Application of Principal Component Analysis (PCA) and Regression with Lagged Variables to Identify the Effect of Blower Speed and Feed Rate in Pneumatic Conveying

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Abstract— **This study investigates the dynamic behaviour of particle velocity in a pneumatic conveying system for bird food, focusing on the effects of blower voltage and feed rate on system performance and stability. Particle velocities were recorded under blower input voltages ranging from 4.5 to 7 V (2310 to 3260 rpm) and feed rates from 30% to 70%, using a rotary feeder. Principal Component Analysis (PCA) revealed that the first two components accounted for most of the variance in particle velocity, indicating a significant but not exclusive impact of the studied variables. Autocorrelation analysis of detrended particle velocity showed substantial system inertia, with a decay rate of -0.046 over five 1-second intervals, highlighting the influence of historical conditions on current dynamics. This insight is crucial for refining control algorithms to manage temporal dependencies within the system. Cross-correlation analysis identified a time-lagged response in particle velocity following adjustments in blower voltage, with a peak correlation at a 1-second lag, underscoring the system's dynamic nature. The study identified optimal stability at specific voltage-feed rate combinations, such as 5.75 V and 30%, which exhibited a low standard deviation in particle velocity (0.63 m/s). In contrast, settings like 4.5 V and 70% led to significant fluctuations, indicating potential instability. The findings underscore the importance of understanding the interplay between blower voltage and feed rate in developing predictive models and advanced control strategies, thereby enhancing the efficiency and reliability of pneumatic conveying systems.**

Keywords: Pneumatic Conveying; Closed-loop Control; PCA

1. Introduction

Pneumatic conveying is a widely used method of bulk material transport where a gas, typically air, is employed to move materials through a pipeline. This technique is common in various industries such as chemical, pharmaceutical, food processing, and power generation due to its flexibility, safety, and reduced maintenance costs[1]. Despite these advantages, the inherently complex and nonlinear nature of pneumatic conveying systems presents significant challenges in understanding and controlling their behaviour[2].

Historically, research on pneumatic conveying systems has focused on empirical and experimental approaches to understand their unpredictable behaviour[3]. While these studies have provided valuable insights, they often fall short in explaining the underlying system dynamics. Specially, there has been limited research evaluating the effects of blower speed and feed rate on pneumatic conveying systems, despite practical understanding within the industry, particularly regarding control aspects.

Previous studies, such as those by Klinzing [4], have explored unusual phenomena in pneumatic conveying, including reduced gravity effects and electrostatics. More recently, we conducted system identification and stability analysis based on key variables like blower input voltage and particle velocity[5]. Understanding these variables is crucial in the context of Industry 4.0, where minimizing energy consumption is a priority [6].

This study aims to investigate the dynamic behaviour of particle velocity in a pneumatic conveying system, focusing on the effects of blower speed and feed rate. Using PCA and regression with lagged variables, this research seeks to provide deeper insights into the system's performance and stability, ultimately contributing to the development of advanced control strategies for improved efficiency and reliability.

2. Methodology

2.1. Experimental Setup

The experimental setup consisted of a pneumatic conveying system approximately 26 meters long with four bends, designed for conveying bird food. The air mover in this system was a blower, whose rotational speed (rpm) could be controlled by adjusting the input voltage, ranging from 0 to 10 V. This input voltage was directly proportional to the rpm of the blower and, consequently, the inlet air mass flow rate. A rotary feeder was used to introduce the material into the system, with feed rates controllable as a percentage. The study did not measure inlet air velocity, pressure, or the feed rate in kg/s, as the primary focus was on analysing the effects of variations in blower voltage and feed rate on the system.

Particle velocity, a critical parameter in this study, was determined using electrostatic signals captured by two electrodes positioned at a known distance apart. By applying cross-correlation techniques in the time domain to these signals, the particle velocity was accurately calculated.

2.2. Data Analysis Techniques

To analyse the effects of blower voltage and feed rate on particle velocity, several statistical techniques were employed:

Principal Component Analysis (PCA): PCA was used to reduce the dimensionality of the dataset and to identify the principal components that account for the variance in particle velocity. The independent variables (blower input voltage and feed rate) were standardised and combined into a matrix, on which PCA was performed. The analysis aimed to capture the most significant features affecting particle velocity, thereby simplifying the data structure for further analysis.

Autocorrelation Analysis: Autocorrelation analysis was applied to the detrended particle velocity data to investigate the temporal dependencies within the system. This method assessed how current values of particle velocity were influenced by past

values, thus highlighting the inertia within the system. The decay rate over a specific number of time intervals was calculated to quantify this dependency.

Cross-Correlation Analysis: To understand the dynamic response of particle velocity to changes in blower voltage and feed rate, cross-correlation analysis was conducted. This technique helped identify time-lagged relationships between the independent variables and particle velocity, thereby providing insights into the system's dynamic nature and the time delay effects of input changes on particle velocity.

These methods collectively provided a comprehensive framework for understanding how variations in operational parameters influenced the system's behaviour, particularly in terms of particle velocity dynamics.

3. Results and Discussion

This study focused on the dynamic behaviour of particle velocity in a pneumatic conveying system for bird food, examining the effects of blower voltage and feed rate on system performance and stability. The results highlight several key findings.

Principal Component Analysis (PCA) indicated that the first two components accounted for a significant portion of the variance in particle velocity, with regression coefficients of 1.57 and 0.51. The PCA model explained approximately 52.8% of the variability in particle velocity, suggesting that while blower voltage and feed rate are influential, other factors may also affect system behaviour.

Autocorrelation analysis of the detrended particle velocity showed a substantial system inertia with a decay rate of -0.046 over five 1-second intervals. This slow decay rate underscores the influence of past conditions on the current state of the system, indicating persistent temporal correlations. The inability to reach 80% decay within the specified lags further highlights the prolonged impact of previous system states, which is crucial for refining control algorithms to manage these temporal dependencies effectively.

Cross-correlation analysis revealed a peak correlation at a 1-second lag between blower voltage changes and particle velocity, underscoring the system's dynamic nature and the delayed response of particle velocity to adjustments in blower voltage. This lag is critical for developing responsive control strategies that can anticipate and compensate for these delays.

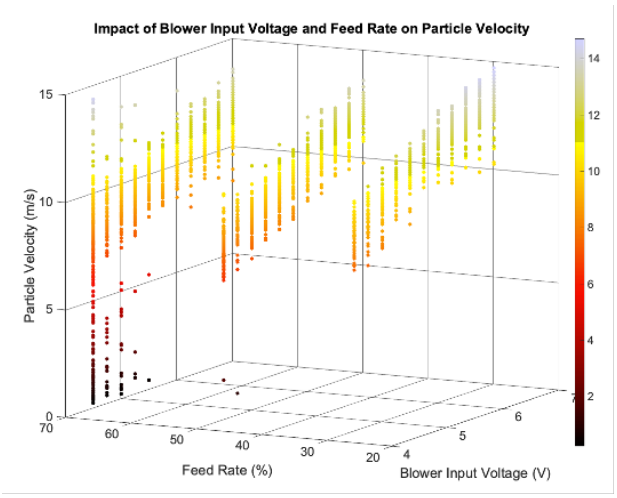

Figure 1. Impact of Blower Input Voltage and Feed Rate on Particle Velocity

The study identified optimal operating conditions at a blower voltage of 5.75 V and a feed rate of 30%, where particle velocity exhibited a low standard deviation of 0.63 m/s. In contrast, settings such as a blower voltage of 4.5 V and a feed rate of 70% resulted in significant fluctuations, with a standard deviation of 3.27 m/s, indicating potential instability. These findings emphasize the importance of carefully controlling blower voltage and feed rate to maintain stable and efficient system operation.

4. Conclusion

This study investigated the impact of blower voltage and feed rate on particle velocity in a pneumatic conveying system. PCA showed that the first two components accounted for significant variance in particle velocity, highlighting the influence of these operational parameters. Autocorrelation analysis revealed a decay rate of -0.046, indicating substantial system inertia, while cross-correlation analysis identified a 1-second lag in the response of particle velocity to changes in blower voltage.

Optimal stability was achieved at a blower voltage of 5.75 V and a feed rate of 30%, minimizing fluctuations in particle velocity. In contrast, settings like 4.5 V and 70% led to increased variability, indicating potential instability. The study emphasises the importance of precise control over blower voltage and feed rate, considering both immediate and delayed responses, to enhance system efficiency and reliability.

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