Plc-Based Multi-Hopper Chemical Weighing System

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Abstract—This paper presents the design and experimental evaluation of a PLC-based multi-hopper chemical weighing system for accurate and automated material batching. Precise material proportioning is critical in industries such as chemical processing, pharmaceuticals, and food manufacturing to maintain product quality. The system uses a three-hopper configuration with pneumatic control valves and a load cell-based weighing unit, controlled by a PLC using time-based logic. A multi-stage feeding approach (coarse, intermediate, and fine) is implemented to reduce overshoot and improve accuracy. Experimental testing with wheat, bajra, and rice demonstrates consistent performance, good repeatability, and reduced material wastage. The system offers a simple, cost-effective, and scalable solution suitable for both industrial and educational applications.

Index Terms—**PLC, Multi-hopper system, Chemical batching, Load cell, Pneumatic control, Industrial automation, Material weighing, Time-based control, Process accuracy, Automatic Weighting system.**

I. INTRODUCTION

Accurate material weighing and batching play a crucial role in industries such as chemical processing, pharmaceuticals, and food manufacturing, where even minor deviations in material composition can lead to significant quality issues, production losses, and safety risks. In modern industrial environments, the demand for high precision, repeatability, and automation has increased significantly due to the need for consistent product standards and efficient resource utilization.

Traditional batching systems primarily rely on manual or semi-automatic methods, which are often prone to human error, inconsistent flow rates, and lack of precise control. These limitations result in material wastage, reduced productivity, and increased operational costs. Although advanced feedback-based systems using load cells and PID controllers have been developed, they often involve complex implementation, higher costs, and are not always suitable for small-scale or educational applications.

To address these challenges, this paper proposes a PLC-based multi-hopper chemical weighing system designed to achieve accurate and automated batching using a simplified control approach. The system utilizes a three-hopper configuration with pneumatic control valves and a load cell-based weighing unit. A time-based multi-stage feeding strategy comprising coarse, intermediate, and fine feeding is implemented to ensure faster operation while minimizing overshoot and improving accuracy.

The proposed system focuses on achieving a balance between simplicity, cost-effectiveness, and performance, making it suitable for both industrial and academic applications. Experimental validation is carried out using different materials to evaluate system behaviour under varying flow conditions. The key contributions of this work include: development of a multi-hopper batching system using PLC-based control, implementation of a staged feeding strategy to improve accuracy, analysis of material flow characteristics under time-based control, and demonstration of a cost-effective and scalable automation solution.

II. LITERATURE REVIEW

Significant research has been carried out in the field of automated weighing and batching systems, particularly with the integration of industrial automation technologies such as PLCs, load cells, and sensor-based control systems. These systems aim to improve accuracy, efficiency, and reliability in material handling processes across various industries.

Earlier systems were primarily manual or semi-automatic, which were simple but suffered from low accuracy and high dependence on human intervention. To overcome these limitations, researchers introduced PLC-based automation systems that provide improved control, repeatability, and operational efficiency.

Several studies have focused on load cell-based batching systems employing closed-loop control techniques such as PID control. These systems continuously monitor weight and dynamically adjust material flow to achieve high precision. However, such approaches often involve complex system architecture, higher implementation cost, and require advanced tuning and calibration, making them less suitable for small-scale or cost-sensitive applications. Recent developments include IoT-based monitoring, smart sensor integration, and real-time data acquisition systems, which enhance system intelligence and remote accessibility. Additionally, advanced techniques such as gravimetric feeding and loss-in-weight systems have been proposed for continuous and highly accurate dosing. Despite their advantages, these systems are typically complex and expensive.
Based on an extensive review of available literature, it has been observed that very limited research has been reported on simple PLC-based multi-hopper batching systems that rely on time-based staged control while still achieving acceptable accuracy. Most existing works emphasize feedback-based or highly sophisticated control methods.

To the best of the authors' knowledge, no closely related work was found that specifically combines a multi-hopper configuration with a time-based multi-stage feeding strategy using PLC control for cost-effective and simplified batching applications. This highlights a clear research gap in developing a system that balances simplicity, cost, and performance.
The present work addresses this gap by proposing a PLC-based multi-hopper chemical weighing system that utilizes a staged feeding approach to improve accuracy while maintaining a simple and economical design.

III. SYSTEM ARCHITECTURE

The proposed PLC-based multi-hopper chemical weighing system is designed to perform accurate and automated material batching using pneumatic actuation and time-based control logic. The complete system integrates mechanical, pneumatic, electrical, and control components to achieve controlled material dispensing with improved accuracy and repeatability. The experimental setup consists of a primary storage hopper mounted at the top of a rigid fabricated frame, as shown in the developed prototype. The hopper stores bulk material and distributes it into three separate outlet channels positioned below it. Each outlet acts as an independent dispensing path and is designed to provide different flow characteristics during the batching process.

The three outlet pipes are connected to pneumatic flow control mechanisms operated through solenoid valves and double-acting pneumatic cylinders. Compressed air supplied by the compressor is regulated and directed to the pneumatic actuators through air tubing and fittings. The PLC generates control signals to energize the solenoid valves, which in turn actuate the cylinders and regulate the opening and closing of the outlet paths. All three outlet channels converge into a single discharge point positioned directly above the weighing platform. A container placed on the digital weighing scale collects the discharged material. The weighing unit continuously measures the accumulated weight and displays the output digitally.

The PLC acts as the central control unit of the entire system. It executes the programmed time-based control logic and sequentially operates the pneumatic valves according to predefined timing parameters. The PLC ensures synchronized operation between material discharge stages and process timing, thereby reducing overshoot and improving batching accuracy.

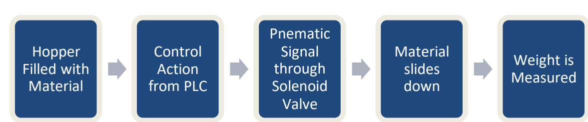

Fig:1 Block Diagram of Automatic Weighting System

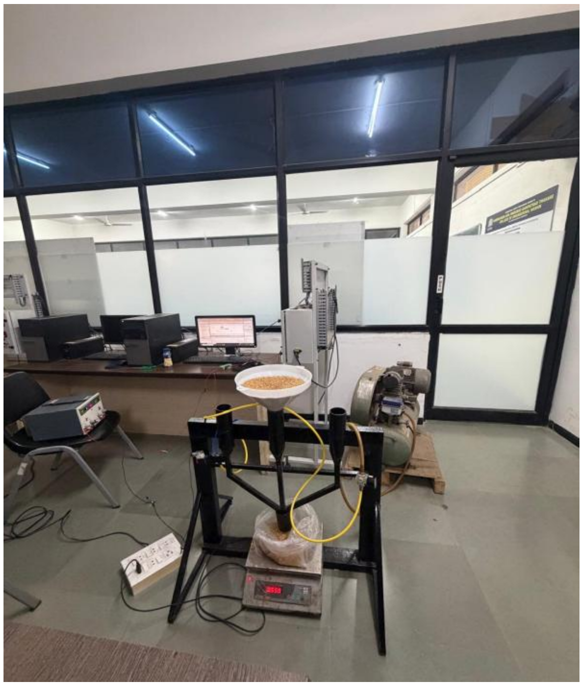

Figure:2 Physical Prototype

IV. MATH

The operation of the proposed multi-hopper chemical weighing system is based on the relationship between material flow rate, dispensing time, and accumulated weight. Since the system utilizes time-based staged feeding, the quantity of material discharged from each hopper depends on its flow rate and valve opening duration.

The material discharged from each hopper can be expressed as:

$$Q = \frac{T_{final} - T_{initial}}{W_{final} - W_{initial}}$$

1.Wheat Measurement (Sample):

Pipe	Weight at 25 s (g)	Weight At 1s(g)
Q1	548 g	28g
Q2	550 g	34g
Q3	555 g	30g

Flow calculation(Q):

$$Q = \frac{T_{final} - T_{initial}}{W_{final} - W_{initial}}$$

= (548-28) /24

=21.7g/s

(Approx. Quantity is ≈22 per second)

2.Bajra Measurement (Sample):

Pipe	Weight at 25 s (g)	Weight At 1s(g)
Q1	838g	34g
Q2	868g	40g
Q3	866g	38g

Flow calculation(Q):

$$Q = \frac{T_{final} - T_{initial}}{W_{final} - W_{initial}}$$

= (844-38) /24

=34.5g/s

(Approx. Quantity is ≈35 per second)

3.Rice Measurement (Sample):

Pipe	Weight at 25 s (g)	Weight At 1s(g)
Q1	742g	28g
Q2	752g	26g
Q3	760g	22g

Flow calculation(Q):

$$Q = \frac{T_{final} - T_{initial}}{W_{final} - W_{initial}}$$

= (760-22) /24

=30.7g/s

(Approx. Quantity is ≈31 per second)

V. WORKING PRINCIPLE

The developed system operates on a sequential material dispensing mechanism controlled by a PLC. Bulk material stored in the main hopper flows through three separate outlet channels. Pneumatic valves regulate the opening and closing of each outlet based on predefined timing logic programmed in the PLC.

Initially, the first outlet allows rapid discharge for bulk filling. After reaching a major portion of the desired quantity, the second outlet supplies material at a moderate rate for controlled addition. Finally, the third outlet performs slow and precise dispensing to achieve accurate final weight with minimal overshoot. The discharged material is collected in a container placed on a digital weighing scale, where the accumulated quantity is continuously monitored. Once the required weight is achieved, the PLC deactivates all pneumatic valves and stops further flow. This staged operation improves precision, reduces wastage, and ensures consistent batching performance for different materials.

VI. SOFTWARE IMPLEMENTATION

The software implementation of the proposed system is based on PLC programming used to control the sequential material dispensing operation. The Siemens S7-1200 PLC is programmed using the TIA Portal environment, where the complete control logic, timing sequence, and actuator operation are configured. The control program is developed using ladder logic programming, which enables easy monitoring and reliable industrial operation. The PLC continuously executes the programmed sequence to control the pneumatic solenoid valves connected to each outlet channel.

The operation begins with system initialization and timer activation. Based on predefined timing parameters, the PLC energizes the first solenoid valve to perform coarse feeding for rapid material discharge. After completion of the first stage, the PLC switches to the second outlet for controlled feeding, followed by activation of the third outlet for fine dispensing. Each stage operates for a specific duration to achieve accurate batching and minimize overshoot.

VII. HARDWARE IMPLEMENTATION

Table1: Components used during the prototype

Sr. No.	Component	Specification
1	PLC (Siemens S7-1200)	24V DC supply, Digital I/O control
2	Solenoid Valve	5/2 Pneumatic Solenoid Valve, 24V DC
3	Double-Acting Pneumatic Cylinder	Stroke length as per outlet mechanism
4	Air Compressor	Operating pressure: 2–4 psi
5	Relay Module	24V DC relay
6	Load Cell-Based Weighing Scale	Digital weighing scale with gram-level measurement
7	Hopper Assembly	Conical plastic hopper
8	Outlet Pipes	Mild steel/PVC fabricated pipes
9	Pneumatic Tubing	Polyurethane air pipe
10	Connectors and Fittings	Pneumatic push-fit connectors
11	Structural Frame	Mild steel fabricated structure
12	DC Power Supply	24V DC regulated supply
13	Control Panel	Electrical control enclosure
14	Personal Computer (PC)	PLC programming interface

VIII. RESULTS AND DISCUSSION

Experimental trials were conducted using wheat, bajra, and rice to evaluate the performance of the developed multi-hopper batching system under identical operating conditions. The obtained results showed stable and repeatable dispensing characteristics with a gradual increase in accumulated weight over time. Among the tested materials, bajra exhibited the highest discharge rate, while wheat showed comparatively slower flow behavior due to differences in particle properties. The staged dispensing mechanism effectively improved control near the desired quantity and reduced excess material flow during final filling. The system demonstrated reliable operation, consistent sequencing of pneumatic actuators, and satisfactory batching accuracy using the implemented time-based control approach.

Here are the experimental graphs plotted using data

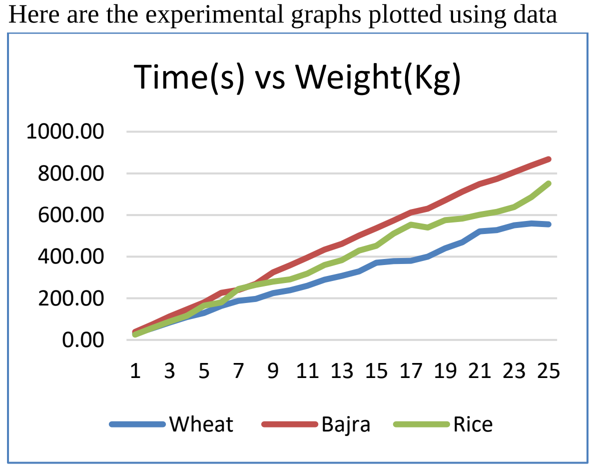

Fig:3 Graph Plotted using sample data

The plotted graphs of average weight versus time for wheat, bajra, and rice show a nearly linear trend, indicating uniform flow under controlled conditions. Minor deviations in slope were observed, reflecting changes in material discharge behavior during different stages of operation.

IX. CONCLUSION

This paper presented a PLC-based multi-hopper chemical weighing system designed for accurate and automated material batching using pneumatic control and time-based staged feeding. Experimental testing with wheat, bajra, and rice demonstrated stable operation, good repeatability, and consistent dispensing performance under identical conditions. Bajra showed the highest flow rate, followed by rice and wheat, highlighting the effect of material properties on discharge behavior. The implemented multi-stage feeding approach effectively reduced overshoot and improved batching accuracy. Overall, the developed system provides a simple, cost-effective, and reliable solution for industrial and educational material handling applications.
Another aspect should be highlighted is that the weight at output is also dependent on the size of sample as you can clearly see through the graphs the bajra sample was more precise than wheat.

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