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Design and Fabrication of Mechanical Teaching Aid for White Board Cleaning

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ABSTRACT: Whiteboards are a well-known writing medium in which drawings, notes, charts or other written notations are made. The written notations or information can be erased by means of a duster or any wiping material manually and this material needs to be carried along. Also erasing the board (especially of larger sizes) manually is time-consuming and tedious which mostly causes distractions and often breaks the link between the instructor/professors and the students since these boards are mostly used in schools and colleges. Also sometimes the remnants of the prior hand-written notes remain even after erasing which causes dust formation on the board. Based on these problems we propose a working prototype of an electro-mechanical teaching aid which consists of an electro-mechanically operated inbuilt duster which will be actuated for moving linearly by means of belt transmission mechanism from rotating shaft which is mostly used in 3D printing devices. The idea is to fabricate a system in which with one push of a button, the duster will erase only the required and specific region of the board with the use of stepper motor, timer-pulleys, belt and solenoid. The operation is sequentially programmed using a microcontroller circuit (Arduino) and a stepper motor driver.

KEYWORDS: Prototyping, Duster, Arduino, Microcontroller, Electro-mechanical, Stepper Motor, Belt Transmission.

I. INTRODUCTION

Boards play a major role in both business and educational sector. It is known to be one of the major ways amongst many for teaching, presentation and display. Although it started out as the blackboard, it has emerged into enhanced technological boards such as the electronic board, interactive whiteboard and plain whiteboards. The whiteboard which is commonly used in the educational sector is the basis of our work, aiming to ease teachers as well as students, time and effort it takes to clean the board.

A whiteboard is a name for a glossy surface, most commonly coloured white, where non – permanent markings can be made. Whiteboards operate analogously to the chalkboard in that they allow markings to temporarily adhere to the surface of the board. The popularity of whiteboards increased rapidly in the mid–1980s and they have become a fixture in many offices, meeting rooms, school classrooms and other work environments [1].

The whiteboard has gone through numerous changes over the past decade, most of which are not easily noticeable [2]. The cost of the Whiteboard has gotten cheaper over time, the surface has become easier to wipe and the glare has been reduced. Although there have been new constructions and replacements of existing chalkboards, the magnetic whiteboard still remains the most popular. Whiteboards are also similar to chalkboards, allowing rapid marking and erasing of markings on the surface. The use of whiteboards in learning environments can affect learning in many ways, including raising the level of interaction in a classroom, inspiring students and stimulating eagerness for learning.

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Educators were the first people to recognize the whiteboard's potential as a tool for collaboration, improving student learning outcomes and streamlining lesson plans [3].

Unfortunately, most whiteboards used by institutions are still erased by manual user action, which is tedious. In our lecture rooms, the dire need for a duster that would be readily available at all times for cleaning the whiteboards has been a major concern, the height of some boards cleaners also affect the section of the board to be cleaned. Even when the board cleaners are available, it takes lecture time away from the lecturer to erase the board. This need for a faster, time saving and readily available cleaner has given birth to the design of an automated whiteboard cleaner that can clean the board in the least amount of the time possible [4].

We propose an automatic whiteboard erasing system which consistently cleans boards with the push of a button is created. It is an electro-mechanical system that applies the use of combinational circuits and stepper motor to automatically control the wiping of a board. It's a tool for teaching and a tool for learning. These two broad categories emerged in this reports: the Automatic Whiteboard wiper as a tool to enhance teaching, and as a tool to support learning. Not just does it help teachers and lecturers but it supports students to also learn by its flexibility and versatility, the interactivity of teachers and students, efficiency and modelling electronic skills. The proposed system can solve the problems related to discomfort for the teacher and wastage of time while erasing the board.

II. RELATED WORK

We have studied various published research papers. The comparative study is given below:

Table I. Comparative study of existing methods

Sr.No	Authors	Methodology used	Components used	Limitations
1	Simolowo, (2014) [1]	Sprocket and chain drive mechanism at the top with guide rollers at the bottom.	Sprockets, an electric motor, guide rollers and a chain	Frequent lubrication required for the chains. Cost of a chain drive is higher than belt drive.
2	Sunil R. Kewate et.al., (2014) [5]	Sliding type wipe mechanism using cross guide rails.	Motors, guide rails and sliders	Motors generate noise
3	Gaurav Gangurde (2016) [6]	Rack & pinion with the application of steering mechanism	Rack, pinion, bearing, DC motor.	Bulky, complicated mechanism, not user-friendly.
4	Dong Yeop Kim et. al, (2014) [7]	Mechanical sensor method using ARS sensors	Limit switches, ARS sensors, Height sensor	Expensive components, maintenance cost is high.
5	G.Rajesh , X.Mercilin et. al. (2016) [8]	Arduino Based Smart Blackboard Wiping System	DC motor, Arduino, servomotor	--
6	Puneet M., Bhushan C, Ravina N., and M. S. Rohokale (2015) [9]	Duster Detaching Mechanism for Automated Motorized Whiteboard	Whiteboard surface material, dusters, plastic rollers, cam and follower, four-bar mechanism and motors	High maintenance cost. The design is complicated as they have used a cam and follower mechanism.

III. PROPOSED METHODOLOGY AND WORKING

The proposed working of the mechanism is such that when the pushbutton is actuated the input is given to the microcontroller (Arduino) and the microcontroller processes the data to actuate the solenoid to push the wiping material against the board according to the region which needs to be erased. After the solenoid is actuated the microcontroller processes the information and code to actuate the stepper motor in order to rotate the side shafts and timer pulley. On rotation, a linear motion would be actuated by the linear bearing- block assembly due to the tangential force exerted by

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the belt mechanism. This linear actuation would thus help in the erasing mechanism of the duster and after each cycle, the duster would come back to its original position within a specific time slot say $t=3s$.

The arrangement of the motor and microcontroller circuit is shown in figure 1:

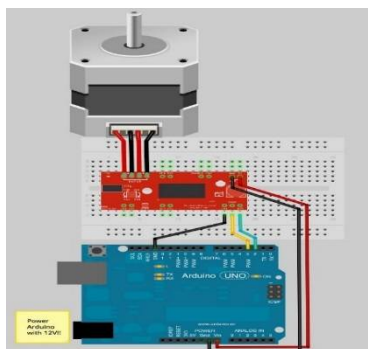


Figure 1. Arrangement of Stepper motor Circuit

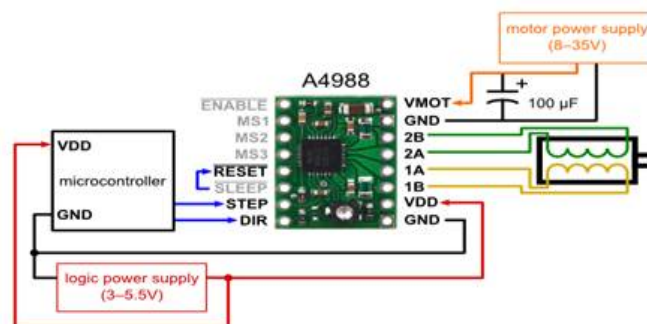


Figure 2. Microcontroller to an A4988 Stepper Motor Driver Carrier.

For rotating a motor both clockwise and anti-clockwise a motor driver is used along with the Microcontroller (Arduino). The A4988 is a micro-stepping bipolar stepper motor driver and it features adjustable current limiting, over-current and over-temperature protection, and five different micro-step resolutions (down to 1/16-step). The driver requires a logic supply voltage (3 – 5.5 V) to be connected across the VDD and GND pins and a motor supply voltage (8 – 35 V) to be connected across VMOT and GND. These supplies should have appropriate decoupling capacitors close to the board, and they should be capable of delivering the expected currents (peaks up to 4 A for the motor supply).

The motor is located on the top left side of the whiteboard. The shaft of the motor is coupled to the left rotating shaft of whiteboard which has two timer- pulleys fitted on each end. The top-left pulley is connected with the top right pulley by means of a conveyor belt like the ones which are used in 3D printers for linear motion actuation. The same setup is used for the pulleys at the bottom. Both the belts are held tightly between the male block and female block of the linear bearing block assembly so as to get actuated linearly by the rotational motion of the shaft to facilitate the cleaning action. The duster also contains two holding or supporting vertical rods that are fixed to the top and bottom linear bearing- block assembly by an interference fit.

The Duster contains a vertical plate in it which is fitted to the tip of a solenoid. On the other side of the plate, there is a wiping material which would clean the board. The solenoid would actuate a to and fro motion as per command which would help in moving the plate front, pressing the wiping surface of the plate against the writing surface of the whiteboard.

When the solenoid moves the plate back, it would disengage the wiping surface of duster away from the whiteboard. The duster also contains three buttons, controlled by the Microcontroller (Arduino) board which would give the signal to the solenoid, for it to actuate at which step of the stepper motor. This, as a result, would allow us to clean only the first portion (when pushed Button 1), the second portion (when pushed Button 2) of the board and as well as the whole board at once (when pushed Button 3).

IV. DESIGN AND CONSTRUCTION

White Board Dimensions for the prototype: The board used for the prototype will be a white marker board of the dimensions (3ft × 2ft). The detailed dimensions of the whiteboard and writing surface are as given below in figure 3.

3D Model of the Prototype

The final conceptual model of the prototype is given as shown in figure 4.

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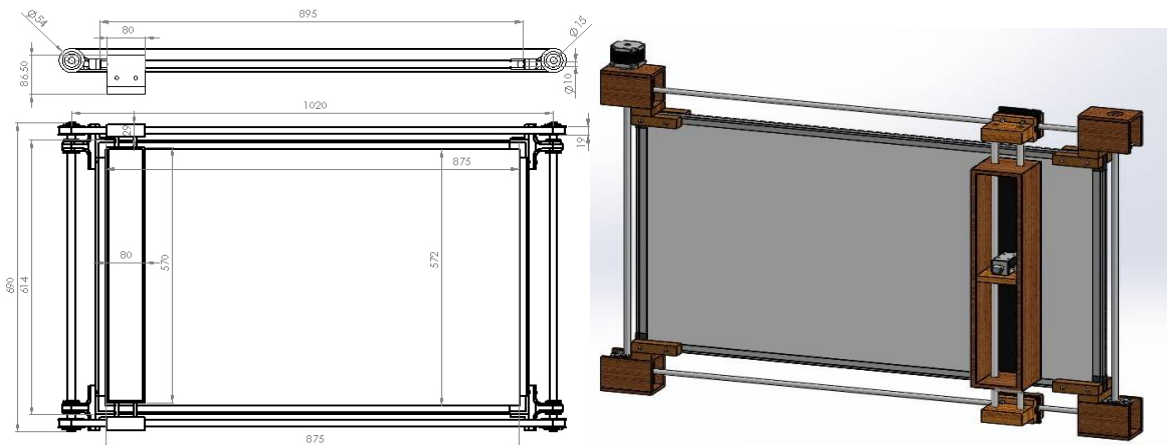
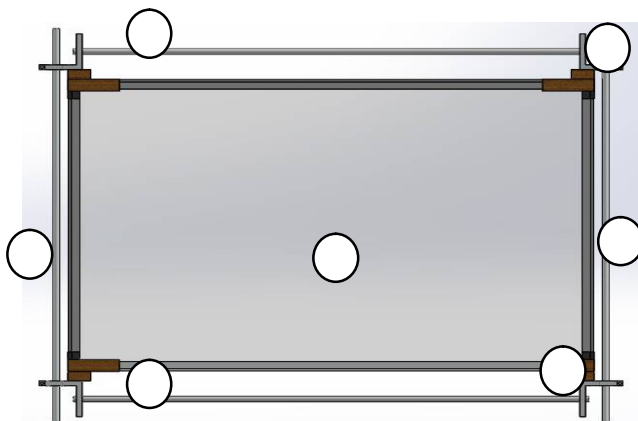


Figure 3. Dimensions of the initially proposed prototype (in mm) Figure 4. Final Assembly Model of the prototype

As per the availability of standard parts, materials and requirement of the mechanism for wiping action to take place, the designed model of the prototype has been improvised and edited. The final 3D model of the prototype has been given as shown in figure 4.

Basic Framework of the Prototype: Having a rigid framework is a necessary aspect of the design since the framework not only gives rigid support but also facilitates the motion of moving objects (linear bearing- block assembly, rotating shafts and duster assembly). The basic and necessary parts of the framework are as illustrated below:



- 1- White Board
- 2- Sliding Rod (Upper)
- 3- Sliding Rod (Lower)
- 4- Rotating Shaft (Right)
- 5- Rotating Shaft (Left)
- 6- Supporting Block
- 7- L-Bracket

Figure 5. Prototype Framework

Duster Assembly Design: The duster assembly is comprised of 3 parts assembled; they are the duster casing, acrylic sheet and the wiping material. The wiping material will be stuck to the acrylic sheet which would be assembled on the casing supported by two holding rods of 12mm diameter each. The casing is hollow from the other side in order to facilitate mounting of the electronic components (solenoid, wires etc.) that will control the wiping action of the duster and provide room for the holding rods to pass through. The casing is a hollow box of 10cm width and 56.5 cm height. The wiping material would be approximately 10mm thick and the acrylic sheet of about 5mm thick.

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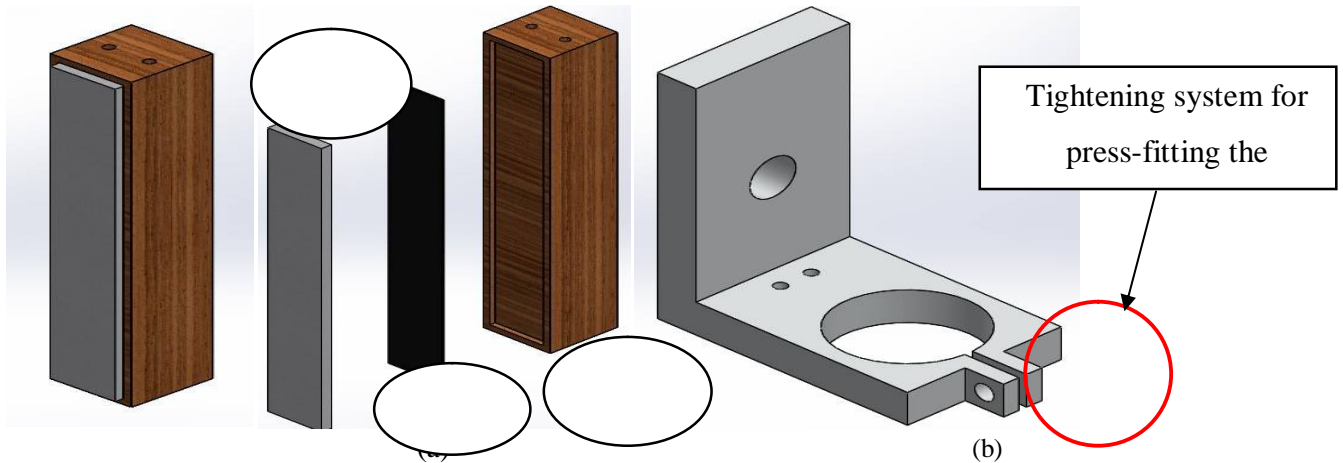


Figure 6. Duster Assembly (a) Assembled View (b) Exploded View Figure 7. Aluminium Bracket Model

Aluminium Bracket Design: The L- brackets used in the end corners of the framework are one of the most critical designs used in the model. This bracket is used for supporting the sliding shafts (top and bottom) and the rotating shafts (at the left and right) along with the DGBB bearings (to facilitate smooth rotation).

One plane of the bracket is drilled with 12 mm hole where the sliding rod of 12mm would be press-fitted. On the adjacent plane, there are two small holes of 3mm diameter to fasten the brackets to the supporting blocks and thus the board using M3 nuts and bolts. Also, there is a hole of 32mm diameter bored to support press-fitting of the ball bearing which would facilitate the rotation of the side shafts. As shown in Figure 8 there is tensioning system is designed in which the bearings can be press-fitted by tightening with standard nut bolt system or allen screws.

Linear Bearing- Block Assembly:

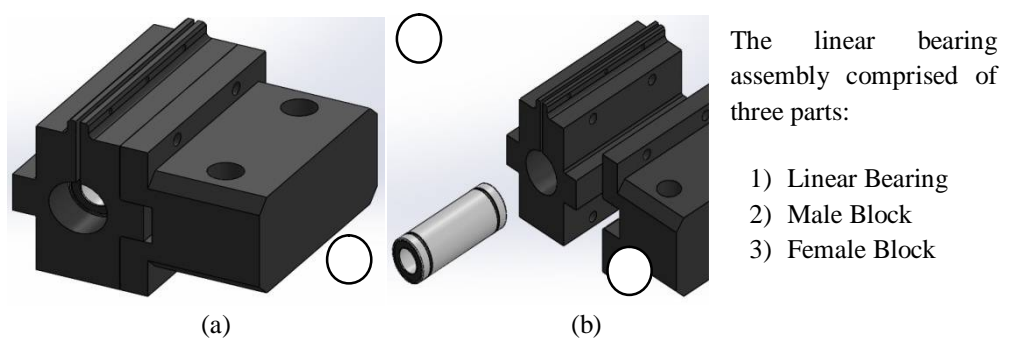


Figure 8. Linear Bearing-Block Assembly (a) Assembled View (b) Exploded View

The linear bearing is press-fitted in the male block to facilitate the sliding movement in the sliding chromium steel shaft. The male block and female block are joined together using Allen screws holding the belt firmly meshing with the belt teeth so that the rotating shaft can cause a linear motion actuation through belt and timer pulleys which would cause the erasing action.

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Bill of Materials:

Table II. Bill of Materials

Part No.	Part Name	Number of units	Material	Part No.	Part Name	Number of units	Material
1	Support Blocks	4	Plywood	9	Duster Casing	1	Plywood
2	L- Brackets	4	Aluminium	10	Timer Pulleys	4	Aluminium
3	Rotating Shafts	2	Aluminium	11	Belts (210cm)	2	Vulcanised Rubber
4	Sliding Rods	2	Chromium Polished Steel	12	Wooden Cover for motor casing (U-Shaped)	4	Plywood
5	Ball Bearings	4	Stainless Steel	13	Allen Keys (Screws & Bolts)	8 pairs	Plain Carbon Steel
6	Linear Bearings (LM21UU)	2	Stainless Steel	14	Screws and Nuts (Ø4mm)	8 pairs	Plain Carbon Steel
7	Linear Bearing-Block (Female)	2	Teak Wood	15	Screws and Nuts (Ø3mm)	12 pairs	Plain Carbon Steel
8	Linear Bearing-Block (Male)	2	PLA				

V. CALCULATION AND ANALYSIS

Motor Sizing Calculations

There are three factors to calculate when sizing a motor; Moment of Inertia, Torque, and Speed.

i. Moment of Inertia

Moment of inertia is the measure of an object's resistance to changes in its rotation rate. When an object is just sitting without any motion, the moment of inertia is 0. When you try to make it move that means you want to change the speed of the object from 0 to any, there will be a moment of inertia effect.

Fundamental Inertia (J) Equation:

$$J = \iiint \rho (x.y.z)(x^2 + y^2) dx dy dz$$

Here, we will need the moment of inertia of the rotating components of one side in order to derive the required torque for selecting the motor. The rotating components would involve a rotating shaft with two timer pulleys (one on either side). The approximate moment of inertia can be evaluated and found out from the mass properties table of the 3D CAD Model. From the mass properties table, we can conclude the mass moment of inertia is

$$J = 0.04 \text{ kg.m}^2 \dots\dots (1)$$

ii. Speed of the linear motion of the duster assembly and rotating shaft

Length of the writing surface = 877 mm = 0.877 m

Since the duster has to erase the board writing surface and return back to the initial position, the duster assembly will have to travel the distance double the length of the board at a given time frame, say t= 3s

Therefore, distance covered (S) = 2 × 0.877 = 1.754 m

Since Speed (v) = Distance / Time

$$v = S/t$$

$$= 1.754/ 3 = 0.585 \text{ ms}^{-1}$$

$$\therefore v = 0.585 \text{ms}^{-1} \dots\dots (2)$$

Now, acceleration rate, a = v/t = 0.585/3 = 0.195 ms⁻² = 0.2 ms⁻² (approx.)

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iii. Torque

Torque, moment, or moment of force is rotational force. Just as a linear force is a push or a pull, a torque can be thought of as a twist to an object. In three dimensions, the torque is a pseudo vector; for point particles, it is given by the cross product of the position vector (distance vector) and the force vector.

The symbol for torque is typically (τ), the lowercase Greek letter tau. When it is called moment of force, it is commonly denoted by M.

The magnitude of torque of a rigid body depends on three quantities: the force applied, the lever arm vector connecting the origin to the point of force application (or radius), and the angle between the force and lever arm vectors. In symbols:

$$\tau = F \times R$$

Where, τ = Applied Torque

F = Force Applied

& R = Radius of the timer pulley (= 0.045/2 = 0.0225 m)

Now since, $F = M_{eq} \times a$

Where, M_{eq} = Equivalent mass acting

& a = acceleration rate

$$\therefore M_{eq} = \text{Inertial mass by the shaft and pulley } (M_i) + \text{Mass of Shaft and pulleys } (M_s) \\ + \text{Mass of duster assembly } (M_d)$$

$$\text{Inertial Mass by shaft and pulley, } M_i = \frac{J}{R^2} = 0.04 / (0.0225)^2 = 79.01 \text{ kg.}$$

Mass of the Shaft and Pulleys at one side, $M_s = 0.45 \text{ kg.}$

Mass of the Duster Assembly in linear motion, $M_d = 3 \text{ kg.}$ (Assuming)

Hence, $M_{eq} = 82.46 \text{ kg}$

& $F = 82.46 \times 0.2 = 16.49 \text{ N}$

$$\therefore \tau = 16.49 \times 0.0225 \\ \tau = 0.371 \text{ N.m} = 3.7 \text{ kg.cm}$$

Motor Selection

Now as per approximate calculations the required torque for the system to work will be around 3.7 kg.cm. Hence accounting all the irregularities, losses and errors we will select a motor of capacity a little higher than calculated. Hence we can select a NEMA 17 series stepper motor of two options as stated

- NEMA 17 Stepper Motor (4.2kg.cm Torque)
- NEMA 17 Stepper Motor (5.5kg.cm Torque)

VI. IMPLEMENTATION

This is the phase which constitutes of actual fabrication and assembly of the components that would be used in making the prototype based on the optimum design and 3D CAD model. The design is implemented in following steps-

1. Assembling the framework of the project
2. Fabrication of the Linear Bearing Blocks
3. Fabrication of the Duster Assembly

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1. Assembling the framework of the project

This is the first step towards the fabrication and assembly of the prototype. The basic framework consists of the Support Blocks, L- Brackets, Rotating Shafts, Sliding Rods, Ball Bearings and Timer Pulleys. They are assembled and fixed together by means of standard fasteners, nut-bolts or allen screws.

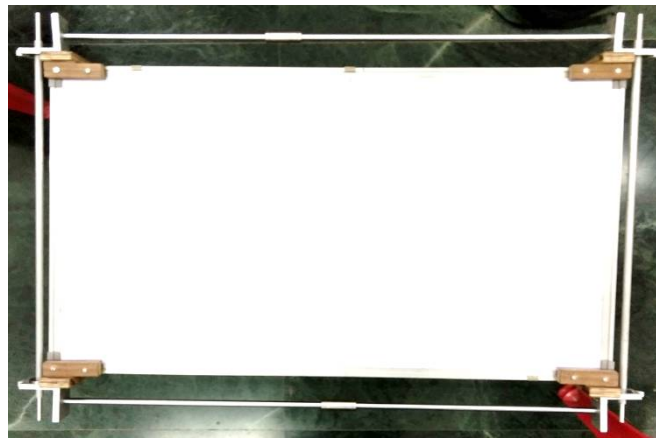


Figure 9. Framework of the Project Assembled

2. Fabrication of Linear Bearing- Block Assembly

The linear bearing- block assembly is the part which would be linearly actuated by the motion of the belt followed by the rotation of timer pulley fitted to the rotating shafts at the sides. This is also one of the most critical parts of the design and needs precise location of holes and dimension. The linear bearing- block assembly consists of three parts i.e. the linear bearing, the male block and the female block.

3. Fabrication of the Duster Assembly

The outer casing of the duster assembly is fabricated using plywood. The height of this duster assembly would be of 564 mm (56.4cm) and the section would be of 10 cm x 10cm. The inner plate that would move in to and fro motion due to the solenoid action would also be fabricated out of plywood nearly 5mm thick. The solenoid would be placed inside of the casing exactly in the between so as to exert uniform stress over the retractable plate. The wiping material would be stuck to the retractable plate by means of adhesives.

VII. CONCLUSION AND FUTURE SCOPE

The basic idea of this project was to develop a design which would ease the erasing process of the whiteboard or blackboard in terms of time, speed and convenience. Hence the system has been designed in such a way which would involve the use of a microcontroller (Arduino) to control the motion of the duster and a motor driver which would be programmed for the operation of the Stepper Motor.

This kind of automation would facilitate fast, smooth and precise movement and action of the duster. As per various empirical relations, assumptions and calculations, the time taken for single rubbing action of the board would be around 3-4 seconds, whereas the time taken for manually erasing the entire board using a conventional duster would be 20-25 seconds (which is nearly 5-6 times more).

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Technically, the programming of the function in the Arduino microcontroller is also easier compared to other methods since Arduino Programming is quite user-friendly and faster. In the convenience point of view, unlike conventional methods, an additional duster need not be maintained or carried which would avoid the fuss of carrying an extra duster or wiping cloth. As per maintenance point of view, regular replacement of parts would not be so much necessary as the framework is designed in such a way that it can be used for the long run. Only replacement that would be required periodically is the wiping material.

This type of system would be very useful and handy in educational institutions (Schools, Colleges, Training Centres, etc) and for official purposes (conference boards, self-updating notice boards etc.) To decrease the weight of the setup, lighter materials can be substituted with steel. Also, more use of standard parts can contribute towards decreasing the initial cost of the setup. Further technically, the setup and working can also be programmed to be controlled by mobiles using Bluetooth or remote controls using infrared sensors and limit switches.

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