Bibliometric Analysis on the Application of Electro-Pneumatic Control System as Automation Technology

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Abstract: - The study aims to comprehensively explore the details of electro-pneumatic control systems through bibliometric and scientometric analyses. The capabilities, limitations, and identified problem areas are defined and reviewed, as well as the reasons for choosing this type of control system are described in this paper. The potential of electro-pneumatic control systems for automation applications is discussed, with a focus on load capacity, finest system simplicity, interoperability and self-containment of the control system and power package, and prolonged storage capacity rather than environmental constraints. Also, illustrations of such control systems were implemented through case studies utilizing the Fluidsim programming software. The paper concludes by highlighting the additional development work required.

Key Words— ***automation technology, electro pneumatics, control systems, actuators, bibliometric and scientometric analyses, Fluidsim.***

I. Introduction

The utilization of air has been the working medium in mechanization for thousands of years. The wind is well-known as a propellant for sailing ships in ancient times and windmills. The term pneumatics is derived from the Greek word *pneuma*, which means "*breath or breeze*," which is the study of air movements and processes. (Ebel, F., Idler, S., Georg, P., & Scholz, D., 2010). Compressed air is used in pneumatic drives to store and transmit power or signals. As a result, its properties are critical to the behavior of the drives, and a good mathematical model is required for accurate numerical analysis and simulation. Clean, dry air is a mechanical mixture of approximately 78 % nitrogen and 21% oxygen by volume. The remaining 1% is made up of trace amounts of fourteen other gases in minor quantities. Between sea level and an altitude of about 20 km, the composition of air remains largely unchanged, but its density varies with pressure and temperature.

Manuscript revised April 22, 2022; accepted April 23, 2022.
Date of publication April 24, 2022.

This paper available online at www.ijprse.com

ISSN (Online): 2582-7898; SJIF: 5.59

The density of air is 1.185 kg/m^3 under standard technical reference conditions, which include pressure of 105 Pa, a temperature of 20 °C, and relative humidity of 65% (Beater, P., 2007).

Both pneumatics and electro-pneumatics have proven to be effective in a variety of industrial automation applications. Electropneumatic control systems are used to run production, assembly, and packaging systems all over the world. Furthermore, technological advancements in materials, design, and manufacturing methods have improved the quality and variety of pneumatic components, allowing them to be used for longer periods.

Control systems have undergone significant transformations because of changing requirements and technological advancements. In many fields of application, the relay has been gradually replaced by the programmable logic controller in the signal control section to meet increased demand and versatility.

The goal of this study is to provide a systematic review of electro-pneumatic control systems before outlining promising future research directions on automation applications. The remaining portion of this paper is structured as follows. The succeeding section provides a high-level overview of the electro-pneumatic control systems. Subsequent sections would provide discussions on the transformation of automatic control systems. In the final section, industrial-related of electro-pneumatic control systems through a case study are illustrated, different researches that uses electropneumatic are also included.

II. BIBLIOMETRIC ANALYSIS

Exploring data from various sources would be comprehensively reviewed through the application of bibliometric and scientometric analyses in a plethora of ways, including discovering emerging trends in article and journal performance, engagement patterns, and research agents, as well as discovering the philosophical underpinnings of a particular domain in the published literature. The information at the center of bibliometric and scientometric analyses tends to be humongous and objective, with occurrences of keywords and topics; though its interpretations depend heavily on both unbiased like performance analysis and interpretive such as thematic analysis reviews founded via insightful methods and practices.

Bibliometric analysis is a vital statistic tool for mapping the state of the art in a specific area of scientific knowledge and identifying essential information for a variety of applications, including generating leads research directions, and corroborating scientific research. As a result, the goal of this section is to present a bibliometric analysis method for tracing the top of the line and highlighting gaps in research and patterns. The method includes tools for identifying and analyzing the scientific performance of articles, authors, institutions, countries, and journals based on the number of citations, revealing trends in the field studied through keyword analysis and identifying and clustering scholarly gaps in the most recent papers (Oliveira, O.J., et.al, 2018). Similarly, scientometric analysis allows researchers to have the visual rendition of bibliometric records intended to provide a global view of a particular realm, the structural details of a sphere, the pertinent attributes of a domain such as its dynamics, most cited authors, or papers, bursting concepts, and others or all the three (Battista, F. and Otgaar, H.; 2022).

To perform the bibliometric and scientometric analyses, the researcher started with the compilation and summarizing the number of published research outputs from the Scopus database on the articles related to electro pneumatics as shown in Table 1. These summarized values are translated into a graphical representation through bar graphs and time series for better understanding and interpretations as shown in Figure 1. For the succeeding part, network and overlay visualizations would be done by utilizing the VOSviewer software, which can be seen in Figures 2 and 3.

Table.1. Published research outputs on electro pneumatics from various years

Publication Year	No. of Papers Published per Year	Cumulative Papers Published
1942	2	2
1948	1	3
1953	1	4
1956	1	5
1961	1	6
1962	4	10
1963	1	11
1965	1	12
1966	1	13
1967	4	17
1968	1	18
1969	3	21
1970	3	24
1971	4	28
1972	7	35
1973	10	45
1974	20	65
1975	10	75
1976	10	85
1977	8	93
1978	9	102
1979	9	111
1980	14	125
1981	23	148
1982	14	162
1983	21	183
1984	19	202
1985	41	243
1986	43	286
1987	35	321
1988	32	353
1989	33	386
1990	34	420
1991	31	451
1992	12	463
1993	17	480
1994	8	488
1995	19	507
1996	22	529
1997	18	547
1998	29	576

1999	26	602
2000	28	630
2001	23	653
2002	26	679
2003	34	713
2004	29	742
2005	43	785
2006	42	827
2007	48	875
2008	36	911
2009	72	983
2010	95	1078
2011	90	1168
2012	92	1260
2013	92	1352
2014	108	1460
2015	101	1561
2016	114	1675
2017	111	1786
2018	119	1905
2019	127	2032
2020	123	2155
2021	104	2259
2022*	40	2299

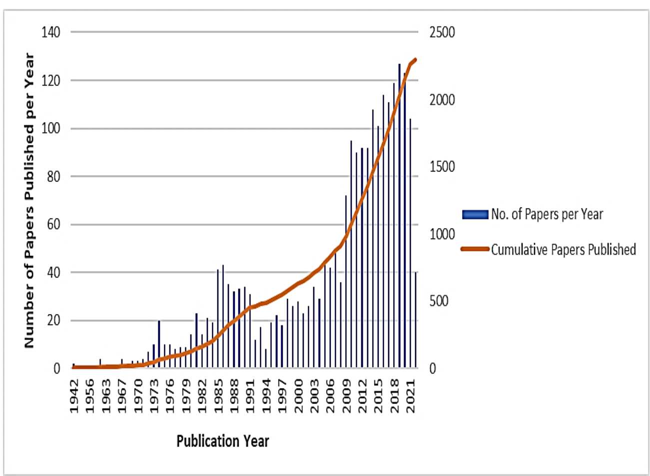

Fig.1. Trend analysis of published research outputs on electro pneumatics under Scopus based on Table 1 (* means ongoing publication)

As shown, this figure entails the trend in the number of papers published each year from 1942 up to 2022* about the topic of electro pneumatics with a total of 2,299 published papers documented and counting. It could be seen that year 2019 incurred to have the highest number of publications with a total of 127 research papers to be followed by the years 2020 and 2018 with 123 and 119 research papers published respectively.

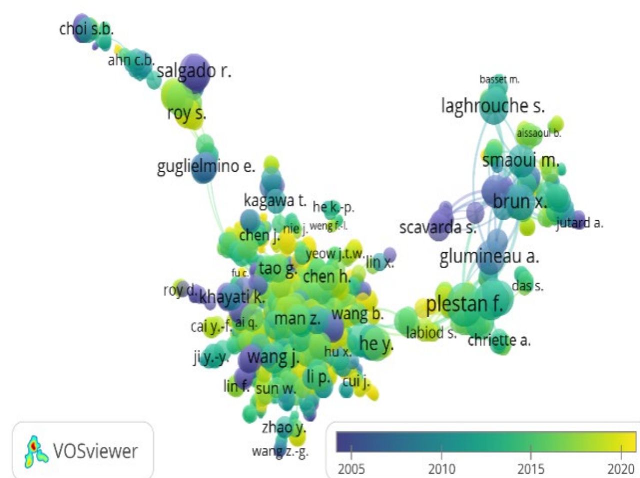

Fig.2. Visualization map for citations based on publication year

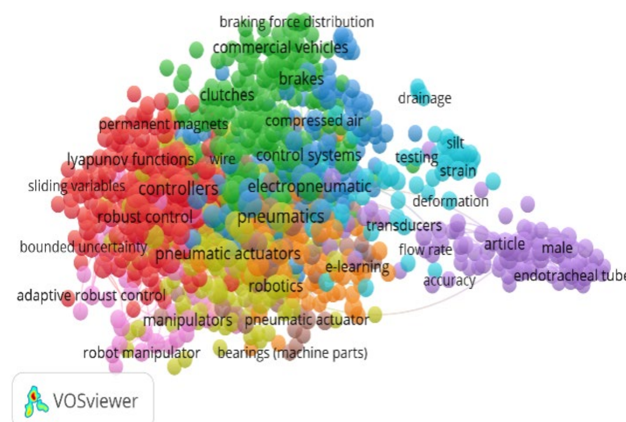

Fig. 3. Visualization map for index keywords based on the occurrence

The visualization maps shown in Figure 2 describe 1081 different authors, who contributed research ideas related to electro pneumatics in various years through color-coding. based on citations with 53 clusters identified, 3357 links, and a total link strength of 4553.

On the other hand, 861 different index keywords were identified with 10 clusters related to electro pneumatics as shown in Figure 3. Thus, 33,369 links are present both from network visualization with a total link strength of 64,104.

III. Transformation Of Automatic Control Systems

3.1. Pneumatic Control Systems

The pneumatic signal transmission was used in the early implementations of automatic control systems. Signal transmission and actuation were carried out with compressed air. Elements like springs and bellows were used to calculate the actual control commands. Industrial and manufacturing plants used large mechanical structures known as local pneumatic controllers. Later, these were miniaturized and centralized on control panels and consoles. A pneumatic controller has a large margin of safety, and it can be used in hazardous environments because it is explosion-proof however, these are slow to respond and prone to interference. The pneumatic signal range is 3-15 psig, with 3 psig being the lower-range value and 15 psig being the upper-range value (Mehta, B.R. and Reddy, Y.J., 2015).

3.2. Electronic Analog Control Systems

Electronic analog control became available over time. This implementation used electrical signals as the transmission mode and computation devices are mechanical, just like pneumatic control. To allow the coexistence of pneumatic and electrical signals, electrical signals to pressure signals converters (E/P transducers) and pressure to electrical (P/E transducers) are used to transmit signals. Analog signals have the disadvantage of being susceptible to contamination from stray fields, resulting in signal degradation over long distances. Current signals of 4-20 mA are the most common standard electrical signal. A transmitter transmits a small amount of current through a series of wires using this signal. The input signal functions as a gauge, with 4 mA representing the lowest possible measurement, or zero, and 20 mA representing the highest probable standard measure (Mehta, B.R. and Reddy, Y.J., 2015).

Table.2. Comparison between pneumatics with electronic control systems in terms of the elements (Ebel, F., Idler, S, Prede, G., & Scholz, D., 2009)

Elements	**Pneumatics**	**Electronics/Electric**
Working elements	cylinders, pneumatic motors	electric motors, linear motors solenoids
Control elements	directional control valves	power contactors, power transistors, power thyristors
Processing elements	directional control valves, isolating valves, pressure valves	contactors, relays, electronic modules, programmable logic controllers (PLC)
Input elements	switches, push-button actuators, limit switches, program modules, sensors	switches, push-button actuators, limit switches, program modules, sensors, indicators/generators

Table.3. Comparison between two working media (Ebel, F., Idler, S, Prede, G., & Scholz, D., 2009)

Properties	**Pneumatics**	**Electronics/Electric**
Storage	easy	difficult
Transport of energy	approximately 1000 m (20 to 40 m/s)	distance-limited
Costs	very high	low
Linear motion	easy with a limited force of 25000 N	difficult and expensive (solenoid) with small force execution
Rotary motion	easy, inefficient	easy, efficient
Explosion-proof	intrinsic	not intrinsic
Signal Speed	approximately 10 to 70 m/s	speed of light
The distance which can be covered	limited by the signal speed	practically unlimited
Switching times of elements	> 1 ms	> 10 ms

IV. Case Study And Other Applications

This section illustrates some basic industrial-related applications of electro-pneumatic control systems to be implemented using the FESTO Fluidsim simulation program, which is a comprehensive and robust software intended for the creation, instruction, and simulation of electro-pneumatic, electrohydraulic, and digital circuits.

Case Study 1. Inspecting Beverage Cases

Consider beverage cases, which are to be inspected for completeness with a test device as shown in Figure 5. Incomplete cases are pushed off on the roller conveyor by pressing a pushbutton. The task is to develop a control system with which this process can be executed given the different parameters and control sequence cited as follows:

Parameters:

- A single-acting cylinder is to be used.
- The cylinder will be actuated using a pushbutton.
- In the event of a power failure, the cylinder's piston rod should move to the retracted end position.

Control sequence:

- After pressing a pushbutton, the piston rod of a single-acting cylinder pushes the beverage case from the conveyor.
- When the pushbutton is released, the piston rod moves to its retracted end position.

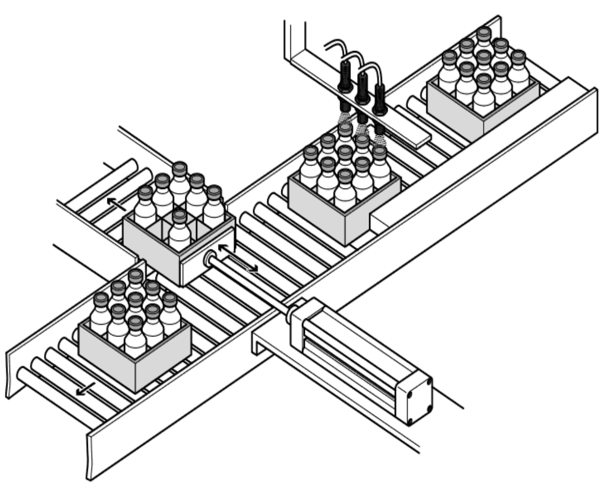

Fig.4. The test device of the sorting system (Pany, M. & Scharf, S., 2012)

The corresponding electro-pneumatic circuit diagram for case 1 is shown in Figure 5, where the list of the components required for the operation of the test device of the sorting system is summarized in Table 4. The operation of the said system describes the application of voltage to the solenoid valve 1V2, where the valve is reversed, and flow is facilitated from supply port 1 to the working port via solenoid coil 2. When the signal is turned off, the valve returns to its original position. A reset spring is used to return the device to its normal position, and supply port 1 is closed which results in halting the flow. If the solenoid coil 1M1 of the directional control valve is deactivated, the cylinder chamber is vented through exhaust port 3 at a directional control valve hence, the piston rod has been retracted. The solenoid coil is activated, and the directional control valve is opened. The cylinder chamber is pressurized after the switch is flipped, hence, the rod of the single acting cylinder piston advances. When the solenoid coil is turned off, the valve opens and returns to the previous state and the compressed air from the cylinder chamber would be exhausted into the atmosphere. This will result for the piston rod 1A1 to retract.

In the case of a pushbutton, the chosen switching position is only held while the pushbutton is pressed. The normally open function is demonstrated by the pushbutton S1 shown here. When the pushbutton is in its normal position such as in the inactivated state, the electrical circuit is disrupted by normally open contacts. The electrical circuit is closed and current flows to the consuming device when the control stem is actuated. When the control stem is released, the pushbutton returns to its normal position due to spring force, and the electrical circuit is disrupted.

Table.4. Equipment list for the test device of the sorting system

Quantity	Components
1	single-acting cylinder
1	one-way flow control valve
1	3/2-way solenoid valve with spring return, normally closed
1 1 1 1 1	pushbutton, normally open distribution block on-off valve with filter regulator compressed air source/compressor power supply unit, 24 VDC

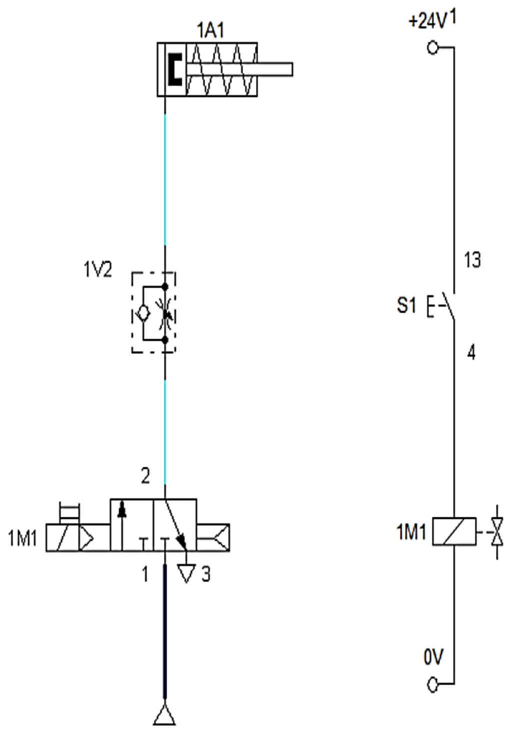

Fig.5. Electropneumatic circuit diagram for case study 1

Case Study 2. Opening and Closing a Supply Pipe

Numerous pipes must be opened and closed in a water treatment system with the help of shut-off components. During the test set-up, an actuation for the shut-off valve will be sought. The task is to develop a control system with which this process can be executed given the different parameters and control sequence cited as follows:

Parameters:

- A double-acting cylinder is to be used.
- The cylinder will be actuated using a pushbutton.
- In the event of a power failure, the cylinder's piston rod should move to the retracted end position.

Control sequence:

- The gate is opened when a pushbutton is pressed
- When the pushbutton is released, the gate is closed again

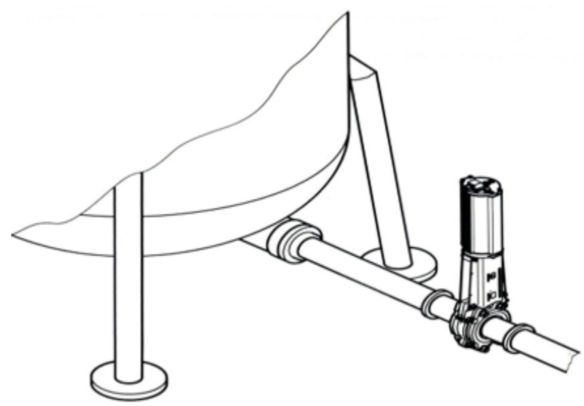

Fig.6. Supply pipe in a water treatment system with shut-off (Pany, M. & Scharf, S., 2012)

The corresponding electropneumatic circuit diagram for case 2 is shown in Figure 7, where the list of the components required for the operation for the water treatment system are summarized in Table 5. The valve is a pilot actuated 5/2-way solenoid valve with manual override and pneumatic spring. The piston is a t the left-hand limit stops when the valve is in its normal position and ports 1 and 2 (supply port and consumer port) as well as ports 4 and 5 (consumer port and exhaust port) are connected. If the solenoid coil is energized, the valve piston moves to the right-hand limit stop. In this position, ports 1 and 4, as well as 2 and 3 (exhaust port) are connected (the internal pilot line for pilot control is designated 14, function when actuated: supply port 1 and consumer port 4 are connected). When the solenoid coil is de-energized, the valve piston is returned to its normal position by means of spring force and pilot air is vented. In the de-energized state, the valve can be switched by means of manual override.

Table.5. Equipment list for the test device for the water treatment system

Quantity	Components
1	double-acting cylinder
2	one-way flow control valve
1	5/2-way solenoid valve with spring return, normally closed
1	pushbutton, normally open
1	relay
1	distribution block
1	on-off valve with filter regulator
1	compressed air source/compressor
1	power supply unit, 24 VDC

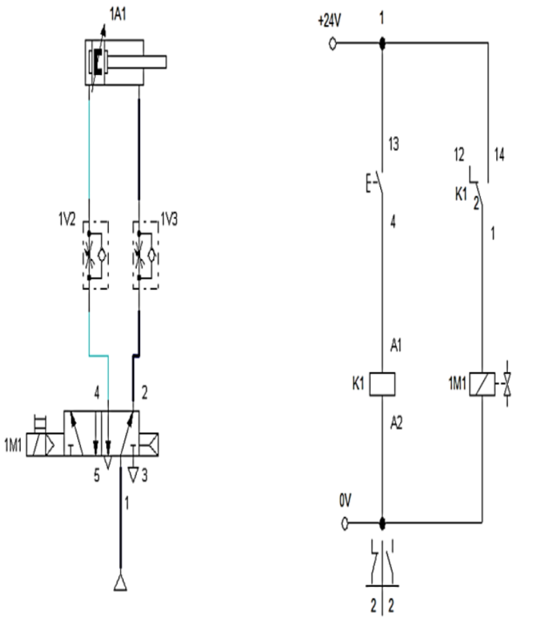

Fig.7. Electropneumatic circuit diagram for case study 2

4.1 Medical Application

4.1.1 Device for Artificial Capillary Pulse Generation

The study looks at the creation and testing of an electro-pneumatic device for wound healing following neck surgery. The device uses electrical circuitry to control an electro-valve and an air compressor to create air pressure values in a miniaturized cuf. The gadget has two modes of operation: constant pressure and pulsing pressure. The pulsing pressure mode's working frequency range is around 0.1 to 0.3Hz, and the pressure value setting ranges from 3 to 11mmHg. The device's correct working in both continuous and pulsing pressure modes was evaluated in the laboratory. Neck wound healing therapy utilizing the electro-pneumatic device was also evaluated in a four-day prospective research with animals (n=10). Only one of the twelve histological characteristics examined for differences between the experimental and control wounds revealed a significant difference. Three of the 10 animals given the device exhibited a significant difference in terms of benefit following treatment. As a result, assuming the pre-set air pressure value does not exceed 8mmHg, we may assume that the device may help with wound healing in the neck area. (Foltyn, J., et.al, 2019).

4.2 Robotics Application

4.2.1 Pneumatic Robot Arm

As a multifunctional end effector for material handling systems, the study designed a pneumatic robot arm operated by pneumatic actuators. The arm is made up of a pneumatic hand and wrist. Without force sensors or feedback control, the hand may grip a variety of items. As a result, the goal of this research is to regulate wrist motions in order to increase the area available for hand motions. The hand is shaped like a human hand and can grab things of various forms and mechanical properties. The wrist has an excessive number of degrees of freedom. When the robot moves to avoid obstacles, this is beneficial. However, from a mechanical standpoint, the wrist drive mechanism is nonlinear. Hysteresis characteristics are also present in the pneumatic actuators utilized as the drive source. The wrist movements are difficult to regulate because of these qualities. The wrist must be able to move freely since it is employed in material handling systems. As a result, experimental models of the pneumatic robot wrist's drive system have been built in this study. Simulations were used to create the control systems using the built models. After that, they used the built controllers to try to control the wrist motions. As a result, wrist models and wrist motions are in sync. Finally, experimental results were found to be consistent with simulation results. (Maeda, S., et.al, 2012)

4.3 Agricultural Application

4.3.1 Pneumatic-driven Soft Grippers for Harvesting

Soft actuator technology and its application in robotic manipulation is quickly gaining traction. Soft robotics, on the other hand, has received less attention for its potential benefits in the agricultural sector, where its better flexibility, cheaper cost, and ease of production might be game changers. This article describes a new soft gripper design technique based on modules that combine the bellows idea with the adaptability and replicability of a 3D printed structure. As a result, the modules may be flexibly configured to produce grippers that can respond to crops of various diameters. Furthermore, a method's definition to determine the soft grippers features is also presented, with the aim of serving as the basis for soft actuators will be the subject of a future benchmarking research. The results of the experiments showed that the end-effectors' capacity to control different fruits and ensure a sufficient supply contact area for safe handling of targets and avoidance of product damage. (Navas, E., et.al, 2021).

4.4 Automation Application

4.4.1 Electro-pneumatic Clutch Position Control

For the position control of a pneumatic clutch actuator deployed in heavy-duty vehicles, the study presents a gain-scheduled controller with direct tuning. Pneumatic clutch actuators are nonlinear systems that are difficult to regulate. A simple controller design that is easy to comprehend and involves minimal trial-and-error calibrations is required by industries. As a result, we used a gain-scheduled proportional integral derivative (PID) control rule, a well-known and simple nonlinear control approach. A gain scheduler is stated using polynomials made up of coefficient parameters and controlled object states in this method. Without using a controlled object model, the unknown coefficient parameters of the polynomials are directly adjusted from the controlled object input/output data. The suggested controller design technique is straightforward and eliminates the need for system identification or trial-and-error tweaking. An experiment with a real car verifies the usefulness of the suggested strategy. The experimental findings show that the suggested approach for controlling the position of pneumatic clutch actuators is successful. (Yahagi, S., Kajiwara, I., 2021)

V. CONCLUSION

In this study work, it was found from the VOS viewer map that the application of electropneumatic control system is just not limited only on automation, but it also applies in other research areas such as biomedical, robotics, agricultural machinery, and automotive as shown to the case studies and published research.

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