Earth-Satelite Monitoring System for Storaged Grains

Jose Dalton Cruz Pessoa
Embrapa Instrumentação
São Carlos, Brasil
email: jose.pessoa@embrapa.br

Ladislau Marcelino Rabello
Embrapa Instrumentação
São Carlos, Brasil
email: ladislau.rabello@embrapa.br

Victor Bertucci Neto
Embrapa Instrumentação
São Carlos, Brasil
email: victor.bertucci@embrapa.br

Sérgio da Silva Soares
CRIAR Space Systems
Ribeirão Preto, Brasil
email: sergio@grupocriar.com.br

***Abstract*— Despite Brazil being the fifth country in the world in area and population, it is the largest in terms of cultivated land area, becoming a global player related to food production and exportation in the last decades. At the same time, food production increases year by year as do infrastructure problems. One of the crucial problems is related to grain storage. The availability of grain storage now is lower than the total of grain produced, leading producers to promptly sell production that could not be stored. Some companies sell to farmers solutions like silo bags, or plastic bags, as a fast way to overcome this kind of problem. Grains stored in silos are susceptible to insect infestation and fungal growth, depending on initial conditions and storage conditions, which can lead to the loss of part or even the entire stock. The statistics are unclear or do not exist, but it is estimated that technology can reduce losses from 40-50% to 1-2%. This project proposes monitoring post-harvest variables to detect or even forecast potential risks to the quality of the stored product. This solution requires data transmission in areas that lack cellular network coverage. To overcome this limitation and offer a robust solution, the team chose to use a satellite to communicate between two ground stations: one that sends the measured data and the other close to the data center to receive and process the data. This demand was embraced by the company CRIAR Space Systems which is, together with Embrapa, working on solutions such as installing silo bags, monitoring physical and chemical variables in those silos to automatically produce alert signals. These signals can indicate the presence of contamination in the silos due to local fermentation, or due to the presence of high/low bulk moisture and temperature, for instance. Another CRIAR feature is the development of communication antennas for satellite signals with the purpose of further launching a private satellite dedicated to monitoring all farms covered by this service. The scope of this work in progress is to show how this is being planned and applied.**

Keywords – silo; antenna; grain; soy; corn; forage.

I. INTRODUCTION

The Brazilian Institute of Geography and Statistics (IBGE) [1] registered 47,578 farms with more than 1,000 hectares in Brazil. Part of these farms is located in the Center-West Region, composed of states with vast areas: Mato Grosso, Mato Grosso do Sul, Goiás (1,612,000 km²) and Tocantins (277,621 km2). These states are the main producers of soybeans and corn.

According to Agência Nacional de Telecomunicações (ANATEL) [2] data from December 2023, 8% of Brazil's territorial area still does not have mobile phone coverage, or 850,000 km2. This area includes remote regions, rural areas, roads, and highways. This data indicates that 12% of the rural population does not have access to cell phones. The data, however, does not specify the quality of the mobile service provided: stability, reliability, and availability [1].

Grain storage units are established in rural areas, close to producing properties. Conventional warehouses, inflatable warehouses, bulk warehouses, silos and silo bags have structural and functional characteristics that differentiate themselves, but they are all intended for storing large volumes, especially of grains.

Oxygen makes up 21% of the air, and at 2%, corn begins anaerobic respiration. Up to this limit, the seed absorbs O2 from the silo environment and releases CO2 in a ratio of 3:1. A silo with a diameter of 2.5 m and a length of 60 m has approximately 294.5 m3. If filled with corn at a density of 750 kg/m3 and 10% dead volume (occupied by air), the silo will contain 220,875 kg of corn and 29.5 m3 of air. According to the ISA [3], the density of air at 15°C at sea level is 1225 kg/m3. As the molar mass of air is approximately 28.9 g/mol, 1 m3 of air contains 42.2 mol of air. Considering the percentage (21%) of Oxygen (O), that volume contains 8.8 mol of O2, that is 284.15 gO2. Under the storage conditions described above, the dead volume of the silo would contain 261.96 molO2 or 8.38 kgO2.

The respiratory rate of corn is quite elastic, between 0.5 and 2.0 mgO2/kg.h. Considering a value of 1 mgO2/kg.h, the corn load would consume 220,875 mgO2/h (220.8 gO2/h). If the temperature was kept constant and the oxygen consumption was independent of the concentration, the time for the load to consume 98% of the available O2 (considering the simplifications of the model) would be approximately 37 days. After this time, the grains would begin anaerobic respiration.

This model is very simple because it does not consider the sidereal day or environmental parameter values, but it provides a rough estimate for time.

The objective of this work is to reduce the risk of damage to stored grains, considering that different storage environments have characteristics that increase different types of risk.

In silos exposed to the environment, the intergranular temperature and the relative humidity of the air inside the silo are two basic observable variables of the internal ecosystem of the silo, but they are insufficient to detect signs of deterioration in the quality of the stored grains. Several authors have sought to identify monitoring variables that could serve as indicators of grain quality [4][5][6]. In practice, however, increasing the number of sensors also increases the cost of monitoring.

One of the working hypotheses of this project is that specific variables must be added to the intragranular temperature and the relative humidity of the air inside the silo according to the characteristics of the stored product. Taher et al. [7] provides some relevant information for the development of sensors and their distribution in silos.

Monitoring storage systems would be an alternative to reduce the risk of most types of accidents. In this approach, sensors would measure the 'monitoring variables' whose signals would be processed and sent to the manager of the warehouse.

Figure 1 illustrates a probe that encapsulates one or more sensor elements with their respective electronics, one electronic for signal pre-processing and another responsible for the sensor's communication with a receiving base.

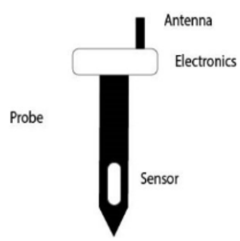

Figure 1. Probe schematic. The probe is composed of sensors, conditioning electronics, and antenna.

The probe's sensors monitor post-harvest variables to detect changes in grain quality. In their review, Bartosik et al. [6] investigate the following factors affecting grain quality within silo-bag storage systems:

Environmental Influences: Temperature, CO2, O2, and humidity levels; Temperature Fluctuations: The impact of temperature cycles on moisture migration and subsequent grain quality losses; Mycotoxin Formation: The underlying mechanisms of mycotoxin contamination; Insect Infestation: The incidence, dynamics, and impact of insect presence on grain quality. When choosing sensors, authors like Danao et al. [10] prioritize experimental objectives and cost, with cost becoming a major consideration for commercial products."

The modified atmosphere within silo-bags, with CO2 concentrations ranging from 3 to 25% and O2 concentrations from 10 to 25%, plays a crucial role in inhibiting insect presence and mold development (Bartosik, 2011)

The extension of the storage unit demands a number of sensors proportional to its size, each one sending data periodically to a data center, where it will be used to identify the type of sensor, its location, and measured values. In isolated areas, this configuration requires the solution of problems related to the power supply of the electronics, the integrity of the data packets, and the robustness of the communication.

Figure 2 illustrates the positioning of probes like the one in Figure 1 at different points of the storage unit (e.g. silo-bags) forming a network of sensors classified by type, geolocation, and organized in a database.

Figure 2. Ground communication network is formed by probes installed in the silos, a hub (data concentrator) coupled to a ground station that transmits the signal to the satellite

The probes communicate data over a wireless network to a data concentrator unit that may or may not be near an antenna. The LoRa (Long Rangejlcp) and LoRaWAN (Long Range Wide Area Network) technologies from Semtech Corporation were chosen for terrestrial communication because they offer advantages such as low power consumption (20mA) and long range (up to 15 km) [8] [9].

One alternative for accessing data from a storage unit in a remote area is satellite communication. This approach enables silo load monitoring even in areas with no cellular coverage or poor signal quality.

The data concentrator unit may or may not contain an antenna forming a ground station for signal conditioning, antenna positioning, and transmission to a low-orbit satellite. The satellite would amplify the signal and retransmit it to another ground station that would send it to a database and then to the interested parties.

The uplink and downlink communication tasks are critical to the satellite performance solution and the most susceptible to failure. Other critical points of the project include the operational quality of the antenna, its mechanical robustness and the precision of its positioning mechanisms, the dynamic positioning of the satellite and its robustness considering space conditions, the correct sizing of the electronic systems architecture and the synchronization of the communication elements to ensure that all data is properly delivered to the ground station.

This section introduced the main concepts of the project and its motivation. Section II (Working on Solutions) will present the development of ground communication solutions, contextualizing them for the project. Section III concludes the paper.

II. Working on Solutions

Figure 3 presents the solution architecture for terrestrial grain monitoring. Here, the signal flows unidirectionally from the probes to the target user.

The probes contain sensor elements for measuring CO2, O2, temperature, and humidity, along with signal conditioning electronics, a battery, and a radio. The number of probes installed in the storage unit depends on the volume to be monitored and the storage conditions. The first three columns of Figure 3 represent these probes. Each probe periodically wakes up, reads the sensors, and transmits the data using a LoRa radio.

The Earth Station receives radio signals through a dedicated receiver. It comprises a radio antenna, signal conditioning and temporary storage electronics, a satellite antenna positioning system, and equipment for transmitting (uplink) data to the satellite via VHF or UHF bands. All sensing and communication elements must be encapsulated in IP65 standard for protection against atmospheric conditions and dust.

A Low Earth Orbit (LEO) satellite captures the Earth station signal. Monitoring satellites typically operate in LEO, between 200 and 2000 km from Earth's surface. This orbit offers advantages like higher revisit frequency over a particular location and lower communication latency. The satellite must receive the signal, amplify it, and retransmit it back (downlink) to the second ground station.

At the second Earth Station the data will be received and sent via the internet to the database and then to the target user. The user will receive the data in a format appropriate to their needs.

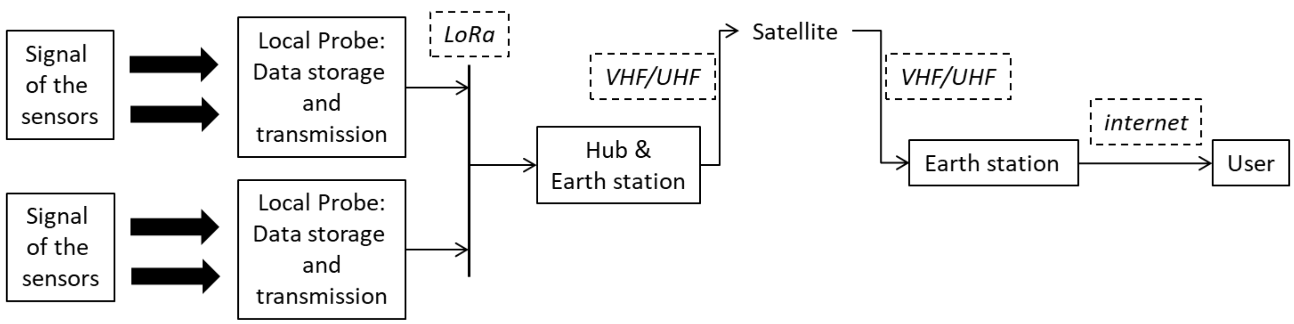

Figure 3. Data obtained by the probes are sent by radio to a first Earth Station, which then transmits it to the satellite. After amplification, the signal is retransmitted to a second Earth station and to the silo manager.

A. Sensing and ground communication

CRIAR Space Systems manufactures its own measurement devices from commercial transducers. The process includes the development of the signal conditioner and calibration.

Periodically, the probes send the reading packet of a given moment in time to a data concentrator located in a suitable location that can be several kilometers away. In general, the communication protocol (named JLCP) developed in the project includes the following general characteristics:

- The message is divided into packets.
- For each packet sent by a transmitter, a confirmation from the receiver is awaited.
- Only after confirmation does the transmitter discard the sent piece and move on to the next.
- If the receiver does not respond with a confirmation within the period defined in the timeout parameter, the transmitter performs a new send.
- After exceeding the maximum number of send attempts, both the transmitter and the receiver understand that there was a connection error, and the session is terminated.
- Data integrity is guaranteed by enabling and verifying the Cyclic Redundancy Check (CRC), which is a part of the LoRa Frame dedicated to verifying the integrity of the sent bits.
- The completeness of the packet is verified by attempting to parse the received string to a Java JsonArray object and the completeness of the message is guaranteed by a final packet check.
- The redundancy of received packets (generated by a delay in the delivery of packet copies in the middle of the distribution) is solved by means of route locking, which guarantees that the fastest route is maintained from the beginning to the end of a session, and by means of the sequential packet reception filter.
- Payload encryption is not part of the protocol itself, and it is up to the two ends to encrypt the packets and share

keys. This decision was made because block encryption algorithms significantly increase the content size.

The terrestrial communication architecture and its implementation including the communication protocol between the probe and the collector will be evaluated on two aspects: Data loss with respect to distance is shown in Figure 4. Figure 5 shows data loss for packets of 3 and 255 bytes transmitted over 3134 meters.

The tested system was capable of processing 3-byte and 255-byte data packets over distances of up to 3134 m, with a TX power of 18 db.

On the time line, the first event was a test of distance (Figure 4).

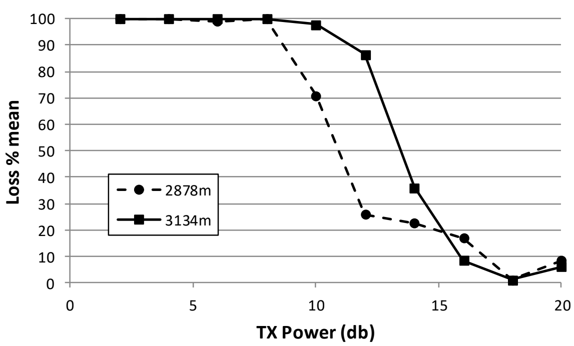

Figure 4. Payload mean loss at 2,878 meters and 3,134 meters transmission distances with different radio transmission powers

A 3-byte data packet was transmitted over different distances and radio power levels. Figure 4 shows the mean information loss across the two longest tested distances. The Figure also indicates that at a transmission power of 18 dB, there is minimal signal loss.

Following improvements, a second test was conducted to evaluate the transmission of 3-byte and 255-byte data packets over a distance of 3134 meters at various transmission powers.

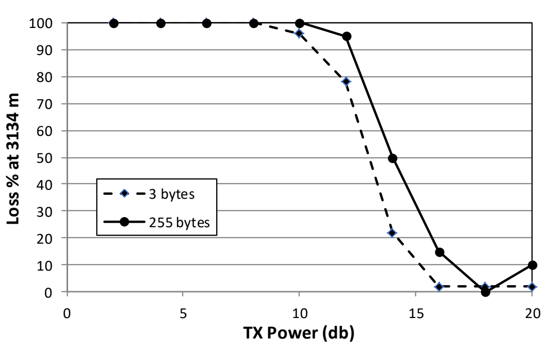

Figure 5. Percentage Packet Loss (3-Byte and 255-Byte Packets) over a 3134-Meter Transmission at Varying Radio Transmit Powers

Figure 5 shows that the minimal signal loss for a 3-byte payload was 16 dB, while the minimal loss for a 255-byte payload was 18 dB.

III. CONCLUSIONS

Under suitable conditions, it is expected that in a silo-bag, corn can be stored for up to 24 months. During this time, Oxygen will be consumed, and the grains will maintain a low metabolism. In inadequate humidity conditions, the cargo can be infested by fungi and bacteria, and after the consumption of oxygen the fermentation process will begin.

A 60 m and 2.5 m diameter silo can store 220 tons of corn, which at the current price corresponds to a capital stock of approximately USD 47,000. To avoid partial or total loss of cargo, the proposed alternative is cargo monitoring. The proposed solution, suitable even for remote areas, is data transmission via satellite, which includes a terrestrial transmission stage, the uplink, the downlink and another terrestrial stage.

The team is working on the low-orbit satellite design and the development of the terrestrial transmission system, which allowed the transmission of sensor measurements over a distance of more than 3 km, but it is expected to double or triple this range.

The project faces several technical challenges, including limitations of the power source, sensor and electronics robustness, and data integrity. This paper presents the latest developments in Earth Station instrumentation, specifically focusing on sensor technology and data transmission. However, the most significant challenge lies in the business aspects, where maintaining an attractive final product price is crucial.

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