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INTEGRATED SYSTEM FOR MONITORING CRITICAL PARAMETERS OF FOOD STORAGE

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Key words: food storage monitoring, grain silo, sensors, data transmission, information exchange

Automated generation of information relevant to safety and quality issues of foods and their storage processes is one of the recent, fundamental problems of European agriculture and food industry. Moreover demand for such information result from legislation such as on European food and feed hygiene or Common Agricultural Policy as well as from global trading such as on requirements for food safety management systems (ISO 22000 incl. HACCP).

This paper presents an approach for the development of a robust, cost-effective and user-friendly system for integrated monitoring of food production and storage parameters on the example of post harvest storage of grain. Integration of measuring equipment with multi-modal data transmission (such as GSM/GPRS, low power radio as well as satellite) as well as with industrial standard SCADA data processing stations gives possibility of real-time monitoring of food production and storage process. For ensuring availability of relevant information throughout the food chain, the implementation of interface standards such as agroXML is discussed. The approach would provide possibility for verifying food storage quality and reducing risk for citizens.

Key elements for an integrated system's approach, including concepts of novel sensors, are described in this paper. Moreover general guidelines for best practices of its application are presented.

INTRODUCTION

Monitoring of food storage process (especially in grain silos, during on-farm storage or overseas vessel transports) is very important from both safety and quality point of view. The potential risks connected with grain storage processes are linked both with risks for consumers as well as for servicing personnel. From the point of view of safety for consumers it is important to avoid the germination and accumulation of fungi and toxins in stored grain, resulting in monitoring their levels. From the economic view, changes in quality or even decay during transport or storage processes may result in substantial economic losses, even in rejecting the entire batch/supply. On the other hand stored grain may create serious risk of explosion due to self-heating with spontaneous combustion or by high concentration of dust.

To avoid such risks and losses, effective measures should manage the following factors for risks and losses [TIS, 2006]: temperature, humidity/moisture, ventilation, biotic activity, gases, odor, contamination, mechanical influences, toxicity/hazards to health, shrinkage/shortage, self-heating/spontaneous combustion, and insect infestation/diseases.

The control of these factors does not only demand for effective measures to avoid such risks. In particular it creates strong pressure on the development of automated systems for monitoring of quality in bulk grain storage and cargo, as well as relevant silo and storeroom parameters.

According to recent EU legislation for the hygiene and traceability of food [Anonymous, 2002, 2004, 2005a] and feedstuffs [Anonymous, 2005b], it is the responsibility any food business operator at its position in the chain to ensure feed/food safety throughout the chain, starting with primary production, including storage and transports. If the final destination or use of stored bulk grain is not clear (food or feed), the storage conditions have to meet the requirements as apply for foodstuffs. From this requirement, a particular challenge might result for primary producers, which run on-farm storage facilities.

Within the entire businesses under its control, the food business operator has to ensure that feed/food satisfy the requirements of any law relevant to its activities and shall verify that all requirements are met. One general objective is the high level of protection of human health and taking account of the protection of plant health and of the environment. To assure this, all measures taken by the operator shall be based on the five principles of: risk analysis, precaution, protection of consumers' interests, public consultation, and public information.

Unsafe feed/food that is injurious to health, or unfit for consumption shall not be placed on the market. If the operator considers or even has reason to believe a feed/food is not in compliance with safety requirements, it shall immediately initiate withdrawing it from the market and shall inform and collaborate with the competent authorities on actions to avoid or to reduce risks.

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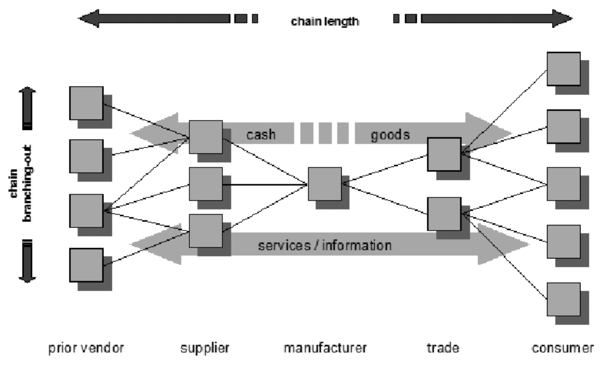

FIGURE 1. Model of a food supply chain [Horváth, 2004].

If unsafe food is part of a batch of the same class, it shall be presumed that all food in that batch is also unsafe, unless there is no evidence of unsafeness resulting from a detailed assessment. It is commonly not easy to ensure that bulk grain is stored and transported under appropriate hygienic conditions, preventing animals and pests from causing contamination.

The two major responsibilities of feed/food business operators for efficient measures and for enabling an effective traceability result in an increasing demand for communicating more complex information relevant for safety and quality issues throughout the entire food chain [Kramer, 2005; Anonymous, 2005].

In most of today's outward-focused, dynamic and multi-enterprise food chains, there is the trend to supply information independently and even in advance of the delivery of product towards the involved partners which may include (Figure 1): (1) the primary producer (*i.e.* farmer or grower) with its suppliers (seeds, plants, fertilizers, pesticides, packaging…); (2) the intermediaries (*i.e.* marketing organizations, merchants, brokers, wholesalers); (3) the processors; (4) the retailers and caterers; and (5) the consumers, inspection and customs services.

Appropriate systems should therefore provide on-line information about both product and storage facility parameters including fungi germination and related potential toxicity with the aim to support business decisions concerning the further use of the bulk grain. The systems should be integrated with IT infrastructure of the food business operator, especially with its quality management systems.

It should be also stressed that from technical point of view the most important task would be to enable multi-modal, robust, cost effective and reliable data transmission for such monitoring system.

METHODS

Analysis indicates that for successful management of grain silo management system information about temperature is required, but also it is often useful to know other parameters, for example filling level, humidity, and quantity of other contaminant.

Schematic block diagram shown in Figure 1 presents ground grain silo management system methodology. Data from monitoring area are collected with the assistance of telemetric module equipped with programmable logic controller (PLC), which can obtain measuring parameters. Moreover programmable logic controller enables digital data transmission from the technological station to the dispatch office (PC module) by usage of RS 485 link with parallel-assembled GSM and satellite modules. Accumulator feeds the whole telemetric module optionally from solar batteries, which consequently raises the reliability of the system (Figure 2). Collecting measured data can be obtained from constant time interval, as well as there is possibility of "on demand" measurement in the case of necessity.

Practical analysis showed that data transmission subsystem is most susceptible for damages element of grain silo monitoring system [Gliński & Szewczyk, 2002]. For this reason telemetric module was provided by two independent data transmission systems: pockets transmission in GSM network (GPRS) as well as satellite transmission. Schematic diagram is shown in Figure 3.

Monitoring system can be mainly based on the GSM/GPRS data transmission, because it is reliable and rather cheap. In rare cases, when GSM/GPRS system failures, satellite system should be activated. Main task of both modules is data transmission from measured area to Field Server, where Supervisory Control And Data Acquisition (SCADA) software is installed; transferred data can enable visualization, archiving and reporting. Reports from Field Server can be sent by Internet or satellite to end-users (*e.g.* local authorities), who has possibility to observe the state inside of grain silos.

Main advantages of this system are reliability and low exploitation costs, as well as possibility to observe all important parameters by end–user located away from research area. Moreover this measuring data can be archived, which can allow statistical analysis as well as creation of reliable rapports. This advantage creates new possibility of objective costs and profit analysis arising from undertaking modernization or savings actions.

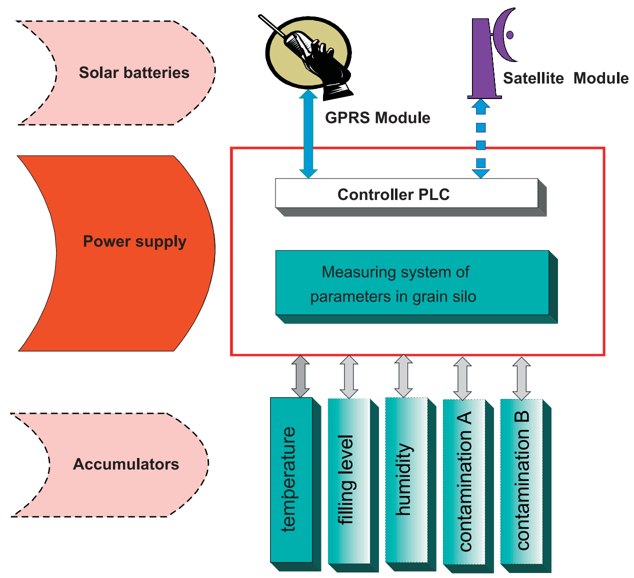

FIGURE 2. Telemetric module application used in grain silo monitoring system.

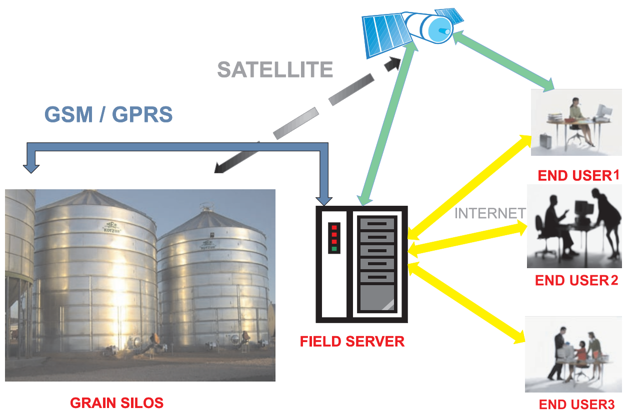

FIGURE 3. Scheme of the communication system between research area and end-users.

Computer-aided monitoring system will enable switching on the measured data as well as statistical rapports for grain silo management system. Due to this fact main part of decision process could be wake automatically that could discharge Field Server operator from boring and routine actions, as well as connection of reaction of the system with sophisticated decision process.

Because, as it is shown below, data transmission is one of the most important pieces of the monitoring system, before achieving last choice consideration of advantages as well as disadvantages of each available methodology should be made.

Measuring system. In this section, an approach is described that is subject of a recently initiated research project "Indicators and sensors for the detection of Fungi and their mycotoxins during grain processing". It is aimed to detect the minor part of rather highly contaminated grain clusters in a predominately non-contaminated bulk volume. It has been observed that *e.g.* in out-door silos heat and moisture transfer may induce growth of fungi and generation of toxins [Anonymous, 2002]. These processes may in particular occur in critical sections in the upper and outer surface layers, independent of silo type, but not in layers inside the bulk volume.

The approach is to detect and to grade grain clusters contaminated by Fungi or their mycotoxins during loading and unloading of silos, vessels or other bulk storage rooms. By this way, the protraction of contamination throughout the process as well as the thinning effect by mixing contaminated and healthy volumes may be reduced.

The major challenge for this approach consists in a continuous measuring in a moving grain volume. So, one subject of investigation is if contamination of grain may be detected in the grain dust that is generated by conveyance during placing in storage or releasing from stock by worm gears, conveyor belts or pneumatic conveyors.

In this case, an array of sensors for detection of volatile organic compound patterns together with sensors for spectroscopic properties would be used to monitor grain dust in a bypass of the conveyor.

For basic experiments with grain and grain dust, the following sensor principles will be assessed: electronic gas sensor arrays (E-Noses), spectrometrical analyses of surface reflections, ion spectroscopy, flow cytometry, and analysis of stable C isotopes.

To give examples for recent application of sensor applications, it has been shown that the metabolism of Fungi and in some cases the generation of mycotoxins goes in line with the emission of off-odorous microbial volatile organic compounds (MVOs) which induce typical signal patterns in E--Nose systems [Olsson *et al*., 2002; Farkas, 2003; Bartlett *et al*., 1997]. At present, patterns of about 200 MVOs have been identified.

Further, laser based fluorescence spectroscopy (LIFS) has been used for the even faster and more robust detection of toxins, *e.g.* OTA [Maragos, 2004a, b].

Flow cytometry has been employed so far for the differentiation of micro organisms causing decay or sickness [Cheung *et al*, 2005]. The trend towards development of small-size but high-capacity flow cytometry systems [Edwards *et al*., 2004] in fusion with e.g. spectroscopy detection units [Tung *et al.*, 2004; Fu *et al.*, 1999] as well as the expected capability of such fusion for the analysis of dusty, non-fluidic substances provide a promising approach for investigation in this project.

In contrast, approaches based on the measuring of colors or of their changes should not be subject of further investigation [Beplate-Haarstrich *et al*., 2005; Hellebrand *et al*., 2005].

The information obtained by such a sensor fusion should be processed and converted in a format that enables data communication between all partners in the supply chain (Figure 1), without costly conversion for individual interface requirements. AgroXML (XML: eXtensible Markup Language) is a language that has been designed for a chain-wide, system-spanning data exchange in the agricultural sector. It is an open source standard available on the Internet that is independent from industry, and based on common terms such as introduced by the ISOBUS standard. Further, agroXML is based on the methodology of ebXML, on its core components as well as on the ebXML based Universal Business Language (UBL) [Böttinger, 2005]. Therefore, the agroXML standard should be used for the communication of any information at both farm and chain level.

GSM/GPRS transmission. Data transmission system available in GSM networks relay on users whose data are divided into packets, and after that they are sent in transmission channel (in fact composed in 8 time slots), where user have permanent but not solely access. This will enable most effective utilization of the link as well as charging with real quantity sending data.

This service is optimized for mobile users, taking advantages mainly form stationary Internet resources. Besides listed advantages has got serous disadvantages in case of using it in service application [Simmonds, 1997].

Newly lunched service called GPRS (General Packet Radio Transmission) is a step foreward solution in data transmission via GSM network. The most important feature is charging not time of handled connection but the quantity of transferred data. Next new feature is possibility of connection "one to many" instead "peer to peer " which was only available in traditional systems. Next advantage comparing

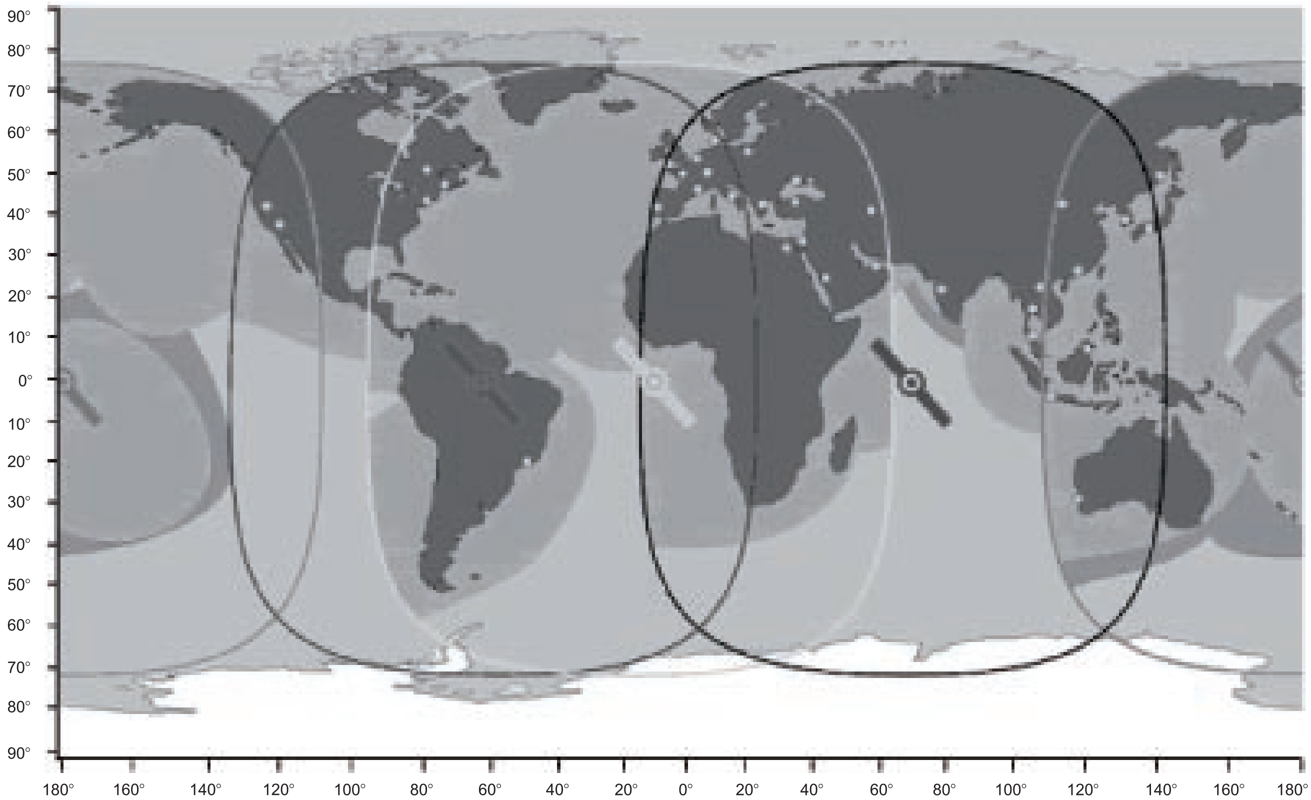

FIGURE 4. Satellite INMARSAT global range [Inmarsat, 2007].

with traditional CSD (Circuit Switched Data) mode used in *e.g.* telephone modem connection, is a lack of proceeding a long and complicated procedure of data channel establishing [Sanders *et al*., 2003].

The rest of advantages of wireless data transmission are: flexibility, non-restricted range (which means huge possibilities), low exploitation costs (the same cost for 20 km as well as for 100 km), reliability of the system when reaching GSM operator is possible. As a disadvantage it should be mentioned that some rural and not urbanized areas are not covered by GSM network.

Satellite data transmission. Satellite communication is based on the few satellites placed on geosynchronous orbits. Round-the clock communication between any two points on the Earth (beyond the polar area) provide three stationary satellites, located on angular distance 120° at the altitude of 35 800 km [Wieczyński *et al*., 1999].

Definitely the advantage of the satellite data transmission is its reliability, as it is the most advanced technology in data transmission science. Figure 4 presents range of the currently working INMARSAT satellites. It is clearly shown, that the satellites range covers all the Europe.

The only possible problem of such applications could be the high price of the modules, as well as price of continuous transmission.

Unquestionable is fact, that the usage of satellite module has high price, but taking into consideration its reliability, the price could be acceptable. In integrated monitoring system of grain silo resources, satellite system role is "first aid" in case of decay GSM network, therefore part of the cost will be distributed proportionally to the work life of the satellite module.

Transmission *via* Internet. Transmission *via* Internet is a cheap, fast and reliable from every place on the earth. It is also very easy to use for each final user.

From this point of view main disadvantage this way of data transmission is necessity of the cable infrastructure. For this reason it is proposed for transmission between dispatch centre and end–users, in this range creates huge and flexible possibilities, mainly because of that aggregated data can be presented on every WWW browser anywhere on the world.

CONCLUSIONS

The above solution for monitoring of food storage process were presented on the example of grain silo monitoring. It should be indicated that from technical point of view similar problems are connected with monitoring of other food production and storage applications. As a result presented methodology of system development may be easily adapted for frozen food production and transportation monitoring process or for monitoring in fishery industry.

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ZINTEGROWANE SYSTEMY DO MONITOROWANIA PARAMETRÓW KRYTYCZNYCH PRZECHOWYWANIA ŻYWNOŚCI

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Aktualnie kluczową dla europejskiego rolnictwa i przemysłu żywnościowego kwestią jest automatyczne generowanie informacji związanej z bezpieczeństwem i jakością żywności. Ponadto informacja taka musi spełniać wymagania legislacyjne – zarówno ze strony Europejskiej Polityki Żywności i Higieny Żywności lub Wspólnej Polityki Rolnej Unii, jak również wymogi globalnego obrotu towarów – przykładem są wymagania systemu zarządzania bezpieczeństwem żywności (ISO 22000, włączając HACCP).

Artykuł przybliża kwestię rozwoju bezpiecznego, taniego i łatwego w obsłudze systemu zintegrowanej kontroli produkcji żywności, jak również monitoring parametrów jej przechowywania, na przykładzie przechowywania ziarna po zbiorach. Integracja sprzętu pomiarowego z multimodalną transmisją danych (jak np. GSM/GPRS, radio o małej mocy czy satelita), a także ze standardem przemysłowym stanowisk przetwarzania danych SCADA, umożliwia monitorowanie produkcji żywności i procesu przechowywania jej w czasie rzeczywistym. Aby zapewnić dostępność ważnej informacji we wszystkich ogniwach łańcucha żywnościowego jest niezbędne wdrożenie standardów interfejsu typu agroXML. Należy także zapewnić możliwość weryfikacji jakości magazynowania żywności oraz zredukować ryzyko, na jakie narażeni byliby obywatele. W artykule zostały opisane elementy kluczowe podejścia dobudowy systemu zintegrowanego, włączając w to rozwój nowych czujników. W podsumowaniu zaprezentowano ogólne wytyczne dla praktycznych zastosowań tego typu systemów.