LOW COST COMPUTER BASED SYSTEM FOR QUALITY EVALUATION AND PRESERVATION OF GRAINS STORED IN SILOBAGS

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1 PROBLEM STATEMENT

Grain growers in Latin America are concerned on how to ensure the quality and safety of the storage method for their crops. This concern is derived from the fact that the storage conditions strongly influence both the quality of the food that people consume and the profits that growers can obtain from their production.

To preserve the quality of the grains, the storage strategy must fulfill several requirements e.g. to protect grains against bad weather, to diminish the badly effect produced by insects and microorganisms and to maintain for the longer time as possible the initial quality conditions in which grains have been received.

In addition to those requirements, in the last years, some factors have leaded the growers, specially small and medium ones, to develop ad-hoc strategies for the storage and quality assurance of their grains. For example, most small farmers cannot afford the cost of traditional storage methods (such as galvanized silos), there is an insufficiency (and in some cases an absence) of suitable routes or railroads to send out the production to the storage places, the market conditions are subjected to significant variations that make it more convenient for farmers to sell their crop not close to harvest time.

In this context, we observe a great expansion in Argentina, Uruguay and Chile of an ad-hoc low-cost storage technique named “harvest bags” that consists in keeping the grains into hermetic polyethylene bags [1] [2] which are stored in the same field of crop (on-farm). The term “harvest bags” is colloquial and other terms are often used, e.g. “silobags”. In Argentina the most common term is “silobolsas”.

1.1 The harvest bag grain storage system

Harvest bags are a grain storage system that is being increasingly adopted by growers across many countries. The system includes a specialized polymer bag and dedicated grain loading and extraction equipment.

Harvest bags are still a technology in progress; however they have already become a major on-farm grain storage option in Latin American countries, especially in Argentina where in excess of 20 million tons was stored per year in the 2005/06 and 2006/07 seasons.

The major manufacturers of harvest bags are located in Argentina, with IPESA Industrias por Extrusion SA (Ipesasilo®), PLASTAR Grupo de Empresas (Silobolsa®) and Inplex Venados (Agrinplex®), being the dominant producers of these plastic membrane systems. Argentina also exports this product to distant countries, such as Australia.

The use of plastic membrane type bags for grain storage has evolved steadily in Argentina, growing from initial experiences in 1995 to in excess of 20 million tons of grain in the 2005/06 and 2006/07 seasons being held on farms and commercial enterprises. Farm storage of grains in Argentina includes the use of harvest and forage type bags, and there are dedicated handling machinery designed specifically for the different bag types. Their success has resulted in a rapid expansion in the use of these bags to store soybean, wheat, maize, sorghum, sunflower and other grain types.

The National Institute of Agriculture INTA [3] in Argentina and the CSIRO [4] in Australia, among others, have undertaken research activities to determine the limits and risks of existing harvest bag technology. This includes investigating the potential of this technology to be improved or used more effectively to overcome any issues identified.

There are a series of benefits attributed to harvest bags based around improved harvest management, increased marketing opportunities, and non-chemical insect control. The primary attraction of harvest bags to growers was their comparatively low investment cost. A recent cost analysis by Holmes Sackett and Associates [5] found that harvest bags provide the most cost-effective storage option.

The benefits attributed to the harvest bag system include:
- A low capital cost storage system;
- A rapidly implemented system for opportunistic or marginal cropping;
- Improved harvest logistics and associated cost savings;
- Increased marketing flexibility. Storing grain in bags creates more marketing flexibility for the business as the growers could sell the grain as prices improved during the season;

- Easily expanded storage capacity to accommodate crop size variations. The bag system may play an important role in harvest management during the years where the crop exceeds existing on-farm permanent storage facilities;
- A well-sealed storage for insect, mould and quality control. Well-sealed and maintained harvest bags provide an effective barrier to insect ingress and the incidence of stored grain insect pests in the harvested crop is likely to be low. The modified atmosphere inside the bag restricts the growing of insects and fungus, granting longer periods of storage of the grains without alteration of their quality degree;
- Cost effective grain segregation. Separation of grain into small, identifiable batches can help farmers to better manage and market their crop as they can meet specific demands of marketers and end-users;
- Safe storage of early harvested high moisture grain;
- A user-friendly on-farm grain handling system compared to bunkers, pits, weld mesh bins;
- No residual insect populations in store structure as new bags are used each season;
- Storage management is not complicated.

Several research works [6] [7] [8] [9] [10] confirm that although harvest bags have some limitations, they offer farmers a relatively cheap and reliable on-farm grain storage solution in the short to medium-term, especially during good seasons where the crop yield is likely to exceed the capacity of permanent on-farm storage facilities.

1.2 Main Threats to the success of silobags

The main idea behind this technology consists in storing the grains, as dry as possible, into a hermetic polyethylene bag. Since the bag is hermetically closed, the inside atmosphere will change its composition with respect to the exterior atmosphere; as a result of the biological activity of the grains, the carbonic anhydride (CO2) level will increase and the oxygen (O2) level will decrease.

The loss of grain quality highly depends on storage duration and humidity levels at harvest. The increment in the humidity levels inside the bag is a very dangerous threat to the preservation state of grains. Investigations reported by the Argentinean National Institute of Agricultural Technology (INTA) show that the more the humidity of the grains at the moment of closing the bag is, the more the risk of damage that the farmers can expect in the grains [6]. These research works show that in the hermetic polyethylene bag system the humidity of each single grain becomes homogenized and also as a consequence of the condensation process, the humidity gets stratified (in stratums or layers). Once the humidity reaches the hygroscopic balance and the stratification process is finished, the humidity level remains constant as long as the hermetic conditions are preserved into the bag. It has been confirmed in [1], [2] and [6] that under proper humidity conditions the quality of the grain stored into bags can be guaranteed for long periods of time.

The INTA has extensively evaluated the storage of grains in harvest bags and established recommended “safe” storage limits for different grain types. These recommended levels are dependant on a range of factors, including ambient temperature, initial grain condition at harvest (or inloading) and level of impurities. INTA’s general guide to grains storage is that humidity levels must not exceed the accepted industry limits. The humidity content and overall condition of grain at harvest will significantly influence the storage potential (the capacity to safely store grain over time) of different grains in the bag system.

Premium condition grain harvested at **low humidity** content and stored at **low temperatures** has a **high storage potential**. In contrast, grain that has weathered or aged on the stalk before harvest has lower storage potential. Ideally, grain should be stored cool and dry. Low, uniform humidity levels are likely to be critical for safe short-term storage of grain in harvest bags.

2. EXPECTED OUTCOMES AND DISEMINATION

It is likely that several million tons of grain will be stored in harvest bags on-farm and by private storage and stockfeed enterprises within the next years, in Latin America countries and also in other parts of the world. Research confirms that although harvest bags have some limitations, they offer growers a relatively cheap and reliable grain storage solution. Therefore, it is important to work towards the improvement of the harvest bag technology; in particular, the incorporation of computer technology would be a valuable asset. We believe that a low-cost intelligent software system for monitoring and adapting the internal conditions of the grain stored into silo bags can be of great help to improve the quality standards of this type of storage system. Besides, we plan to apply advanced software engineering methodologies for the development of such software system, which will bring us additional benefits.

2.1 Specific Objectives

The present project aims to design and implement an intelligent system for monitoring and automatically adapting the internal conditions of the grain stored into harvest bags, in order to improve their preservation state. This system will be developed using modern techniques of software engineering and control engineering.

In particular, we will model the hygroscopic process into the bag in order to characterize the system and be able to predict its behavior. We will develop an advanced control system to apply intelligent aeration to reach the optimal final state of the involved variables (i.e. hygroscopic equilibrium) and to monitor the state of the grain.

Due to the fact that the results of this project are addressed to small and medium growers, to develop a low-cost solution is a mandatory requirement of our work.

The hypotheses that we are going to prove are the following ones,

Hypothesis 1. It is possible to develop low-cost testing methods for harvest bags that allow users to measure and supervise humidity levels, gas tightness and temperature of the grain that is stored into harvest bags.

Hypothesis 2. In order to seal the bag with an adequate humidity level in all its stratums, it is possible to incorporate an intelligent aeration system to the polyethylene bag, without substantially reducing the bag's storage capacity.

Hypothesis 3. The humidity level into the bag will reach the optimal values as a consequence of the layered homogenization process. The proposed optimization procedure will favor the preservation quality of grains for long periods of time.

Hypothesis 4. *M*odern techniques of Software Engineering can be applied to the development of intelligent control systems in order to favor their productivity, portability and maintainability.

2.2 Work methodology and research challenges: applying MDD and theory of control

To reach our goals we plan to develop low-cost sensors to measure the humidity and temperature of the grain that is stored into hermetic polyethylene bags, and to build an aeration system being suitable to be incorporated into the bag with the aim of modifying the inner humidity conditions at the different levels. Besides, it will be necessary to determine the volume of the section where the aeration system will be deployed and also to determine the optimal value of humidity to be reached in the section under the direct effect of the aeration system, so that the hygroscopic equilibrium in the whole bag can guarantee high-quality conservation conditions for the grains.

All the information will be gathered through a control software system [11] [12] to be deployed in heterogeneous hardware platforms, consisting of micro-controllers with scarce computational and energy resources and pc-style hardware. The software system will provide assistance to the grower through a very simple and friendly human-machine interface. We propose to build and apply a software development process fitting this kind of systems in order to favor productivity, portability, reuse and maintenance. In particular we plan to adopt the technique named Model-Driven Software Development (MDD) [13] [14] [15], which is a software engineering approach that places the abstract, formal system model in the center of the development activity.

The core of our software system will be designed through Automatic Control techniques. In general terms, Automatic Control aims to develop technically, environmentally, and commercially feasible ways of acting on a practical system or plant, in order to control its outputs to desired values while ensuring a satisfactory level of performance. Closed-loop Control Systems include: quantifying the desired behavior, measuring the actual values of relevant system variables by sensors, inferring the actual system state from the measurements, comparing the inferred state to the desired state, computing a corrective action to bring the actual system to the desired state, applying the corrective action to the system via actuators, and then repeating the above steps.

Let us explain our research challenges more in detail:

- **Model Driven Software Development:** In the context of software engineering, the *model-driven development* approach (MDD) [15], has emerged as a paradigm shift from code-centric software development to model-based development. Such an approach promotes the systematization and automation of the construction of software artifacts. Models are considered as first-class constructs in software development, and developers' knowledge is encapsulated by means of model transformations. The essential characteristic of MDD is that software development's primary focus and work products are models. Its major advantage is that models can be expressed at different levels of abstraction and hence they are less bound to any underlying supporting technology. This is especially relevant for software systems within the ubiquitous computing domain, which consist of dynamic, distributed applications and heterogeneous hardware platforms. Since ubiquitous computing systems aim at creating an invisible, unobtrusive environment, there is a need of supporting various hardware platforms with different resource constraints. These platforms range from micro-controllers with scarce computational and energy resources to pc-style hardware. While some software components will be tailored to a specific hardware platform, most components of these systems –in particular, the communication middleware– must be able to run on multiple platforms. The application of MDD brings us improvements of the software development process,.

Control systems: Traditional control systems design is based on mathematical models in which the system is described using differential equations that define the system's response to its inputs. Several control techniques exist to develop ad-hoc controllers. Among them, the most widespread topology is the well known proportional-integral-derivative (PID) controller. PIDs are the products of decades of development and theoretical analysis, and proved to be a versatile solution to manifold applications. Therefore, in a preliminary approach, we plan to investigate the applicability of modified PID topologies to the harvest bag system. In a second stage, we will assess the applicability of the advanced control techniques, such as robust control and fuzzy logic, for building the control software system. In particular, fuzzy control system design [16][17] is based on empirical methods, basically a methodical approach to trial-and-error. It has some advantages. In many cases, the mathematical model of the control process may not exist, or may be too "expensive" in terms of computer processing power and memory, and a system based on empirical rules may be more effective. Furthermore, fuzzy logic is well suited to low-cost implementations based on cheap sensors, low-resolution analog-to-digital converters, and one-chip microcontroller chips. Such systems can be easily upgraded by adding new rules to improve performance or add new features. In many cases, fuzzy control can be used to improve existing traditional controller systems by adding an extra layer of intelligence to the current control method.

2.3 Conclusion: tangible assets and original contribution

The most important tangible assets produced by the project are the following ones:

- The design of humidity sensors and aeration devices specially customized to silobags;
- A software control system for monitoring and adapting the state of the silobags;
- Mathematical models of the behavior of the humidity levels into the silobags;
- A software framework based on MDD for developing similar kind of systems in other areas of agro-tech

At the present time the solution for restoring the optimal humidity conditions of grains consists in sending the whole volume of grains to another silo. This process naturally produces aeration and decreases the humidity. Another traditional solution, adopted in cases of very high level of humidity, consists in sending the grains to drying facilities where the grain drying process is done. This project proposes a new approach to deal with this problem. Our approach aims at offering a set of tools for drying the grains on-farm, into the same harvest bag where grains had been initially stored. We believe that this solution offers an efficient alternative in comparison with traditional techniques above mentioned. The proposed technique is particularly attractive for small farmers that cannot afford the cost of traditional methods for drying their grains. Additionally, the software solutions we will develop also contain a high degree of originality due to the novelty of the MDD paradigm applied on agro-technology development.

The current state of the project can be observed in the project's web site at http://www.lifia.info.unlp.edu.ar/laccir/

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