



Design and Fabrication of a Bluetooth Controlled Automatic Sliding Door

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Abstract

Available automatic sliding doors are activated mostly by motion sensors or touch buttons which offer no or little restriction to access. The Bluetooth activated automatic sliding door provide the necessary restriction. The Bluetooth is a radio technology which transmits signals wirelessly over short distances. The aim of the work is to design a door controller, to programme an application software and load the software to a mobile phone, link the software on the phone to the controller for the purpose of door activation and to evaluate the performance of the constructed sliding door. The designed door set has six sub-assemblies viz: the head and frame assembly, door panels, two wheel assemblies, and drive and driven pulley assemblies. The sliding door operator, which automates the door system, is integral to the door head and is made up of the following main components: a power source, an electric motor, a belt-pulley system, a controller and battery. The electric motor drive a pulley at one end of the belt, and at the other end, is the driven pulley. To open the door, the motor turns the pulley, which in turn turns the belt, which in turn drags the door. To close the door, the reverse occurs. The performance of the door was tested by using a stop watch to record the time it takes the door to move from the completely closed position to completely open position and vice versa. This procedure is repeated for different speed of the motor. The results obtained in the design evaluation shows that the door has a mechanical efficiency of about 82% for opening and 80% for closing. The optimum speed was 35 rpm having cycle time of 4.76 seconds for opening and 34 rpm with a cycle time of 4.89 seconds on closing.

Keywords: Bluetooth, controller, door operator, wheel assembly, Aluminium profiles.

Introduction

Gaining access to door entrances requires some measure of physical force or strength and as the entrances increase in size, the force required also increases. The situation is compounded when both hands are needed other than for opening of the door itself and also when the pedestrian is physically handicapped, then a mechanism which provide an immense relief to ease these situations is required. An automatic door is automated electro mechanically to provide controlled access at the entrance of a room, building or



space. (Gaur, 2019; Osaro and Aliu 2021). Automatic door is widely used in public places such as grocery stores, businesses, transportation stations, airports, and wholesale department stores (Chomo, 2021).

Automatic doors, activated by sensors, are common. They are used in areas where security restriction is low, like government buildings and supermarket. If, however, security is to be upgraded, other means of activation is required and one of them is the use of the Bluetooth. The technology of using the Bluetooth to activate the opening or closing cycle of an automatic door is not common, therefore, the design and development of the Bluetooth activated automatic door becomes imperative. The designed door communicates with the pedestrian through the Bluetooth of a handset. An application software, programmed and loaded to the handset, effect the communication (Chomo, 2021).

The Bluetooth device connects various pieces of technology in our wired world. It is a radio technology which transmits signals wirelessly over short distances. The short range, low power consumption characteristics of Bluetooth make it an ideal choice for connecting battery-operated mobile technologies without cables and wires (Bluetooth.com, 2013; Ian, 2013). Range of Bluetooth is dependent on its class and primarily there are three classes of Bluetooth. Class 1 devices transmit at 100mW with a range of 100m. Class 2 devices transmit 2.5mW with a range of 10m. Class 3 transmit at 1mW with a range of fewer than 10m' (ScienceABC, 2019).

Description of the Bluetooth Controlled Door

The designed door set has six sub-assemblies viz: the head and frame assembly, door panels, two wheel assemblies, drive pulley assembly, and driven pulley assembly. The sub-assemblies are captured in Figure 1.

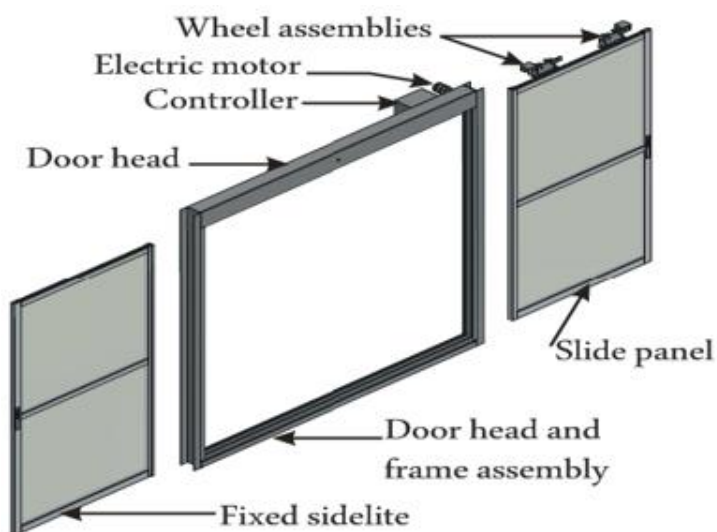


Figure 1: Exploded Automatic Sliding Door

The sliding door operator, which automates the door system, is integral to the door head and is made up of the following main components: a power source, an electric motor, a belt-pulley system, a controller and battery (Bhatt, Rokad and Patel, 2009; Susilo, Listijorini, Ardiansyah and Ula, 2023). The operator components and the slide panel are displayed in Figure 2. The power source, microcontroller and battery are housed in a box at the rear of the door and can be seen in Figure 2.

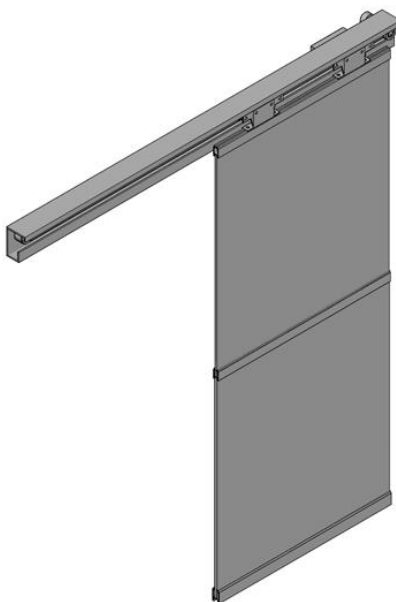


Figure 2: Door operator and slide panel



Aluminium is selected not just for its aesthetic qualities, but in addition, its availability in the Nigerian market, its corrosion resistance and its low cost. Also selected are mild steel sheets. The mild steel sheets increase the mechanical strength of the door by reinforcing the aluminium profiles. It is also readily available in the Nigerian market (Chomo, 2021).

Design Theory and Calculations

The slide panel of the sliding door must be moved through the complete opening of the door. This is achieved by applying a force F , which overcomes all resistive forces acting against it and in addition accelerate or decelerate the panel. The resistive forces include rolling resistance F_1 , of the wheel assembly rollers, belt resistance F_2 and force F_3 required to accelerate or decelerate the panel.

$$F = F_1 + F_2 + F_3 \dots\dots\dots 1$$

Mass of Slide Panel

The slide panel moves on rails on the door head using the wheel assembly. The mass (M) of the slide panel is calculated from the total mass of aluminium profiles on the panels, total mass of the components of the wheel assembly (fabricated from steel) and total mass of glass employed.

$$M = \sum M_{AL} + \sum M_G + \sum M_S \dots\dots\dots 2$$

Where M_{AL} , M_G , M_S = Mass of aluminium, glass and wheel assemblies respectively.

$$\sum M_{AL} = \rho_{AL} t_{AL} \sum_1^n \frac{b_{AL}}{n} \sum L_{AL} \dots\dots\dots 3$$

Where ρ_{AL} = Density of aluminium (= 2700kg/m³; Aluminium, 2021), t_{AL} = average thickness of aluminium (=0.002), $\sum_1^n \frac{b_{AL}}{n}$ = average width of aluminium profiles, n = number of aluminium profiles = 4 for slide panels (interlock=0.167m, lockstyle=0.153m, top rail= 0.157m, bottom rail=0.208m, and $\sum L_{AL}$ = sum of the height of all the aluminium profiles interlock = 1.945, lockstyle = 1.945, top rail = 0.940x2, bottom rail = 0.940),

$$\text{Hence } \sum M_{AL} = 2700 \times 0.002 \times \left(\frac{0.167+0.153+0.157+0.208}{4} \right) \times (1.945 \times 2 + 0.940 \times 3)$$

$$= 5.400 \times 0.343 \times 6.710$$

$$= 12.453\text{kg}$$



$$\sum M_G = \rho_G t_G b_G \sum L_G \dots\dots\dots 4$$

Where ρ_G = Density of glass (= 2200kg/m³; Glass, 2021), t_G = thickness of glass (=0.003), b_G = width of glass and $\sum L_G$ = sum of the height of aluminium

$$\begin{aligned} \text{Hence } \sum M_G &= 2200 \times 0.003 \times 0.969 \times 0.974 \times 2 \\ &= 12.458 \text{kg} \end{aligned}$$

$$\sum M_S = \rho_S t_S b_S \sum L_S \dots\dots\dots 5$$

Where ρ_S = Density of steel (8050kg/m³; Steel, 2021), t_S = thickness of glass (=0.003), b_S = width of steel and $\sum L_S$ = sum of the height of steel

$$\begin{aligned} &= 8050 \times 0.003 \times 0.096 \times 0.216 \times 2 \\ &= 1.002 \text{kg} \end{aligned}$$

$$\begin{aligned} \text{Hence } M &= 12.453 + 12.458 + 1.002 \\ &= 25.915 \text{kg} \end{aligned}$$

Glass Panel Operating Speed

According to Chomo, Yawas and Johnson (2018), the velocity required for the sliding glass panel is a function of the required opening/closing time and the travel length (i.e. breadth) of the glass panel. This is stated as

$$v = \frac{b_G}{\tau_g} \dots\dots\dots 6$$

Where v is linear speed of the glass panel (m/s); b_G is breadth of glass panel (m) (= 1.05m) and τ_G is the required opening/closing time > 3secs (AAADM, 2006) (= 4secs)

$$v = \frac{1.05}{4} = 0.263 \text{m}^2/\text{s}$$

Rotational Speed of Motor

The rotational speed is required to calculate the power on the wheel rollers. From Chomo, Yawas and Johnson (2018).

$$\omega = \frac{v}{r_p}, \dots\dots\dots 7$$



where ω is the speed in radians per second, v is the instantaneous speed in m/s, and r_p ($= 0.027\text{m}$) is the radius of driver pulley.

$$\text{Hence } \omega = \frac{0.263}{0.027} = 9.741 \text{ rads/s}$$

Power Required to Overcome Rolling Resistance (F_a)

The carriage wheel, which moves the sliding door, has rollers. These rollers have rolling resistance.

For rolling wheels rolling resistance, $P = F_1$ from Beer, Johnston, and Mazurek (2011) and Osaro and Aliu, (2021) is given as:

$$F_1 = W \frac{b}{r_R}$$

Where, r_R is the radius of the rollers, b is the horizontal distance between centre of wheel and point of application of resistance R and W ($=mg$) is the weight of the wheel. According to Chomo, Yawas and Johnson (2018) “The distance b is commonly called the coefficient of rolling resistance and varies from about 0.25mm for a steel wheel on a steel rail to 125mm for same wheel on soft ground”. For a sliding door the wheel is on steel to steel ($b=17\text{mm}$). Let the force acting on wheel be F_1 . From Chomo, Yawas and Johnson (2018).

$$\begin{aligned} P_1 &= r_R F_a \omega \\ &= r_R m g \frac{b}{r_R} \omega \\ &= m g b \omega \end{aligned} \quad \dots\dots\dots 8$$

Where, P_1 is the power required for moving carriage wheel, r_R ($r_R=18\text{mm}$) is the radius of one wheel, and ω is the velocity of roller in radians per second. Taking $m=19.471\text{kg}$ and $g=9.81\text{m/s}$.

$$\begin{aligned} \text{Hence } P_1 &= 21.474 \times 9.81 \times 0.017 \times 9.417 \\ &= 33.096\text{W} \end{aligned}$$



Power Required for Acceleration (P_2)

When initial velocity of a body is zero (0), Chomo, Yawas and Johnson (2018) states Newton's law of motion as:

$$F_2 = m \left(\frac{v^2}{2s} \right) \dots\dots\dots 9$$

$$P_2 = m \left(\frac{v^3}{2s} \right) \dots\dots\dots 10$$

Where, a is the acceleration of the slide panel, v is the maximum velocity attained by the panel and s ($= \frac{1}{2}b_g = 1050/2 = 0.525$) is the total distance covered.

$$\text{Hence } F_2 = 21.074 \left(\frac{0.263^2}{2 \times 0.525} \right) = 1.458$$

$$\text{And } P_2 = 21.074 \left(\frac{0.263^3}{2 \times 0.525} \right) = 0.383 \text{ W}$$

Power Required to Overcome Belt Resistance (P_3)

According to Chomo, Yawas and Johnson (2018), Power to overcome belt resistance is given by:

$$F_3 = T_1 \left(1 - \frac{1}{e^{\mu\pi}} \right) \dots\dots\dots 11$$

and

$$P_3 = T_1 \left(1 - \frac{1}{e^{\mu\pi}} \right) v \dots\dots\dots 12$$

Where, T_1 ($= F_2 = 1.458$) is the tension on tight side of belt, μ ($= 0.42$) is the coefficient of friction between belt and pulley, P_3 is power required in overcoming belt friction.

$$\text{Hence } P_3 = 1.458 \times 0.733 \times 0.263 = 0.281 \text{ W}$$

Total Power Required to move the slide panel (P)

From equation 1

$$P = 33.096 + 0.383 + 0.281 = 33.760 \text{ W} \approx 34 \text{ W}$$



Sliding Door Efficiency

According to Chomo, Yawas and Johnson (2018) the sliding door efficiency can be stated as

$$\eta_{Theo} = \frac{P_o}{P_i} \times 100\% \dots\dots\dots 13$$

Where η_{Theo} = theoretical efficiency, $P_o = P_1$ (= 33.096W) is the total output power, and $P_i = P$ (P33.760W) is the total input power.

$$\begin{aligned} \text{Hence } \eta_{Theo} &= \frac{33.096}{33.760} \times 100\% \\ &= 98.033\% \end{aligned}$$

Door Testing Methodology

The door controller set is switched on and the door application on handset turned on. The application is designed to either operate the door forward i.e. open the door or reverse i.e. close the door. On both the forward and reverse side, there are different speeds to either open or close the door.

To operate the door:

1. On the ‘forward’ side of the application the ‘speed 1’ button was pressed which activates the open cycle.
 - i. A stop watch was used to record the time to complete the open cycle.
 - ii. A tachometer was used to measure the speed in revolutions per minute (rpm)
2. On the ‘Reverse’ side of the application the ‘speed 1’ button was pressed. This activates the close cycle. The time it takes to complete the close cycle and the speed was recorded.
3. The above procedure was repeated for speed 2, speed 3, speed 4, and speed 5 buttons and data generated is tabulated.
4. Graphs of speed (rad/s) against time are plotted. The door performance was assessed and from the results the best speed for the door chosen.
5. Procedure 1 – 4 can be performed with the fingerprint module, but only the lowest speed can be used (i.e. speed 1).



Results and Discussion

The results of the tests conducted showing the relationship between the speed number, designed into the software, and the time it takes to complete either the open cycle or the close cycle along with the tachometer reading are shown in Table 1. To ascertain the optimum speed to be utilized for the sliding door, graphs of opening and closing speed is plotted against their respective cycle time. These are drawn in Figure 3 and Figure 4.

Table 1: Cycle Time and Tachometer Reading at Application Speed Number

Speed Number	Cycle time (s)		Tachometer Reading (rpm)	
	Opening	Closing1	Opening	Closing
Speed 1	22.94	28.31	7	6
Speed 2	9.76	11.94	17	14
Speed 3	5.51	6.30	30	26
Speed 4	4.76	4.89	35	34
Speed 5	4.75	4.79	35	35

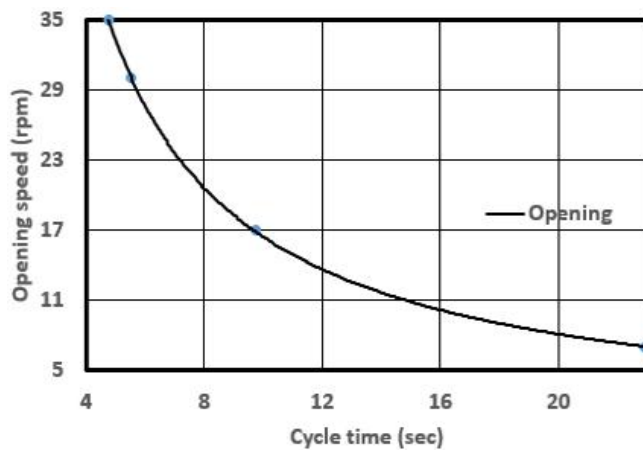


Figure 3: Variation of opening speed with cycle time

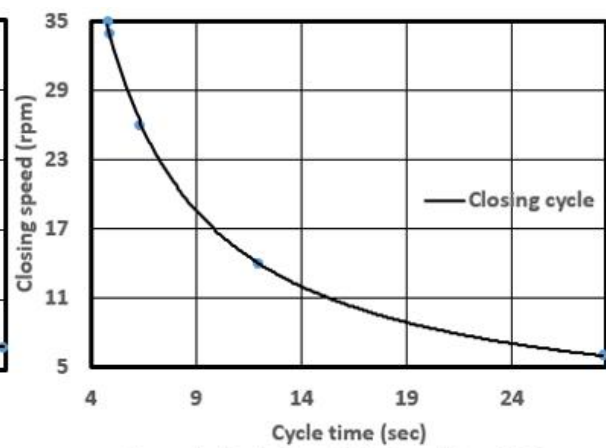


Figure 4: Variation of closing with cycle time

From Figure 3 and Figure 4, there is a marked increase in cycle time and velocity from speed 1 up to speed 4. There is however no marked increase between speed 4 and speed 5 therefore speed 4 is accepted as the best speed for the slide panel.

The efficiency of the door at opening is calculated from Chomo, Yawas and Johnson (2018)

$$\eta_{Mech} = \frac{\text{Actual time}}{\text{Calculated time}} \times \eta_{Theo} \% \quad \dots\dots\dots 14$$

$$\text{Hence } \eta_{Mech} = \frac{4.00}{4.76} \times 98.033\% = 82\% \text{ for opening}$$



and

$$\eta_{Mech} = \frac{4.00}{4.89} \times 98.033\% = 80\% \text{ for closing}$$

where η_{Mech} = mechanical efficiency

The selected speed was 35 rpm having a total cycle time of 4.76 secs for opening and 34rpm with a cycle time of 4.89secs on closing. The theoretical efficiency was 98.148%. With this value and the selected cycle time the door mechanical efficiency was estimated as 82% for opening and 80% for closing. The Bluetooth activation was active twenty meters away between the door and the phone.

The Bluetooth activated automatic door has taken care of area where security restriction is low and provided the technology of using the Bluetooth to actuate the opening or closing the door.

Conclusion

A Bluetooth controlled automatic sliding door was designed, constructed using locally sourced materials, and the performance of the door evaluated using standard procedure. The mechanism has easy operational procedure and will be efficient with respect to time and energy. The construction was done in such a way that it makes maintenance and repairs an easy task and affordable for the user should there be any system breakdown. The results obtained in the design evaluation shows that the door has a mechanical efficiency of about 82% for opening and 80% for closing. This shows that the power generated by the motor can overcome the resistances imposed on the door. Bluetooth activation was sensitive twenty meters away from the door. From the materials and equipment used to manufacture the door, it can be observed that these are obtained in this country hence conserving foreign exchange.

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