Development of Fluid Bed Dryer Process Control Module for Fluidization and Drying of Pharmaceutical Powder

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Abstract — **As the fluidization of powdered active ingredients is crucial before compressing into desired forms or shapes, the importance of the fluidized bed dryers cannot be over-emphasized. Many studies had been carried out to improve the fluidization of particle bed by measuring and controlling process parameters to achieve quality output, but the implementation of these proved cost intensive. This work was focused on developing a control module using conventional low-cost components for monitoring the drying process of fluidized bed dryer. The module was developed following design calculations of parameters required to determine its rated current capacities, and selection of required components. The components used were selected putting in mind cost and durability, without compromising their suitability in achieving the set objectives for the developed control module. Thereafter, a performance test was carried out to ascertain its performance characteristics. From the design calculations, the overall load (current) rating of the module was 13 amperes. Relays, temperature controller and push buttons were major components selected, putting in mind the overall module capacity of 13 amperes. The selected components suitably performed the expected control operations, and the efficiency was over 98%. The control module was able to regulate the drying procedure to achieve a reduced percentage moisture content of 1.4% at 85^{0}c drying temperature. The control module performed the expected function at a reduced cost when compared to control units being adopted in the industry for such purpose. Therefore, the module could be further explored for implementation on large scale commercial dryers.**

Keywords — **Active Pharmaceutical Ingredient, Fluidization, Granulation, Moisture Content.**

I. Introduction

In the production of drugs in tablet form, granulation of pharmaceutical powder is a key part in the process value chain [1]. This process transforms coarse or fine powder mixture containing pharmaceutical ingredients into large agglomerates referred to as granules, and in which bed particles form long lasting bigger masses that retain the intrinsic characteristics of the original particles [2], [3]. Granulation is normally planned to commence after blending all the active ingredients in order to achieve uniform distribution of the blended materials [4]. The invention of the tablet presses as far back as 1843 led to the development of granulation [5]. Pharmaceutical powder is a mixture of active pharmaceutical ingredients in predetermined specific or measured quantities for external or internal administration. More importantly, pharmaceutical formulations must be uniformly blended, for even particle size distribution (homogeneity), otherwise, the powder can segregate as per particle size, causing unsatisfactory and erratic performance. Therefore, the importance of uniform particle size distribution cannot be over-emphasized; it yields even dissolution rate if the powder is to dissolve, evens sedimentation rate if the powder would remain in a suspension and reduces stratification when are stored or transported [6]. Efficient and effective mixing contributes to the attainment of uniform distribution of the several ingredients mixed together [7]. As every tablet drug consists of several active ingredients, in addition to bulking agents, binders, lubricants, and so on, it is imperative to ascertain that all components are mixed to homogeneity [8]. Certain factors do exist that can influence mixing efficiency, and these include: (i) Particle properties, such as size, shape, density, cohesiveness and hardness. (ii) Mixer capacity and specification. (iii) Tendency of separation of each of the components of the mix. Granules are prepared to aid dispensing method, control drug release, reduce dust generation (which could result to exposure to drug), as well as improve the product aesthetics [9]. Granulation of pharmaceutical powder could either be done dry or wet. Dry granulation does not use any solvent or liquid binder to granulate powder mixture, meaning that granulation is usually done without liquid [10]. Wet granulation follows three steps:

i. Sifting: Raw materials in drug production are usually sifted through 40 mesh and 60 mesh sieves. These materials mix during sifting. [1], [4].
ii. Mixing: Dry mixing is implemented to achieve best results. Granulating fluid is introduced systematically as the mixing operation is being done [1], [4].
iii. Fluidization and Drying: The process is completed with the use of fluidized bed dryer, an equipment that dries and fluidizes the mixed material before it is milled and compressed [4], [11].

Fluidization is achieved when the force generated from the inlet airflow is high enough to overcome the particle bed downward force of gravity [12]. At this stage, air inflow through the bed of particles reaches sufficient velocity to support the particles without carrying them away in the fluid stream [13]. Fluidization in its own sense is the process of converting solid particles more or less a suspension in gas or liquid [14]. When fluidized, the bed of particles behaves like a boiling liquid. The properties of the fluidizing system are conferred on it by the choice of the fluidizing medium, which

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could be gas or liquid. This will in turn affect the choice of processes that may be used [13]. Gaseous fluid is adopted in the production process of tablets in the pharmaceutical industry [15]. In operation of a fluidized bed dryer, the temperature of the inlet air is increased to improve the drying rate of the material bed. Heat is introduced into fluidized bed dryers through heaters that have been incorporated into its designs. These heaters are immersed with tubes that indirectly transfers heat to the drying materials [16]. The fluidized bed dryer is used in reducing moisture from the pharmaceutical powder mix [17]. The operation and maintenance of fluidized bed dryer for industrial and commercial purposes are best optimized when the dryer design is easy to comprehend and implement, but this is not the case for most commercial bed dryers. The bed remains compact and at rest with low gas velocity, however, pressure embedded in the particle bed becomes high with high gas velocity. At a certain point, identified as the minimum fluidization velocity, the gas velocity becomes high to the extent that the whole bed gets suspended by gas stream [16]. Usually, the use of talc or talcum powder is normally employed as the sample material for fluidized bed trial run [18]. Talc consists of a hydrous magnesium silicate mineral with the chemical formula $Mg_3Si_4O_{10}(OH)_2$. In the development of the fluidization control concept, it is noteworthy to be able to deduce right from the preliminary phase if the turbulent flow will occur or not [19]. Process control entails manipulating the output of a system by comparing the magnitude of output to the value of desired output range, and by so doing, controlling input parameters by feeding back an error signal in order to achieve desired output [20]. Monitoring of fluidized bed drying of pharmaceutical granules can be capital intensive, and requires special skills, techniques and expertise, depending on the complexity of the design of the bed dryers. For instance, extensive studies have been carried out over time in relation to fluidized bed dryer process control techniques [15], [21]-[24], which all proved to be expensive to execute and maintain. Moreover, findings have shown that extensive works had been previously carried out around fluidized bed dryer process control techniques [9], [25]. This work was centered on developing a control module with simplified design, in addition to low implementation and maintenance costs. The module would monitor bed moisture content and control the drying process on the pharmaceutical bed.

II. Methods And Materials

A. Design Calculations

1) Inductive load reactance

The relays and blower used in this work are inductive loads; the reactances are calculated using (1) [26].

$$X_L = 2\pi fL \quad (1)$$

where,
X_L=Inductive load reactance
f=Line frequency
L=49.6 is relay coil inductance [27]

X_L = 2 x 3.142 x 50 x 49.6
= 15,584.32Ω

2) Amperage calculation

Current across relays used and blower motor, I_r is determined using (2) [26].

$$I_r = \frac{V}{X_L} \quad (2)$$

$$I_r = \frac{220}{15{,}584.32}$$

$$I_r = 0.014A$$

Current across air blower and heater, I_b is found using (3)

$$I_b = \frac{P}{Vcos\theta} \quad (3)$$

$$I_b = \frac{2300}{220 \times 0.86}$$

$$I_b = 12.156A$$

where P is power, V is line voltage and $cos\theta$ is power factor. The amount of current across the components specifies their capacities. This value is needed to select auxiliary components such as push buttons, with appropriate power specifications and ratings.

3) Overall load requirement calculations

The total load requirement is the summation of the current across all connected components and load. This was given by [26] as (4).

$$\sum(I) = \sum\frac{V}{X_L} \quad (4)$$

$$\sum(I) = 4(0.014) + 12.156$$

$$\sum(I) = 12.212A$$

B. Identification and Selection of Required Components

The required components were identified and selected following internationally acceptable standards [19],[21], [26],[28]; the following criteria were considered during the selection process:

i. The power and voltage ratings of the components.
ii. The size in terms of dimensions of the components. Components with small sizes were most preferred.
iii. The cost of components selected. Minimum project cost kept in mind during components selection.
iv. Components adaptability towards achieving module objectives.
v. Components availability in the open market.

1) Drawing the circuit diagram

After identifying and selecting the required components, the module circuit design layout was drawn using a single line diagram [22]-[29]. Each component was connected together putting in mind their inter-relations and how it would perform specific functions towards achieving the module design purpose, as shown in Fig. 1. 't1' is a normally open contact of the temperature controller. It closes and thus energizes relay coil 'k1' when the chamber reaches a preset temperature value. 'ls1' is a limit switch contact, it is set to actuates once the pressure drop in the bed is sufficiently increased to the

point of the minimum fluidization velocity. This set point is determined during the dryer initial trial run, closing contact 'ls1' energizes coil k2. Relay contact for coil k3 is a normally closed contact used as an interlock on the blower starter contactor. Coil k3 is actuated once conditions for maximum drying limit and minimum fluidization velocity is achieved, the normally close contact k3 then opens, thus shutting the dryer operations. 'sw' is the start switch which initializes the control operations when actuated, while 'ds' is a variable resistance switch used in regulating inlet air velocity.

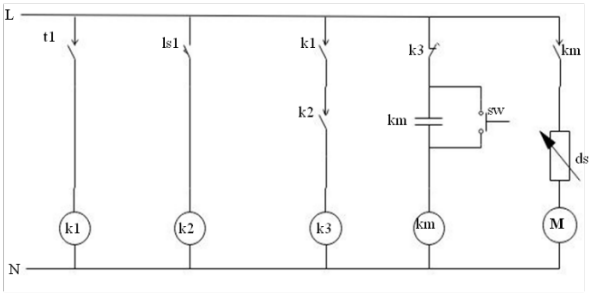

Fig. 1. Control module circuit diagram.

2) Constructing the control module

After designing the control circuit layout of the module, the following procedures were maintained in the construction of the module:

i. Procurement of required components and materials with specifications conforming to the design calculations.
ii. Simplified layout and positioning of components. The slots in Fig. 2 were created to accommodate start and stop push buttons, indicator light, Thermocouple selector switch and the set of relays used. Fig. 3 shows the panel box. The box houses the relays and temperature controller used in the module development. This box also contains the wirings and connections of the components. Fig. 4 shows an update on development of Fig. 3. It shows the mounted temperature controller, relays and the component wirings and connections. Fig. 5 shows an update on development of Fig. 2. It shows the back view of the mounted Start and Stop switch, thermocouple selector switch and the power ON indicator. It also shows the component wirings and connections.
iii. Compatibility of module structure.

The quantities and price of materials used for the module development are summarized in Table I. They are purchased at the best market price at electrical retail outlets in Ibadan as at when their procurement was made.

TABLE I: BILL OF ENGINEERING MEASUREMENTS AND EVALUATION (BEME) FOR CONTROL MODULE CONSTRUCTION

S/n	Item Description	Units	Quantity
1	Pressure Switch	Pcs	1
2	Temperature Controller	Pcs	1
3	Thermocouple	Pcs	2
4	Push Button	Pcs	1
5	Indicator	Pcs	1
6	Toggle Switch	Pcs	1
7	AC relays	Pcs	5
8	Panel Box	Pcs	1
9	Cable	Meters	3

Fig. 2. Module front panel with slots.

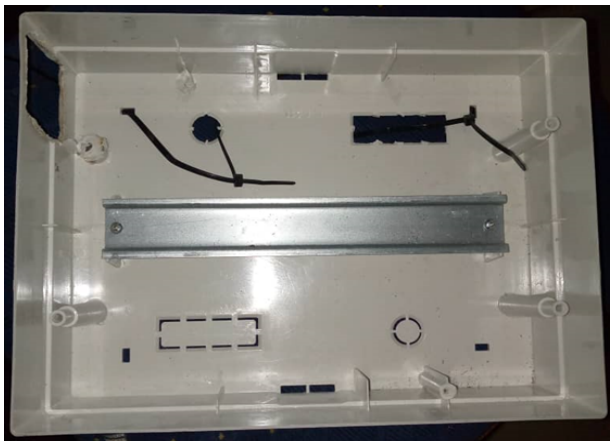

Fig. 3. Inner view of panel box.

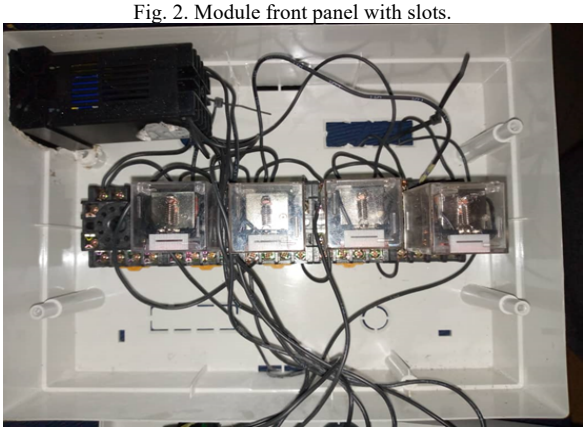

Fig. 4. Inner view of panel box while development was ongoing.

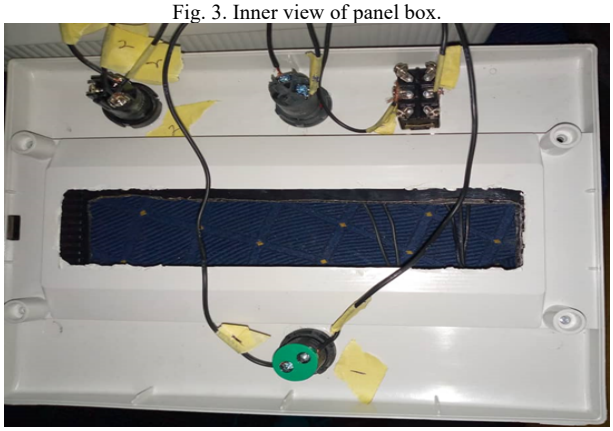

Fig. 5. Back view of front panel while construction was ongoing.

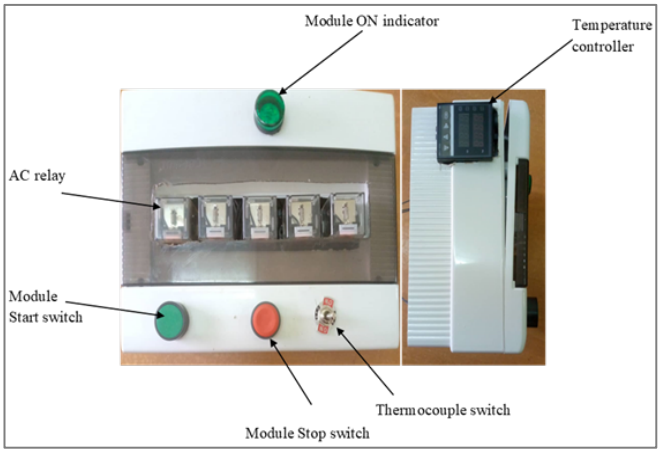

Fig. 6. Developed Control Module.

3) Dryer operation

The drying operation starts when the pressure switch in the drying chamber is initialized by loading the dryer with mixed powder material, and the module START switch is pressed. Once the start switch is pressed, the module turns on the blower motor and the digital temperature controller. The temperature controller monitors the drying temperature, while the pressure switch monitors the pressure drop in the drying chamber. Once the bed is fluidized and the moisture content has been sufficiently reduced to the desired value, the module shuts the operation of the air blower, thus cutting off airflow into the drying chamber. The thermocouple switch enables the temperature controller to read temperature values from both the inlet and outlet temperature sensors by switching between the two sensors. The module indicator is ON once the module START switch is pressed, indicating the module is powered ON. The module STOP switch shuts power from the module when pressed. Fig. 6 shows the switches and indicator in the developed control module.

4) Control Module performance testing

The developed module was put to test by connecting it to a mini-drying chamber that has been constructed for the purpose. The module monitored the drying temperature of dryer and the fluidization rate of the bed particle. The performance of this module was assessed by:

i. Evaluating its thermocouple response time in measuring drying temperature.
ii. Evaluating the responsiveness of the pressure control switch.

5) Thermocouple responsiveness measurement

Inlet and exhaust thermocouple coupled with a temperature monitoring and control device were installed to control the drying column temperature [30]. The responsiveness of the thermocouple was evaluated by the following procedures:

i. Preheat the drying chamber to about 60^0c.
ii. Insert thermocouple into preheated chamber.
iii. Allow thermocouple to balance and equalize to the chamber temperature.
iv. Remove thermocouple quickly and allow to cool down in still air at ambient temperature.
v. Monitor and record the time constants at which the thermocouple responds to its output signal when a step change in temperature occurs [30].

6) Pressure control switch responsiveness

Performance of the module was also measured by how responsive the pressure switch is in controlling the drying operation. The following procedure was used to measure pressure switch responsiveness:

i. Perform bed drying to reduce percentage moisture content to desired level.
ii. Monitor and record time the pressure switch responded to perform drying control.

Compare the time at which the pressure switch responded to control the drying operation and the time the desired moisture content level was achieved (Note: The pressure switch is expected to respond to control at desired moisture content level) [30].

III. Results and Discussion

A. Design Calculations

The data presented in Table II was used to generate the graph in Fig. 7. From Fig. 7, it could be deduced that the average duration it takes the thermocouple to respond to temperature change reduces as temperature increases. This implies that the thermocouple's sensitivity increases as temperature increases.

B. Pressure Control Switch Responsiveness Measure

While a trial sample run was carried out, the system was closely observed to monitor the performance of the pressure switch. It was observed that a time lag of 5 minutes was recorded in the pressure switch responsiveness during control operation. In other words, after the desired moisture content has been reached, the switch responded 5 minutes later than the expected response time, further reducing the percent moisture content of the bed. This has a little impact on the drying output quality as the final moisture content was still within an acceptable tolerance. Fig. 8 shows the difference in desired percent moisture content and actual percent moisture content.

TABLE II: Thermocouple Responsiveness Measure

Duration	Temperature
3.8	81
6.0	80
8.0	79
13.5	78
13.3	77
14.0	76
3.6	75
6.6	74
4.1	73
12.7	72
11.7	71
4.8	70
13.6	69
5.8	68
16.9	67
17.6	66
8.6	65
20,0	64
9.3	63
27.4	62
26.4	61
12.1	60
39.8	59
15.9	58
16.6	57
28.2	56

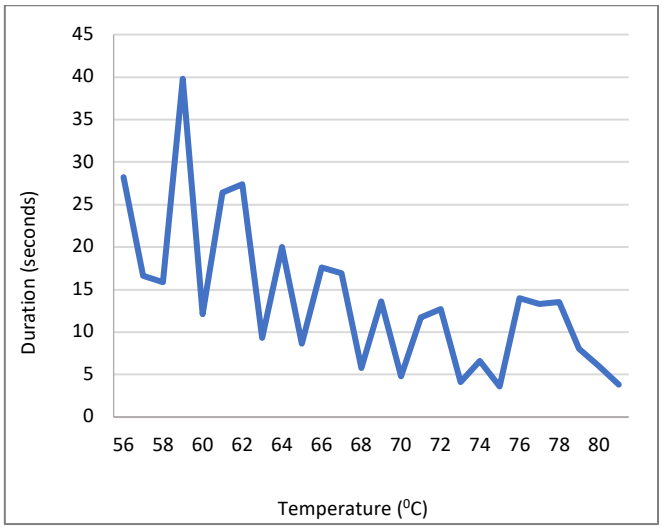

Fig. 7. Thermocouple responsiveness chart.

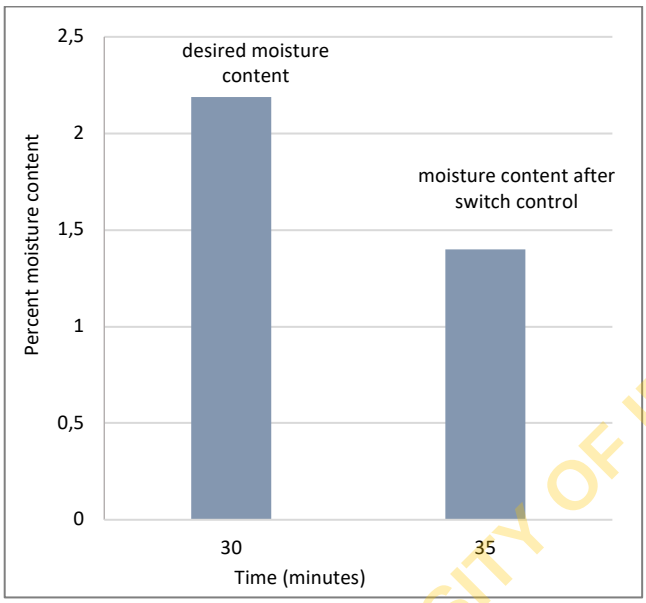

Fig. 8. Pressure control switch responsiveness chart.

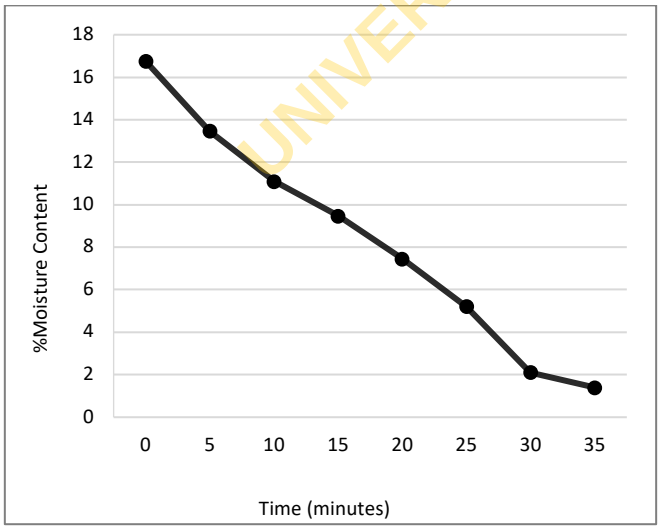

Fig. 9. Drying rate chart.

C. *Drying Rate*

The module was tested on a developed mini-drying chamber. Table III presents the data generated during sample trial run of the module on the developed dryer. Weight of the particle bed was monitored at time intervals and change in percent moisture content was recorded.

The efficiency of the dryer improves as drying progresses. On the average, the dryer is both efficient and effective as it achieved the intended moisture content with about 99% efficiency in less 35 minutes.

Table III was plotted in a graph as shown in Fig. 9, the graph shows reduction in moisture content as drying time increases. The desired moisture content was achieved after 30 minutes of drying.

TABLE III: WEIGHT AND MOISTURE CONTENT VARIATION OF SAMPLE TRIAL

Time (mins)	Bed weight (g)	Moisture content
0	895	16.75
5	861	13.47
10	838	11.1
15	823	9.47
20	805	7.45
25	786	5.21
30	761	2.1
35	755	1.4

D. *Drying Efficiency*

The following data in Table IV represents the efficiency of the dryer at various time intervals during the drying operation.

TABLE IV: DRYING EFFICIENCY

Time (mins)	Moisture content
0	16.75
5	13.47
10	11.1
15	9.47
20	7.45
25	5.21
30	2.1
35	1.4

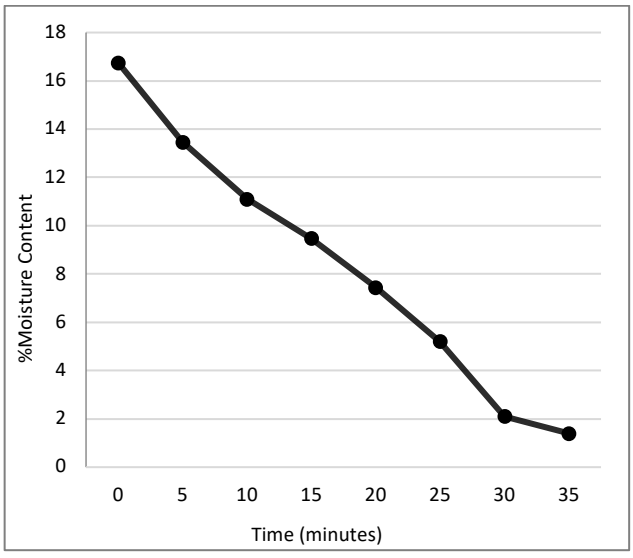

Fig. 10. Drying efficiency chart.

IV. CONCLUSION

The developed model was attached to a drying chamber and trial samples were run, data showing percent moisture content removed were taken and recorded. The final percent moisture content at the end of the trial run was 1.4% at 850c drying temperature, which was comparatively within the output range of most commercial dryers that operates at

above 1000c while achieving 1.5% to 2% moisture content. This showed how efficient the module was, which was satisfactory in achieving the intended purpose.

The module development was also cost efficient. The module development cost was 28,800 Naira, while an alternative module that is widely adopted in commercial dryers was 225,000 Naira as at the time this project was carried out. Ability to efficiently reduced moisture content satisfactorily at this reduced cost was a pivotal factor while developing the module. This work could further be adapted for additional control capabilities. Methods used in its development would foster interests in the industry on how it could be implemented for specific automation needs. In addition, the concept adopted in this work could be further explored for subsequent implementation on large scale commercial purposes.

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CONFLICT OF INTEREST

Authors declare that there is no conflict of interest.

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