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PLC Controlled Servo Motor Powered Sorting System

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ABSTRACT: Industrial automation education necessitates hands-on experience with practical systems to cultivate essential skills in programming, control, and system integration. This paper presents a cost-effective and versatile educational platform designed to facilitate experiential learning in industrial automation. The centrepiece of this platform is a modular flat belt conveyor system driven by a stepper motor, augmented with a colour sensor-based pneumatic material handling system.

The conveyor system's modular table, constructed from aluminium profiles, provides flexibility and adaptability, allowing students to reconfigure the setup for various applications. The flat belt conveyor is powered by a TB6600 stepper motor driver, offering precise control and efficient operation. Additionally, it incorporates a colour sensor-based pneumatic material handling system, enhancing its functionality and versatility. Controlled by an Allen Bradley Micro 820 QBB PLC, the system enables students to learn industrial programming techniques while incorporating colour sensing capabilities for material detection and sorting. This feature adds an extra dimension to the learning experience, allowing students to explore the integration of colour sensing technology with industrial automation systems. The endless flat belt conveyor, coupled with the colour sensor-based pneumatic gripper mechanism, enables the transfer of components or materials based on their colour, providing hands-on experience in implementing colour sensing and pneumatic control systems concurrently.

The primary objective of this platform is to empower students to explore and execute various industrial programming practices, now with the added feature of colour sensing technology. Through hands-on experimentation, students can develop skills in PLC programming, stepper motor control, pneumatic system design, conveyor optimization, and colour sensing technology integration. The reconfigurable nature of the project allows for easy modification and experimentation, encouraging students to explore different scenarios and develop innovative solutions utilizing colour sensing technology. With its comprehensive setup and practical applications, the Stepper Motor Controlled Flat Belt Conveyor project with Colour Sensor-Based Pneumatic Material Handling System provides a valuable learning experience for students in the field of industrial automation.

KEYWORDS: PLC, Servo Motor, Color Sensor, Sorting System

I. INTRODUCTION

In today's dynamic industrial landscape, automation embodies efficiency, precision, and adaptability. As manufacturing processes increasingly embrace automation, the need for skilled professionals proficient in complex control systems, component integration, and production workflow optimization is paramount. Educational institutions must equip the next generation of industrial automation experts with hands-on training experiences that simulate real-world scenarios.

Several researchers have delved into stepper motor-controlled flat belt conveyor systems, addressing critical parameters for enhanced performance. A. Srinivasulu et al. [1] explored servo motor selection, PLC programming, and motion control techniques to achieve precise positioning and synchronization. M. H. Ahmad et al. [2] emphasized parameter optimization's significance for improved performance, including accurate position control and reduced settling time.

Additionally, R. Wang and X. Guo [3] proposed a mathematical model and control strategy for precise position control, validated through simulations and experiments. S. A. Sheikh et al. [4] focused on real-time speed control optimization using a genetic algorithm to achieve desired speed profiles and minimize tracking errors. H. Li et al. [5] introduced an adaptive neuro-fuzzy inference system (ANFIS) to learn system non-linear characteristics for precise position control. K. P. Saji and M. S. Abish [6] analysed system dynamics and parameter effects on overall performance through dynamic modelling and simulation.

The literature review highlights extensive research on stepper motor-controlled flat belt conveyor systems, encompassing design, control techniques, optimization, fault diagnosis, and synchronization. This body of work establishes a solid foundation of understanding for projects in this domain, providing valuable insights into the intricacies of stepper motor integration within conveyor systems.

Building upon this knowledge base, the color sorting technology project endeavours to seamlessly incorporate a stepper motor into the conveyor system, ensuring precise object movement along the belt. To achieve this, the project entails the development of software logic for the Micro 820 QBB PLC, orchestrating the operation of the stepper motor while effectively coordinating with the color sensor (CMS 5X) and other peripherals. Essential to the project's success is the establishment of reliable communication protocols between these components, guaranteeing seamless data exchange and system synchronization.

The color sorting technology project, with its seamless integration of a stepper motor into the conveyor system, aligns closely with the primary objective of empowering students to explore industrial programming practices. By incorporating color sensing technology, students gain a deeper understanding of the complexities involved in PLC programming, stepper motor control, pneumatic system design, and conveyor optimization. Through hands-on experimentation, they develop practical skills in integrating color sensing technology into industrial automation systems, enhancing their ability to tackle real-world challenges in the field.

Moreover, the project's reconfigurable nature fosters a culture of innovation and exploration among students. The ease of modification and experimentation encourages them to explore diverse scenarios and devise creative solutions using color sensing technology. This iterative process not only reinforces their understanding of industrial automation principles but also nurtures their problem-solving abilities and creativity. With its comprehensive setup and practical applications, the Stepper Motor Controlled Flat Belt Conveyor project with Colour Sensor-Based Pneumatic Material Handling System offers a valuable learning experience for students in industrial automation. Beyond theoretical knowledge, students gain invaluable hands-on experience in designing, implementing, and optimizing automation systems, preparing them to excel in the rapidly evolving industrial landscape.

II. METHODOLOGY

Key technologies used: The utilization of cutting-edge technologies in the color sorting technology project presents an invaluable learning opportunity for student communities, allowing them to gain hands-on experience with emerging innovations in the field. Here's how each technology contributes to this enriching educational experience:

a. Color Sensor (CMS 5X): By incorporating the CMS 5X color sensor, students can explore firsthand the capabilities of advanced sensing technology in industrial automation. They can learn how to effectively integrate color sensors into systems for precise object detection and sorting, gaining insights into the practical applications of color sensing technology.

b. Belt Drive System: Hands-on experimentation with belt drive systems enables students to understand the fundamental principles of power transmission and motion control. They can learn how to design and assemble belt drive mechanisms, gaining practical skills in ensuring proper tensioning and alignment for efficient operation.

c. Stepper Motor: Working with stepper motors allows students to delve into the intricacies of precise motion control and positioning. They can experiment with different stepper motor configurations and control techniques, gaining a deeper understanding of how stepper motors are employed in industrial automation for tasks requiring accuracy and reliability.

d. Stepper Motor Driver: Through hands-on interaction with stepper motor drivers, students can learn how to interface control signals with motor actuators effectively. They can explore the role of motor drivers in translating high-level commands into specific motor movements, honing their skills in configuring and optimizing motor control parameters.

e. Controller: The integration of the renowned and cutting-edge Allen-Bradley Micro 820 QBB PLC, along with the Connected Components Workbench (CCW) software, offers students unparalleled access to recent industrial automation technologies. This PLC serves as the central nervous system of the color sorting technology project,

providing students with a robust platform for programming and coordinating the operation of various system components.

f. Communication Protocols: Exploring communication protocols used in stepper-controlled systems offers students practical experience in networked control environments. They can learn how to establish communication links between devices and exchange data seamlessly, preparing them for real-world scenarios where integration with external systems is essential.

Overall, the incorporation of these technologies into educational projects provides students with a hands-on platform to explore and experiment with newer technologies, fostering their development as future professionals in the field of industrial automation.

Model Fabrication: The system construction process encompasses three crucial stages, each contributing to the seamless operation and integration of various components:

Aluminum Frame Fabrication for Belt Assembly: The initial stage focuses on crafting an aluminum frame to uphold the belt assembly, essential for bolstering the structural integrity and stability of the conveyor system. Precision and alignment are meticulously observed during fabrication to uphold peak performance standards. The utilization of a 2040 aluminum frame serves as the foundation of the conveyor system, establishing the groundwork for subsequent construction phases. Fig 1 shows the cross-section of 2040 profile used in this work. Utilizing 60mm flat belts with 30mm rollers, this frame ensures seamless object movement along the belt. The Figure 2 illustrates the aluminum structure for belt assembly.

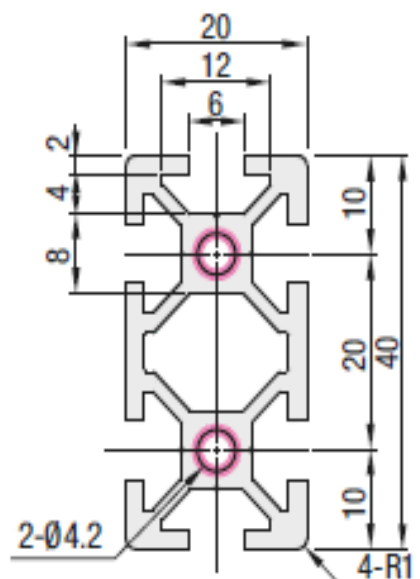


Fig 1: 2040 Aluminium Profile Cross-Section



Fig 2: Aluminum Structure for Belt Assembly

Pneumatic Pick and Place Arrangement: In the second stage, pneumatic pick and place arrangements are designed and implemented to facilitate efficient material handling. Various pneumatic actuators, including twin cylinders, double-acting cylinders (DAC), and vacuum grippers, are employed in the pick and place mechanism. These actuators are meticulously controlled using two 5/2 single solenoid direction control valves (DCVs) and a 3/2 single solenoid DCV with a vacuum generator. Strategically positioned along the conveyor belt, these pneumatic components enable precise gripping and releasing of objects in sync with the conveyor motion. This synchronized pneumatic system facilitates accurate positioning and transfer of objects according to predefined criteria. The design and integration of pneumatic components demand careful planning to ensure dependable operation and minimal downtime, underscoring the importance of meticulous attention to detail in this stage of construction. Fig 2 shows the pneumatic gripper circuit employed in the conveyor system.

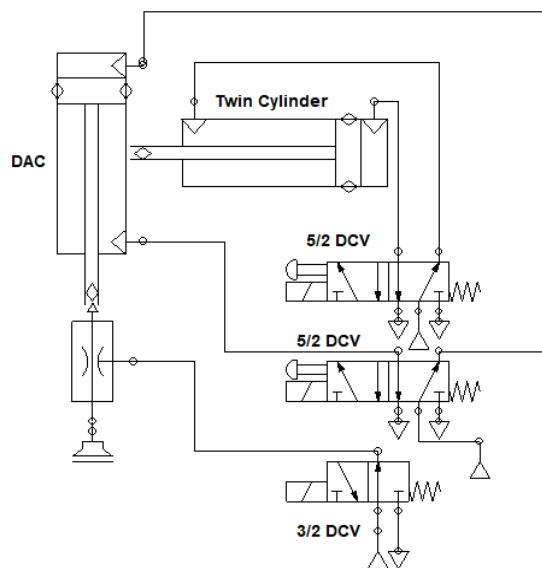


Fig 3: Pneumatic Pick Place Circuit with vacuum gripper

PLC Integration with Sensors, Stepper Drivers, and Solenoids: In the final stage of construction, the focus is on integrating a PLC with sensors, stepper drivers, and solenoids to control the system's operation. The Allen Bradley Micro 820 QBB series PLC is employed for its robust capabilities, capable of handling 12 inputs and 7 outputs. Output 6 is dedicated to producing PWM signals to drive the stepper motor efficiently. This PLC configuration caters to the system's requirements, which entail the utilization of two belt conveyors: one driven by a stepper motor and the other by a Geared DC motor.

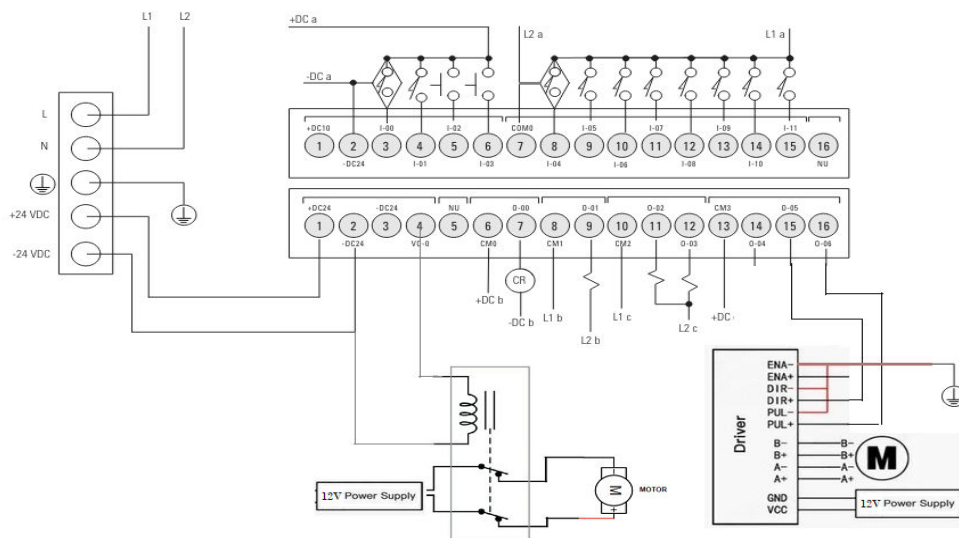


Fig 4: Wiring Diagram of PLC with Various IO devices

Various sensors, including color sensors, optical sensors, and reed switches, are interconnected with PLC inputs to detect and classify objects based on predetermined criteria. The PLC is also linked with two 5/2 single solenoid DCVs to control the double-acting cylinders (DACs) of the pick and place mechanism, and a 3/2 single solenoid valve to manage the vacuum cup. Stepper drivers are responsible for regulating the movement of the conveyor belt and other mechanical components with precision, ensuring smooth operation and accurate positioning. Meanwhile, solenoids are activated to manipulate pneumatic mechanisms for pick and place operations, enhancing the system's efficiency and versatility.

This integrated setup allows for appropriate control and coordination of all system components, enabling precise material handling and efficient operation. The utilization of advanced PLC technology and strategic component integration highlights the system's reliability, versatility, and suitability for industrial automation applications.

Programming PLC for Pick-Place application

Programming plays a crucial role in projects involving stepper motors, where precise control and coordination are essential. Stepper motors, frequently used in automation and robotics, need carefully designed instructions to function efficiently. Ladder programs are developed to manage parameters such as steps, speed, direction, and acceleration profiles, ensuring accurate motion control. Moreover, programming allows for the integration of advanced features like micro-stepping, which improves the motor's precision and movement smoothness. Beyond belt control, programming also governs pneumatic pick-and-place mechanisms, triggered by inputs from color sensors for precise material handling.

III. EXPERIMENTAL RESULTS

This section presents an analysis and interpretation of the findings obtained from the servo motor controlled flat belt conveyor project. This section aims to evaluate the performance of the system, discuss the achieved results, and provide insights into the project's implications. It offers an opportunity to reflect on the project objectives, discuss any challenges encountered, and suggest potential improvements or future directions.

The performance of the stepper motor controlled flat belt conveyor system in terms of speed, accuracy, and repeatability. Following table measure of the conveyor's capability to transport materials efficiently and smoothly.

Table 1 Observations of Speed at different time for the 5kg weight

Observations	Time (Minutes)	Speed (RPM)
1	15	150
2	30	150
3	45	150
4	60	150

Overall performance of the stepper motor and drive are excellent since there is no variation of speed over time.

Gripper Mechanism

The pneumatic gripping mechanism employed in the project showcased outstanding performance in securely holding and releasing components. This mechanism leveraged twin cylinders, a double-acting cylinder, and two 5/2 single solenoid direction control valves, along with a single solenoid 3/2 valve. Together, these components synergized to establish a dependable and effective gripping system.

The gripping mechanism utilized a 40mm diameter vacuum cup to firmly grip materials during the transfer process. The vacuum cup, powered by a vacuum generator, effectively created suction to securely hold the components in place. The reed switch, positioned strategically, sensed the position of the gripped components, providing feedback for precise control and monitoring.

The performance of the pneumatic gripping mechanism was evaluated based on several factors, including grip strength, reliability, and responsiveness. The mechanism exhibited a strong grip, ensuring that the materials remained securely held throughout the transfer process, even with varying loads or vibrations. The grip strength was consistently maintained, minimizing the risk of component slippage or mishandling.



Figure 5: Pneumatic Gripping Mechanism

Moreover, the gripping mechanism displayed a high level of reliability. The components were designed to withstand continuous use and repetitive gripping cycles, providing consistent performance and durability. The pneumatic solenoid valves and cylinders operated smoothly and efficiently, allowing for rapid gripping and releasing actions, contributing to the overall productivity of the conveyor system.

The responsiveness of the gripping mechanism was another notable aspect of its performance. The pneumatic system, controlled by the PLC and integrated with the conveyor's automation system, exhibited quick response times to commands, enabling precise and timely gripping actions. This responsiveness enhanced the overall efficiency of the material transfer process, reducing cycle times and increasing throughput.

In summary, the pneumatic gripping mechanism showcased excellent performance in terms of grip strength, reliability, and responsiveness. Its robust design, efficient operation, and integration with the conveyor's automation system contributed to the smooth and efficient handling of materials, ensuring reliable and precise transfers throughout the servo motor controlled flat belt conveyor system.

System Performance

The overall system performance of the stepper motor controlled flat belt conveyor project was highly satisfactory, meeting and even surpassing the intended objectives. The system demonstrated exceptional capabilities in terms of speed, accuracy, configurability, and material handling efficiency.

In terms of speed, the conveyor system achieved a maximum speed of 1 m/s, allowing for swift and efficient material transportation. This high-speed capability significantly enhanced the overall productivity of the system, reducing transfer times and increasing throughput.

The accuracy of the system was also commendable. The servo motor and drive combination, including the Kinetix 5100 servo drive and TLP servo motors, provided precise positioning control, achieving an average accuracy of ± 0.05 mm. This level of accuracy ensured precise and reliable material placement and transfer along the conveyor belt, minimizing errors and rework.

The reconfigurability of the system was a key advantage. The modular table made of aluminium profiles offered flexibility and ease of modification, allowing for quick and efficient repositioning of components such as the pneumatic gripping mechanism, component magazine conveyor, motor, and control panel.

This reconfigurability enabled the system to adapt to different production requirements and workflows, maximizing versatility and operational efficiency.

Furthermore, the system's material handling efficiency was notable. The integration of the pneumatic gripping mechanism, controlled by the PLC, ensured secure and reliable gripping of components during the transfer process. This efficient material handling minimized the risk of damage or mishandling, contributing to the overall efficiency and quality of the system.

IV. CONCLUSION

Overall, the stepper motor controlled flat belt conveyor system exhibited outstanding performance in terms of speed, accuracy, reconfigurability, and material handling efficiency. Its robust design, precise motion control, and flexible configuration options made it a highly reliable and adaptable solution for material transfer in various industrial settings. The system's performance exceeded expectations, showcasing its potential to enhance productivity, optimize workflow, and improve overall automation processes.

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