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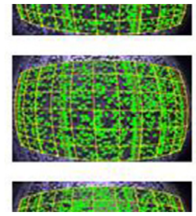
General introduction to precision livestock farming



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Implications

Many people in several countries worldwide, particularly in Asia, India, and South America, are getting more financial possibilities to buy animal protein. This fact, combined with the changing diets of these people in those countries, will result in an increase of the worldwide demand for animal products (meat, eggs, and milk) of 70% by 2050. Consequently, the number of livestock is increasing, while at the same time, the number of farmers is decreasing. This results in much bigger herds per farmer. It has become impossible for farmers to follow all of their animals in a reliable way in such big groups. At the same time, several issues must be solved now in the livestock sector, such as monitoring animal health and welfare, reducing the environmental impact, and assuring the productivity of the process. Precision livestock farming (**PLF**) aims to offer a real-time monitoring and managing system for farmers. This is fundamentally different from other approaches that tried to monitor the animal welfare by human experts scoring animal-based indicators. These methods do not improve the life of the animal under consideration. It is nice to detect a problem after an animal has arrived at the slaughterhouse, but it is much better to detect a problem while the animal is being reared and to take immediate management action. The idea of PLF is to provide a real-time warning when something goes wrong so that immediate action can be taken by the farmer to solve the problem. To bring PLF technology further into field application, increased development and testing of PLF technologies is required in real farms to implement reliable solutions. To further develop and introduce such supporting management PLF systems, some basic principles must be respected.

Key words: general introduction to PLF, principles of PLF

This paper aims to sum up the main challenges in the livestock sector and to describe how the technology of precision livestock farming (**PLF**) can offer solutions by describing the main principles of the PLF technology and by suggesting next steps to implement PLF technology at a larger scale. Precision livestock farming is a multidisciplinary science that requires collaboration among animal scientists, physiologists, veterinarians, ethologists, engineers, information and communication technology (**ICT**) experts, etc. The second objective is to achieve some agreement in the terminology used by these different disciplines to improve communication among specialists from different disciplines.

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Main Challenges for the Livestock Sector

If the worldwide increase of animal products is increasing 70% by 2050, we face some serious problems. Those who state that the solution lies in stopping or reducing the meat consumption seem to forget that it is not easy to stop or forbid people to eat meat and change their habits. We need to find solutions to anticipate growing problems.

A major problem for the next 10 yr is the continuous monitoring of ***animal health*** within the big groups of animals. Due to the increasing number of animals and the decreasing number of farmers, every farm will count more animals. In the future, a single farm (or animal city) could see 25,000 milking cows, 200,000 fattening pigs, or a few million broilers. Infections in such big groups will have disastrous consequences while the reduction of the use of antibiotics is a primary challenge. The development of vaccines will take time, and the efficiency of applying vaccines in big herds must be monitored to improve them. Animal health is a top priority in relation to human health. In Europe, more than 25,000 people died due to not responding to antibiotics anymore while treatments cost of €1.5 billion (Anne Mottet, FAO, unpublished). The big density of animals living so close to humans in some countries is another issue. The number of zoonosis diseases that can be transferred to humans is very high. The safety and quality of the food products must be guaranteed at every moment. Another huge problem to be solved is the ***environmental impact*** of the livestock sector. More than 90% of the NH_3, 37% of CH_4, and 65% of N_2O in the atmosphere comes from the livestock sector (Anne Mottet, FAO, unpublished). Up to 30% of all land and 8 to 15% of water resources are used by the livestock sector. Since high density of livestock has a serious impact on the environment, this is a primary reason why regions like Flanders in Belgium, North Italy, or Brittany in France cannot accept and take more animals. A serious contribution to environmental impact would be to manage livestock in such a way that the animal productivity is closer to animal's genetic potential—less use of feeder, less manure, and higher productivity. Overall, we stay in practice too far away from the genetic potential of today's genetic lines. Within the international competition, it is a challenge to keep farmers competitive, and animal productivity is a key factor.

Animal welfare is part of animal health, but an animal can look very happy while it might carry an infection, virus, or bacteria. The importance of animal welfare is demonstrated by the new Animal Health Law in the EU (European Commission, 2016; Gebreyes et al., 2016). The idea, however, that farmers must be controlled might not be very realistic since they are the first victim of reduced animal welfare: They depend on the animals for the income and living. It is more realistic to understand that farmers must be supported to get the tools and means to monitor individual animals within the big group that they have to manage. Farmers would be happy to run their farm with fewer animals, but since the public will not pay more for animal

Figure 1. Precision livestock farming systems based on image analyses, sound analyses, or sensors (Berckmans, 2013).

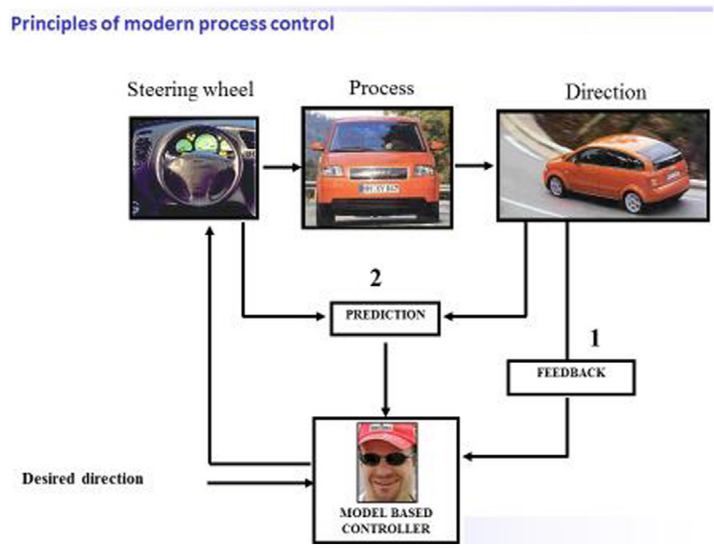

Figure 2. Model-based or prediction-based control of processes.

products, they don't have a lot of choice if they want to stay in business and manage the productivity of their animals. The consumer often forgets that they pay more or less the same price for an egg as what their grandparents paid. As of 2018, most people worldwide will not be living in rural areas anymore; rather, they will be living in cities. The familiarity with and the understanding of the farmers' activities might not improve.

Definition of Precision Livestock Farming

The aim of PLF is to manage individual animals by continuous real-time monitoring of health, welfare, production/reproduction, and environmental impact. The word "continuous" means in this case that PLF technology is measuring and analyzing every second, 24 h a day, and 7 d a week. Farmers get a warning when something goes wrong in such a way that the PLF system brings them to the animal(s) that need their attention at that moment. The monitoring can be done by camera and real-time image analyses, by microphone and real-time sound analyses, or by sensors around or on the animal as shown further (Figure 1).

Basic Principle of the Precision Livestock Farming Approach

When looking to other fields of real-time process management (space applications, military systems, airplanes, industrial processes, etc.), it is clear that the concept of so-called model-based control can be applied in all problems of process management. When driving a car, for example, the driver tries to control a certain driving direction, which is the process output that he tries to control. One of the main process inputs to control this process output is the position of the steering wheel. The reason why a driver can control the direction of the car is because he has a good model in his brain on how the driving direction of the car will respond to the variation of the position of the steering wheel (Figure 2). When the model is not accurate enough (slippery road, too fast, wind, etc.) to predict the behavior of the car, the driver is not able to control this process. When you have a model for driving a car, that doesn't mean that you can sail a boat or fly an airplane because these need a different model.

This demonstrates that the key to process control or management is to predict how the process output (the variable to be controlled) will respond to a variation of the process inputs that we use to steer the process output. Indeed, the real secret of every efficient process control or management system is the prediction of how the process output will respond to a variation of the control input(s). This general scheme of the so-called model-based control is the backbone of the approach behind PLF systems (Figure 3).

A Living Organism Is a CITD System

Since we are aiming to create an early warning system for the farmer to guard animal responses, it is wise to focus on the first signs that can be monitored in a non-invasive and contactless way in a group of animals. The hypothesis is that when an animal experiences less-than-ideal conditions, it will exhibit an initial response in terms of behavioral changes. These first signs of problems should be picked up by the PLF sensing technology, such as by image and/or sound analysis or sensors on the body. As stated in the first European Conference PLF conference in 2003 (Berlin), a living organism is a so called *CITD system* where CITD stands for complex, individually different, time-varying, and dynamic (Berckmans and Aerts, 2006; Quanten et al., 2006).

It is obvious that a living organism is much *more complex* than any mechanical, electronic, or ICT system. The complexity of information transmission in a single cell of a living organism is much higher than most other systems that can be considered. In biological research and the management of biological process (e.g., medical world and livestock world) in industry and society, the general trend is still to compare groups of living organisms by looking for statistical differences in experiments. Statistical methods have been developed primarily to find significant differences between the averages of groups.

However, there is not a single living organism that lives or acts as the purely theoretical average of a group. The average of a group is a purely theoretical number used to compare groups in a statistical analysis. Living organisms are (luckily) *individually different* in their responses. This raises serious ques-

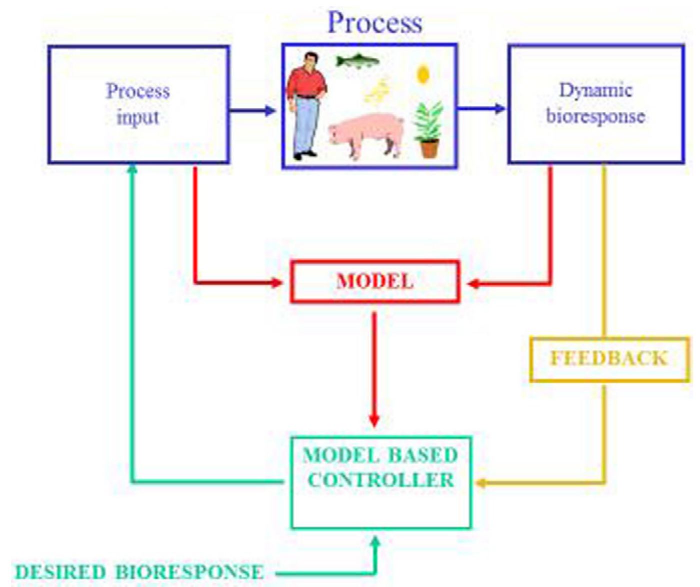

Figure 3. General scheme of model-based monitoring and management of biological processes (used by our research group M3-BIORES, since 2003).

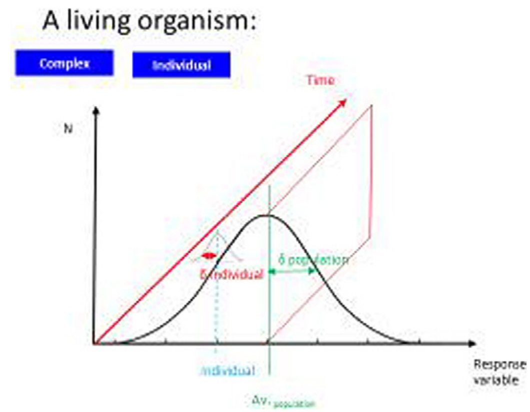

Figure 4. Individual living organisms have a much smaller standard deviation in time than the standard deviation of their population.

tions about the way a lot of research is performed on humans and animals. The *time varying* character of a living organism means that the response of a living organism to a (environmental) stimulus or stressor might be different each time it happens. A homoeothermic living organism is constantly looking for a good energy balance and, as a consequence, is continuously changing its physical condition and mental status. The individual has an individual variation in time, which is much smaller than the standard deviation of the group (Figure 4).Of course, living organisms are dynamic systems.

The CITD nature of living organisms has an important impact on the type of algorithms we need to develop. It implies that algorithms to monitor these time-varying individuals must continuously adapt to the individual and/or use principles that can be used in real time in the field application. The consequence is that only some approaches are appropriate to create real-time monitoring tools for human and animals.

Early Warning System for Broiler Houses

As an example on how the PLF technology can create value for the farmer, we take the eYeNamic system to monitor general problems in a broiler house. Farmers with broiler houses are squeezed into a situation in which they always need to grow more animals to make their living from this business. A broiler house with 30,000 animals in one house is not exceptional at all, but it becomes very hard to observe such a high number of birds. Many problems can occur like animal disease, climate control problems, blocked feeder lines, electricity problems, dysfunctional drinking lines, failing lightning systems, and others.

We have tested whether the PLF eYeNamic system (Fancom BV, the Netherlands) allows detecting most of the daily problems in broiler houses by just analyzing the broilers' behavior. The eYeNamic system consists of 3 or 4 cameras mounted at the ceiling that give pictures of the distribution of the birds (Figures 5 and 6).

The setup of the experiment in a commercial farm was the output of the eYeNamic system that calculates in real time the activity number and distribution of the birds: The number of birds per square meter equally spread all over the ground surface. The farmer was asked to fill in a logbook where he noted down all problems that occurred during the whole fattening period.

The PLF system used an algorithm that compared the actual measured distribution of animals with a predicted value at that time of the day. When the real measured value was more than 25% different from the predicted value, an alarm was given to the farmer. As can be seen in Figure 7, the behavior of the broilers is quantified continuously, and by measuring the distribution of the birds, indications of blocked feeder lines and other problems are given.

The PLF system shows that 95% of all problems are detected from the behavior of the birds (Kashiha, 2013). It used a single parameter: the variation in time of the birds' distribution of the available space. This confirms again that the continuous measurement of animal responses is the way to go and there is no need to measure many variables to get systems that add value. In this case, the fact that most problems are detected means that the farmer can save many working hours that he normally spends for controls. He is advised only to enter the building and disturb the birds to solve problems but has no need to disturb them if no problems occur.

The Big Data Approach in the Livestock Application

In the livestock process, the central and most complex component is the animal. Due to the time-varying behavior of animals being living organisms, the monitoring of the PLF approach requires continuous measurements of the animals' responses directly on the animal rather than in the environment surrounding the living organism. The general approach to collecting real-time field data, known as bio-signals, on the animal is to use sensors (e.g., temperature measurement, GPS position, accelerometer data, etc.), real-time image analysis, or sound analysis. The last two techniques have some advantages such as: no need for physical contact, no risk of infection or disease transfer, no risk of influencing the animal response while making the measurement, no need to recover sensors from living animals, reduced costs since one camera or microphone can monitor a large group of animals.

Since animal responses can be very fast, it is useless to carry out a survey once a year, once a month or week, or even twice a day. We need a continuous monitoring/management tool. Depending on the variable that is monitored, the word "continuous" might mean every second (e.g., for stress monitoring) or once a day (e.g., for weight monitoring). Mod-

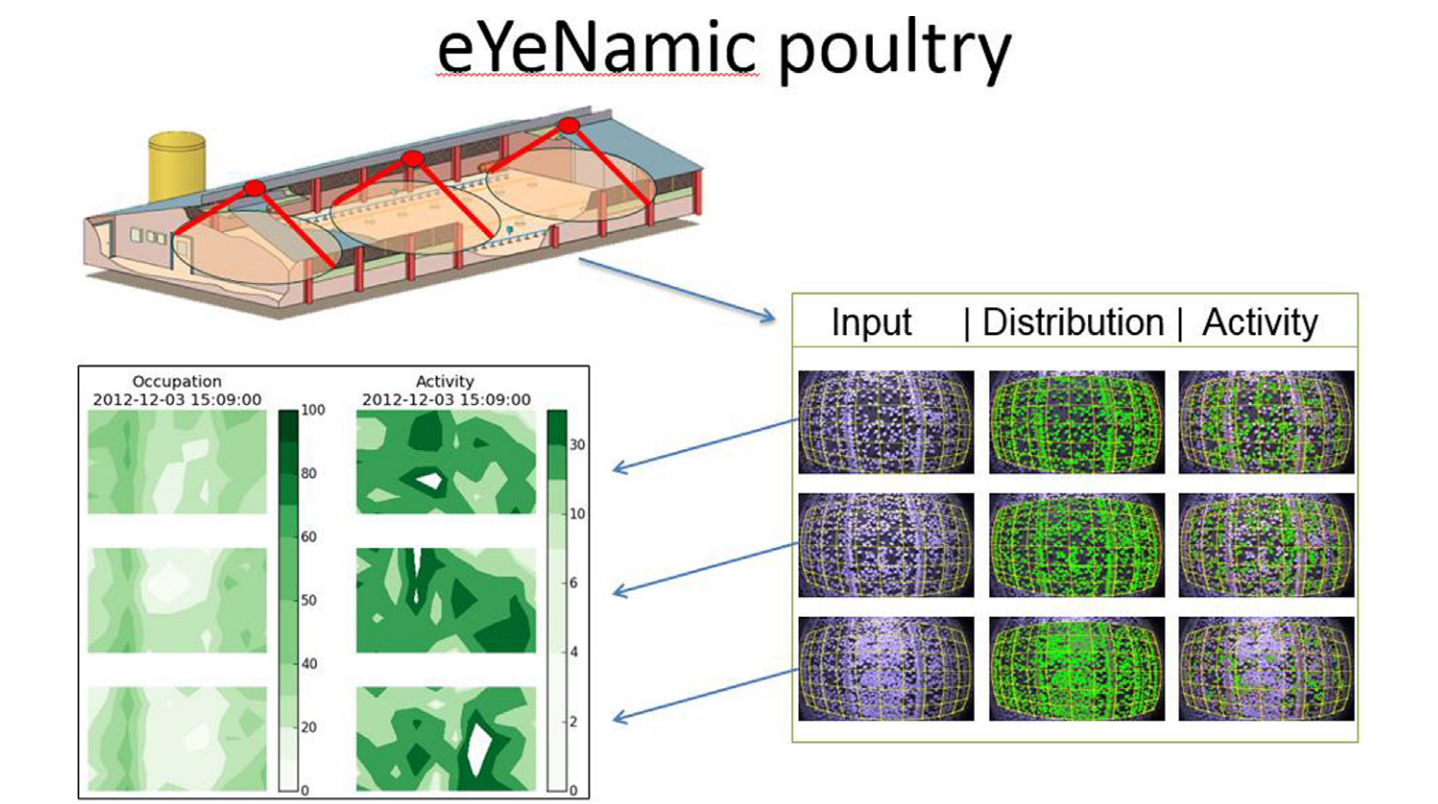

Figure 5. Three top view cameras and real-time image analysis of broiler behavior.

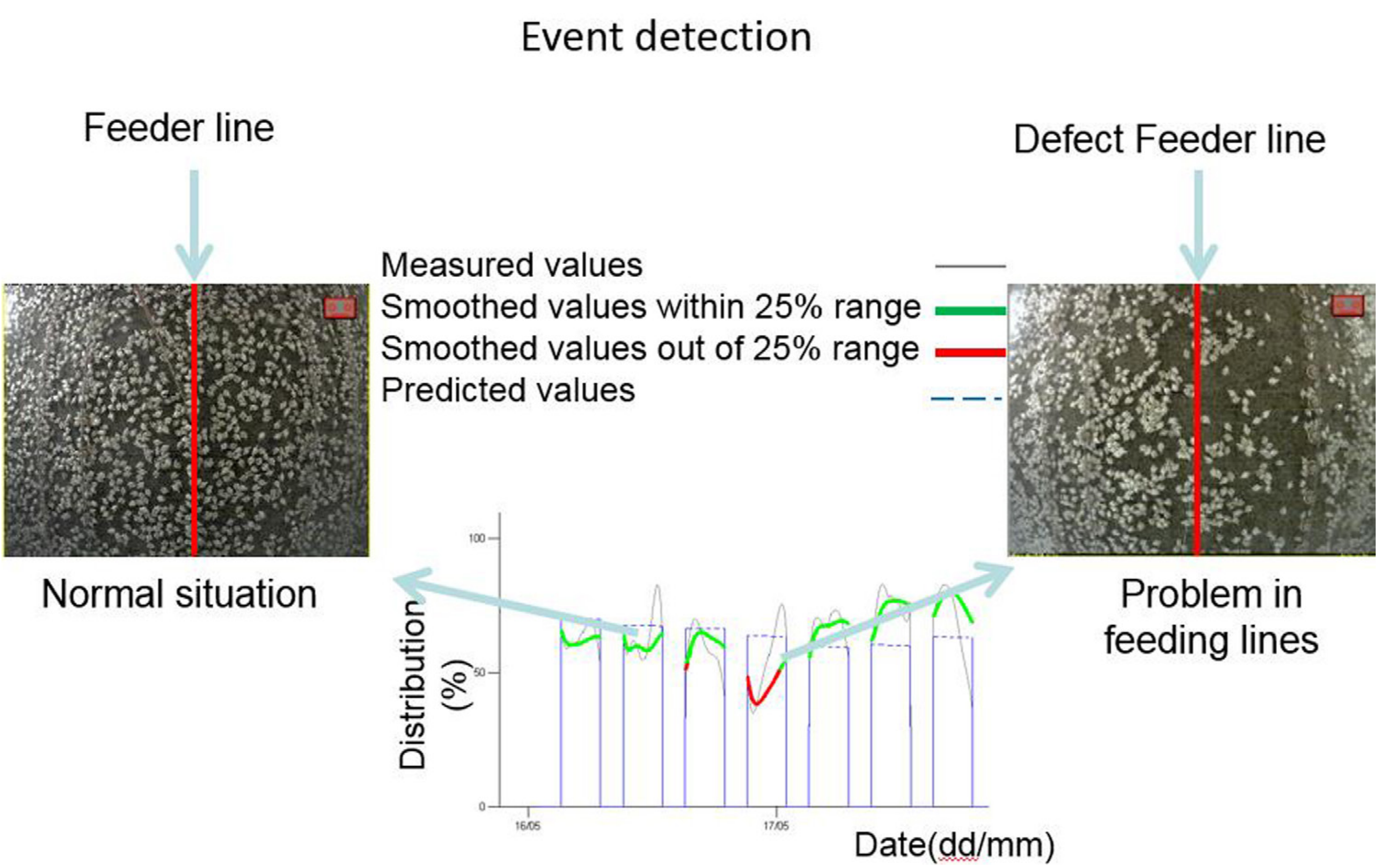

Figure 6. Image from the broilers as analyzed in real time by the eYeNamic system.

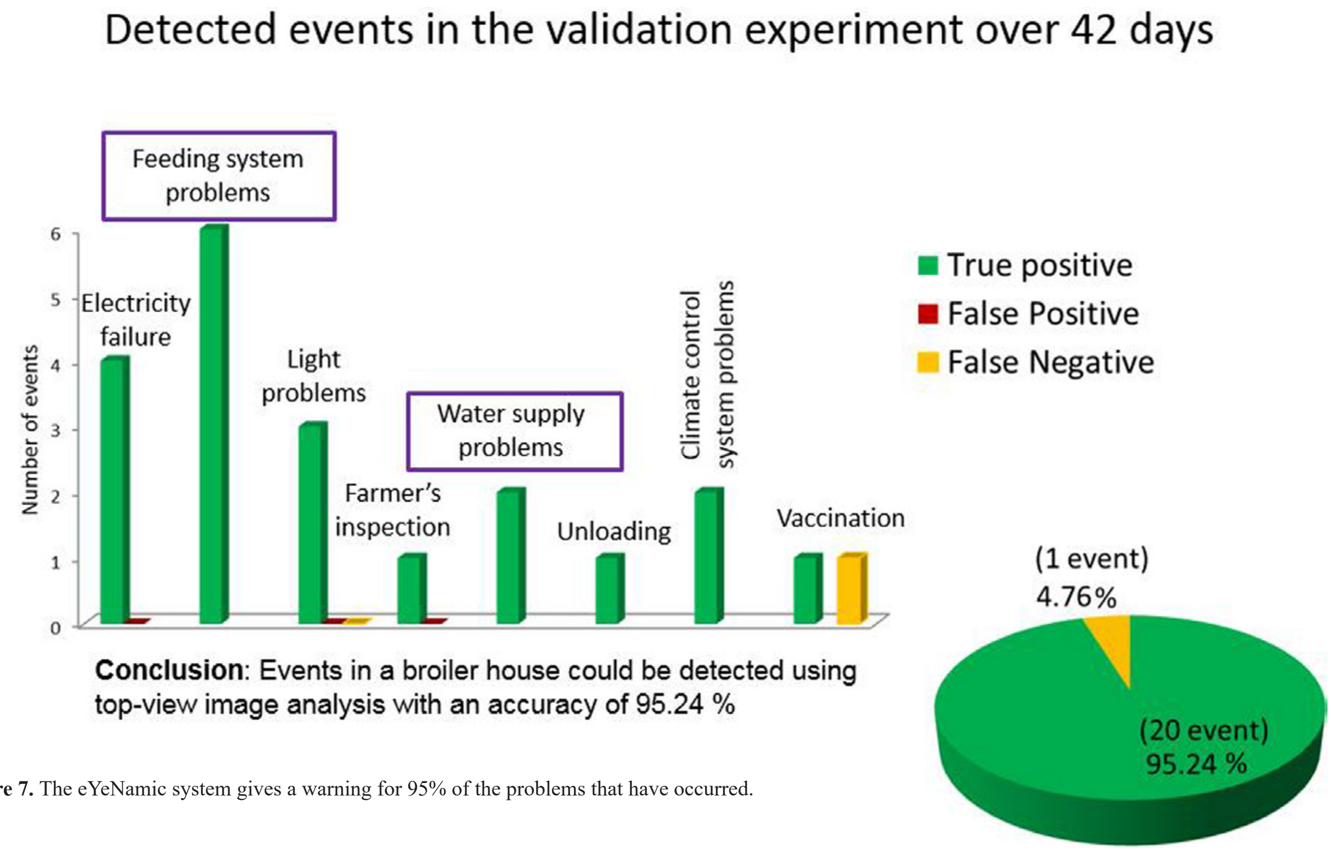

Figure 7. The eYeNamic system gives a warning for 95% of the problems that have occurred.

ern technology makes it all possible. The field data consist of a lot of numbers originating from the sensors (e.g., 240 samples per second for an accelerometer), images (e.g., 25 images per second), or sound signals (e.g., 20,000 samples per second). Within the EU-PLF project (EU-PLF, 2016), the PLF technology was installed in five broiler houses and 10 pig houses. The monitoring over 90 fattening periods for pigs in 3 yr resulted in 5.475 measuring days, generating more than 120 terabytes image data and 4.906.000 files of 5 min each with sound data. In the real-time sound analysis to detect infections it has been shown that many data are generated and have to be reduced by real-time analyses (Exadaktylos et al., 2008; Ferrari et al., 2010; Genazzani and Rodbard, 1991; Guarino et al., 2008; Van Hirtum et al., 1999; Van Hirtum and Berkmans, 2002a,b).

These examples and other examples described further in this special issue demonstrate that it is rather ridiculous to collect all data and push them higher up to a central database. When the PLF technologies are installed in livestock houses, they generate a huge amount of data, and the transmission of so much data takes time, energy, and money. Sending data wirelessly involves energy and costs; we should, therefore, avoid transmitting too much data and develop real-time algorithms that calculate information from the data at the lowest possible level, enabling us to transmit relevant information rather than data. Therefore, we need real-time algorithms that can calculate relevant information from the data preferable on or close to the individual animal (see Figure 8).

Conclusions

The just realized biggest European research project on PLF, the "EU-PLF project," has demonstrated that it is, indeed, realistic to bring the PLF technology into commercial livestock houses. Compared with 5 yr ago, the general idea was that it would take many years to make the PLF technology available for farmers, but the vision has changed seriously. It has been shown that the PLF technology can operate at the farm level. The new technology nowadays offers exciting opportunities to develop automatic monitoring and management products to help farmers remain competitive while meeting many requirements and questions that society imposes on them. Technology, however, is just a tool that supports many farmers as a decision takers. The biological process is just far too complex to replace farmers by technology. The technology will offer more possibilities to save money, change farmers' lives by spending less working hours, and get a monitoring and management system to better approach the genetic potential of today's livestock species.

Development of suitable systems needs much more intensive collaboration between people from different scientific disciplines and technical fields. This appears to be difficult because each discipline, each team, and many individuals are just hunting for more research money instead of focusing on making more progress in their field of research or the sector where their knowledge should be applied.

We hope that this paper and our efforts to define some terms will help to facilitate communication among scientists from the different disciplines that are needed to create useful PLF tools.

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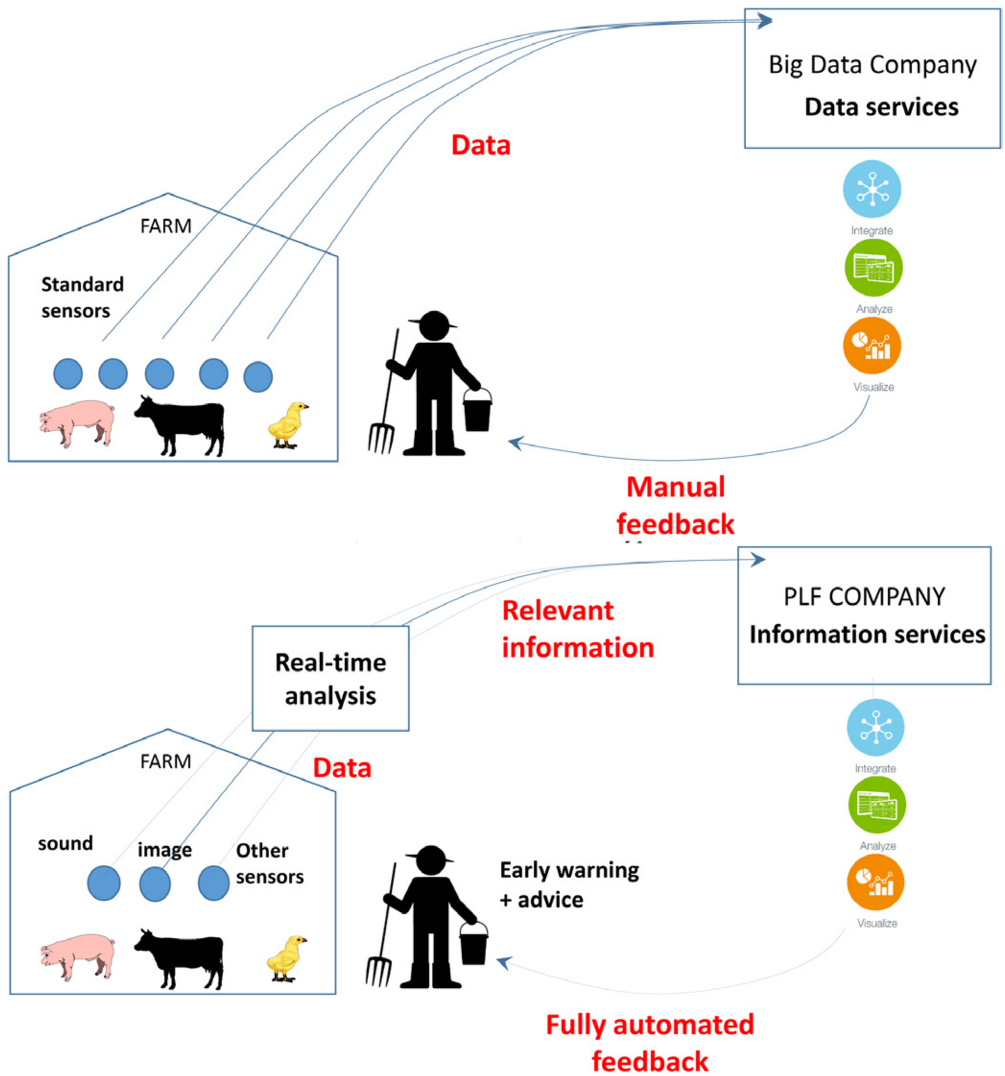

Figure 8. Scheme of a more realistic use of data versus the common idea of big data.

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