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Development of Pid Controller for Conveyor Belt System with Different Tuning Method

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Abstract
A conveyor system is a common mechanical handling equipment that is used to move a product from one point to another place. The system has a variety of shapes and sizes based on the requirement of various sectors. However, most of the conveyer system does not have a monitoring structure to assess the conveyer belt's operation and efficiency. As a result, the conveyer's performance and durability decrease, and significantly interferes the production performance. In addition, the existing method for adjusting the speed is inconvenient. Therefore, this research is proposed to enhance an existing conveyor system that is used in a variety of applications. Its main objective is to design PID controller by using Matlab for conveyer belt system such that all the risks can be reduced. The designed PID controller is then tuned by two different techniques: Ziegler-Nichols method and root locus. The time response performance is analysed based on the requirement and operating method of the system. Visual studio is used as GUI to display the graph and reading of the system. The results show that the system reaches the steady-state value with all these techniques but within different periods of time with different value of K_p, K_i and K_d.

Keywords: Conveyer System, Monitoring, Speed, Proportional Integral Derivative (Pid), Tuning Method

Introduction
A conveyor system is a common mechanical handling solution used to move materials from one location to another efficiently. This system is particularly vital in applications that involve transporting heavy or bulky materials, making it indispensable in industries where speed, efficiency, and safety are essential. Conveyor systems allow for the quick and seamless movement of a wide variety of materials. Therefore, it is widely adopted in material handling

and packaging industries. Typically, a conveyor system consists of a sturdy frame that supports either rollers, wheels, or a belt upon which materials are transported. These systems can be powered by motors, gravity, or manual effort, depending on the specific application and industrial requirements. The automation provided by conveyor systems not only minimizes human error but also reduces workplace risks and significantly lowers labor costs, making them an economical solution for industries looking to optimize their operations. Figure 1 provides an illustration of a typical conveyor belt system used in a distribution center.

Figure 1 : Conveyor belt in a distribution system

There are various types of conveyor systems available, each tailored to the specific needs of different industries. For instance, chain conveyors, both floor and overhead, offer flexibility in environments where standard conveyor systems may not be suitable. Chain conveyors are equipped with enclosed tracks, towlines, power & free mechanisms, and even hand-pushed trolleys, offering a broad range of applications. Conveyor systems find widespread usage across industries such as automotive, agriculture, electronics, food processing, aerospace, pharmaceuticals, chemicals, bottling, canning, print finishing, and packaging. The advantage of conveyer in many applications including increased efficiency, reduced labor requirements, and the ability to handle a wide array of products. The materials commonly conveyed range from food items such as beans and nuts to automotive components, scrap metal, pills, powders, wood, and furniture. They are also widely used in handling grain, animal feed, and packaging materials like bottles and cans.

The fundamental of conveyer system are the conveyor belt, rollers, pulleys, frames, motor and drive system, and control system. The conveyor belt itself is the central element, responsible for carrying materials along the specified path. Rollers are used to support and guide the belt, while pulleys drive and redirect it. Pulleys are placed at both ends of the conveyor system and are typically powered by electric motors or other energy sources. The frame, usually made of steel or aluminum, provides the necessary structural support for the conveyor components. The motor and drive system provide the energy required to move the belt, with motor size and type varying depending on the system's length, load capacity, and speed requirements. Modern conveyor systems often integrate electronic control systems, which not only manage the movement of materials but also monitor speed, detect jams or overloads, and adjust performance to maximize efficiency.

There are numerous types and configurations of conveyor systems tailored to specific needs, including belt conveyors, roller conveyors, screw conveyors, chain conveyors, bucket conveyors, and pneumatic conveyors. Among these, belt conveyors are the most common, consisting of a continuous belt that transports materials along a defined path. Despite the widespread use and numerous advantages of conveyor systems, there are also its drawback. Common operational issues include belt slippage, where the belt loses traction on the drive pulley, leading to decreased productivity and material spillage. Misalignment of the belt, known as belt tracking issues, can cause uneven wear and potential damage to the system. Additionally, conveyor systems are prone to blockages or jams, often due to foreign objects, uneven loading, or equipment malfunctions, all of which can delay production and require manual intervention. Over time, components such as belts, rollers, bearings, and motors wear out, necessitating regular maintenance to prevent breakdowns.

Another important consideration is the design and operation of conveyor systems, as these factors influence energy consumption and overall efficiency. Overloading the system beyond its capacity can lead to inefficiencies, increased wear and tear, and costly downtime. Therefore, careful attention must be paid to the system's design, installation, and maintenance, and safety protocols should always be followed. Regular inspections, preventive maintenance, and proper training of operators are critical to mitigating these issues and ensuring that conveyor systems operate at peak efficiency, providing their full range of benefits across various industries.

Proportional Integral Derivative (PID) Controller

A Proportional-Integral-Derivative (PID) controller is one of the most widely utilized and effective feedback control systems in industrial, automation, and engineering applications. It is employed to regulate and control a variety of processes by continuously monitoring and adjusting the system's behavior. The PID controller operates by calculating an error value, which is the difference between a desired setpoint and a measured process variable. Based on this error value, the controller generates a correction signal through three distinct components: the proportional, integral, and derivative terms. These three terms work in concert to ensure that the error is minimized, helping the system maintain the desired setpoint or reach it as quickly and accurately as possible.

The proportional term (P) of the PID controller provides an immediate response to the current error, applying a correction that is proportional to the size of the error. The larger the error, the larger the corrective action. This allows for a quick reaction to changes in the process variable, making the system responsive to dynamic conditions and fluctuations. However, relying solely on the proportional term may lead to overshooting the setpoint or not fully eliminating the error over time, which is why the integral and derivative terms are also critical.

The integral term (I) is responsible for addressing any accumulated error over time, ensuring that even small, consistent errors are eventually corrected. By integrating the error over time, this term effectively reduces the steady-state error, allowing the system to reach and maintain the exact setpoint. This term is particularly useful when the system experiences persistent deviations that are not corrected by the proportional term alone.

The derivative term (D) predicts future behavior by evaluating the rate of change of the error. It applies a damping effect that helps reduce overshooting and oscillations, which can occur if the system reacts too aggressively to changes in the error. By smoothing the system's response, the derivative term enhances the overall stability of the controller, especially in systems with rapidly changing dynamics.

One of the key strengths of the PID controller is its versatility and adaptability across a wide range of industries and applications. In manufacturing, process control, robotics, automotive systems, aerospace, chemical processing, and even in home automation systems, PID controllers play a vital role in maintaining desired performance levels. Their ability to handle both fast-acting and slow-changing processes makes them highly flexible and effective in dealing with systems of varying dynamics.

Furthermore, PID controllers provide stable and reliable control, even in the presence of disturbances and noise, making them suitable for real-world applications. They can manage systems with varying or uncertain dynamics, which often occur in practical scenarios where exact mathematical models of the system may not be available. This robustness allows PID controllers to remain effective under a wide range of conditions, including when there are changes in load, external disturbances, or variations in system parameters.

A significant advantage of using PID controllers is the ability to fine-tune control parameters— namely, the proportional gain (Kp), integral gain (Ki), and derivative gain (Kd)—to optimize the performance of specific systems. Engineers can adjust these parameters to achieve the desired balance between response speed, accuracy, and stability, tailoring the controller's behavior to meet the unique needs of each application. The fine-tuning process, known as PID tuning, is essential to ensure that the controller delivers optimal performance in terms of minimizing errors and avoiding undesirable effects like excessive oscillations or instability.

Moreover, PID controllers are particularly well-suited for systems that require fast adjustments and rapid responses to changing conditions. The proportional term enables quick reactions to any detected error, allowing the controller to promptly counteract deviations from the setpoint. This makes PID controllers ideal for systems that demand real-time control, such as robotic arms, vehicle cruise control systems, and dynamic positioning systems in ships and aircraft.

The inclusion of the integral term also ensures that the system can reach a steady state with zero or minimal residual error over time. This feature is critical in applications where long-term accuracy is essential, such as in temperature control systems, pressure regulation, and level control in process industries.

PID controllers are known for their robustness, which refers to their ability to handle uncertainties and variations in system parameters without losing control. This is particularly valuable in real-world applications, where it is often difficult or impractical to create perfect mathematical models of complex systems. A PID controller can still function effectively, compensating for unknown factors and disturbances that may affect the system's performance. It is one of the most well-understood and widely implemented control strategies in engineering. Over the decades, PID controllers have proven to be a reliable and consistent solution for a broad spectrum of control problems. This long-standing success has fostered familiarity among engineers and technicians, who are well-versed in its principles and can readily implement, tune, and troubleshoot PID controllers in a wide range of applications.

In summary, the PID controller's combination of proportional, integral, and derivative control provides a powerful, flexible, and reliable method for managing complex systems and processes. Its adaptability to various industries, ease of fine-tuning, and robustness in handling uncertainties make it a fundamental component of modern control systems, ensuring that processes operate efficiently, accurately, and with minimal error over time.

Controller for Conveyer System

The implementation of advanced control systems is vital for optimizing the performance and efficiency of modern conveyor systems, particularly in industrial environments where precision, reliability, and adaptability are critical. In [Dong-Ryul Shin et.al, 1997], a Space Vector Modulation (SVM) technique combined with a Proportional-Integral (PI) controller is introduced to improve the dynamic characteristics of a Single-sided Linear Induction Motor (SLIM) that is designed for use in conveyor systems. SLIMs have inherent challenges, such as a large air gap, which significantly affects their thrust performance. The fluctuation of the air gap during operation can cause thrust ripple, a phenomenon that makes it difficult to achieve precise speed control. The proposed SVM with a PI controller can mitigate thrust ripple, thereby enhancing the overall stability and dynamic performance of the SLIM in conveyor applications. This approach not only improves thrust control but also ensures smoother and more reliable speed regulation, which is crucial for maintaining consistent conveyor operations. In addition, PID correction techniques based on MATLAB software have been employed in [Rong Li et.al, 2012] to improve the electro-hydraulic proportional control technology used in a lead cathode walking-beam conveyor system. This system requires precise speed control to maintain the accuracy and efficiency of its operations. The PID correction algorithm compensates for any deviations in speed by continuously adjusting the system based on real- time feedback. Simulation results show that the PID controller significantly improves speed accuracy, making it an effective solution for enhancing the performance of electro-hydraulic conveyor systems.

The study of wear mechanisms in rubber conveyor belts is equally important for improving the longevity and performance of conveyor systems. In [F.Hakami et.al, 2017], the wear rate and associated mechanisms of rubber used in conveyor belts are examined in detail, with a focus on understanding how parameters like load, sliding velocity, hardness, and friction contribute to the wear process. The primary wear mechanisms identified in this study include abrasion, fatigue, and roll formation, all of which are influenced by these factors. By establishing correlations between the influential parameters and rubber wear, this research provides valuable insights into how conveyor systems can be optimized to reduce wear and improve durability. This is particularly relevant in industrial environments where conveyor belts are subjected to heavy use and must maintain high performance over long periods.

Further advancements in conveyor control systems are highlighted in Sujin Jeon et al, (2006), which explores the relationship between thrust and the interval of Linear Induction Motors (LIMs) used for precise position control in conveyor systems. The research proposes a dynamic control strategy using vector control in combination with a Finite Element Method

(FEM)- based algorithm to enhance the accuracy of LIM movements. This approach ensures that the conveyor system can achieve exact positioning, which is essential for tasks requiring precise material handling and placement. The integration of vector control with FEM modeling allows for a more accurate representation of the LIM's behavior, leading to improved control over its dynamic characteristics.

The integration of Programmable Logic Controllers (PLCs) for enhanced conveyor system performance is presented in (Zhang Jijie et.al, 2011). In this study, an advanced PLC control system is designed for power-plant conveyor systems, emphasizing both hardware and software reliability. The system uses King View as a PC-based monitoring interface, which enables real-time supervision of the conveyor operations. This design leverages a distributed control structure, ensuring strong system stability and continuous operation, even in the event of a component failure. The advanced PLC system enhances the reliability of the power-plant conveyor, ensuring that it can operate efficiently and handle potential faults without compromising overall performance.

In You Wenqiang et al. (2011), a practical program for automatic synchronous speed control is discussed. The system uses a rotary encoder to detect motor speeds and a PLC to sample and analyze these speeds. The system adjusts motor speeds using an automatic frequency converter, allowing the motors to synchronize their operations. This approach ensures that the conveyor motors remain balanced and that the system operates within acceptable error limits. By gradually achieving synchronization, the conveyor system can maintain stable and efficient performance, which is critical for applications requiring coordinated motor operations.

Another important aspect of conveyor system optimization is the selection of appropriate components, such as chains and sprockets. In [Zhuming Bi et.al, 2021], a systematic approach is developed to build an experimental platform for evaluating chains and sprockets, which are commonly used in Material Handling Systems (MHS). This platform guides the selection of sensors and instrumentation for testing the performance of these components. By optimizing the selection process, this approach ensures that conveyor systems are equipped with the most suitable chains and sprockets, leading to improved operational efficiency and reliability.

In the field of rubber conveyor production, Li (2008), introduces a distributed control system that combines an industrial control computer and a programmable controller. This system implements a "four-step weighing method" along with a "parameter-adaptive fuzzy PID frequency conversion control technique" to achieve fast and accurate material weighing. This approach addresses the challenges posed by different material properties, such as the humidity of powdered materials or the fluidity of liquids, which can affect the speed and accuracy of conveyor belt operations. The use of advanced algorithms and precise weighing techniques allows for improved control over the conveyor system, enhancing both its speed and accuracy. The effectiveness of this system has been demonstrated in practice, and it shows significant potential for wider application in industries requiring precise material handling and measurement.

Despite these technological advancements, many conveyor machines still rely on outdated methods that are not in line with the rapid pace of industrial modernization. This creates a need for further innovations to keep up with evolving industry demands. One of the major shortcomings in existing conveyor systems is the lack of real-time monitoring capabilities. Without monitoring systems to assess the operation and efficiency of the conveyor belt, performance and durability are compromised, leading to inefficiencies in production. In addition, the current methods for adjusting conveyor belt speeds are often inconvenient and limited, relying on manual potentiometer adjustments that slow down the process and reduce responsiveness to changing operational needs.

Another key factor to consider is the type of conveyor belt used for different applications. For instance, flat belt conveyors are ideal for arranging goods efficiently, while chain conveyors are better suited for heavy-duty tasks such as cargo transfer. Using the appropriate conveyor belt for each specific task can significantly improve the performance and efficiency of the system, making it more responsive to the demands of modern industries.

To address these challenges, this research proposes the development of a PID controller for conveyor speed control. The controller will be tuned using various methods to optimize performance for different conveyor systems. The research will compare the performance of the conveyor system under different tuning methods to determine the most effective approach for each application. Additionally, a Graphical User Interface (GUI) will be developed to provide real-time monitoring and control of the conveyor system's speed, enhancing operator interaction and system visibility. The proposed controller will be implemented using Arduino, and the system’s speed readings will be displayed using Microsoft Visual Studio, offering a user-friendly platform for controlling and monitoring the system.

In conclusion, the proposed research seeks to develop a more advanced, responsive, and efficient conveyor system by utilizing a PID controller for speed regulation. This approach addresses the limitations of current conveyor systems by providing more precise control, real- time monitoring, and a user-friendly interface for operators. By exploring different tuning methods and incorporating advanced control algorithms, the research aims to improve the overall performance, reliability, and adaptability of conveyor systems in modern industrial environments.

Methodology

The research begins with the development of a comprehensive framework for the conveyor system prototype, utilizing Computer-Aided Design (CAD) software. CAD plays a crucial role in the initial stages, allowing for precise structural modeling and visualization of the conveyor system. Through CAD, the physical layout and mechanical components of the conveyor can be accurately designed, ensuring that all dimensions and specifications align with the desired functionality. This initial phase is vital for identifying potential design issues early and optimizing the mechanical structure for the integration of electronic controls, sensors, and other automation components.

Once the mechanical framework is developed, the next step is the implementation of the control system using an Arduino microcontroller, which serves as the core of the system's PID controller. Arduino is chosen for its flexibility, affordability, and ease of programming, making it ideal for prototyping and experimental research. The PID controller, designed to regulate and maintain the conveyor belt's speed, uses proportional, integral, and derivative terms to correct deviations from the desired setpoint, ensuring stable and precise control of the conveyor's motion. The ability of the PID controller to dynamically adjust to changes in the system allows for smooth operation, even when subjected to varying loads or disturbances, which is common in real-world industrial environments.

To enhance usability and operator interaction with the system, a Graphical User Interface (GUI) is developed using Microsoft Visual Studio. The GUI serves as a real-time interface, allowing users to monitor the conveyor system's operational data, such as speed readings and performance metrics. Through the GUI, users can visualize system parameters in a user-friendly format, enabling them to adjust settings, view trends, and analyze the conveyor's performance. This level of interaction not only improves the system's usability but also allows operators to quickly identify any operational issues and make necessary adjustments, thereby enhancing the overall efficiency and reliability of the system.

In this stage of the research, the integration between the hardware (Arduino-based PID controller) and the software (GUI in Microsoft Visual Studio) is essential. The system is designed to collect real-time data from the conveyor, such as speed readings, and display them in an intuitive format on the GUI. This real-time monitoring capability allows for quick feedback and control, which is particularly important in industrial settings where immediate adjustments may be required to maintain production efficiency and prevent potential breakdowns.

The overall system development is guided by a structured process flow, as illustrated in Figure 2, which outlines each step from the initial design phase to the final implementation of the prototype. The flow chart provides a clear visual representation of the entire development cycle, ensuring that each phase is systematically executed. Starting from the CAD design of the conveyor framework, the process moves to the integration of the Arduino-based PID controller, followed by the development of the GUI and the real-time display of speed readings. Each stage is interdependent, requiring careful coordination to ensure the final system meets the desired performance objectives.

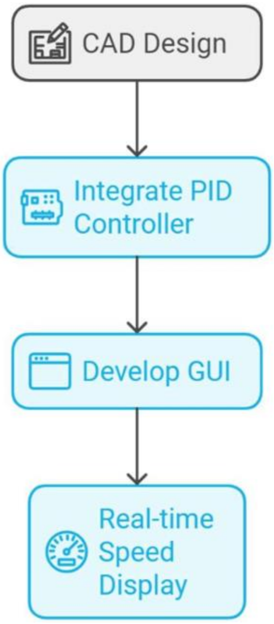

Figure 2 : the process flow chart for the developed system

The research emphasizes not only the technical design but also the practicality of the system in real-world applications. By using widely accessible tools such as Arduino and Microsoft Visual Studio, the research aims to create a cost-effective, scalable solution that can be easily adapted for different conveyor system requirements. The approach taken in this research demonstrates the potential for combining mechanical engineering principles with modern control and software technologies to create a sophisticated, yet practical, conveyor system suitable for various industrial applications.

The main component for this project is Arduino Uno as illustrated in Figure 3. It is used to develop PID controller and monitor the speed of the conveyer by transmitting and receiving the speed data in the sensor module. Arduino is programmed in Arduino Integrated Development Environment (IDE) by using C language.

Figure 3: Arduino Uno
Next component is DC gear motor with encoder which allow the movement of conveyer belt by running the shaft. The component is shown in Figure 4.

Figure 4: DC Motor

Another component is shown in Figure 5 and it is known as H-bridge L298N. It is a dual H-bridge motor driver which allows the control of conveyer's speed and direction simultaneously. However, the component only permits the DC motor control that has a voltage range between 5V to 35V with a peak current up to 2A. It can control the rotation direction by inversing the direction of current flow through the motor.

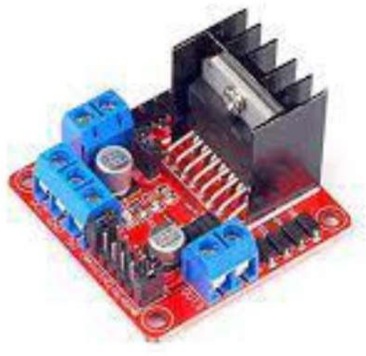

Figure 5: H-bridge L298N

Figure 6 show Interface I2C LCD Monitor, the component that is used as an interface between Arduino and LCD display. It is used to convert the series data from Arduino to parallel data required by LCD display. The LCD will display the speed of conveyer.

Figure 6: Interface I2C LCD Monitor

To ensure smooth monitoring and control action on the conveyer system, the Graphical User Interface (GUI) is developed by using Microsoft Visual Basic. The GUI allows the user to choose the suitable value of controller parameters and observe the speed of conveyer easily. The structure of the conveyer's prototype is illustrated in Figure 7. It is designed by using AutoCAD.

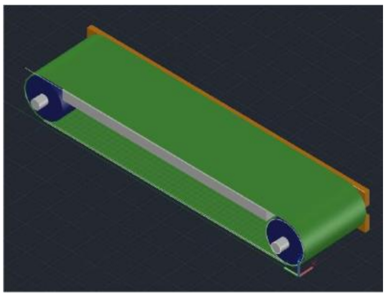

Figure 7: Structure of conveyer's prototype

The designed structure of the conveyer is suitable for each component needed and durable for various tuning speeds. It is also able to bear the weight of the load. The circuit diagram of the designed system is shown in Figure 8.

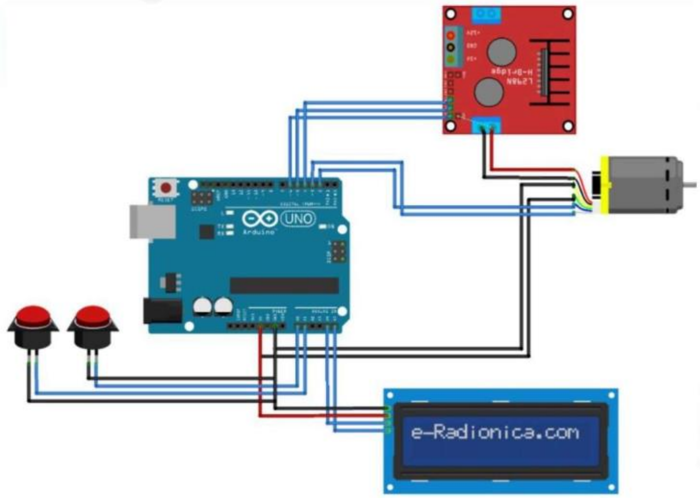

Figure 8: Circuit diagram of the designed system The full design of the system's prototype is illustrated in Figure 9.

Figure 9 : Full design of the system's prototype

The control parameters of PID; K_p, K_i and K_d are fixed based on the calculation obtained from Ziegler-Nichols method and Root Locus. Arduino uno is the main component to design PID controller for conveyer system and it is connected to DC motor which is the main component to start the movement of the conveyer system. The speed of the conveyer is displayed by LCD monitor. At the same time, the speed value shown by LCD can also be seen through GUI developed by using Microsoft Visual Studio. This can be seen in Figure 10.

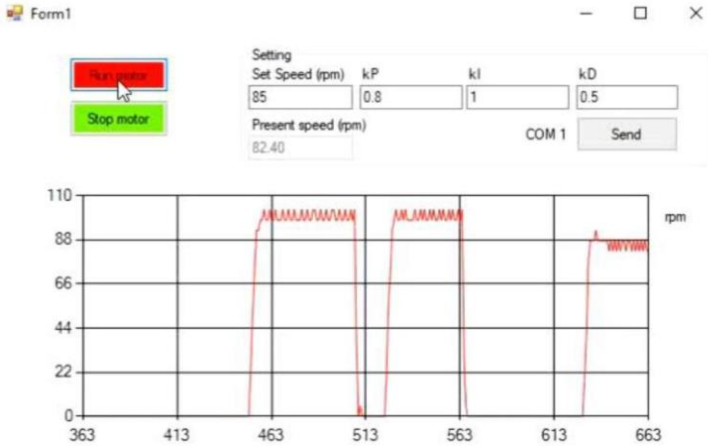

Figure 10:GUI of the developed system

In summary, this phase of the research involves the development of a robust conveyor system prototype, starting from the CAD design of its mechanical structure to the implementation of an Arduino-based PID controller for speed regulation. A Microsoft Visual Studio-based GUI enhances the user experience by providing real-time monitoring and control capabilities. The process flow chart depicted in Figure 2 guides the systematic development of the entire system, ensuring that the final product is both functional and efficient, with the potential for broad applicability in modern industrial settings.

Finding

The performance of the DC motor driving the conveyor system is evaluated using the transfer function derived from its dynamics. The general transfer function for DC motor of the conveyer is given by

$$\frac{W(s)}{V_a(s)} = \frac{k}{jLs^2+(BL=Rj)s+RB+ \quad 2} \quad (3.1)$$

This expression characterizes the relationship between the motor speed W(s)W(s)W(s) and the applied armature voltage Va(s)V_a(s)Va(s). If $k = 0.6$, the transfer function is given by

$$G(s) = \frac{0.6}{0.005s^2+0.07s+0.56} \quad (3.2)$$

Using this transfer function, different PID controllers are tuned using various tuning methods, specifically the Ziegler-Nichols method and the Root Locus method. The goal is to control the speed of the conveyor to reach the target of 100 rpm. The Ziegler-Nichols method is a popular heuristic tuning technique that provides reasonable PID parameters for many systems. By using Ziegler-Nichols method, value of K_p, K_i and K_d are obtained as *7.4648*, *0.0644* and *0.0161* respectively. Using these parameters, the speed response of the conveyor system was shown in Figure 11, indicating that the system could reach the desired speed of 100 rpm.

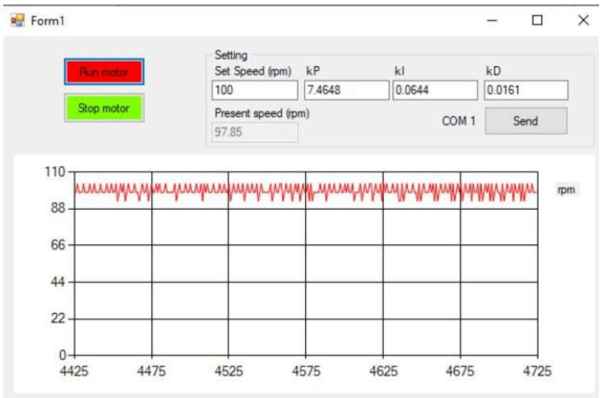

Figure 11: Speed of conveyer system with PID parameters obtained by Ziegler-Nichols method when $k = 0.6$

To analyze the effect of changing the motor constant, k the PID parameters were recalculated for different value of $k = 0.5$, $k = 0.6$ and $k = 0.7$ to achieve the targeted speed at $100 rpm$ as summarized in Table 1

Table 1
PID Parameters with Different Value of k

k	K_p	K_p	K_d
0.5	8.572	0.0698	0.0175
0.6	7.465	0.0644	0.0161
0.7	7.2	0.0616	0.0154

From the table, we observe that the PID parameters remain relatively consistent as the value of k varies. This indicates that the system's dynamics are not highly sensitive to small variations in the motor constant k, and similar PID settings can be used for different values of k to achieve the target speed.

In contrast to the Ziegler-Nichols method, the Root Locus method provides a graphical approach to tuning the PID controller based on the system's poles and zeros. When the Root Locus method was applied to the system with $k = 0.6$, the PID parameters were obtained as $K_p = 20.383$, $K_i = 128.629$ and $K_d = 0.755$. These parameters were significantly larger than those obtained from the Ziegler-Nichols method. The system’s speed response using the Root Locus parameters is shown in Figure 12.

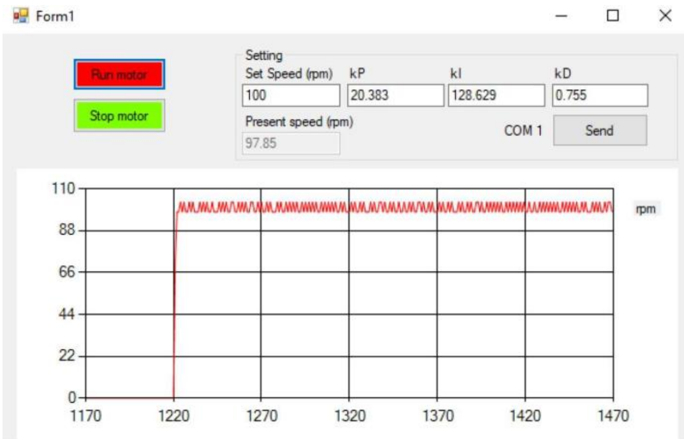

Figure 12: Speed of conveyer system with PID parameters obtained by Root Locus method when $k = 0.6$,

The results from both tuning methods demonstrate that different tuning approaches yield significantly different PID parameters, although both methods aim to achieve the same target speed of 100 rpm. The Ziegler-Nichols method, being heuristic, produces more moderate PID values, while the Root Locus method, which focuses on pole-zero placement, generates much higher controller gains, particularly for K_p, K_i and K_d. The higher PID values obtained from the Root Locus method may result in a more aggressive control action, which could lead to faster responses but might also increase the risk of instability or excessive oscillations in the system. In contrast, the more conservative PID parameters from Ziegler-Nichols may provide smoother control with less overshoot but could result in a slower response.

Conclusion

Based on the analysis of the two tuning methods, it is evident that both the Ziegler-Nichols and Root Locus methods can be used to tune the PID controller for the DC motor driving the conveyor system, but they yield different control dynamics. The Root Locus method requires significantly higher PID values to achieve the same speed target, which could influence the stability and performance of the system. In practical applications, it would be essential to weigh the trade-offs between faster response times and the risk of instability, as well as the control system's ability to handle disturbances and changes in system parameters. Ultimately, the choice of tuning method and the resulting PID parameters depend on the specific performance requirements and constraints of the conveyor system.

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