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A critical review of sustainable radio frequency identification (rfid)-based livestock monitoring and managemnet systems: towards quality products and practices

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Abstract - In the past few decades, technologies on smart farming have been introduced and implemented moderately. Issues such as food security, population growth, climate change, environmental impacts and economical problems have forced the relevant authorities to find new solutions to solve these problems. In this paper, a comprehensive view of the past, current and future RFID technologies are presented. These technologies could be integrated with other technologies such as wireless sensor network, cloud computing and other related technologies to make the process of identifying, tracing, tracking and monitoring individual livestock become more intelligent and productive.

Keywords: smart farming, animal identification, farm management, animal tracking system, automated monitoring systems.

INTRODUCTION

In 2008, the world population growth rate was 1.1% per year. It is estimated that the world population will reach 9 billion by 2050 [1]. Due to the increasing population, the demand for food and related resources will increase. Annual meat consumption will quadruple in developing countries. As illustrated in Table 1 this rate will rise by 1.3% in developed countries between 1980 and 2050 [2, 3]. Because of the growing population and their demands, farmers need to improve their yields at reasonable prices to meet demand and prevent starvation. Furthermore, the emergence of animal diseases such as foot-and-mouth disease (FMD) and the outbreak of food-borne diseases have forced researchers to come up with a new system to monitor livestock continuously over their whole life [4-7]. By applying appropriate livestock management systems, it will help to meet the increased demand for meat.

LIVESTOCK MANAGEMENT SYSTEM

Livestock management is the practice of efficient, productive and ethical care taking of each individual livestock to enhance the productivity, performance and quality with minimum cost. In the past, livestock management was labour-intensive. The labourers have been largely responsible for animal identification, tracking and monitoring, and inspecting the conditions on the farm. In addition, they collect large amounts of information to determine if any actions needed to be taken. This process is laborious, time-consuming, error-prone, inefficient and expensive. In addition, the collected information may not be accurate. These deficiencies can be overcome by electronic livestock management systems. These systems capture and analyse individual animal information automatically. It usually consists of medical and health management, food management, general management and housing for each individual animal. Choosing an appropriate animal identification technique is one of the pivotal prerequisites for a successful livestock management system.

Table 1: Trends in consumption of meat between 1980 and 2050 [2, 3]

	Year	Annual per capita meat consumption(kg)
Developing countries	1980	14
	2002	28
	2030	38
	2050	44
Developed countries	1980	73
	2002	78
	2030	89
	2050	94

IVESTOCK IDENTIFICATION TECHNIQUES

There are diverse techniques to identify animals such as ear notching, tagging, branding, freeze branding and electronic identification [8, 9].

1. Ear Notching

Ear notching is usually used for swine identification. In this technique a V-shape is removed from the ear of the animal. As it is shown in Figure 1, five locations on the right ear and three locations on the left ear indicate litter number and animal number, respectively. The notching can be done quickly with little pain. This method cannot be done until the ear has fully developed and it requires special instruments that are not costly [9-12].

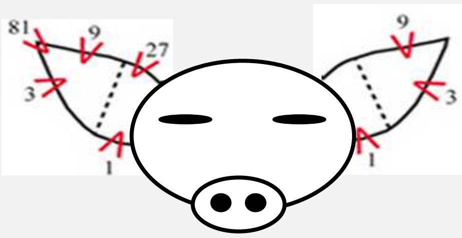

Figure 1: Universal ear notching method

2. Branding

Another animal identification technique is branding. Hot-iron branding and freeze branding are two variants of this method. The hot-iron branding method leaves permanent scars by destroying hair follicles. Although it is easy and inexpensive, it is painful and stressful to the animals [10, 13].

Freeze branding destroys the animal's pigment-producing cells so that when the hairs grow back it is white. Although this method is painless, it is complicated because it requires various tools such as a refrigerant, clippers, a container for coolant, brush, plastic squirt bottle and restraining equipment [9-14].

3. Tagging

Another common animal identification method is tagging. The animal number is written on plastic tags which are attached to the animal's ear or neck. An animal ear tag is illustrated in Figure 2. It is flexible in all types of weather, inexpensive and easy to read. The disadvantage is that it can be easily ripped and lost [9].

Figure 2: Animal ear tag

All these techniques are considered as a traditional animal identification techniques. These are not only contributing to the wastage of resources such as time, energy and money, but they also require a high budget. These methods are labour intensive. Furthermore, traditional animal identification techniques are forbidden in countries with advanced animal welfare laws [15].

4. Electronic Identification

As an electronic identification is based on radio frequency waves, It is proposed to minimize the number and cost of labourers [9].The animal's unique information is saved on this chip, which can be read by electronic devices. The most common electronic animal identification system is radio frequency identification (RFID) technology. A RFID technology uses electromagnetic waves to uniquely identify an object, animal or person. A typical RFID system includes a tag (transponder), reader/writer (transceiver), antenna and a host, as illustrated in Figure 3. The tag is used for storing the object's unique number and is the data carrier part of the system. The reader/writer (transceiver) is used to write the data to, and read the data from, a tag. The reader has an antenna to propagate the waves and receive the signal. The host or an enterprise system saves the data [16, 17]. The RFID technology has been applied in various fields, such as manufacturing, retailing, healthcare, livestock management, security and farm management.

Figure 3: A typical RFID system

RFID-BASED LIVESTOCK MANGEMENT SYSTEMS

One of the most significant fields of RFID technology usage is in livestock management systems [16, 18]. The RFID systems are categorized to low frequency (LF), high frequency (HF) and ultra-high frequency (UHF) according to the applied frequency bands. In this paper, livestock management systems are

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categorized according to their applied frequency bands. Their benefits and drawbacks are discussed in detail.

1. Low Frequency (LF) RFID-Based Livestock Management System

The most common systems for livestock identification use the low-frequency (LF) band (125-134 kHz) [18-20]. In mid-1970s, Matt Lezin and Tom Wilson implanted an RFID tag at the back of a dairy cow in order to track the animal's identification numbers and temperature. The individual animal's health, ovulation, tracking, identification and temperature were determined. Furthermore, automatic feeding was implemented without overfeeding individual animals [21, 22].

Perez-Munoz F. *et al*. developed a quasi-ad libitum electronic feeding system for sows. In this project sows were identified and weighed automatically. When a hungry sow enters the scale, it locks so preventing another sow from entering the scale. The animal ear RFID tag is read and the weight is measured and then all the received information is stored on the computer. According to the recorded information for the sow, the type of food is specified. If animals require high-energy food, they will be sent to the area with high-energy food otherwise they will be sent to the low-energy feeding area [23].

Trevarthen A. and Michael K. enhanced farm management in areas such as automating milking, drafting, door and feeding processes with the help of RFID technology. Automated opening and closing of doors, feeding, drafting and milking are some of the features of the case study. Each animal's required amount of food (depending on the amount of milking) is provided with the help of the automated feeding system. However, cows that need particular attention can be separated from the other animals by an automated drafting system. In addition, information pertaining to individual cow, such as general animal information, treatment and milking rate, are stored in the central animal management database. When a cow passes the RFID reader, its information is obtained by the reader and sent to the host and displayed on the screen. With this feature, the particular requirements of an animal will be specified [24].

Voulodimos A.S. *et al*. proposed an integrated livestock management system based on LF RFID technology. The platform stores and manages various categories of animal information such as nutrition health history, behaviour and production. The mobile RFID subsystem, the local database and the central database are the three main subsystems of the platform. The farm information (address, contact number), veterinarian information, list of authorized veterinarians and the kinds of animals on the farm are kept in the central database. The local databases contain detailed information about the animals. There is a local database at every farm, all of which are connected to a central database [25]. Vrbancic F. focuses on ubiquitous RFID technology for livestock breeding. LF tags are placed on the collar of each animal and RFID readers are installed in the funnel-shaped milking and fodder areas. The software consists of a graphical user interface (GUI) and database. When the fodder area readers detect an animal tag, the animal will be fed according to the exact quantity of food which was detailed in the database. Furthermore, in the milking area the quality and quantity of milk from each animal is measured and saved in the database [26].

Teng C.-C. *et al*. proposed a web-based livestock management application. The proposed system is based on an RFID system, web2.0and mobile-cloud architecture. Furthermore, the occasionally connected application (OCA) is used in the system. This means that field workers are able to access the data stored in local cache memory on mobile devices. The system will connect to the central database frequently to synchronize the contents of the local cache if required. Information about each animal is stored in a central database. Desktop applications such as updates and viewing the information are provided by the web application. The mobile clients communicate with the RFID system. The unique identification number of each animal is read by the mobile RFID system. If these numbers exist in the local database (a cache memory of mobile devices), the animal information and the location of the animal will be shown to users; otherwise, the information will be saved in the local database and then the central database will be updated during the next synchronization process [27]. As the project used cloud computing, the capital cost of project is reduced because the company does not need to spend money on hardware, software and licensing fee. In addition, the information can be recovered and backed up easily. As the company sensitive information is stored in the cloud, it can be accessed by the third-party cloud service provider. Therefore, it can be a serious security issue.

Samad A.*et al*. developed a comprehensive RFID-based system for small-hold dairy farmers. Data is recorded correctly by the system in order to minimize the misuse of livestock insurance. The system collects performance records periodically. The system uses the LF RFID reader with 300 MHz operating frequency, tag, laptop and a universal serial bus (USB) modem, along with central and local servers. The animal will be registered in the insurance system when the animal tag is read by the mobile RFID system for the first time. Afterwards, the animal information and owner name will be saved to the laptop. This information will be transferred to the central database through the internet. Any changes in animal information (e.g., diseases, new owner) are stored in the insurance database [28].

Table 2: Low frequency (LF) RFID-based livestock management systems

Reference	Objective(s)	Benefits	Drawbacks
Matt Lezin and Tom Wilson	To track cows, their health and feed.	• Prevent overfeeding of an animal.	• Requiring large and expensive antennas. • Powering tags inductively so the reader power must increase significantly for increasing the read rang [29]. • Being suitable for a kind of animal such cows or sows only.
Perez-Munoz F.*et al*.	To develop a quasi-ad libitum electronic feeding system for sows.	• Feeding sows according to their requirements.	
TrevarthenA. and MichaelF.	To consider adoption of RFID beyond the need for compliance and toward the perspective of longer term productivity and strategic Visibility.	• Creating automat individual animal feeding, drafting. • Gaining a good return of investment in 20 years.	
Vrbancic F.	To develop ubiquitous livestock breeding system.	• Measure quantity of milk for each animal. • Monitoring an animal food quality.	
Samad A.*et al*.	To developed an animal management system for small-holding dairy farms.	• Cost effective	
Voulodimos A.S. *et al*.	To develop a livestock management system.	• Cover a large category of animal. • Monitor animals' critical information such a feed, health information.	
Teng C.-C. *et al*.(USA)	To control quality and to manage animal health information and infectious diseases using cloud computing.	• Reduce capital cost. • Easy back up the information.	• Security issue

Table 2 presents the systems based on low frequency (LF) RFID technology and the benefits and limitations of each application are indicated. Some applications are suitable for one group on animal such as Perez-Munoz *et al*. andMatt Lezin and Tom Wilson which the systems are only suitable for the feeding of sows and cows, respectively. They designed and worked well for a small number of animals except Voulodimos A.S. *et al*.'sapplication. In addition, all of these systems used a LF RFID technology for animal identification that have short communication range, between 10 cm and 20 cm, slow reading speed, sensitivity to electrical noise, a large and expensive antenna are some of its weak points. It cannot normally handle a dense tag environment [18-20]. Furthermore, they used inductive coupling techniques to power tags so the reader power must be increased greatly to increase the reading rang.

According to the regulations there is no definition of a comprehensive framework for an animal management system [25]. In comparing recent works, greater livestock management systems have been presented by Trevarthen A. and Michael K., and Voulodimos A.S. *et al.*

2. High Frequency (HF) RFID-Based Livestock Management System

Some applications use High-frequency (HF) RFID systems which have a communication range of 10 cm to 1.5 m with an operating frequency range of 13.56 MHz [18-20].

Reiners K. *et al.* simultaneous identified individual weaned piglets at the feed trough using a passive HF RFID system. The HF tag was connected to the ears of piglets. The circular HF antenna was in the round trough of the feeder. The system uses the anti-collision system to register multiple tags simultaneously. Furthermore, the feeding behaviour of animals is monitored by video camera. When the animal comes to have food, they will be recognized and their data will be sent to the server for registering or future analysis. Moreover, the data from the RFID system and video observation was compared with each other and the time discrepancy for the RFID system will be measured in order to find RFID system accuracy [30].

Feng J. *et al.* developed and evaluated an RFID-based traceability system for cattle/beef quality safety in China. The proposed system includes cattle breeding management system, slaughter management system and retrieval system. Animals' general information, feeding information, disease information, treatments that are applied to cure sick cattle, immunization and records on disinfection of cow-sheds and devices are gathered in the cattle breeding management system. In this phase the herd keeper used a personal digital assistant (PDA) to read the HF tag of animals. Afterwards, data is transferred to the PC by serial port in order to be saved to the database. In the beef slaughter data management system the animals are examined; if they are healthy, they will be sent for bloodletting, peeling and disembowelment. Afterwards, the acid decomposition step will be done to resolve the lactic acid from the carcasses and then they will be sent for packaging. As shown in Figure 4, in the slaughter house the data on the animals' HF tags is read and copied into two tags. When animals are slaughtered and divided into dyads, these two RFID tags will be adhered to each dyad. In the next step the dyads are segmented to tetrads and a copy of the HF tag will be attached to each part. Next, this HF tag information is copied into some UHF RFID tag and attached to segmentations of the animal. In the packaging process, the identification information from the UHF tags is converted to 2D barcodes and attached to each package. On the retrieval part of the system users can retrieve the animal's information [31].

The basic objective and strong points as well as the limitations of each application are presented in Table 3. The HF RFID technology has been used for animal identifications purpose in these systems. Reiners K.*et al.* collected information of sows automatically at the food through only with the help of HF RFID technology and sensors. The system identifies multiple piglets shortly and accurately. Feng J.*et al.* developed comprehensive and efficient cattle/ beef tractability systems. They are suitable for a dense reading environment. HF technology used inductive coupling techniques to communicate with tags same as LF technology, they have a higher communication range and read speed.

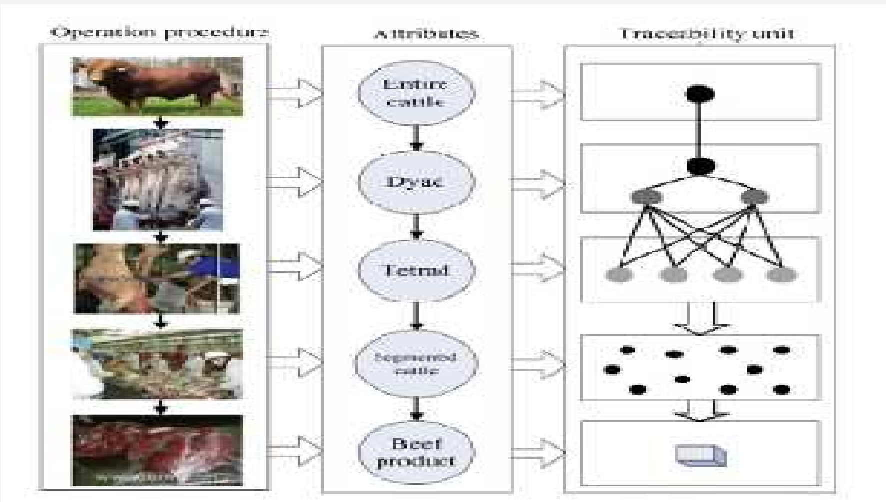

Figure 4: The transformation of traceable units during cattle/ beef production business [31]

3. Ultra High Frequency (UHF) RFID-Based Livestock Management System

Ultra-high-frequency (UHF) RFID technology utilizes the 860 to 930MHz frequency band. ChansudAW.*et al.* developed an RFID poultry traceability system, which consists of hardware, software and a database system. The hardware part of the system comprises of tower lights, sensors, RFID tags and an RFID reader. Access card, e-seal, cage tag and user card are the four types of tag that were used in the project. The access card is an LF tag, which is used by truck drivers to record information like time stamp throughout the transportation path. The e-seal is a UHF tag, which is used by trucks which contains a movement document number and a truck license plate number. The tower lights are the controlling devices. They control the movement of the vehicle in each area. There are two tower lights and entering and existing vehicles are controlled by the first and second tower lights, respectively. Sensors have been used as an automatic management tool. The software part of the project includes poultry transportation management, a web server and a database. The poultry transportation management software allows the tracking and checking of the movement of the vehicles and animals. The software stores the result of the movement of the truck and animals in the database automatically. In addition, it obtains the e-seal number from tags on the truck. The web service is used to exchange information between databases. The software connects to a web service, database and UHF reader. When the vehicle enters the checkpoint, the sensors detect it and trigger the UHF reader automatically. When the reading process starts, the colour of the first tower light will be green. Afterwards, the e-seal and cage tags will be read by UHF readers. The data retrieved from the e-seal is compared with the data stored in the database. If it does not match, the vehicle will wait for further notice. Otherwise, the movement information will be shown on the screen. Then, staff should approve the movement; if the transportation is approved, the timestamp will be written on the access card and the second tower light will turn green to let the truck pass the checkpoint. Finally, the database is updated [32].

Table 3: High frequency (HF) RFID-based livestock management systems

Reference	Objective	Benefits	Drawbacks
Reiners K.*et al.*	To facilitate simultaneous registration of piglets.	• Registering animal with a short time delay. • Real-time identifying animals simultaneously and accurately. • High efficiency of information tracking. • Higher identification rate than LF. • Higher read rang than LF. • Ability to perform on liquid and metal.	• Inductively powered so the reader power must increase significantly for increasing the read rang[29]. • High implementation cost.
Feng J.*et al.*	Developed and evaluated a cattle/beef traceability system that integrated RFID technology with PDA and barcode printer.		

Wisanmongkol J. and Pongpaibool P.used UHF RFID tags for poultry traceability where each cage was outfitted with a UHF RFID tag, in order to be able to trace the animals [33]. Yin J. *et al.* used UHF RFID tags in a provenance system for livestock supplied to Hong Kong in order to improve public confidence. Important animal data from birth to slaughter is collected by RFID readers. The important data in this project consisted of feeding information, cultivation information, disease treatment information, slaughter information, farm information, shelter information, vaccination information, transportation information and veterinary information [34]. Stekeler T.*et al.* developed an application for identifying of fattening pigs by using UHF RFID technology. Twelve pigs equipped with two kinds of UHF tags.

Furthermore, two diverse UHF readers with various angles were installed in three different locations in an alley of the feeding house in order to measure and analyze the identification rate of each of them. By testing this system for several times, the results show that if the correct UHF tag and reader and are chosen, the identification rate will be improved [35]. Details of the objectives, the benefits and limitations of each application are presented in Table 4.

Chansud W. *et al.*, and Wisanmongkol J., Pongpaibool P. and YinJ. *et al.*proposed a traceability system for one kind of animal such as poultry and cattle/beef. Stekeler T.*et al.* used a UHF RFID technology for livestock identification system, while the rest utilised it in animal traceability systems. Although, the UHF technology offers a long read range of up to ten meters, it has some limitations such as susceptible to water and mental and privacy issues [18-20].

4. Multi Band RFID-Based Livestock Management System

Multi-band RFID technology works in diverse frequency bands. It usually covers 867 MHz (UHF frequency) and 13.56 MHz (HF frequency). The multi- band RFID technology was proposed not only to overcome each frequency limitations but also to adopt with diverse standardizations in different places and systems [36, 37].

Table 4: Ultra High frequency (UHF) RFID-based livestock management systems

Reference	Objective	Benefits	Drawbacks
ChansudAW. *et al.* WisanmongkolJ.andPongpaibool P.	To trace back to the origin of poultry.	• Efficient and accurate tractability system.	• Privacy issue. • Sensitive to water and mental.
Yin J. *et al.*	To collect important data to form provenance information	• Improve supervision on the whole process of livestock supply chain	
Stekeler T. *et al.*	To identify multiple fatten pigs simultaneously.	• Reasonable identification rate.	

A multi-band RFID-based livestock tracking and identifying system was implemented in Malaysia. The purpose of the project is to increase the competitiveness of livestock industry. The project was implemented to control outbreaks of disease and identify any animals that had been exposed to the source. Malaysian microchip (MM) was utilized in the project. The MM has been developed under the MM project, which was started in Malaysia in 2003 as a national project to explore RFID technology. The project was in collaboration with FEC International (M) Sdn. Bhd.; an associate company of FEC International Inc. based in Japan, which specializes in radio frequency activities [38].The MM1, MM2, and MM3 are three variations of RFID chips that have been developed under the MM project. Each of these chips has specific features that make them suitable for different types of application. The MM1 and MM2 are multiband chips which means they work on different frequencies from 13.56 MHz to 2.45 GHz. In addition, these chips have an on-chip antenna (OCA), which was developed by Toppan Forms and FEC international (M) Sdn. Bhd. With the help of OCA technology the chip does not require an additional antenna. In addition, the size of the RFID tag is considerably reduced. Because of this feature, small objects can be equipped with tags. Moreover, the communication distance can be increased and the gap between the chip and the antenna is solved. The MM chip needs three types of antenna to support the frequency between 13.56 MHz and 2.54 GHz [38, 39]. The MM chip antenna is depicted in Figure 5.

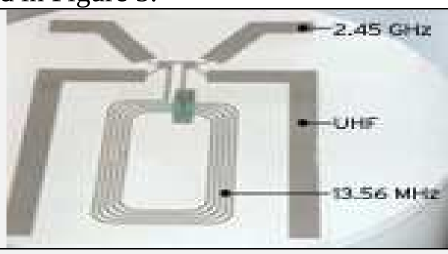

Figure 5: MM chip with three antennae [39]

The MM1 and MM2 chips have highly secure data transmission because they use the original air interface protocol (AIP) technology developed by Zixsys. The MM2 chip is more secure than MM1 because it uses the original algorithm for coding and decryption. The chip is not compatible with international standards. The MM3 chip is a UHF passive RFID tag that is compatible with EPC global Class1 Generation 2. Its operating frequency is 850–960 MHz. It can read multiple tags with anti-collision. The capacity of the user memory is 512 bits [38-41]. Table 5 shows the features of the MM chips.

FUTURE RFID TECHNOLIES

In future the RFID system could be integrated with the other sub-systems such as wireless sensor network (WSN), embedded system, System on chip, cloud computing, green power harvesting technology and other emerging technologies. Current technologies to make livestock management system more intelligent and affordable are demonstrated in Figure 6. The complete structure of RFID system will be changed in future. For instance, readerless RFID system which can reduce the cost and complexity of the system is waiting to be implemented in the future. This will lead to sustainable eco system for the livestock industry.

CONCLUSION

In this paper different RFID-based livestock management systems have been discussed and considered in detail. In addition, the different technological architectures, software and hardware used in the proposed systems were discussed and presented. In future, this system would become more intelligent and sustainable for the livestock industry which can address one of the issues of food security.

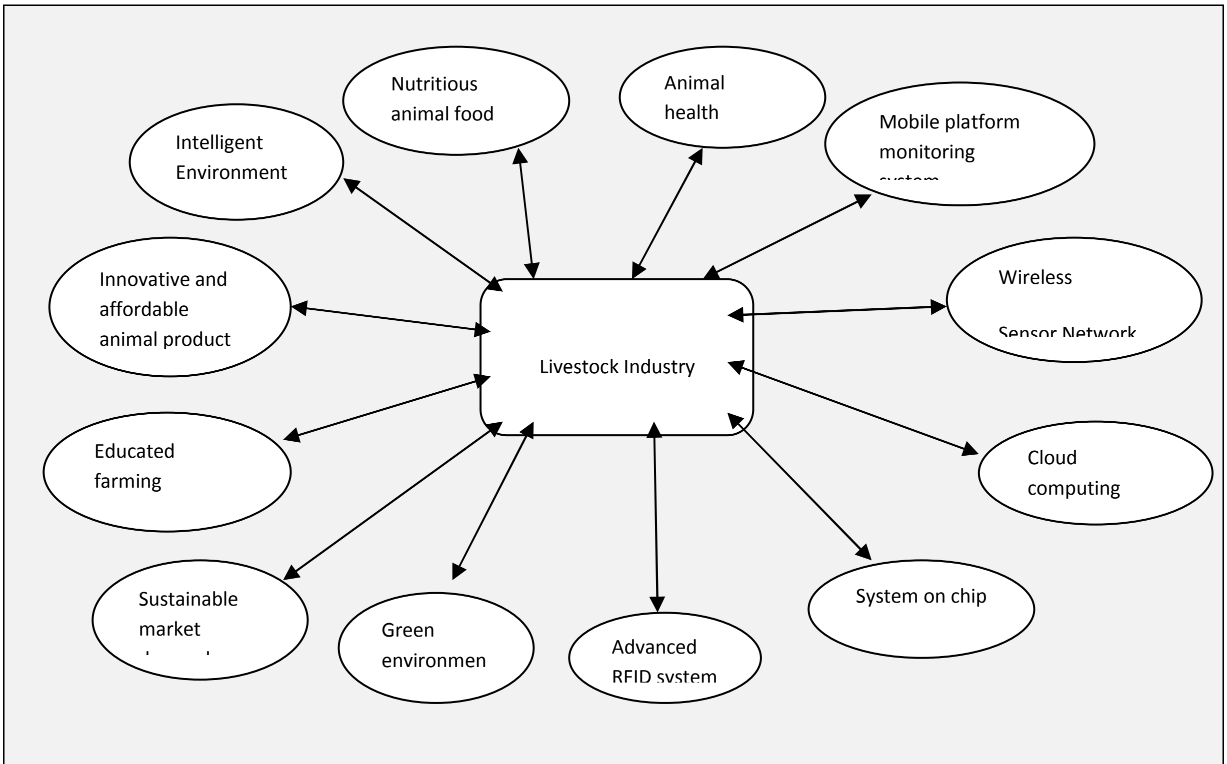

Figure 6: Future trend in livestock industry

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