Microcontroller-based control system for safe grain storage in silo

D Dal-uyen¹, K Yaptenco², E Peralta² and D Suministrado²

¹ Don Mariano Marcos Memorial State University, La Union, Philippines
² University of the Philippines Los Baños, Laguna, Philippines

Email: lailah_may12@yahoo.com, dpdaluyen1@up.edu.ph

Abstract. This study developed a control system that could continuously monitor temperature and relative humidity, measure moisture content non-destructively, and control storage condition to a safe level. The developed control system used Arduino program because it is an open source and the components of the hardware are locally available. It was evaluated using small-scale metal silo during wet season at the University of the Philippines – Los Baños, Laguna, Philippines. During the evaluation, the average temperature, relative humidity, and dewpoint temperature of the ambient air were 27 °C, 87 %, and 24 ºC respectively. These parameters are not favourable for safe grain storage, however, the developed control system monitors the storage condition inside the silo and regulate the environment by switching on and off a fan and heater. The average temperature and water activity of the stored grains were 34°C and 0.65 respectively. Though there was an increase in relative humidity and decrease of temperature inside the silo, the condition was still within the safe level for storage. This was proven by the low moisture content (12.0%) of the stored grains in the controlled silo. During the evaluation period, the moisture content of the grains stored in the conventional silo was maintained at its initial 14% moisture however, it showed a fluctuation trend. The developed device which also reads moisture content with a mean difference value of 0.25% meets the acceptable tolerance of 0.5% for a meter to like-type meter standard. Hence, this confirms the acceptable reading of the device.

1. Introduction
Rice prices have been increasing in recent years in the Philippines. Since Filipinos are one of the largest consumers of rice globally, we are directly affected by any changes in its price. However, the uncontrolled price increase of rice forced us to rebuild and improve storage facilities which will enable us to store for future purposes. By keeping the price of rice low, means making the commodity affordable to the poor and it is critically important in reducing poverty [1].

In addition, storage is the process of maintaining the high quality of agricultural products and preventing them from deterioration for certain period beyond their normal shelf life. Aside from price increase, grains are being stored for different future purposes: seed purposes, forage being processed into livestock feeds, future food consumption, and selling when the price is favorable. Furthermore, storage could balance the fluctuation of grain supply in the market, both from one season to the next by storing the surplus produce and then selling during the off-season. Because it is a critical
postharvest operation, periodic attention is needed to avoid losses when preventive measures are not immediately taken.

Losses during storage are mainly due to the rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae), which lay egg directly inside the kernel [2]. However, these can be controlled and reduced if the temperature, relative humidity (RH), and moisture content (MC) are regularly monitored and addressed, thus, these are unable to multiply when the equilibrium RH is below 65%. Quality deterioration also gives significant impact to storage losses due to pest infestation and exposure of grains to high RH during rainy seasons. Other factors affecting storage are weather, infrastructure, size of operation, level of mechanization, quality of management, operator characteristic, and access to capital. Poor facilities, unhygienic storage condition, and lack of adequate temperature control system (CS) could also contribute storage losses. However, these factors can be overcome through appropriate storage facility, adequate storage environment condition, and preventive measures against microorganisms, insects, and rodents. Hence, improvement of storage systems is critically needed as it plays an important role in preventing losses and will also help farmers to sell their own produce by reducing the role of middlemen thus the price of grains is controlled.

One thing to consider is the appropriate storage facility to use. According to Food and Agriculture Organization (FAO), storage silo is highly recommended to farmers because it prevents losses and protects the grain from rain, extreme conditions, high moisture which causes microbial and fungal growth, and insects and rodents which will damage the stored grains [3]. It is also a technique that could give a significant increase in income to farmers and improve food security situation. Estimates show that a one-ton household metal silo can conserve grains to feed a family of five in one year [4].

However, frequent moisture condensation and subsequent moisture increase within the grain mass are the challenges of using silo. This leads to moisture migration which causes quality deterioration in another part of the silo. Nevertheless, this could be managed using aeration or application of forced air through the grain mass [5]. Aeration promotes air circulation which is not favorable for pests and microorganisms’ growth and activity. Aeration also controls the grain quality as it provides chemical free storage condition and it is an insect-free management option. On the other hand, if the vapor pressure of the aeration air is higher than the grain vapor pressure, moisture adsorption occurs which causes an increase of grain MC. But heating the air could decrease the RH of the air thus, a heater is also needed.

Thus, automated CS was introduced in this study to reduce the risk during storage such as manual data collection, analysis, and decision making by the warehouseman. It is proven that at present, electronic sensing and data acquisition techniques proved to be a better approach. Because it eliminates the distraction of the grain mass for example during storage and reduces error during data gathering. Reference [6] stated that an advanced storage system is one of the solutions to mitigate the grain storage losses and food insecurity. Since grain production is seasonal and consumption is continuous, safe storage must maintain grain quality and quantity; hence, this study was conceptualized. This research developed a microcontroller-based control system for safe grain storage in silo by monitoring the storage parameters and regulating the storage environment condition.

2. Materials and Methods

Arduino program was used in this study because it is an open source and the components of the hardware are locally available. The developed CS was composed of Mega2560 (as the microcontroller), SHT21 sensors (temperature and RH), GSM SIM900A module, and data logger shield (V1.0 Deek-Robot). Five sensors (Sensor 1-5) were installed within the stored grain mass while one each in the aeration chamber (Sensor 6) and outside the silo for measuring ambient conditions (Sensor 0). The sensors used were enclosed individually to avoid entry of dust and dirt. Heater and fan were used for regulating the storage environment condition during storage. The developed CS was also enclosed using weather proof enclosure to protect against intrusion of dirt, dust, and moisture.

The temperature and RH sensors were calibrated separately using national instrument (NI) temperature logger and salt solutions respectively. The temperature and RH values generated were
used to estimate the grain MC nondestructively using the Modified Chung-Pfost (Equation 1) wherein \( A, B, \) and \( C \) are constants. The MC data measured by the CS was calibrated using the primary oven method.

\[
\text{MC} = \frac{\ln \left( \frac{A}{(T + C)(\ln RH)} \right)}{B}.
\] (1)

Algorithm was also developed following three objectives: to minimize the condensation inside the silo; to provide low and uniform temperature within the grain mass and limit the grain temperature difference to 5°C; and to maintain the grain MC at a safe level. The software/application used was Arduino because it is an open source platform which was written as a sketch in Arduino IDE. This algorithm was programmed to control the silo environment, thus, control system for safe grain storage was developed. The developed control system uses microcontroller (Arduino Mega 2560) which communicates to retrieve the real-time temperature and RH data measurements. The CS can calculate other psychrometric properties of air such as dewpoint temperature, vapor pressure, and even water activity, and MC of the grains. GSM was added communication feature of the developed CS which sends the data (storage parameters and aeration component status) as text message to the mobile phone of the operator and receives commands. Calibration equations were obtained and incorporated into the program to have a reliable and accurate data.

The developed CS was evaluated in a laboratory-scale silo (100 kg capacity silo) as controlled silo and the result was compared with a conventional silo. Rice grains were used during the storage performance evaluation for duration of one month. Both silos had 100 kg capacity following the FAO design of silo, but only minimal modification was done on the controlled silo considering the installed control system.

3. Results and Discussion
3.1. Temperature and RH measurement
In this study, the temperature and RH reading of the sensors were calibrated to validate the calibration claimed by the manufacturer. Figure 1 and Figure 2 showed the result of temperature and relative humidity sensors calibration respectively. All \( R^2 \) values are 0.99 which means that the reading of the sensors only has 1% error. This validated the calibration declared by the manufacturer.

![Figure 1](image1.png)  
**Figure 1.** Temperature calibration of the SHT sensor using NI temperature standard.

![Figure 2](image2.png)  
**Figure 2.** Relative humidity calibration of the SHT sensor using salt solutions.
3.2. **MC measurement**
The MC measured by the developed CS was validated with a moisture meter. The mean difference of the two measured MC values is 0.24577% which meets the acceptable tolerance (0.5%) for a meter to like-type meter method specified in NIST Handbook-44 [7]. Hence, this confirms the acceptable grain MC reading of the developed CS.

3.3. **CS performance evaluation**
During the performance evaluation, it was rainy season therefore, the RH of the ambient air was fluctuating and varied from 55.73% to 93.35%, with an average of 86.69% and the temperature values were 24.36°C, 33.91°C, and 26.41°C for the minimum, maximum, and average respectively. Also, the dewpoint temperature was ranging from 23.05°C to 25.17°C with an average of 23.84°C. At the end of the testing, the average values of ambient air temperature, RH, and dewpoint were 27.14°C, 82.18%, and 23.54°C respectively. The temperature could be good for storage, but the RH was too high for the desired environmental condition of safe grain storage. For example, if the rice grain of known MC stored in a certain condition and the RH rise over time with the same temperature, then the grain could be prone to quality deterioration. Figure 3 showed that the RH of the aeration air (RH6) was lower than the ambient (RH0). This is the result of the aeration components wherein the ambient air was heated before entering the grain mass to avoid wetting the grains during such outside/ambient condition. In general, the on and off switching of the fan was used to control the RH of the heated air controls the increasing-decreasing trend of the ambient condition.

![Figure 3. Ambient air parameters (T0 & RH0) and aeration RH (RH6).](image)

Initially, the grain temperature ranges from 29.54°C to 37.68°C with an average of 33.17°C. Figure 4 showed the trend of the grain temperature and water activity. The increase in grain water activity and the decrease of the temperature inside the silo was acceptable since they are still within the required level for safe storage. The condition was maintained throughout the study aided with the aeration components. The aeration installed removes the heat generated by mold growth, the principal source of heat, and helps to slow down mold growth and other deterioration by decreasing the temperature.
The maximum temperature differences measured by the sensors installed inside the silo is presented in Figure 5. The maximum grain temperature difference on the first day of storage was 5.81°C. This is due to the availability of more oxygen among within the grains as result of initial silo loading and this free oxygen facilitates a high rate of respiration [8]. However, the difference was decreased to 3.28°C at the end of the storage with an average of 3.16°C throughout the study. In practice, values up to 5°C difference are acceptable according to Navarro & Noyes [9] and confirms by Martins, Mota & Fonseca [10]. The figure shows that the mean differences were lower than 5°C therefore, the aeration system maintained the storage silo to a safe condition.

The MC of the grains stored in the controlled silo was compared to the conventional silo. The result showed that the MC of grain stored in the controlled silo was significantly different than the conventional silo. This was because of the absence of aeration system that pushed up the heat within the grain. Rice grains are hygroscopic, the grain MC is affected by the RH of the storage environment as described by Vieira, Tekronya, Egli and Rucker [11] and Bradford, Dahal and Bello [12]. Basically, during storage, it is expected that there would be moisture migration within the grain mass as direct consequences of temperature variation. However, in the study, the MC of the grain was maintained with a little bit of fluctuation but still within the safe level. The fluctuation of grain MC resulted from
the change in relative humidity [13]. The grain MC of the controlled silo ranged from 11.28% to 12.46% with an average of 12.00%.

Though the mean of the conventional silo (13.44%) is within the range of safe storage level (12-14%), there was an increasing trend of MC as presented in Fig. 6. It also showed that the MC in the conventional silo was near the upper limit for safe storage, therefore, molds, respiration loss, insect damage, and moisture adsorption could be possible problems that could occur [14]. This was agreed by Warrick [15] who stated that in most storage cases above the 13%–14% MC range, needs to be dealt promptly to avoid such issues.

Figure 6. Moisture content of rains stored in controlled and conventional silo

MC values of stored grains in controlled and conventional silo.

4. Conclusion
Temperature and RH level safe for storage was obtained by using installed control system throughout the storage duration even though the ambient weather during the experimental period was not safe due to the fluctuation of ambient temperature and RH. These measured parameters were used to switch on and off the fan and heater to control or maintain the storage condition to a safe level. Result also showed that the MC measurement of the developed control system was acceptable and comparable to a like-type meter standard. This means that the aeration components coupled with the silo regulated the storage condition to maintain the grain MC to a safe level. With these results, it was concluded that the developed control system could maintain and regulate the storage environment to safe level conditions.

Acknowledgement
The authors wish to thank the Department of Science and Technology (DOST) under the Engineering for Research and Development Technology (ERDT) Program for funding this study.

References
[1] Pandey S, Sulser T, Rosegrant M, Bhandari H 2010 Rice price crisis: Causes, impacts, and solutions Asian J. Agric. Develop. 7 2 1-15.
[2] Phillips T W, Throne J E 2010 Biorational approaches to managing stored-product insects Annu. Rev. Entomol. 55 375-397.
[3] Mejía D 2003 An overview of rice post-harvest technology: use of small metallic silos for minimizing losses 20th Session of the International Rice Commission. Baangkok, Thailand
[4] FAO 2008 Household metal silos. Key allies in FAO's fight against hunger. Rural Infrastructure and Agro-Industries Division FAO UN.
[5] Villers P, De Bruin T, Navarro S 2006 Safe Storage of Grains in the Tropics. GrainPro Inc. Massachusetts USA.

[6] The Economist Intelegence Unit 2014 Food loss and its intersection with food security The Economist Intelegence Unit London UK.

[7] NIST Handbook-44 2017 Grain Moisture Meters. In T. Butcher, L. Crown, R. Harshman (Eds.), Specification, Tolerances, and Other Technical Requirements for Weighing and Measuring Device NIST US Department of Commerce USA.

[8] Navaratne S, Saja Sheriff Ali M 2014 Fabrication of a hydro cooling system to mitigate dry matter loss of stored wheat grains in silos Int. J. Sci. Eng. Res. 5 4 572-577.

[9] Navarro S, Noyes R 2001 The Mechanics and Physics of Modern Grain Aeration Management CRC Press Boca Raton USA.

[10] Martins J, Mota A, Fonseca J 2001 Simulation of an automatic controller for stored grain aeration systems Engenharia na Agricultura 9 1 55-70.

[11] Vieira R, Tekronya D, Egli D, Rucker M, 2001 Electrical conductivity of soybean seeds after storage in several environments Seed Sci. Technol. 29 3 599-608.

[12] Bradford K, Dahal P, Bello P 2016 Using relative humidity indicator paper to measure seed and commodity moisture contents Agric. Environ. Lett. 1 1-4.

[13] Mbofung G, Goggi S, Leandro L, Mullen R 2013 Effects of storage temperature and relative humidity on viability and vigor of treated soybean seeds Crop Science, 53, 1086-1095

[14] Gummert M, Cabardo C 2013 IRRI Training Module on Rice Storage The International Rice Research Institute Accessed from http://www.knowledgebank.irri.org/images/docs/rice-storage-presentation.pdf.

[15] Warrick C 2011 Aerating Stored Grain: A Grains Industry Guide Grains Research and Development Corporation (GRDC) Australia.