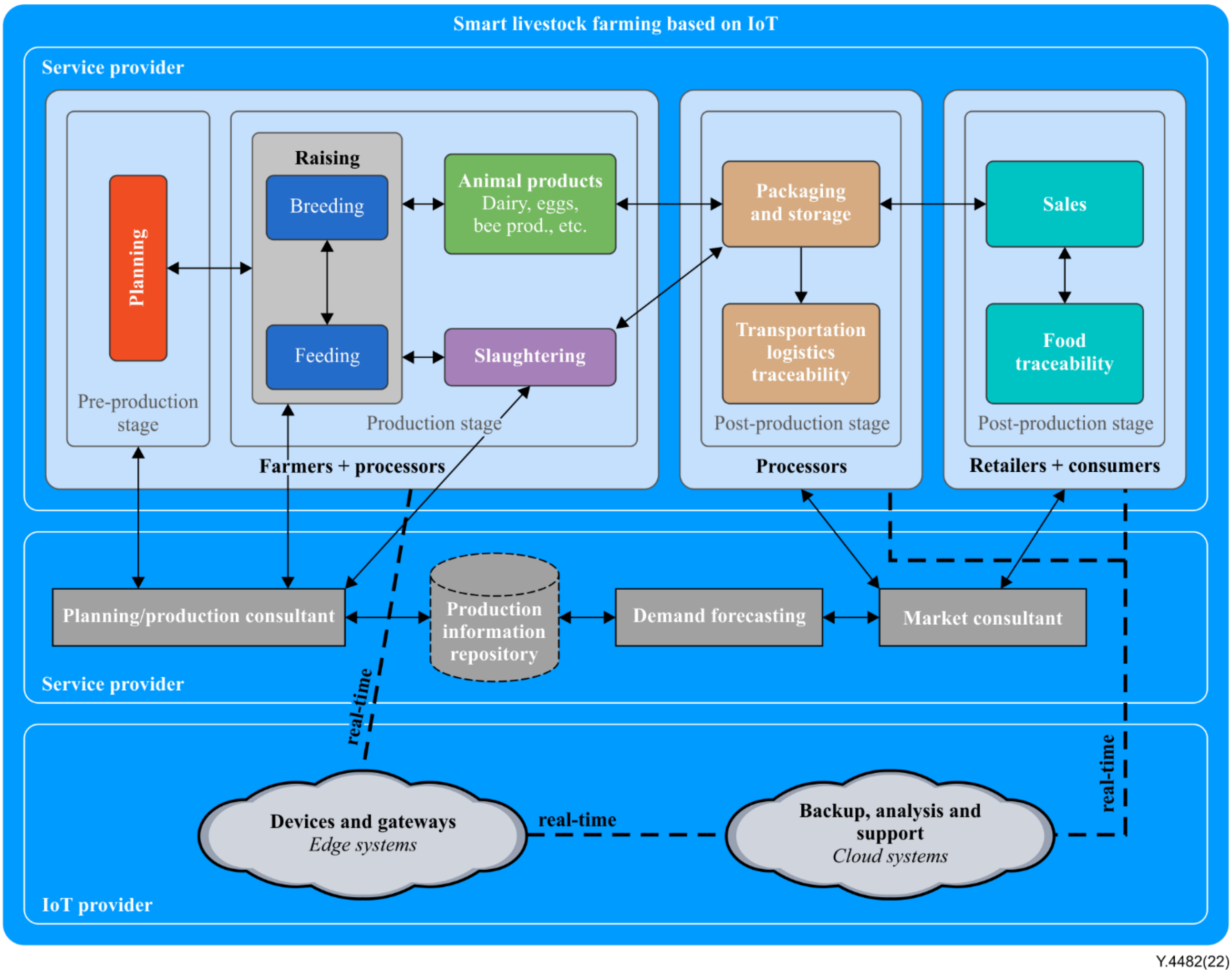

Figure 4 – Reference model for SLF

NOTE – In Figure 4, the links represented by solid lines indicate data flow between steps and/or players, that is, information exchanged either in a digital or physical way. The links represented by dashed lines indicate interconnections between groups of processes, devices and internet and cloud infrastructure; they represent mainly machine communications supported by broadband links.

The description of each phase, its activities and the main aspects related to IoT are provided in the following subclauses, as well as the mapping of the corresponding service-specific requirements described in clause 8.2. The common requirements from clause 8.1 can be applied to the entire value chain.

9.1 Pre-production stage

9.1.1 Planning

The planning phase belongs to the pre-production stage and is the initial step before the production itself begins. In this phase the resources are allocated according to the activities, workforce, materials and production capacity, in order to serve different necessities. It encompasses all the details surrounding how farm operations will generate products for market. It includes land, buildings, equipment, supplies and processes, as well as laws and regulations that impact the business. In this step the IoT requirements are brought up and the system capabilities are planned/designed to meet them.

9.2 Production stage

9.2.1 Breeding

Breeding (or reproduction) is the first step in the production stage shown in Figure 4. It refers to herd increase through reproduction between animals inside the farm or by artificial insemination or embryo transfer techniques, and should always consider the improvement of desirable traits.

This step confirms plans derived from the planning step in the preproduction stage and then interacts with the feeding step which is described in clause 9.2.2. The IoT requirements for this step are described in clauses 8.2.2 and 8.2.5.

9.2.2 Feeding

Feeding is the step that has economic impact during the production stage and can determine the final product result and efficiency. It involves animal feeding and water consumption. This information about feeding should be accessible in real time either by the farmer, service provider or managing system. Extensively reared animals may subsist entirely on forage, but more intensively kept livestock will require energy and protein-rich foods in addition. The ingredients for the animals' food can be grown on the farm or, in the case of compound foodstuffs specially formulated for the different classes of livestock, their growth stages and their specific nutritional requirements, purchased. In the case that food components are purchased from external suppliers, the information regarding the supplier, quality and quantity of all ingredients should be recorded.

This step confirms plans derived from the planning step in the pre-production stage and then interacts with the breeding step. The IoT requirements for this step are described in clauses 8.2.1, 8.2.3-8.2.6.

9.2.3 Animal products

The collection or extraction of animal products is conducted during this step. This includes any product that can be obtained without the need to kill the animals, for example, dairy products, eggs, wool and bee products (honey, propolis). In this step the most important IoT requirements are the animals' identification and the product batches' identification. It can be considered the last step of the production phase, together with the slaughtering step. After this step, the post-production stage begins.

The IoT requirements for this step are described in clauses 8.2.5 and 8.2.8.

9.2.4 Slaughtering

Alternatively to the animal products step, the slaughtering step can also be the last step of the production phase. It is defined as the killing of animals for food and/or to obtain certain products such as fur and silk. After killing the animals, their carcasses are manipulated and several products are obtained, for example, meat cuts, processed meat, bones, blood, hair, skin and leather. However, they might also be slaughtered for other reasons such as being diseased or unsuitable for consumption; in this case their carcasses must be properly discarded.

The IoT requirements for this step are described in clauses 8.2.3, 8.2.5 and 8.2.8.

9.3 Post-production stage

9.3.1 Packaging and storage

After the animal products are obtained, they need to be properly packaged and stored according to standards and regulations to guarantee food safety.

The IoT requirements for this step are described in clauses 8.2.7 and 8.2.8.

9.3.2 Transportation, logistics and traceability

Logistics is important to provide the necessary amount of inputs at the correct time during production, as well as to provide a constant flow of well finished animals for the slaughterhouse to maintain its optimal workflow. Still, animal transportation and handling can be responsible for degradation of product quality. Stress in its many forms, for example, caused by deprivation of water or food, rough handling, exhaustion and fighting, may have deleterious effects on meat quality and the most serious consequence of stress is death, which is not uncommon. From loading on the farm to the slaughterhouse, animals must be treated kindly, and transportation variables should be controlled and recorded for traceability purposes. For this aspect, all information regarding the transportation and the animal's situation should be accessible in real time by the service provider.

The IoT requirements for this step are described in clauses 8.2.3, 8.2.5, 8.2.7 and 8.2.8.

9.3.4 Sales

During the sales step the products can be held for some period of time until they are bought by the end consumer or retailer.

The IoT requirements for this step are described in clauses 8.2.7 and 8.2.8.

9.3.5 Food traceability

Traceability or product tracking is the capability to follow the path of a specified unit of product as it moves through the value chain. In general, a food business engaged in the wholesale supply, manufacture or importation of food must have a system for unsafe food recall. A requirement for this system is to include production records covering, such as manufacturer or supplier of products, volume or quantity of products, batch or lot identification (or other markings), distribution place of products and any other relevant production records. This information should be accessible in real time by all agents involved in the value chain, including government agencies, to know what, how much and from where product needs to be recalled if this becomes necessary. Additionally, traceability within the food processing industry is utilized to identify key production and quality areas of a business versus those of low return and points within the production process that may be improved.

The IoT requirements for this step are described in clauses 8.2.7 and 8.2.8.

10 Security considerations

As far as information and communication security, best practices should be adopted when using IoT in smart livestock farming.

General principles that should be fulfilled are confidentiality, integrity, availability and authenticity.

Appendix I

Use cases for smart livestock farming based on Internet of things

(This appendix does not form an integral part of this Recommendation.)

I.1 Beef cattle traceability monitoring

In Brazil, an individual animal voluntary identification system (SISBOV) (for cattle and buffalo) was implemented and is fostered by the Ministry of Agriculture, Livestock and Food Supply [b-SISBOV]. Briefly, the aim of SISBOV is to register and control animal management and mobility within farms that desire to become eligible to export meat and live animals to countries that require individual animal history tracking. In this context, SISBOV enables the implementation of several other technologies in the livestock value chain, with potential to deliver a more productive and sustainable production, such as:

– Traceability – The use of individual animal identification guarantees its product's tracking and certification, with efficient health management control, logistic and alimentary safety.

– Location monitoring – Adding GPS or local monitoring to the animals allows herd behaviour tracking, supports dominancy identification and the necessary management of feeders and watering points (drinking troughs). In addition, it can help to prevent cattle theft.

– Feed intake – Automatized feeders with weigh cells provide data on feed supply, as well as the dynamic of feed intake by the animals throughout the day – time spent eating, feeder visits, intake rate, etc.

– Animal performance – Drinking troughs may have a collocated scale, which weighs animals while they stand still to drink water. Besides gathering data for the productivity monitoring services, this may assist in detecting disease or dominancy issues.

– Greenhouse gas monitoring – Automatized feeders may have a collocated methane sensor that capture and measure methane emission by a given animal during a feeding period, which can predict daily methane emissions by this animal.

The use cases mentioned above enable farm gathered information to be remotely collected and processed. This would enable remote real time event detection data (e.g., relating to a disease that causes appetite and weight loss), decision support (e.g., on grass and/or supplement management) and context awareness (e.g., deciding the best time to sell the product).

I.2 Dairy cattle monitoring

In the case of dairy cattle, all previously mentioned technologies may be applied. These animals are demanded to produce large amounts of daily product, and are therefore constantly handled. In this sense, rumen boluses are especially useful in dairy cattle. Sensors can be swallowed and lodged in the rumen to monitor its health.

Besides, as productivity is a major issue in modern dairy farms, a precise heat (oestrus) detection becomes very important. This is a task traditionally assigned to veterinary experts watching animal behaviour. More recently, some electronic devices have been developed to monitor a cow's physical activity, but sometimes they require expensive hardware and large batteries. The followings are examples of different methods used to measure activity [b-Bellini].

Figure I.1 – Different methods used to measure dairy cattle activity

In this context, sensors can be implanted into animals to monitor oestrus timing of a given animal, to guide artificial insemination management and to monitor the insemination success rate.

In addition, as the size of dairy farms and the number of animals per stockperson are increasing, timely measurements detecting health problems of individual cows becomes a challenging and costly task, particularly as it relates to energy efficiency. To solve this problem, IoT energy-constrained technologies should be applied in animal monitoring [b-Benaissa].

I.3 Cattle rustling monitoring

As cattle rustling issues exist for extensively raised animals, location monitoring is the most important technology to be applied. The difficulty relies on covering the entire herd, which can be large in number, and also the long distances to cover with wireless communication, together with the need for energy-constrained devices. In this sense, the implementation of related technologies should be considered: cheap devices, wide coverage areas and very low power consumption.

In many African countries, cattle theft happens recurrently, and as it increases, it becomes a major concern for farmers and governments, resulting in a significant constraint on livestock development. Its impacts have social, security and economic aspects. In this sense, IoT related technologies could help restore the limits of traditional solutions for the fight against cattle rustling by facilitating the identification and location of the animals, the management of farms and herds, the management of grazing areas, the study of animal behaviour, theft prediction, and so on. Therefore, system designs encounter several challenges, such as the number of sensors to be deployed, large grazing areas, animal behaviour, transhumance, mobility and cost [b-Dieng].

In Kenya, cattle rustling is one of the main challenges facing pastoralists and commercial cattle farmers, because it involves cross-border and armed cattle rustling violence. Trying to follow animal tracks without knowing their exact location always puts the lives of recovery personnel at risk, and in several cases results in military and civilian casualties. In this sense, some researchers propose a framework that provides a secure and convenient way to identify and track stolen animals based on IoT technologies [b-Wamuyu].

A study case of long-range monitoring for cattle tracking was adopted at Pogoniani and Ioannina in Greece. Data was retrieved from sensors attached to a collar. The technical advantages of using sub-GHz communication technologies for cattle monitoring in wide areas was discussed [b-Zinas].

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