



Design and Fabrication of an Automated Material Handling System Using Pneumatic Actuators

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Abstract

Automated material handling is an important part of modern manufacturing because repetitive transfer, positioning, stopping, and sorting operations can be performed with improved consistency and reduced manual effort. This paper presents a methodology for the design and fabrication of a compact automated material handling system based on pneumatic actuators, a conveyor mechanism, sensors, an air preparation unit, directional control valves, and a programmable controller. The proposed system uses sensor-based detection to initiate a pneumatic actuation sequence in which a cylinder stops, positions, or diverts a workpiece and then retracts to permit the next material to pass. The design procedure covers functional decomposition, actuator sizing, pneumatic circuit selection, frame and conveyor fabrication, electrical control integration, assembly, and performance verification. A design example using a 32 mm bore cylinder at 4 bar is included to demonstrate the force-sizing procedure. The methodology is intended for low-cost laboratory and small-scale industrial material-handling applications where repeatable motion, simple maintenance, and flexible automation are required. Previous research has identified pneumatic actuation as a useful low-cost automation technology, while also noting the nonlinear behavior associated with air compressibility and friction [1–4].

Introduction

Material handling includes the movement, positioning, buffering, and temporary storage of materials within a production system. Material-handling systems may use continuous or discrete equipment to move items between process locations, and their design is closely related to manufacturing productivity and system layout [1]. In conventional small-scale operations, workers may manually transfer components between stations. Such operations can become repetitive, time-consuming, and difficult to standardize. Automation can therefore be introduced at the points where repeated transfer and positioning actions occur.

Pneumatic systems are attractive for these applications because compressed air can provide fast linear motion through compact cylinders. Pneumatic actuators have been used in manufacturing automation because of their relatively simple construction, high power-to-weight ratio, rapid response, and installation flexibility [2,3]. However, pneumatic positioning is affected by air compressibility, friction, valve dead zones, and changing loads. These characteristics make precise control more difficult than ideal rigid mechanical motion and must be considered during design [3,4].

The objective of the present work is to establish a practical design-and-fabrication methodology for an automated material handling prototype.

The proposed arrangement combines a conveyor, sensor, controller, solenoid valve, pneumatic cylinder, and supporting frame. The system is designed around a sequential operating cycle: detect the workpiece, stop or position it, perform the required pneumatic movement, retract the actuator, and release the workpiece for the next stage. This type of automation is consistent with research emphasizing flexible, low-cost automation and systematic material-handling design [1,5,6].

Literature Review

Heragu and Ekren described material-handling systems as combinations of discrete or continuous resources used to move entities between locations, emphasizing the importance of selecting handling equipment according to manufacturing requirements [1]. Choe et al. examined automation in material-handling systems and reported that mechanical and cognitive automation can influence manufacturing flexibility, illustrating the relationship between material movement and production-system performance [5].

Valdiero et al. developed a pneumatically driven manufacturing cell for low-cost automation.

Their work highlighted the simplicity, maintenance advantages, power density, and fast response of pneumatic actuators while also identifying the challenge of designing reliable control logic for pneumatic systems [6]. Salim et al. investigated nonlinear PID control for pneumatic actuators and showed experimentally that pneumatic positioning performance is influenced by nonlinear characteristics and load variation [3]. Boubakir et al. studied adaptive control of an electropneumatic actuator, further demonstrating the need to consider actuator dynamics when accurate motion is required [7].

Within material transport, Xiang et al. numerically investigated an industrial air-slide conveyor and showed that conveying performance depends on operating pressure and flow-related parameters [8]. Yamazaki et al. proposed a design method for material-handling systems for lean automation, with emphasis on reducing waiting and unnecessary handling within flexible production environments [9]. These studies support a design philosophy in which mechanical layout, pneumatic sizing, sensing, and control logic are developed together rather than as isolated subsystems.

Table 1. Summary of Relevant Literature

Reference	Main focus	Key contribution	Relevance to present work
Heragu & Ekren (2015) [1]	Material-handling system design	Framework for handling-system selection and design	Supports system-level design
Salim et al. (2014) [3]	Pneumatic actuator control	Nonlinear behavior and position control	Supports actuator/control considerations
Valdiero et al. (2016) [6]	Low-cost pneumatic cell	Pneumatic manufacturing-cell methodology	Supports low-cost prototype concept
Boubakir et al. (2016) [7]	Electropneumatic control	Adaptive actuator control	Supports feedback/control integration
Xiang et al. (2017) [8]	Air-slide conveyor	Pressure/flow effects on conveying	Supports pneumatic transport analysis
Yamazaki et al. (2017) [9]	Lean automation	Reduction of waiting and handling waste	Supports efficient sequence design

Methodology

1. System Architecture

The proposed prototype consists of seven functional units: (i) compressed-air supply, (ii) air preparation and pressure regulation, (iii) pneumatic actuator, (iv) directional control valve, (v) material-transfer conveyor, (vi) sensors, and (vii) controller and electrical

interface. The compressor supplies compressed air to the filter-regulator-lubricator (FRL) unit. The regulated air is directed through a solenoid valve to the cylinder. A proximity or limit sensor detects the workpiece or confirms actuator position, while the controller executes the sequence. The architecture is shown in Figure 1.

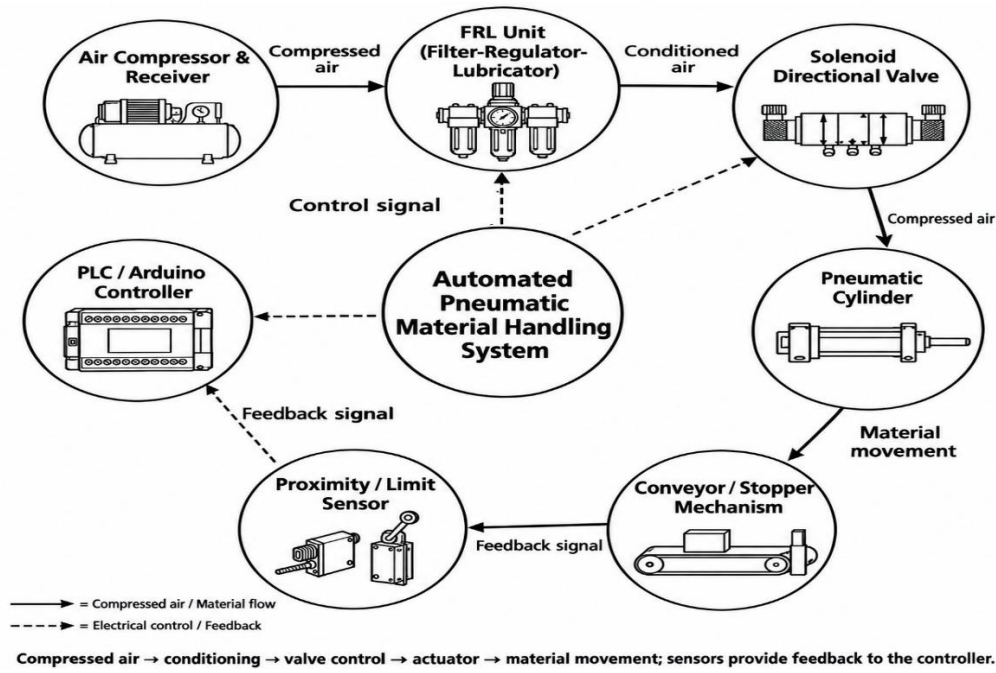


Figure 1. Functional architecture of the proposed automated pneumatic material-handling system.

2. Design Requirements

Before fabrication, the required payload, conveyor speed, stopping distance, cylinder stroke, operating pressure, available workspace, and desired cycle time should be defined. For a laboratory-scale prototype, a nominal operating pressure of 4 bar is selected for the design example. The pneumatic cylinder is assumed to have a 32 mm bore and a 100 mm stroke. The cylinder should provide sufficient force to stop or position the intended workpiece without excessive structural loading. A practical design should also include a safety margin for friction, pressure losses, and load variation.

Table 2. Design Parameters and Assumptions for the Automated Pneumatic Material Handling System

Design parameter	Design value / assumption	Purpose
Supply pressure	4 bar nominals	Actuator sizing
Cylinder bore	32 mm	Generate required linear force
Cylinder stroke	100 mm	Position/stop workpiece
Control valve	5/2 or suitable solenoid valve	Extend/retract control
Workpiece detection	Proximity/limit sensor	Automatic sequence initiation
Controller	PLC or Arduino-compatible controller	Sequence logic
Conveyor	Belt/roller prototype	Material transport

3. Pneumatic Actuator Sizing

The theoretical extension force of a pneumatic cylinder is obtained from $F = P A$, where F is cylinder force, P is gauge pressure, and A is piston area. For a cylinder of bore diameter D , $A = \pi D^2 / 4$. For $D = 0.032$ m and $P = 4 \times 10^5$ Pa, the ideal extension force is approximately 322 N. If

an overall efficiency factor of 0.80 is used to account for friction, pressure losses, and practical effects, the available design force is approximately 258 N. This value should be compared with the force actually required to stop or move the workpiece. Figure 3 illustrates the sizing principle.

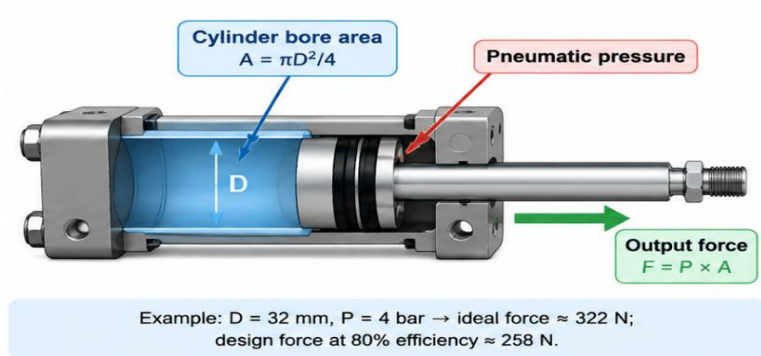


Figure 2. Pneumatic cylinder force-sizing concept for the design example.

4. Mechanical Fabrication

The supporting frame can be fabricated from mild-steel angle sections, aluminum profiles, or another rigid structural material. The conveyor bed should be aligned to minimize belt tracking errors and mechanical resistance. Mounting brackets for the pneumatic cylinder must be sufficiently rigid to prevent angular misalignment. A mechanical stopper or pusher can be connected to the cylinder rod according to the intended operation. During fabrication, the frame is cut and drilled, structural members are assembled, conveyor rollers or belt components are installed, and the actuator bracket is positioned at the material-handling station.

5. Pneumatic Circuit and Control

The pneumatic circuit includes a compressor/receiver, isolation valve, FRL unit, pressure regulator, tubing, fittings, directional control valve, and cylinder. Electrical actuation of the solenoid valve permits the controller to command cylinder extension and retraction. Sensor signals are used to synchronize material arrival and actuator movement. The control sequence can be implemented as a simple state machine: IDLE → DETECT → STOP/POSITION → HOLD → RETRACT → RELEASE → RETURN TO IDLE. This approach is appropriate for low-cost automation because the sequence can be

modified without major mechanical changes. Research on pneumatic actuator control confirms that actuator nonlinearities should be considered when higher positioning accuracy is required [3,7].

6. Fabrication and Assembly Procedure

Prepare the conveyor frame and verify that all structural joints are rigid.

Install the conveyor belt/rollers and check free movement before adding pneumatic components.

Mount the pneumatic cylinder and align the rod with the stopper or pusher mechanism.

Install the FRL unit, directional control valve, tubing, fittings, and pressure gauge.

Install proximity/limit sensors at the material detection and actuator-position locations.

Wire the controller, sensor inputs, solenoid output, emergency isolation, and indicator devices.

Set the regulator to the selected test pressure and inspect the pneumatic circuit for leakage.

Run the sequence first without a workpiece, then with a low-load workpiece, and finally at the intended test load.

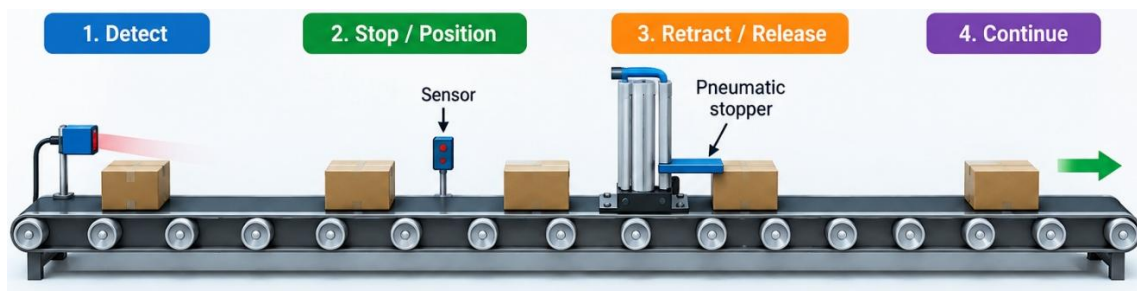


Figure 3. Typical sensor-controlled operating sequence for the conveyor and pneumatic stopper.

Results and Performance Evaluation

Because the present paper defines a design-and-fabrication methodology rather than reporting measurements from a particular manufactured prototype, the numerical values below are design-verification values based on the stated assumptions. Actual experimental results should be inserted after prototype testing. The 32 mm

bore and 4 bar example provides an ideal force of approximately 322 N and a practical design force of approximately 258 N when an 80% utilization factor is assumed. This indicates that the actuator can provide substantial force for a small laboratory-scale stopping or pushing mechanism, subject to the actual workpiece mass, friction, geometry, and safety factor.

Table 3. Design Targets, Verification Methods, and Expected Performance of the Automated Material Handling System

Parameter	Design/target	Verification method	Expected observation
Cylinder extension force	≈322 N ideal; ≈258 N at 80% utilization	Pressure × piston area	Adequate force if required load is below design force
Cylinder stroke	100 mm	Linear measurement	Complete stopper/pusher travel
Pressure	4 bar nominals	Regulator/gauge reading	Stable actuator operation
Detection	Sensor-based	Repeated detection test	Consistent trigger of sequence
Cycle sequence	Detect–stop–retract–release	Controller observation	Repeatable automated cycle
Air leakage	Minimal / acceptable	Soap solution or pressure decay test	No significant leakage at fittings
Conveyor motion	Stable material transfer	Repeated no-load/load runs	Workpiece remains aligned

Discussion

The methodology demonstrates how pneumatic actuation can be integrated with a simple conveyor and sensor system to automate repetitive material movement. The main advantages of the proposed architecture are modularity, relatively simple fabrication, rapid actuator response, and straightforward sequence control. These characteristics are consistent with earlier low-cost pneumatic automation studies [6].

At the same time, the system has practical limitations. Compressed-air consumption can increase operating cost, actuator motion may vary with load and pressure, and pneumatic systems exhibit nonlinear behavior caused by compressibility and friction [3,7]. Sensor placement also affects reliability because false detection or poor alignment can interrupt the material-handling sequence. For this reason, the final fabricated system should be tested over multiple cycles and loads, with measurements of cycle time, positioning repeatability, pressure stability, and failure frequency.

For industrial implementation, additional safeguards such as an emergency stop, pneumatic isolation valve, guarded moving parts, pressure relief, and fault indication should be included. The system can be extended with

multiple pneumatic stations, barcode or vision sensing, PLC communication, or data logging. The general principle of integrating handling equipment with the production sequence is also consistent with lean-automation approaches reported in the literature [9].

Conclusion

This paper presented a step-by-step methodology for designing and fabricating an automated material handling system using pneumatic actuators. The proposed design combines a conveyor, pneumatic cylinder, directional control valve, FRL unit, sensors, and a controller to execute an automatic detect–position–release cycle. The design procedure begins with application requirements and actuator sizing, followed by mechanical fabrication, pneumatic circuit assembly, electrical integration, programming, and systematic testing. The design example shows that a 32 mm bore cylinder operating at 4 bar can theoretically generate about 322 N of extension force, with a conservative 80% utilization assumption giving approximately 258 N. This calculation provides a straightforward basis for selecting an actuator after the actual load requirement is established. The literature indicates that pneumatic systems are well suited to low-cost automation and material-handling

tasks, while accurate positioning requires attention to nonlinear actuator behavior and control design [3,6,7]. Overall, the proposed methodology provides a practical foundation for a laboratory or small-scale industrial prototype. Future work should experimentally measure cycle time, throughput, actuator response, air consumption, positioning repeatability, and reliability under different payloads. Such measurements would allow the prototype to be optimized and quantitatively compared with alternative material-handling technologies.

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