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Development of an Automatic Door System

D. I. G. Chomo[1] D. S. Yawas[2] Z. S. Johnson[1]

1 *Mechanical Engineering Department, Plateau State Polytechnic, Barkin Ladi.*
2. *Mechanical Engineering Department, Ahmadu Bello University, Zaria.*
Corresponding Author: Dikio C. Idoniboyeobu

ABSTRACT: *The automatic doors locally available in Nigeria are all imported which introduces leanness to the nation's foreign exchange and not only that, they have high cost. The high cost is reduced by removing the presence sensors and its circuitry which crisscross the door panel and jamb profiles. The aim of the work is to design, develop and test an automatic door assembly using locally available raw materials at low cost. It is recommended that research should be conducted in Nigeria into aluminium door sections, low speed high torque electric motors and long range sensors that satisfy automatic sliding doors requirements.*

KEY WORDS: *Operator; Microcontroller; Sensors; Automation; Automatic.*

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I INTRODUCTION

Work schedules in modern times require fast and efficient movement of personnel, goods, services and machineries. The door is placed between these schedules and plays a vital role in making the work environment conducive. Any barrier to effective movement is detrimental and must be eliminated. Automatic doors create an atmosphere where barriers to free flow are adequately removed.

The Automatic door system was popularised by the supermarkets. This was started in the United State as a result of the search to ameliorate the hardship experienced by shoppers. The hardships as explained by Halper [1] include; "Pushing the door, pulling the door, and parking the rolling basket carrier". This activity had one thing in common; they frustrated shoppers-at least momentarily. He went further to add that; a "shopper approaching the exit door had no choice but to bring the shopping cart to a halt, open the door one hand, and pull (or push) the shopping cart through with the other. The action forced every shopper behind him or her to come to a momentary but complete halt. When the store was busy, this sequence of movement resulted in a long line of customers waiting for a chance to use the exit door."

Conditions that are vital in the quest for automation of doors include; situations where both hands of the pedestrian are needed other than opening of the door itself or when the door needs large force to open. In the same regard, public and commercial environment require prestige, elegance and comfort, therefore, the installation of automatic door aid in this regard. Furthermore, the automatic doors locally available in Nigeria are imported. This trend introduces leanness to the nation's foreign exchange. Lastly, maintenance and repairs of the available automatic doors in Nigeria are not within the technical capabilities of most technicians in Nigeria.

A door is described as a relatively solid but movable surface, opaque or wholly or partly glazed, usually of wood, metal, glass, or a combination of materials, that closes an entrance to a building or a room (i.e. serves as a barrier or screen) and is fixed in an opening in a wall[2][3][4].

When open, doors admit ventilation and light into buildings, rooms and other enclosures. When closed doors are used to control the physical atmosphere within a space by enclosing the air drafts so that interiors may be more effectively heated or cooled. Doors also aid in preventing the spread of fire, can act as barriers to noise, and are also used to screen off areas of a building for aesthetics and other purposes. Doors are generally used to separate interior spaces (rooms, closets, etc.) for privacy, convenience, security, and other reasons. Doors are also used to secure passages into a building from the exterior for reasons of safety and climate control.

Doors have different designs and styles of construction. Based on working operations, doors can be sliding doors (slide along tracks into the wall or behind other doors), revolving doors, swing doors, collapsible steel doors, and rolling steel doors. Sliding doors are designed to slide along tracks. Swing or hinged doors are hinged along one side to allow the door to pivot away from the doorway in one direction but not in the other. Folding doors have multiple panels which fold upon one another when such doors are opened [4].

A sliding door is a type of door which opens horizontally by sliding. Sliding doors are commonly used for shower doors, glass doors, screen doors, and wardrobe doors [5].

Sliding glass doors are popular in southern Europe and throughout the United States of America, being used in: hotel rooms, condominium, apartment, and residences; for access to upper balconies; for large views out, enhanced natural light in; and to increase incoming fresh air. In addition sliding glass doors are commonly used in some regions as doors between the interior rooms of a home and a courtyard, deck, balcony, patio, garden, backyard, barbecue or swimming area. They are often called Patio doors in this context. They are also used in interior design, often in offices and automobile sales areas, to give soundproof but visually accessible private office space. In residential interiors they are used, often with translucent 'frosted' glass replicating a traditional shoji door, to allow daylight to penetrate further into the dwelling and expand the sense of interior spatial size [6].

An automatic door is an automated movable barrier installed at the entrance of a room, building or space to control and restrict access or provide privacy. Also an automatic door indicates a door that opens on its own as a moving object approaches it. It is an electro-mechanical door that has undergone the process of automation. The reason for making the sliding door automatic is to allow pedestrians to gain easy entrance in and out without having anyone to keep opening and closing the sliding door. [5][7][8]

For people in wheelchairs and other disabled individuals, automatic doors are an immense boon, since conventional doors can be very hard to work with. It may be impossible to open a conventional door while seated in a wheelchair or navigating with crutches, for example, and for people with disabilities in their hands and arms, conventional doors can present a real obstacle. [9][10].

Many automatic doors have a manual override so that in the event of a power failure or a mechanical problem, the doors can still be opened. The doors are also designed to be sensitive to obstacles in the doorway, so that they will not close on someone or something which happens to be in the middle of the path of the doors. These safety measures ensure that automatic doors are safe in a variety of situations [11].

II RELATED DESIGNS AND WORKING PRINCIPLE

The designed automatic sliding door consists of an operator and a door frame as seen in figure 1. The sliding door operator, which automates the door system, is placed in a space in the head of the door frame.

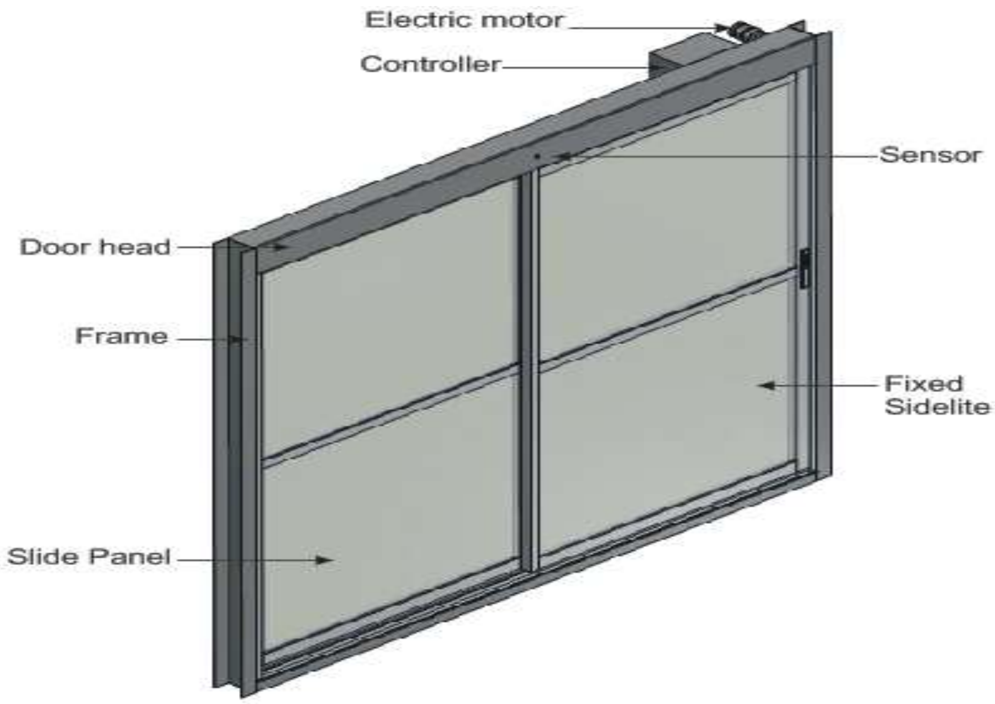

Fig 1: Automatic Sliding door

Ogishi [12][13][14][15] designed four sliding door variants two of them in collaboration with other designers. In all cases he used a linear motor as a prime mover which also doubles as the drive or actuator. All Ogishi's designs tried to solve the problem of stopping the slide panel without collision at the ends of a cycle.

Markus [16] and Bello [17] used an electric motor coupled to a separate actuator. For Markus, the actuator is a chain drive, whereas, for Bello the actuator is a rack and pinion drive.

This project is designed to address the shortcoming of Bello [17] in one major area, namely, the replacement of the rack and pinion drive with a simple belt drive. The major disadvantage of the rack and pinion drive is the loss of power due to backlash.

Chain drives have the disadvantage that there is a need to grease the chain periodically; this not only introduces a dirty environment around the operator, but poses maintenance difficulties. Chains also have heavy weight which causes it to sag in operation, this increases space requirement at the door head. There is also the problem of noise during operation in spite of the greasing.

Bello [17], Diarah et al [18] , Yang et al [19] and Oladunmoye et al [4] used a microcontroller to regulate the motion of the slide panel. This concept was adopted. The concept of intentional analysis of Yang et al 19] was also adopted.

The designed door was limited to two PIR sensors. The controller was programmed to detect the pedestrian when approaching the door, to keep the door open till the next sensor detects the pedestrian, in which case the close cycle is then activated.

The justification for this project is its simplicity in design. It can be replicated easily and maintenance and replacement of parts is easily achieved due to the simple design and local availability of components.

The sliding door operator, Figure 2, is made up of the following main components: a power source, an electric motor, a belt-pulley system, sensors, a microcontroller and battery. Power from the supply is first routed to the power source, which then distribute the power to the electric motor, sensors, and microcontroller. The rechargeable battery is charged by a charging circuit from the power source and serves as an auxiliary power source in case of power failure. The electric motor is used to drive the system. The motor drive a pulley at one end of a belt, and at the other end, is a fixed pulley.

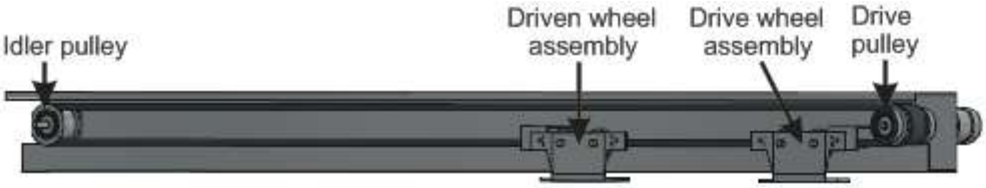

Figure 2: Sliding door operator

The door frame encloses two panels; one is fixed while the other can slide. The slide panel is clamped to the belt of the operator. 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.

III DESIGN CALCULATIONS

3.1 Rotational Speed of Motor

According to Haliday, Resnick and Walker [20]

$$\omega = \frac{v}{r} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad 1$$

and $$N = \frac{60}{2\pi}\,\omega \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad 2$$

where ω is the speed in radians per second, v is the instantaneous speed in m/s, r is the radius of driver puller and N the rotational speed in revolutions per second.

V = 0.6m/s and r = 0.927m

Substituting

$$\omega = \frac{0.6}{0.027} = 22.222\text{rads/s}$$

and $$N = \frac{60}{2\pi} \times 22.222$$
$$= 212.204 \text{ rev/min}$$

3.2 Power required moving carriage wheel (F_a)

Beer and Johnson [21] postulated that for rolling wheels

$$F = \mathbf{W}\frac{\mathbf{b}}{\mathbf{r}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad 3$$

Where r is the radius of wheel, b is the horizontal distance between O and B, and W is the weight of the wheel. The distance b is commonly called the coefficient of rolling resistance. Values of the coefficient of rolling resistance, according to Beer and Johnson, vary 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, i.e.25mm. Let the force acting on wheel be F_a i.e.

F_a $= \frac{\mathbf{Wb}}{\mathbf{r}}$
But m = 20kg (mass of slide panel + accessories)
g = 9.81m/s
r_R = 36/2 mm = 18 mm = radius of a roller
b = 17mm
$\therefore F_a$ $= 20 \times 9.81 \times \frac{17}{18}$
= 185.300N
From Haliday, Resnick and Walker [20].
$P_a = r_R F_a \omega$ ……………………………………………………… 4
Where P_a is the power required to move carriage wheel, r_R is the radius of one wheel, and ω is the velocity of roller in radians per second.
Substituting
P_a = 0.018 x 185.300 x 22.222
= 74.119W

3.3 Power required for acceleration (P_b)

From Haliday, Resnick and Walker [20].
$v^2 = u^2 + 2aS$
or a $= \frac{v^2}{2S}$ (u = 0) ……………………………………………… 5
from equation 4 and using appropriate subscript
F_b = ma ………………………………………………………………… 6
$= m\left(\frac{v^2}{2S}\right)$(acceleration force)
Where **a** is the acceleration of the slide panel, **v** is the maximum velocity attained by the panel and **s** is the total distance covered by the slide panel.
But s $= \frac{2.1}{2x2}$ (travel of slide panel)
= 0.525
$\therefore F_b = 20\left(\frac{0.6^2}{2x0.525}\right)$ = 6.857N
$P_b = F_b$ v (from equation 4)
= 6.857 x 0.6
= 4.114 Watts

3.4 Power to Overcome Belt Resistance (P_c)

Power transmitted by a belt drive, according to Kurmi and Gupta [22], is given by
$F_c = T_1\left(1 - \frac{1}{e^{\mu\pi}}\right)$ ……………………………………………… 7
Where T_1 is the tension on tight side of belt and μ is the coefficient of friction between belt and pulley, P_c is power required to overcome belt friction.
But $T_1 = F_b = 6.859$
And μ = 0.42
$= 6.857\left(1 - \frac{1}{e^{0.42\pi}}\right)$
= 5.431N
$P_c = F_c$ v (from equation 4)
= 5.431 x 0.6
= 3.259W

3.5 Power Required Driving the Sliding Door (P)

P $= P_a + P_b + P_c$
= 74.119 + 4.114 + 3.259
= 81.492W
≃ 82W

3.6 Length of Belt Required (L)

Kurmi and Gupta [22] gave the length of open belts as
$$L = \pi(r_1 + r_2) + \frac{(r_1 - r_2)^2}{d} + 2d$$
When the two pulleys are equal, i.e. $r_1 = r_2 = r$ = radius of a pulley.
L $= 2(r\pi + d)$ ……………………………………………………………… 8
= 2(0.027π + 1.8)
= 3.76m
≃ 4m

3.7 Determination of Bearing Diameter

Shigley & Miscke,[23] postulated that from experiment

$$F_R \;=\; F_D \left(\frac{L_D n_D}{L_R n_R}\right)^{1/a} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 9$$

This means that the bearing selected to satisfy a design must have a radial load rating greater than or equal to F_R. Where F_R = catalogue rating life (kN), L_R = catalogue rated life (h), n_R = catalogue rated speed (rev/min), F_D = required radial design load (kN), L_D = required design life (h), n_D = required radial design (rev/min). The designer's problem is: Given F_D, L_D, and n_D, what value of F_R should be used to enter the catalogue to find an appropriate bearing?

d = 1.8 (centre to centre distance of pulleys)

L_{10} = 10^6 (from Shigley & Miscke [23])

L_D = 500hrs (from Khurmi and Gupta, [22])

F_D = $F_a + F_b + F_c$

= 185.300 + 6.857 + 5.431

= 197.588N

$$\therefore\ F_R = 197.588\left(\frac{60\text{x}500\text{x}106.093}{10^6}\right)^{1/3}$$

= 254.294 x 1.619N

= 0.254kN

IV MATERIAL SELECTION, FABRICATION AND TESTING

Based on the calculated results, the materials selected for automatic door manufacturing and the reason for the selection and machines used for manufacturing the door are as outlined in table 1 and table 2 below.

Table 1 Materials Selection and machines required for fabrication

s/n	Component	Material	Reason for use	Machines required
1	Head	Sheet Steel	Flexibility	Guillotine, Bending machine, welding machine
2	Pulley	Aluminium Bar	Lightness	Power saw, lathe, Hydraulic press
3	Wheel Assembly	Steel plates	Strength	Power saw, lathe, Hydraulic press
4	Door frame	Sheet Steel	Strength/ Flexibility	Guillotine, Bending machine, welding machine
5	Double Jamb & Double Tract	Aluminium Sections	Aesthetics	Al cutting machine, Al punching machine, Al milling machine
6	Door Panels	Aluminium Sections	Aesthetics	Al cutting machine, Al punching machine, Al milling machine

Table 2 Standard components selection

s/n	Description	Component	Reason for use
1.	Actuator	Belt	Simple in design, power utilization, efficiency, ease of application, low noise level, clean environment, low maintenance
2.	Prime mover	DC motor	Size considerations, control efficiency,
3.	Sensor	Infra red	Long range, high resolution.
4.	Control	Microcontroller	Space considerations, control efficiency, increased reliability and performance.
5.	Prime Mover	Electric	Ease of control, manipulation and distribution.
6.	Bearings	Bearing no 300	Standard.

V CONCLUSION

The door was designed, developed and tested from materials selected and fabricated locally. It is recommended that aluminium sections specifically designed for automatic doors should be researched into, designed and marketed by aluminium products manufacturers in Nigeria, low speed high torque electric motors designed specifically for automatic doors should also be encouraged and long range motion sensors are not readily available in the Nigerian market, therefore, the design and manufacture of this component is an imperative.

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