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Development of an Automatic Mini-conveyor System for Product Monitoring

Joel Ewa Bassey[1*], Katsina Christopher Bala[1] and Nurudeen Abdul[2]

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ABSTRACT

This chapter highlights the details in the development of an automatic mini-conveyor system for product monitoring. The design analysis was done in line with Fenner Dunlop conveyor belt design manual and other conveyor design manuals and electronic manuals and journals. It is a wireless-based monitoring, control, data acquisition system, MCDAS, enable immediate update of the detail of production line activities as the production runs are being initiated from one production shift to another. For every production run, information is gathered, therefore, with this system there is no downtime in data reporting and transmission and this data can be printed at the end of every production shift. And also has data log, where previous data can still be assessed. Therefore, with rapid advance in wireless information technologies, many solutions are emerging and its application in industries have been researched and developed. It can be concluded that this system which merges four technology that is; mini-conveyor, sensing and counting and signalling wireless network system into one solution is highly compatible and suitable to meet the requirement of any production line layout output monitoring system application in the manufacturing industries.

Keywords: Conveyor; automatic; monitoring system; industries.

1. INTRODUCTION

Material handling is a field involving the transportation, storage, and control of goods and products throughout the processes of manufacturing, distribution, consumption and disposal of all related materials [1]. The focus of the material handling industry is on the methods, mechanical equipment, systems and related controls used to achieve necessary functions. The use of conveyors in material handling has been in practice since the early 20th century and is known to be the back bone of material handling (CEMA). Conveyors is commonly known as a piece of equipment that moves material from one place to another and are specifically for quick and efficient transportation of wide variety of materials of all shapes and sizes [2,3]. In a production system where, large quantities of products are produced with high production rates, the products are to be transported with material handling system that is sophisticated yet safe and reliable. According to [4], “material handling looks at the problems of moving, transporting, storing materials and product; improvement of handling methods”. Automated materials handling can be referred to as the management of material handling system by use of automated machineries and electronic equipments to reduce or eliminates the need for humans to do certain or all the activities in a material handling process manually. It also helps to increase the efficiency and speed by which materials or products are shipped, stored, and handled. This can significantly cut down on costs, human error or injury, and lost man hours [5,6]. Wireless network may be referring to any type of computer network. This work explores the adoption of ASSEMBLY programming language instead of C++, JAVA, and FORTRAN on a Programmable Logic Controllers (PLC); Atmel 89C52 (AT89C52) microcontroller for control and monitoring protocol for the mini-conveyor. The system is developed on the back drop that in the future many production systems will need to adopt ICT in its operations with a choice to pick and adopt monitoring, control and data

[1]Mechanical Engineering Department, Federal University of Technology, Minna, Nigeria.
[2]Physics Department Federal University of Technology, Minna, Nigeria.
**Corresponding author: E-mail: pajoebanet.jb@gmail.com;*

acquisition systems (MCADS) in the mist of diverse ICT base wireless production monitoring system that is effective, efficient and at low cost of implementation. A conveyor machine is developed on which products can be monitored during production run. There are several literatures concerning belt design with more focus on structural modification, maintenance efficiency, safety and some other research focuses on the automation area of maintenance, inspection and monitoring using different wireless sensor network (WSN) system and programmable logic controllers (PLC) structure and devices [7,8]. There are many WSN system, PLC algorithm structural unit design and devices that are yet to be fully tested within a semi or full automated conveyor system as an alternative to the already implemented ones [9]. The emphasis in recent time is on the application of ICT in manufacturing and industrial process to help improve production process and increase productivity.

2. MATERIAL HANDLING PRINCIPLES

Though no definite "rules" are there to follow when designing a material handling systems that are effective, nine Principles of Material Handling, were compiled by the College-Industry Council on Material Handling Education (CIC-MHE) in collaboration with the Material Handling Institute (MHI), stand for the product of many years of accumulated expertise and knowledge of many practitioners and students of material handling, Bharatbhai, Dimeshbhai and Babubhai, [10]:

i. Planning Principle. Every material handling must come from calculated plan where all the needs, objectives to be performed, and practical specification of the projected methods are entirely defined at the beginning.
ii. Standardization Principle. Material handling methods, tools, controls and software ought to be regulated within the limits of achieving overall performance goals and without sacrificing needed flexibility, modularity, and throughput.
iii. Work Principle. This is defined as material flow multiplied by the distance moved. In material handling, they should be minimization of work without sacrificing productivity and/or service required of the operation.
iv. Ergonomic Principle. Human capabilities and limitations must be recognized and respected in the design of material handling tasks and equipment to ensure safe and effective operations.
v. Unit Load Principle. Unit loads shall be properly sized and structured to accomplish material flow and inventory objectives at each phase of the operation. They must be an effective and efficient use of the available (cubic) space.
vi. System Principle. Material movement and storage activities should be entirely integrated to form a coordinated, functional system which involves receiving, inspection, storage, production, assembly, packaging, unitizing, shipping, and transportation, and handling of returns. vii. Automation Principle. This principle state that material handling operations can be mechanized and/or automated where practicable to enhance operational efficiency, increase responsiveness, enhance consistency, decrease operating costs, and to eliminate monotonous or potentially unsafe manual labor.
viii. Environmental Principle. Environmental impact should be measured as condition when design is done and/or when alternative equipment and material handling system are selected.
ix. Life Cycle Cost Principle. A detailed economic investigation should give report for the entire life cycle of all material handling systems.

3. MATERIALS CHARACTERISTICS

Materials characteristics that affect material handling includes; size (width, depth, height); weight; shape (round, square, long, rectangular, irregular); and other (slippery, fragile, sticky, materials that explodes, frozen). Table 1 shows the categories of materials.

Table 1a. Categories of Materials

S/n	Categories of Materials	Solid	Liquid	Gas
1	Individual units/ Loose materials	Part, subassembly, nuts bolts, castings, forging		
2	Containerized items/ packages	Carton, bag, boxes, Pallet, wooden boxes drums etc.	Barrel	cylinder

(Source: Kay, [1] and Bharatbhai et'al., [10]

Table 1b. Categories of materials

S/N	Categories of materials	Solid	Liquid	Gas
3	Bulk materials	Sander, clay, cement, Granular product, sand, Mineral ores, coal, stones Powered materials such as; Flours,	Liquid chemicals, Solvents. Gasoline	oxygen, nitrogen, Carbon dioxide
4	Hazardous materials	These are explosive substance which cannot be handled by hand, hoists or elevator conveyor due to their potential risk of explosion under impact but can be handle by belt conveyor		

(Source: [1,10])

4. CONVEYORS

Conveyor is a powerful material handling tools, used in many manufacturing and processing industries for transporting goods and materials between various stages of a process. They enhance production processes, limit material handling problems, damage and reduced manual content in the industries and /or transportation facilities [11].

4.1 Purpose of Conveyors

Conveyors are used for the following purpose, [11]:

i. Conveying of materials/products between processing stations or points
ii. Transporting products through a fixed rout.
iii. For quick and immediate transportation of product and materials across the factory floor.

4.2 Type of Conveyors

Conveyors come in different configurations and/or structure and are designed for a particular purpose. Table 2, shows different types of conveyors in used.

4.2.1 Flat belt conveyor

Flat belt conveyors are use for moving loads between processing operations, departments and buildings, providing significant control on the arrangement and style of loading, even buildup, amalgamation, and categorization of belt system. Belt can be supported by slider bed or rolling structure. The slider bed is used for items that are miniature and unevenly shaped [1].

4.2.1.1 Types of flat belt conveyor drive orientation

The four drive systems shown in Fig. 1 are basic example of drive arrangements that can be constructed depending on the general belt conveyor profile.

Table 2. Types of conveyor system

1.	Chain conveyor system	13. Vertical conveyor
2.	Flat belt conveyor	(a) Vertical tilt conveyor
3.	Roller conveyor	(b) Reciprocating vertical conveyor
	a) Gravity roller	14. Monorail
	b) Live (powered) conveyor	15. Trolley conveyor
4.	Chute conveyor	16. Tow conveyor
5.	Slat conveyor	17. Power-and-free conveyor
6.	Vibrating conveyor	18. Cart-on-track conveyor
7.	Magnetic belt conveyor	19. Sortation conveyor
8.	Trough belt conveyor	(a) Diverters
9.	Wheel conveyor	(b) Pop-up device
10.	Bucket conveyor	(c) Sliding shoe device
11.	Screw conveyor	(d) Tilting device
12.	Pneumatic conveyor	(e) Cross-belt transfer device

a) Dilute phase pneumatic conveyor
b) Carrier-system pneumatic conveyor
(Source: Kay, [1])

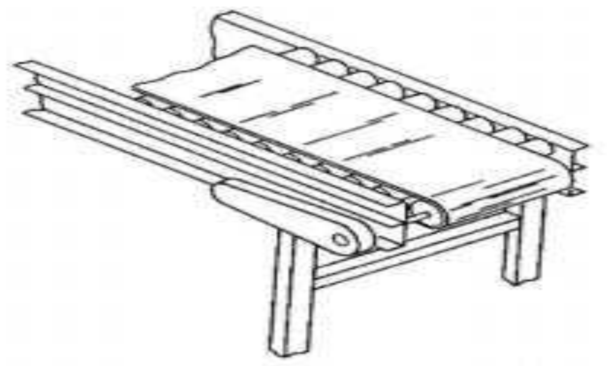


Fig. 1. conveyor structure
(Source: Kay, [1])

4.2.2 Guidelines for selecting material handling equipment

The following are guidelines for the selection of material handling equipment, Bharatbhai et al. [10]:

i. The characteristic of production process
ii. The distance the load will travel
iii. The direction the load will travel.
iv. The properties and type of the load being handled.
v. The capacities of power required to move the units load.
vi. Method of stacking load at the initial and final points.
vii. The environmental/surrounding conditions.
viii. The initial and operating cost.

4.2.3 Technological advancement in conveyor system modification

Belt conveyors are suitable compared to supplementary ways used to transport goods and products. Conveyors operate quietly, and do not cause air pollution or cause ear deafness. They can be located above the disorder and secure hazards of surface traffic or for out of view and audible range in small and large tunnels. Over the years they have been review of belt conveyor design modification and latest technological and methodologies adopted for different industrial application [12]. Based on past research reviewed and design modification, the step by step design modification is shown Fig. 2.

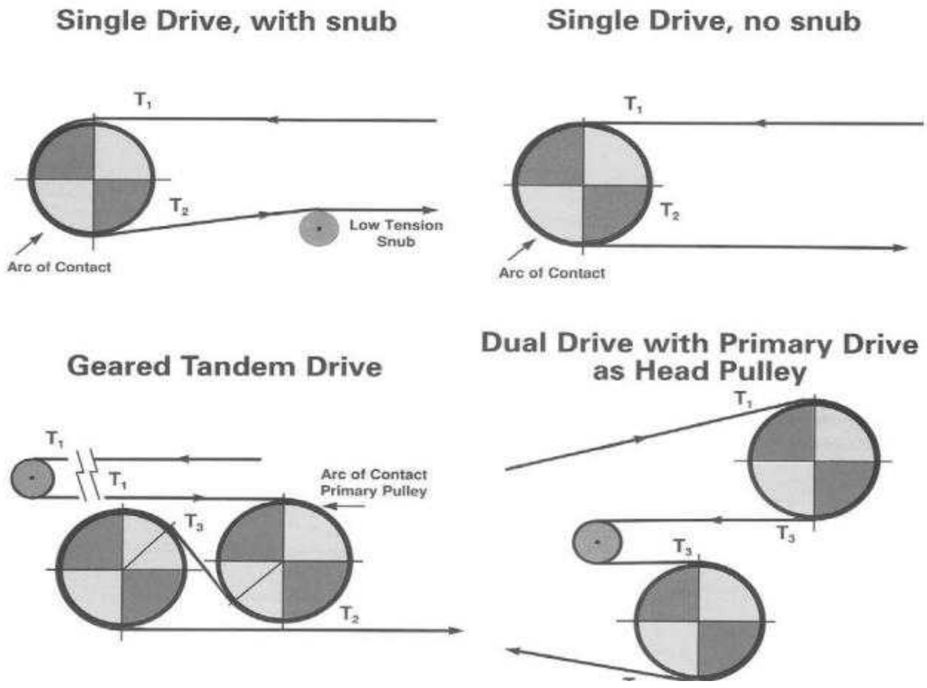


Fig. 2. Types of flat belt conveyor drive orientation
(*Source: Fenner Dunlop conveyor belt design manual, 2009)[8] www.fennerdunlopamericas.com)*

Note: in this work the belt conveyor type to be constructed is that of single drive with no snub, because of the relative short distance that is involve.

4.3 System Architecture

The system is made of many functional units which includes; AT89C52, IR sensors, MAX232 interfacing device, radio-frequency identification (RFID) tag (encoder) and RFID reader (decoder), the PLC plays vital role i.e. it is the main heart of this system. The PLC is burnt with program that is necessary to control the sensors and interfaced relays to it. The interfaced units are controlled by the PLC in an efficient and faster manner, thus, this provides a system that is more reliable and efficient. The building block of the control unit drawn to reveal the system architecture is shown in Fig. 4.

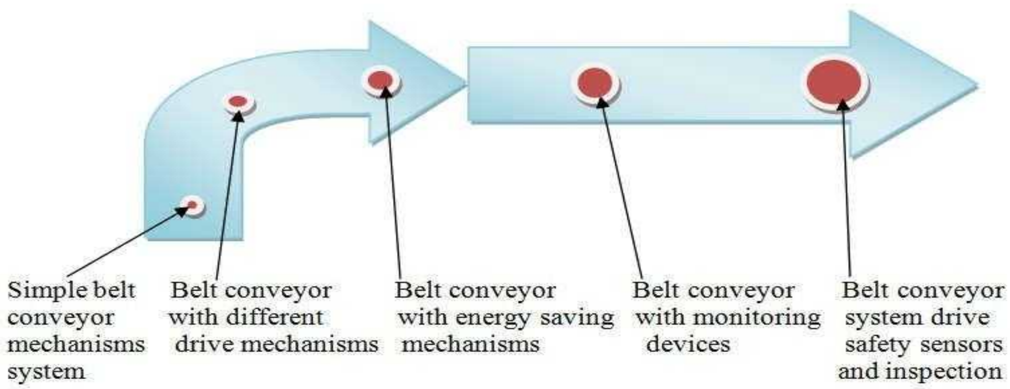


Fig. 3. Step by step designs modification in a belt conveyor
(Source: Kumar and Mandloi, [12])

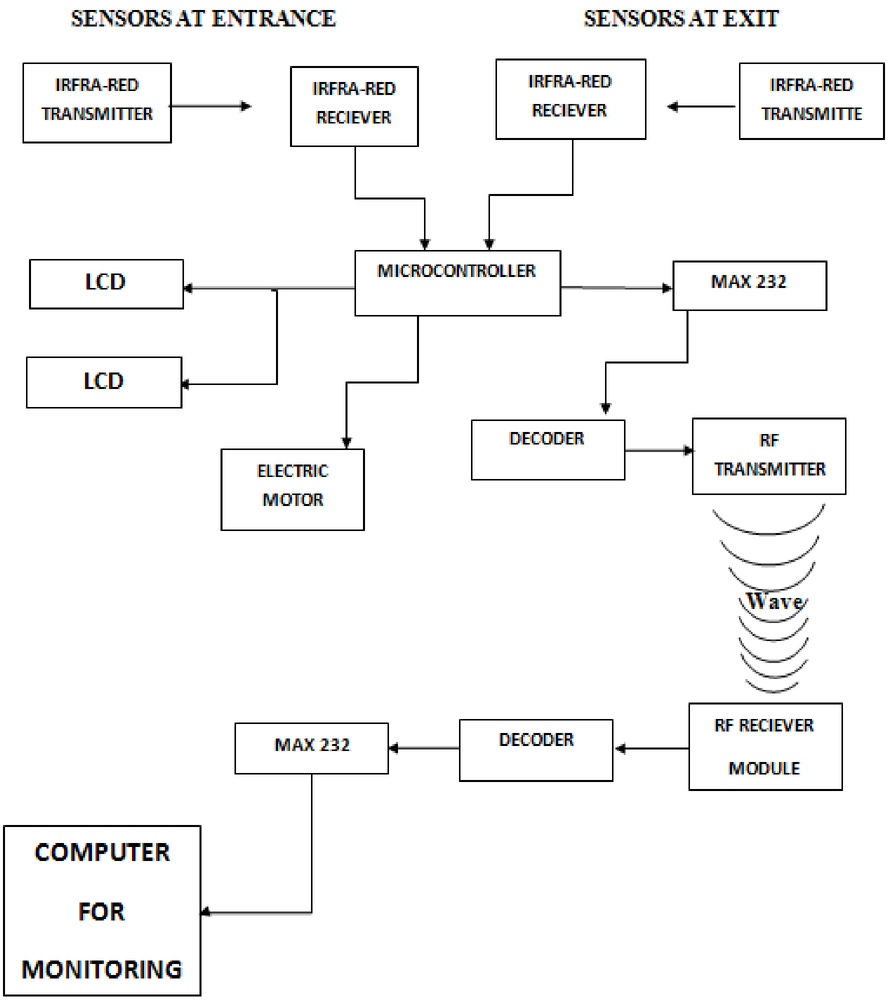


Fig. 4. System architecture for the automatic product monitoring system

4.3.1 Components of system and functions of major electronic and electrical components

The functions of the major electronic components used in the automated counting and signaling system on the conveyor include [13];

i. AT89C52 Micro-controller: this a programmable logic controller (PLC) chip where all program is rewritten to act as artificial brain to control the machine, the chip read the massage that comes from the sensor and in returns deliver the data to the computer through the radio module, which is interpreted and executed. The chip has 40 pins which execute different function; it has data storage of up to 130Kb.
ii. MAX 232: this is another device that helps to interface micro-controller to the computer system. The MAX 232 has both receiving and transmitting of data part, which helps to execute data between computer and micro-controller. A typical MAX 232 device is shown in Fig. 5 and Plate I.
iii. RF module transmitter: massage sender (HT12E)
iv. RF decoder: information/massage receiver (HT12D)
v. IR (infra-red) sensors: product/material detector and signaling device. These sensors are infrared sensor which senses any product or material that pass through, and send the signal to the radio module which is interface through MAX 232 device to the computer. The computer receives the signal and in turn controls the motor and the motion depending on the data it received.

vi. Electric motor: the motor controls the movement of the belt over the pulley/roller.
vii. LCD: this is a crystal liquid display all data executed through the micro-controller and computes will be displayed on the screen of the LCD, to show the in and out function of the system

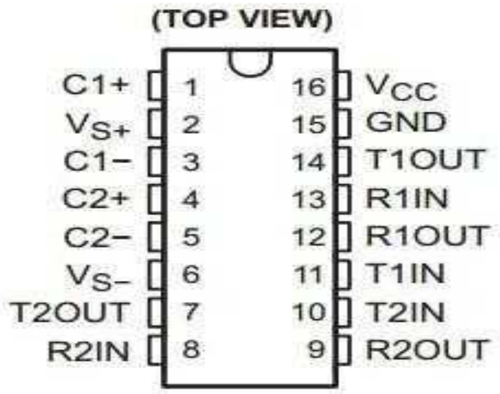


Fig. 5. MAX232 x Dual EIA-232 Drivers/Receivers
(Source: Texas Instrument incorporated, [14] and Hardy, 2005) [14]

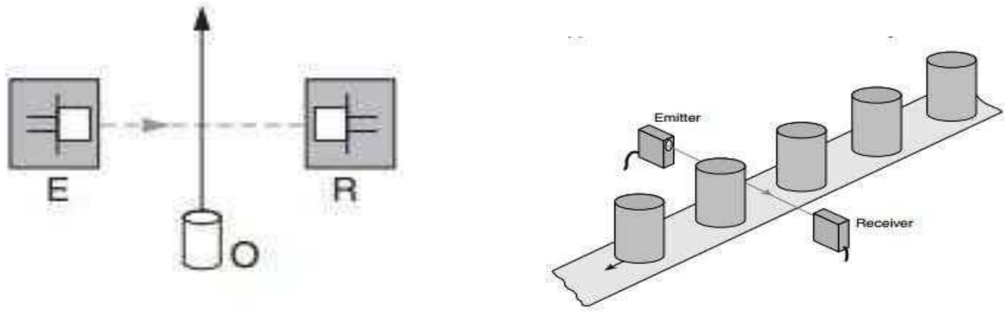
4.3.2 The sensors mechanism of detection

According to transduction principles, infrared (IR) radiation detectors can be classified broadly as either quantum (opto-electronic) detectors or thermal detectors, such as pyroelectric, thermoelectric, thermo-resistive (bolometer), Wood, [15] and more recently micromechanical (or MEMS) thermal detectors, Perazzo et al. [16]. Conventionally, IR photons detection relied on quantum absorption phenomena in semiconductor materials at cryogenic temperature [17].

4.3.2.1 Practical principles of photoelectric sensors

The type, size, shape and surface characteristics of the objects are recorded, the distance between the sensor and the object, and the environmental condition suitable to the sensor types. The transmitter and the receiver are infrared (IR) transmitter and photodiode receiver. The emitter of IR will directly transmit to the receiver photodiode. If an object O interrupts the rays of light, the receiver voltage drops and the switching function is initiated [17].

Plate I. MAX232 chip in DIP-16 package
(Source: Texas Instrument incorporated, 2014)[14]



(a) **(b)**

Fig. 6. (a) an object, (b) Products passing between two sensors (transmitter and receiver)
(Source: Panos and Nickolay, [17], Construction and principles of operation of photoelectric sensors, 2009)

Characteristics of Photoelectric sensors include:

i. Opaque and reflecting objects are detected
ii. Operating range is large and has high stability control, since the light beam only cover the signal path once.
iii. Not affected by interference, and therefore suitable for application in intricate conditions.

Typically, the type of sensor system used in this research work is known as the thru beam sensors, and it is used to monitor production and packing line for various purposes including; product counting, transparency of the object etc.

4.3.2.2 Infra red (IR) transmitter (emitter)

Infrared sensor is an electronic device that emits light. Infrared is electromagnetic radiation with a wavelength between 0.7 and 300 micrometers [18]. An infrared sensor measures the heat of an object as well as detects the motion. The types of sensors that measure only infra radiation, rather than emitting it, are called passive infrared sensor. Although in the infrared spectrum, all the objects radiate some form of thermal radiations. These types of radiations are undetectable by the naked eyes. Infrared emitter is simply an infrared light emitting diode (LED) and the detector is simply a photodiode which is sensitive to IR light with similar wavelength as that emitted by the infrared LED.

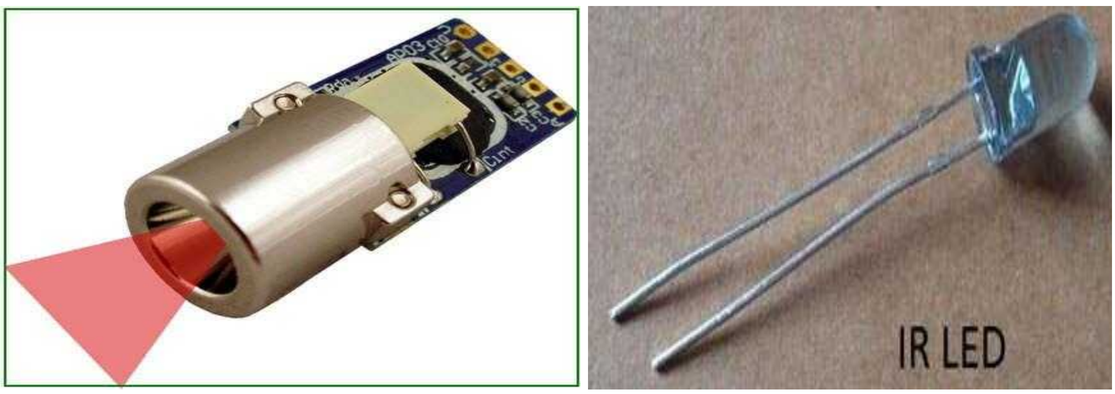


Plate II. Infrared (IR) sensors
(Source: Tarun, 2015 and Jayant, 2017)

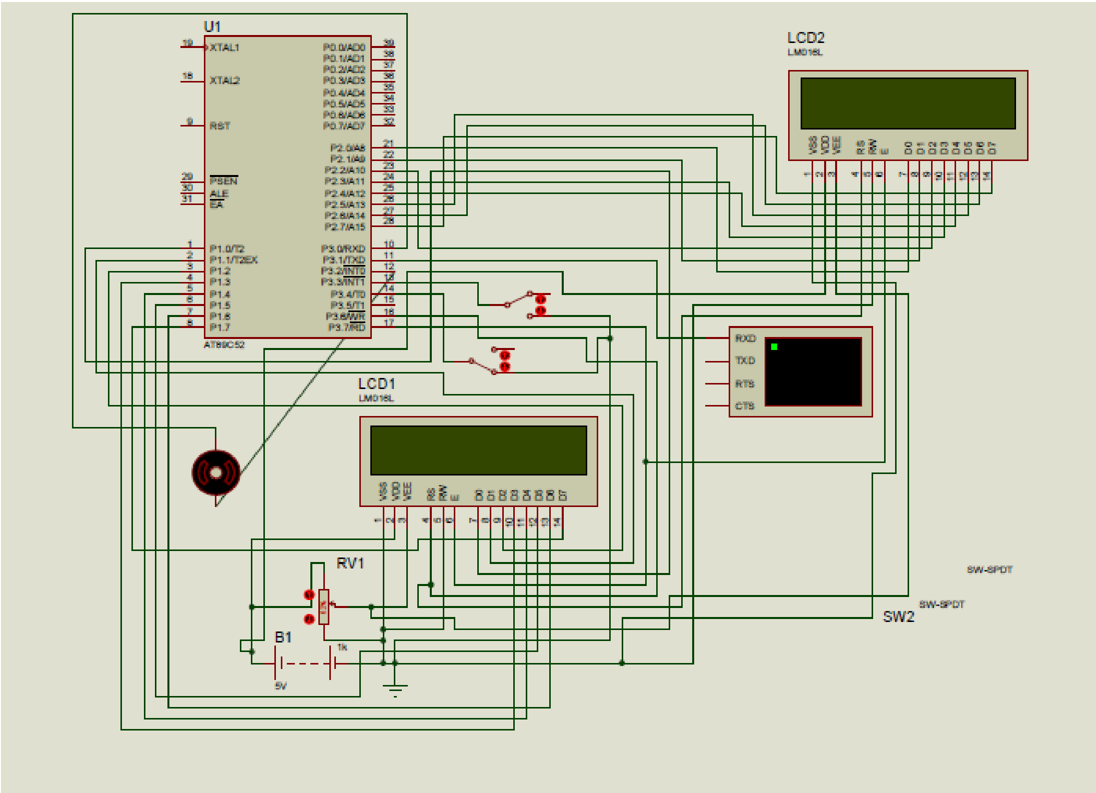


Fig. 7(a). Electronic circuit for the counting system

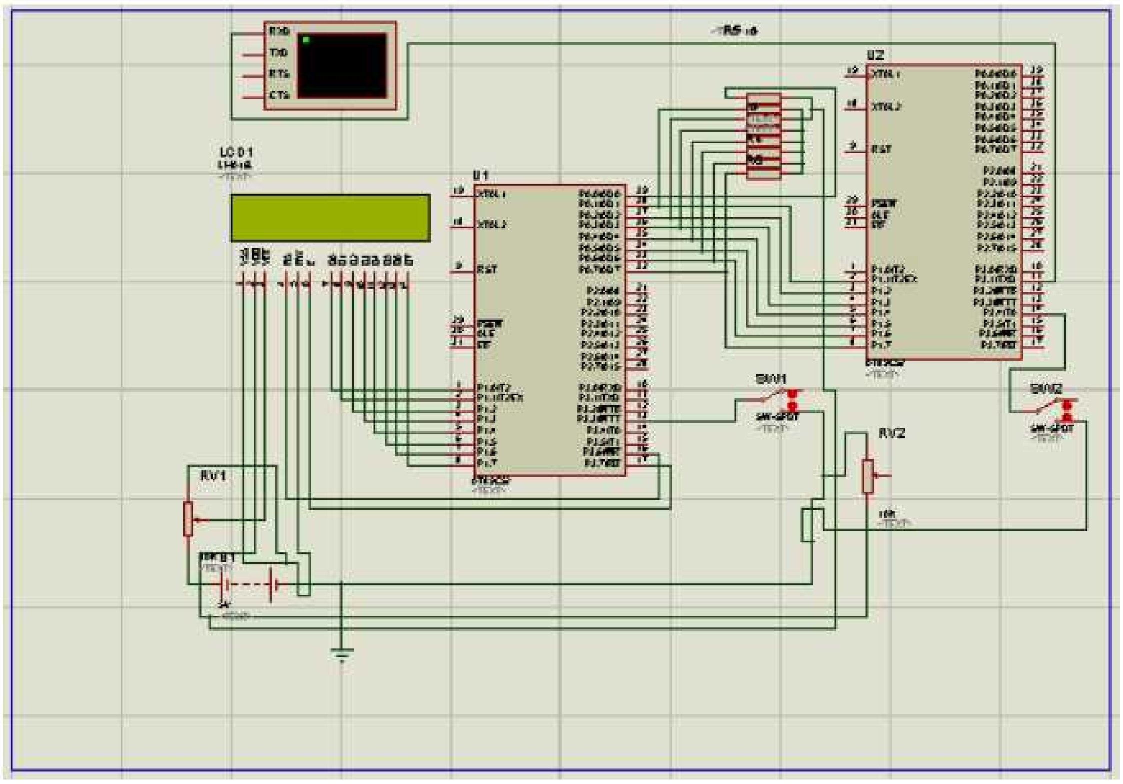


Fig. 7(b). Electronic circuit for the counting system modified

4.3.2.3 The photodiode

Photodiodes are light detector that converts light into voltage or current, depending on the function of the device. With an increase in their surface areas, photodiodes have a slower response time. A photodiode is a semiconductor device. It produces photocurrent by inducing electron hole pairs, due to the absorption of light in the intrinsic or depletion region. The photocurrent thus generated is proportional to the absorbed light intensity [19]. This means that When IR light falls on the photodiode, the resistance and the output voltage changes in proportional to the magnitude of the IR light received. Francheschinis et al. [13])

4.4 Principle of Operation and Circuit Design

The infra-red transmitter radiates the infra-red light perpendicular to the path of the moving product. As the product passes by, it blocks the ray light from reaching the IR receiver (photodiodes). The receiver in return senses the sudden blockage and send the signal to the micro-controller, by so doing it count the product. The micro-controller in turn receives the signal and compares the input signal and the out signal, if the number of input product is not equal to the output product, the micro-controller send a data code 5 on the computer monitor or display screen which means "product missing" or "product/material in-balance", through the interface (MAX232) device, which interface to the radio frequency transmitter, RF module transmits the information to the RF module receiver in which the module receives the data and convey the data to the computer through MAX 232, the computer display the massage incubated inside the data.

4.4.1 Electronic circuit design

The design of the circuit was carried out using proteus electronic circuit design platform and the circuit is shown in Fig. 7(a) and (b).

4.4.2 Simulation software for electronic circuit simulation

Electronic simulation software is used to test how the design will work in the real condition. There are many electronic simulation software available for use to simulate electronic design with many in- built tools to use. The most popular simulation software for electronic project is PROTEUS. Proteus provides the features that is called with ISIS and ARES and that allows the designer to design an electronic circuit and then simulation it. It also gives room to create a printable circuit board (PCB) layout using the software. The proteus software version is 7.0 which is compatible with window operating systems was used, although the simulation was done using window XP and window 7 operating system. As an electronic simulation software and application, proteus 7.0 has been developed for schematic capture, microprocessor simulation again for printable circuit board (PCB) designs. It is the widely used version all over the world and about 98% of installations are currently using this version. Labcenter electronics (2013) and John [20].

4.5 Theoretical Framework for Design Analysis of Conveyor System

4.5.1 Design mathematical equations for conveyor system

4.5.1.1 Conveyor belt design

In the design analysis of a conveyor belt system the following parameters are calculated; Belt capacity, C;

$$C = 3.6\ x\ \begin{matrix} load\ cross\ section \\ perpendicular\ to\ belt \end{matrix}\ x\ belt\ speed\ x\ \begin{matrix} material \\ density \end{matrix} \tag{1}$$

The belt width can be obtained from equation 2 given by Deshmukh and Trikal, [7]

$$\text{Belt width} = \frac{T_1}{Belt\ strength} \tag{2}$$

According to Ananth, Rakesh and Daniyan, Adeodu and Dada [21]. The belt thickness (*tb*) is as given from equation 3 and 4 as:

$$P_A = A_b\left(6 - \frac{\rho_b \text{ x } V_b^2}{10^6}\right)\left(1 - \frac{1}{e^{\mu\theta}}\right)V_b \tag{3}$$

$$A_b = W_b \, x \, t_b \tag{4}$$

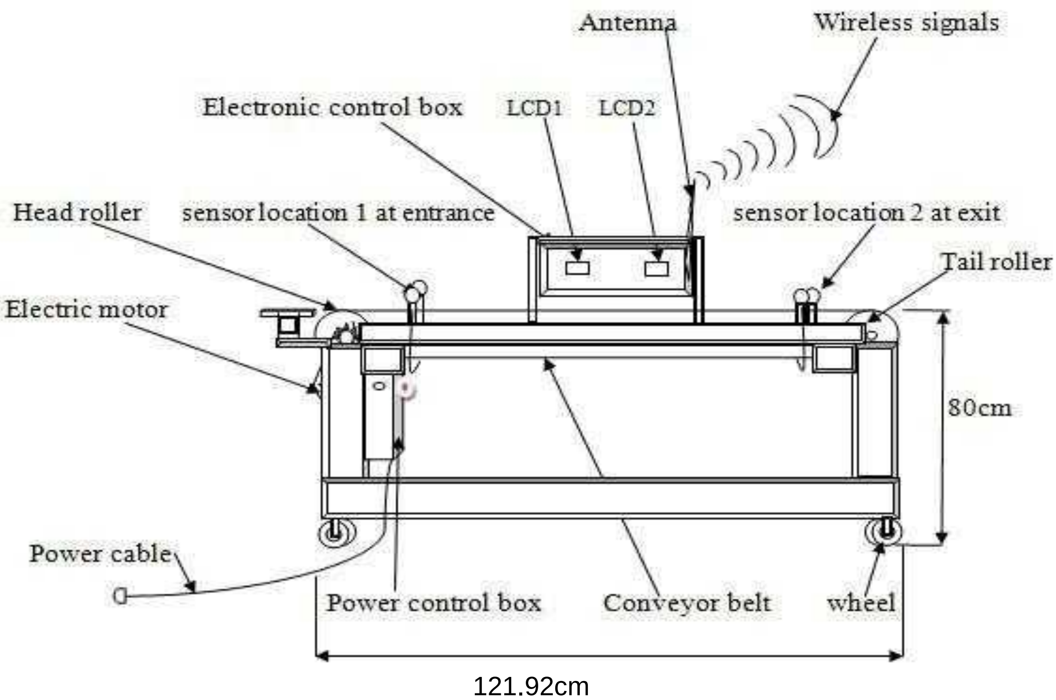


Fig. 8. The automatic conveyor machine structure

4.5.1.2 Belt friction and tension

To determine the minimum tension which must be introduced into the belt as it leaves the driving pulley, to ensure that the effective tension or power can be transmitted into the belt passing around the drive pulley, without slip. It is necessary to understand the effect that friction and tension have on the driving characteristics of a pulley. The mathematical equations for the calculation of the friction and tension are as follows;

$$\text{Effective tension } T_e = \begin{matrix} total\ empty \\ friction \end{matrix} + \begin{matrix} load \\ friction \end{matrix} \tag{5}$$

The return side friction, total empty friction and carrying side empty friction can be obtained using equation 6, 7 and 8 as given by Deshmukh and Trikal [7].

a) Return side friction = F_c x Q x L x 0.4 x g (6)

$$\text{Total empty friction} = F_e = F_c \text{ x } (\text{L} + t_f) \text{ x Q x L x 0.4 x g} \quad (7)$$

$$\text{Carrying side empty friction} = \frac{total\ empty}{friction} - \frac{returned\ side}{friction} \quad (8)$$

The load friction, load slope tension friction and carrying side empty friction can be obtained using equation 9, 10 and 11 as given by Deshmukh and Trikal, [7].

$$\text{b) Load friction} = F_l = F_1\left(L + t_f\right)\frac{c}{2.6 \, x \, S} \text{ x g} \quad (9)$$

$$\text{c) Load slope tension} = \text{L}_{\text{ST}} = \frac{CH}{3.65}\ x\ g \quad (10)$$

$$\text{d) Load slope} = B\ x\ H\ x\ g \quad (11)$$

The effective tension was determined using equation 12 as given by Ananth et al. [21].

$$\text{Effective tension} = \text{T}_\text{e} = F_C + F_L + L_{ST} \quad (12)$$

4.5.1.3 Power requirement

Power absorbed (PA) can also be calculated form effective tension from equation 13 according to Khurmi and Gupta [22] thus;

$$\text{Power absorbed, P}_\text{A} = T_e x\ v\ (kW) \quad (13)$$

The power of the motor as stated by Ananth et al. [21] was obtained from equation 14.

$$\text{Motor power P}_\text{m} = \frac{P_A}{\eta} \quad (14)$$

4.5.1.4 Calculations of sprocket parameters

In the analysis of a sprocket, the following factors are considered [22];

i. Type, dimensions of the sprocket.
ii. The number of teeth on the sprocket.

4.5.1.5 Mathematical equation for determining sprocket parameters

In other to calculate the parameters of a sprocket the formula that can be used is obtained from velocity ratio of a chain drive system and is shown in equation 15, according to Khurmi and Gupta, [22].

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} = \frac{T_2}{T_1} \quad (15)$$

4.5.1.6 Determination of the length of the chain

The chain length of open chain drive system consisting of two sprockets of T1 and T2 number of teeth, is obtained from the equation 16 as given by Khurmi and Gupta, [22] thus;

$$L = \frac{p}{2}((T_1 + T_2) + 2X + \frac{[\frac{P}{2}Cosec(\frac{180}{T_1}) - \frac{p}{2}Cosec(\frac{180}{T_2})]^2}{X} \quad (16)$$

4.6 A typical design Steps in Belt Conveyor System

Design calculation is necessary to guide decision on the require drive unit capacity, belt speed, belt width and the type of belt material and also to establish the basic parameters of the conveyor design. The important factors to be considered are;

i. Material and material geometry to be conveyed
ii. Belt width (effective belt width for the materials)
iii. Belt speed
iv. Transport capacity (belt conveyor capacity) and volume capacity of the belt
v. Mass capacity of belt
vi. Belt tension
vii. Motor power.

4.6.1 Material to be conveyed

The materials to be conveyed on the system are packets of matches with the configuration of the product to be conveyed, specified in Fig. 9.

Packet of matches (product type: double rabbit safety matches)

Net mass of packet = 68.96 g = 0.06896kg = 0.069 kg

Net weight of packet of matches = mg = 0.069 x 10 = 0.69 N

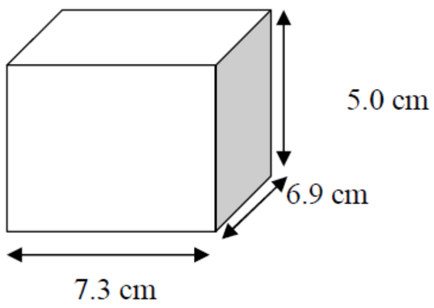


Fig. 9. Material structural configuration

Length of packet = 7.3 cm
Breadth of packet = 6.9 cm
Height of packet = 5.0 cm

Cross sectional area of the packet base = 7.3 cm x 6.9 cm
= 50.37 cm2
= 5.073x 10-3 m2

Volume of the packet of matches = cross sectional area x height
= 50.37 cm x 5.0 cm
= 251.85 cm3 = 251.85 x 10-6 m3

Density of packet of matches = $\rho = \frac{mass}{volume} = \frac{69.0g}{251.85\text{cm}^3}$.

= 0.27397 g/cm^3

= 0.274 g/cm^3 = 274 kg/m^3

= 0.274 tonne/m^3

4.6.2 Design input parameters

During the design of a belt conveyor, the first step to be taken as stated by Bhoyar and Handa, [23] is that, "the design of a belt conveyor with specific conveying capacity is to determine the speed and width of the belt". Table 3 shows the design input parameters used for the belt conveyor design.

Table 3. Design input data used for the belt conveyor

Parameters	Dimension
Belt speed (Vb)	0.05m/s (0.25 below the lowest value for non abrasive material on a flat belt with any belt width, (Belt conveyor design manual Mechanical engineering department, Carlos University)).
Height of conveyor H	80cm (0.80m)
Conveyor length	4Ft (1.2192m)
Tensile strength of belt material (leather)	2MPa

The velocity of the belt Vb is obtained from appendix A, with reference to material type and geometry. (Source: Khurmi and Gupta, [22]).

4.6.3 Volume/transport capacity of belt conveyor

The transport or belt capacity of the belt conveyor is obtained using the expression or equation below;

$$C = 3600\text{x } V_b \text{ x } A \text{ x } \gamma \tag{17}$$

Where:

Vb = belt speed = 0.05 m/s (Belt conveyor design manual Mechanical engineering department, Carlos University)
A = cross sectional area of material over the belt (m^2) = 5.073x 103 m^2
γ = material specific weight (t/m^3) = 0.274 tonne/m^3

Then;

C = (3600 x 0.05 x 5.078 x 10^{-5} x 0.274) tone/m^3
C= 2.504 x 10^{-3} tonne/h
= 2.504 kg/h

C is the belt conveyor capacity based on the configuration of the material.

4.6.4 Material mass M_m (live load) per metre

The material Mass M_m per metre (kg/m) loaded on a belt conveyor can be obtained according to Daniyan [24] as fellow:

$$M_m = \frac{C}{3.6 \text{ } X \text{ } V_b} \tag{18}$$

Where:

C = Conveyor/transport capacity = 2.504 x 10-3 t/h
Vb = belt speed = 0.05 m/s

Then, $M_m = \frac{2.504}{3.6 X 0.05} = 13.91 = 13.91$ kg/m

Other important factors that determine belt capacity is troughing angle and angle of surcharge (especially for gain or lump size type of materials or products). For this design, the troughing angle is zero, that is λ = 0, because it is a flat roller [21].

4.6.5 Volumetric belt load VL

When belt is running horizontally and evenly loaded, the volumetric belt load as given by [24] is also given as;

$$V_L = \frac{L_C}{W} \quad (19)$$

Where:

VL = Volumetric belt load (m3/hr)
L_C= Load capacity of the belt (tone/hr) = 2.504 x 10 tonne/hr
W = specific weight of the conveyor material (tone/m3) = 0.274 tone/m3

$$V_L = \frac{L_C}{W} = \frac{2.504 \text{ x } 10^{-3}}{0.274} = 9.14 \text{ x } 10^{-3} \text{ m}^3/\text{hr}$$

.

This shows that almost 9.14 x 10-3m3 of the test products can be loaded on the conveyor per hour.

4.6.6 Conveyor Belt Length

The conveyor belt orientation is that of open belt type. This is the orientation used for must belt conveyor systems.

4.6.6.1 The horizontal distance of the conveyor

But conveyor length (mini conveyor length) = 4.0 ft = 1.2192 m

Horizontal distance = 1.2192 m

Therefore, horizontal distance = conveyor length.

According to Daniyan et' al. [24], the belt basic length is given thus:

The belt basic length = 2 x length along conveyor route

= 2 x 1.2192 m = 2.4384 m

But, the length is shorter by 1%, for proper level of tensioning. (Module 13, lecture no 31)

Therefore, the required belt length = 2.4344 – (2.4384 x 1%)
= 2.4384 – 0.024384 = 2.4140 m

Actual belt length round the rollers, Lb ≈ 2.410 m
= 2410 mm

4.6.6.2 Belt wraps length (W_L) AB over roller

The bet wrap length (W_L) is the length of the belt that makes direct surface to surface contact round with the roller.

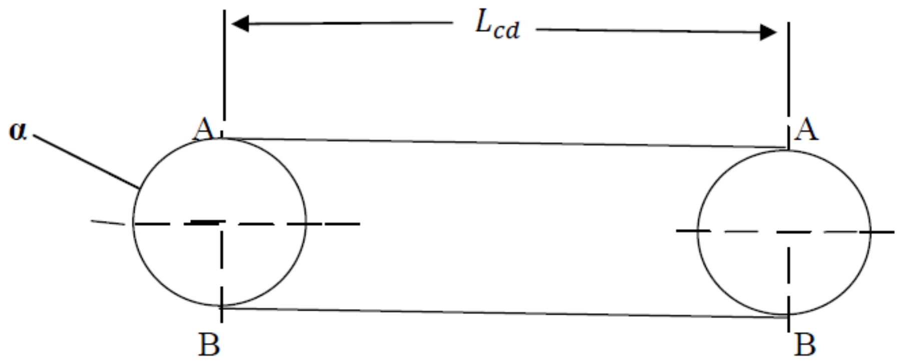


Fig. 10. Conveyor belt and roller geometry

The angle of wrap, α = 180°
Roller diameter = 50.8 mm

Roller radius = $\frac{\text{Roller diameter.}}{2}$ = 25.4 mm = 0.00254 m

$$W_L = \text{length of arc } /AB/ = \frac{\alpha}{360}\ x\ 2\pi r$$

$$= \frac{180}{360}\ x\ 2\pi(25.4) \tag{20}$$

$$= \pi\ (17.5) = 79.8 \text{ mm}$$

But, there two rollers of equal diameter, then total wrap length = $2W_L$
= 2 (79.8)
= 159.6 mm

4.6.6.3 Centre distance (centre to centre distance between rollers), $\boldsymbol{L_{cd}}$

The centre to centre distance is the distance from the centre of roller at the conveyor drive head and the roller at the conveyor tail end where the driven roller is located. From Fig. 10, the centre to centre distance, /AA/ or /BB/ is obtained thus;

$$L_{cd} = (\frac{L_b - 2W_L}{2})$$

$$= \frac{2410 - 159.6}{2}$$

$$= 1125.2 \text{ mm} \tag{21}$$

$$L_{cd} = 1.1252 \text{ m}$$

4.6.6.4 Mass of moving parts

The mass of moving parts on a conveyor is shown in Table 4;

Table 4. Conveyor components and their mass per unit length

Conveyor moving components	Mass (kg)
Belt	1.64
Chain	0.48
Sprocket (large)	0.82
Sprocket (small)	0.13
Live load	1.39
Roller (2)	1.65 X 2 = 3.3

Mass of moving parts, M_Q is obtained thus:

$$M_Q = (M_r + M_b + M_r)$$
$$= 7.76 \text{ kg} \quad (22)$$

Mass of moving parts part per centre to centre q is;

$$M_q = \frac{Q}{L_{cd}} = \frac{7.76}{1.1252} = 6.897 \text{ kg/m} \quad (23)$$

4.6.6.5 Component frictions

These parameters and their value are obtained using the mathematical model equations stated in section 1.6.

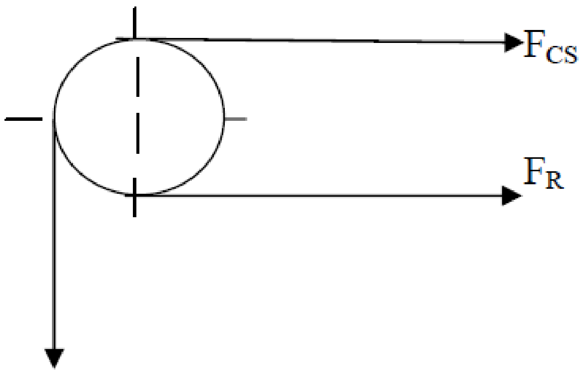


Fig. 11. Friction and tension on belt conveyor

The return side frictional force F_R

The return side frictional force F_R is calculated using the following expression;

$$F_R = (F_e \; x \; M_Q \; x \; L_{cd} \; x \; 0.4 \; x \; 9.8 \; x \; 10^{-3}) \text{ kN} \quad (24)$$

Where:

F_e = 0.020 (for horizontal conveyor equipment friction factor [21]

M_Q = 181.415kg/m (mass of moving parts per metre length
L_{cd} = 1.15m (centre to centre distance of rollers)

$$F_R = (\,0.020\ x\ 7.76x\ 1.1252\ x\ 0.4\ x\ (9.8\ x\ 10^{-3}))\ \text{kN} \quad (25)$$

$$F_R = 6.846x\ 10^{-4}\ \text{kN}$$

Total empty friction, FTE

$$F_{TE} = (\,F_e\ x\ (L_{cd} + t_f)\ x\ M_Q\ x\ (9.8\ x\ 10^{-3}))\ \text{kN} \quad (26)$$

Where, from Fenner Dunlop conveyor manual, (2009):

$$t_f = 45$$

$$F_{TE} = (\,0.020\ x\ (1.1252 + 45)\ x\ 7.76\ x\ (9.8\ x\ 10^{-3}))\ \text{kN}$$

$$F_{TE} = 701.54\ x\ 10^{-4}\ \text{kN}$$

Carrying side empty friction, F_{CS}

$$F_{CS} = F_{TE} - F_R$$

$$F_{CS} = 701.54\ x\ 10^{-4}\ \text{kN} - 6.846x\ 10^{-4}\ \text{kN}$$

$$F_{CS} = 69.47\ x\ 10^{-3}\ \text{kN}$$

Load friction, F_L

$$F_L = (\,F_t\ (L_{cd} + t_f)\ x\ \frac{C}{3.6V_b}\ x\ (9.8\ x\ 10^{-3}))\ \text{kN} \quad (27)$$

Where: Ft = 0.025 for horizontal and elevating conveyor, C = 2.504kg/h,

Vb = 0.2

$$F_L = (\,0.025\ (1.15 + 45)\ x\ \frac{2.504}{3.6\ (0.2)}\ x\ (9.8\ x\ 10^{-3}))\ \text{kN}, \qquad F_L = 5.096\ x\ 10^{-3}\text{kN}$$

4.6.6.6 Belt tension

The minimum tensions which the conveyor belt will be subjected to are calculated as follows; Load slope tension (TLS); the slope tension is the product of the belt weight and the vertical lift and has its maximum value at the highest point (height) of the conveyor.

TLS can be calculated thus:

$$T_{LS} = \frac{CH}{3.6\ x\ V_b}\ (9.81\ X\ 10^{-3})\ \text{kN}$$

$$T_{LS} = \frac{2.504\ X\ 0.8}{3.6\ x\ 0.05}\ (9.81\ X\ 10^{-3})\ \text{kN} \quad (28)$$

$$T_{LS} = 0.1092\ \text{kN}$$

Effective tension, Te

Te = Total empty friction + load friction + load slope tension
= ($701.54 \times 10^{-4} + 5.096 \times 10^{-3} + 0.109$) kN
= 0.1845 kN

Carrying side tension, T1

$$T_1 = T_e\,[\frac{\xi}{e^{\mu\alpha} - 1} + 1] \quad (29)$$

Where:

ξ = 1.66 (Drive coefficient), [8].
μ = 0.30 (coefficient of friction for bare roller under dry condition) [8].

$\alpha = 180 =$ (angle of belt wrap or contact)

$$T_1 = 0.1845\text{kN}\,[\frac{1.66}{e^{(0.30 \, x\, 3.142)} - 1} + 1]$$

$$T_1 = 0.1845\,[2.057] = 0.3794 \text{ kN}$$

Return/slack side belt tension, T2 is obtained from equation 30 as given by Ananth et al. [21].

$$T_2 = T_1 - T_e$$

$$T_2 = 0.3794 - 0.1845 \quad (30)$$

$$T_2 = 0.1949\text{kN}$$

Therefore, the ratio of T1to T2 is = 1.95 ≈ 2.0

Table 5. Arc of contact and ratio of tensions

Arc of contact on Driving pulley degree	Ratio $\frac{T_1}{T_2}$		Ratio $\frac{T_1}{T_2}$		Ratio $\frac{T_1}{T_2}$		Type of Drive
	Bare pulley	Lagged pulley	Bare pulley	Lagged pulley	Barred pulley	Lagged pulley	
180	2.19	3.00	3.00	0.85	0.50	1.85	Plain
190	2.29	3.19	3.19	0.78	0.46	1.78	Snubbed
200	2.39	3.39	3.39	0.72	0.42	1.72	do
210	2.50	3.16	3.61	0.67	0.38	1.67	do
220	2.61	3.83	3.83	0.62	0.35	1.62	Snubbed
230	2.73	4.13	4.13	0.58	0.32	1.58	do
240	2.85	4.33	4.33	0.54	0.30	1.54	do
360	2.48	9.02	9.02	0.26	0.13	1.26	Tandem
380	5.25	10.19	10.19	0.23	0.11	1.23	do
400	5.72	11.51	11.51	0.21	0.09	1.21	do
420	6.25	13.00	13.00	0.19	0.08	1.19	do
440	6.90	15.29	15.29	0.17	0.07	1.17	Tandem
460	7.67	15.90	15.90	0.15	0.063	1.15	do
480	8.15	19.21	19.21	0.14	0.055	1.14	do
500	8.86	21.21	21.21	0.13	0.050	1.13	Tandem
600	13.17	39.06	39.06	0.08	0.030	1.08	do

Source: Indian Standard (2000); Selection and design of belt conveyors —code of practice (First Revision) ICS 53.040.10; Bureau of Indian Standards

Note: The pulley developed is a bare type and angle of contact 180°. From calculation, the ratio of T1 to T2 is approximately 2.0.

4.6.6.7 Conveyor belt width

The fundamental purpose of a conveyors' belt is to carry the loaded material along the length of the conveyor structure, from the feed point at the tail of the conveyor, to the discharge point at the head of the conveyor.

The conveyor belt width can be calculated from equation 31 and is given by;

$$W_b = \text{Belt width} = \frac{T_1}{Belt\ strength} \tag{31}$$

According to Khurmi and Gupta [22], the Belt material strength = 2.0 MPa

= 2.0 N/mm2

$$W_b = \frac{0.3794\text{kN}}{2.0\ x\ 10^6} = 189.7\text{ mm (minimum belt width)}$$

The effective belt width can be smaller or larger than the minimum belt width, this was also adopted by Deshmukh and Trikal, [7], so in this work the belt width of 200mm is used with reference to the width and length of the product/material to be conveyed or tested on the system and also to prevent rapid failure of the belt and to make the system more robust. Also, Ananth et al. [21] stated, I quote "when a belt width of certain value is obtain one may have verify the relationship between the belt width and the maximum lump size of the material according to the following expression";

Belt width ≥ maximum lump size or product size

From the system design specification for this conveyor the belt width is 200 mm and a corresponding value of 0.05 metre/sec for the belt speed was obtained with reference to belt conveyor design guide manual (mechanical engineering department, Carlos (III) University, USA), set for a non abrasive materials with any width for flat belt conveyor system, although this is subject to adjustment as other design conditions and parameters changes.

4.6.6.8 Belt thickness

The belt thickness can be obtained from equation 3 and 4 as given by (Module 13, Belt Drives)
Design stress for leather belt =2.0MPa = 2.0N/mm^2

$$Belt\ width = 200\ mm$$

$$\text{Belt thickness} = t_b$$

$$P = A_b\left(б - \frac{\rho_b\ x\ V_b^2}{10^6}\right)(1 - \frac{1}{e^{\mu\theta}})\ V_b$$

$$10 = A_b\left(2 - \frac{1000\ x\ 0.05^2}{10^6}\right)\left(1 - \frac{1}{e^{0.3\ x\ 180}}\right)0.05$$

$$10 = A_b(2 - 0.0000025)(1 - 0.3896) x\, 0.05$$

$$10 = A_b\ (0.0610)$$

$$A_b = \frac{10}{0.0610} = 163.83\ mm^2$$

But $A_b = W_b\ x\ t_b$

$$t_b = \frac{A_b}{B_w} = \frac{163.83}{200} = 0.82\ mm$$

$t_b = 0.82mm \approx 1.0$mm (Minimum belt thickness), and a 2.0mm belt thickness was used.

4.7 Absorbed Power (P_A)

The amount of power required by the conveyor is by definition of power equal to the product of the force applied and the speed at which the conveyor belt travels. The force applied is the effective tension and hence the power required at the shaft of the drive pulley.

The power P_A required due to the entire load on the drive system is;

$$P_A = T_e\ x\ V_b$$

$$= 0.1845kN\ x\ 0.05 \qquad (32)$$

$$P_A = 9.225\ x\ 10^{-3}\ kW$$

P_A is also referred to as the power required by drive pulley to move.

4.7.1 Determination of motor capacity

The motor power is given by $P_m = \frac{P_A}{\eta}$ (33)

Where:

η = 0.93 (from Fenner Dunlop conveyor manual, [8] and CEMA, [1] conveyor manual for conveyor chain drive system), see appendix E.

$$P_m = \frac{9.225\ x\ 10-3\ kW}{0.93}$$

$= 9.919$ W ≈ 10 W (this is the minimum power requirement of the motor)

12 volt satellite actuator motor of low speed was selected. Motor characteristic;
Motor Speed = 5mm/s = 0.005 m/s
Shaft diameter = 10 mm
Load capacity = 3000 N.

4.7.2 Motor output r.p.m

According to Khurmi and Gupta, [22] the speed of an electric motor is given by equation 34.

$$V_m = \frac{\pi D_{ms} N}{60} \quad (34)$$

$$\text{Hence; } N = \frac{60V_m}{\pi D} = \frac{60\ X\ 0.005}{\pi(0{,}01)} = 9.55\ \text{rpm}$$

4.7.3 Torque on system

The torque developed on the system can be calculated using the following expression in equation 3.35 and 3.36, as given by Khurmi and Gupta, [12] thus;

$$P_A = \frac{2\pi NT}{60} \quad (35)$$

$$T = \frac{60P_A}{2\pi N}$$

$$= \frac{60\ x\ 9.919}{2\ x\ \pi\ x\ 9.55} = 9.918\text{N-m} = 9.92\ \text{N-m} \quad (36)$$

4.8 Roller Design

Standard rollers for conveyor frame are available of varying diameter depending on load capacity and configuration.

4.8.1 Roller width or length design

Also, it is true that all belt tend to wander a bit during operation, so the overall width of the roller should exceed the belt width by a certain factor or value, for instance at belt width up to 650 mm the added value is 100 mm, [8]. This is to avoid serious edge damage. From Habisat conveyor belt engineering guide, the relationship between roller width and belt width is given as;

Table 6. Width of roller/pulley recommendation

Belt width Bw	Pulley/roller width Rw
Bw ≤ 100 mm/4 in	Rw = Bw + 20 mm/0.8 in
Bw ≥ 100 mm/4 in	Rw = (1.08 x Bw) + 12mm/0.5 in

(*Source: www.Habisat.com) Rw*

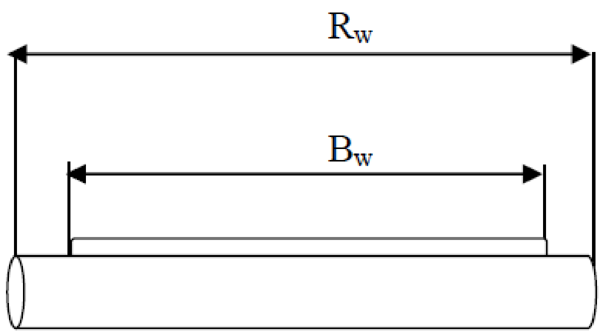


Fig. 12. The relationship between roller width and belt width
(Source: www.Habisat.com)

Therefore, the minimum width of roller for a belt width of 200 can be calculated thus;

Bw ≥ 100 mm/4 in
That is, for Bw = 200 mm,
Then, Rw = (1.08 x Bw) + 12 mm/0.5in
But 0.5inch = 12 .7 mm
Rw = (1.08 x 200) + 12 mm/1 .7 = 216.95 ≈ 217 mm

In this conveyor design a roller with of 230 mm is use to avoid serious edge damage to the belt.

4.8.2 Head and tail roller shaft design

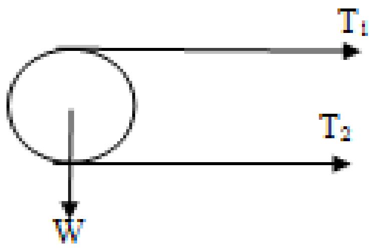


Fig. 13. Tension and weight on roller

$$F_H = T_1 + T_2$$

$$= 379.4 + 194.9 \quad (37)$$

$$= 574.3N = 0.5743\ kN$$

$$F_V = W = mg$$
$$= 1.65 \times 9.8 = 16.17N = 0.01617\ kN \quad (38)$$

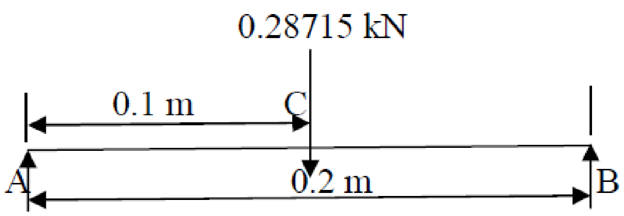


Fig. 14a. Load and moment diagram

Point load acting at C

$$R_{CH} = \frac{0.5743}{2} = 0.28715\ kN$$

Taking moment at A

$$\sum M_{AH} = 0$$

$$R_{CH} \times 0.1m - R_{BH}\,(0.2) = 0 \quad (39)$$

$$R_{BH} = \frac{R_{CH} \times 0.1}{0.2} = \frac{0.28715 \times 0.1}{0.2} = 0.1436\ kN$$

Similarly, RAH = 0.1436 kN
Horizontal moment

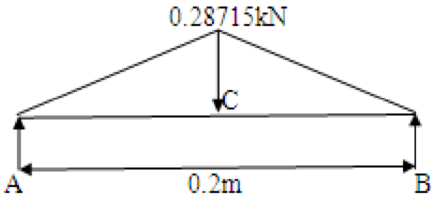


Fig. 14b. Load and moment diagram

Moment at C,

MCH = RCH x 0.1= 0.28715 kN x 0.1
= 0.028715 kN-m

Vertical loading

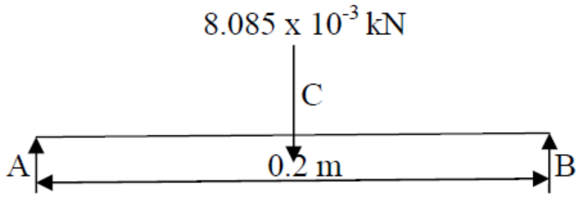


Fig. 14c. Load and moment diagram

Point load acting at C,

$$\sum M_{AV} = 0$$

$$R_{CV} \text{ x } 0.1\text{m} - R_{BV}\ (0.2) = 0 \tag{40}$$

$$R_{BV} = \frac{R_{CV} \text{ x } 0.1}{0.2} = \frac{8.085 \text{ x } 10-3 \text{ x } 0.1}{0.2} = 8.085 \text{ x } 10^{-4} \text{kN}$$

Similarly, RAV = RBV = 8.085 x 10-4 kN

Vertical moments

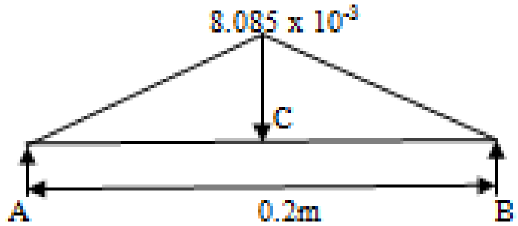


Fig. 14d. Load and moment diagram

Moment at C,

$M_{CV} = R_{CV} \times 0.1$

$= 8.085 \times 10^{-3} \times 0.1$

$= 8.085 \times 10^{-4}$ kN-m

Resultant moment at C, MR was obtained from equation 41 as stated by Khurmi, (2012).

$$M_R = \sqrt{(M_{CV}{}^2) + (M_{CH}{}^2)}$$
$$= \sqrt{(8.085 \times 10^{-4})^2 + (0.028715^2)} = 0.028726 \approx 0.0287\text{kN-m} \quad (41)$$

Equivalent torque

The equivalent torque Teq is calculated, by using the expression in equation 41 according to Khurmi, (2012).

$$T_{eq} = \sqrt{[(M \times k_b)^2] + (T \times k_t)^2]} \quad (42)$$

Where:

T = 0.00992 kN

According to Deshmukh and Trikal, [7] and Ananth et al. [21] Kb = bending service factor
= 1.5.

Also, as stated by Deshmukh and Trikal, [7] and Ananth et al. [21], Kt = torque service factor = 1.25.
Therefore,

$$T_{eq} = \sqrt{[(M \times k_b)^2] + (T \times k_t)^2]} = \sqrt{[(0.0287 \times 1.5)^2] + (0.00992 \times 1.25)^2]}$$

Teq = 0.0448 kN-m

Equivalent moment

By using equivalent moment formula, stated in equation 43 given by Khurmi, (2012).

$$M_{eq} = \frac{1}{2}[(M_R \times k_b) + (T_{eq})]$$

$$M_{eq} = \frac{1}{2}[(0.0287 \times 1.5) + (0.0448)] \text{ kN-m} \quad (43)$$

$$M_{eq} = 0.0439\text{kN-m} = 43.9\text{N-m}$$

Allowable bending stress ($б_b$)

The allowable bending stresses can be obtained from the following formula according to Khurmi (2012), Khurmi and Gupta, [22].

$$б_b = \frac{32\ M_{eq}}{\pi d^3} \quad (44a)$$

Where, $б_{b\ =\ 65MPa}$

Where, $б_b$ = 65MPa

Therefore,

$$d = \sqrt[3]{\frac{32\ x\ M_{eq}}{бb\ x\ \pi}} = \sqrt[3]{\frac{32\ x\ 43.9}{65\ x\ 10^6\ x\ \pi}}$$

$$d = \sqrt[3]{6.8833x10^{-6}}$$

$$d = 0.00262m \quad (44b)$$

$$d = 2.6mm$$

Therefore, the required minimum roller/pulley shaft diameter is 3mm and a 9mm was used.

4.8.3 Pulley/roller diameter

Pulley/roller diameter is obtained from the following expression:

$$D = \sqrt{d^2 + (0.001273\ x\ L_b\ x\ G)}$$

Where; D = pulley diameter (m)
d = centre core diameter
= belt length

G = Belt thickness (mm)

$$D = \sqrt{(0.0026)^2 + (0.001273\ x\ 2.41\ x\ 0.82)}$$

D = 0.0502 m = 50.2 mm (minimum diameter), the roller diameter fabricated is 50.8 mm this is due to the thickness of the different stainless steel pipe that was cut and used.

4.9 Sprockets Design

In other to know the size of the sprocket to use the following analysis are carried out.

4.9.1 Calculations of sprocket parameters

D_1 = Driving sprocket (larger) diameter =?
D_2 = Driven (smaller) sprocket diameter = 58 mm
N_1 = Driving sprocket speed = 9.55 rpm
N_2 = Driven sprocket speed =?
T_L- Number of teeth of the driving (large) sprocket =?
T_S - Number of teeth of the driven (small) sprocket = 14

The number revolution per minute of the small sprocket attached to the roller, N2 is obtained thus;

$$N_2 = \frac{60V_b}{\pi D} = \frac{60 \; x \; 0{,}05}{\pi \; x \; 0.058} = 16.5 \; rpm$$

But, from velocity ratio of a chain drive system

$\frac{N_1}{N_2} = \frac{D_2}{D_1} = \frac{T_2}{T_1}$ (Khurmi and Gupta, [22] (machine Design) from equation 14

The number of teeth on the driving sprocket can be calculated from equation 14 thus:

$$T_1 = \frac{N_2 \; x \; T_2}{N_1} = \frac{16.5 \; X \; 14}{9.55} = 24.2$$

Note: The sprocket attached to the motor is selected with 24teeth.

4.9.2 The chain pitch

Then; p = Chain pitch

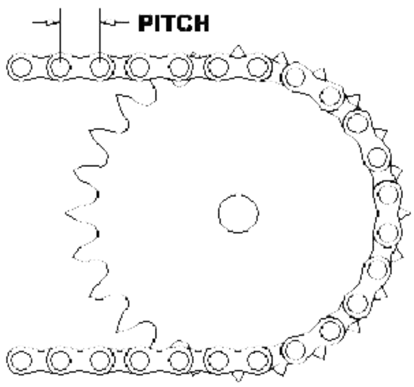


Fig. 15. Sprocket and chain showing pitch

Circle pitch diameter of sprocket that is driven = 58mm, pitch circle radius, r2 = 29 mm = 0.029 m

$$r_2 = \frac{P}{2} \text{cosec} \left(\frac{180}{14}\right) = 0.029$$

The, 5.7369p = 0.029

$$p = \frac{0.029}{5.7369} = 0.00505 \text{ m} = 5.05 \text{ mm}$$

Then, the chain length is given by Khurmi and Gupta (2012) from equation 20 as follows;

$$L = \frac{p}{2}((T_1 + T_2) + 2x + \frac{[\frac{P}{2} Cosec\left(\frac{180}{T_1}\right) - \frac{p}{2} Cosec\left(\frac{180}{T_2}\right]^2}{X}$$

Then,

T1 = 24
T2 = 14
P = 5.05 mm
D2 = 58 mm
D1 = 100.2 mm
x = 178 mm (distance between the centre of the driven and the driving sprocket)

$$L = \frac{p}{2}((T_1 + T_2) + 2x + \frac{[\frac{P}{2}Cosec\left(\frac{180}{T_1}\right) - \frac{p}{2}Cosec\,(\frac{180}{T_2}]^2}{X}$$

$$L = \frac{p}{2}((T_1 + T_2) + 2x + \frac{[\frac{P}{2}Cosec\left(\frac{180}{T_1}\right) - \frac{p}{2}Cosec\,(\frac{180}{T_2}]^2}{X}$$

$$L = \frac{5.05}{2}(24 + 14) + 2(178) + \frac{[\frac{5.05}{2}\,cosec\left(\frac{180}{24}\right) - \frac{5.05}{2}\,cosec\,(\frac{180}{14})]^2}{178}$$

$$L = 2.525\,(38) + 356 + [\frac{[19.34 - 11.35]^2}{178}]$$

$$L = 451.95 + 0.045$$

$$L = 451.995\text{ mm} \approx 452\text{ mm}$$

Therefore, the length of the chain used is 452 mm

The chain use for this work is an example of power transmitting chain and is bush roller chain

4.10 Design of Frame Support

This analysis is carried to ensure the stability, strength of the structure. The objective here is to produce a structure capable of resisting all applied loads without failure during its intended life because it primary purpose is to transmit or support load(s) on it.

4.10.1 Analysis of frame geometry

The shape weight analysis in accordance with Khurmi and Gupta [22] was done on a square, rectangular and circular section and then a square section was selected as shown in Fig. 3.10.

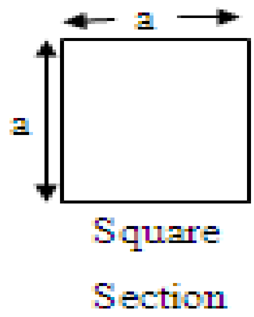


Fig. 16. Frame geometry

Three different cross sectional geometries were analyzed; that is rectangular, circular and square section. In the analysis it was assumed that, if the sections were made of the same material, then they have the same allowable stress (бa) and bending moment (m) and taking the modules of each section of the three columns to be equal.

Therefore, from the analysis a circular frame will weigh more, while a rectangular frame will weigh least. But for more stability of cross section a square frame is selected.

4.10.2 Stability of square support frame

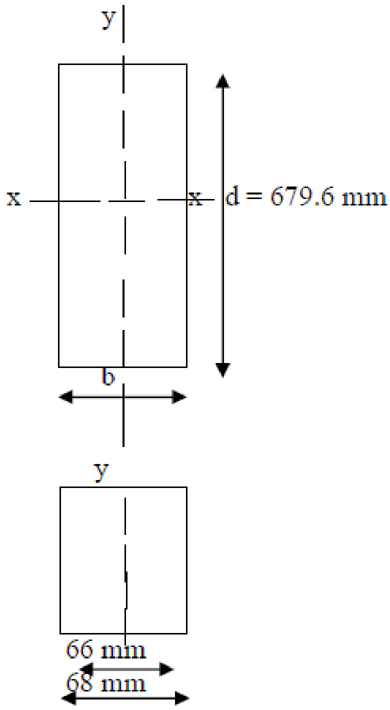


Fig. 17. Sectional view of support frame

The moment of inertia of the column section

$$I_{xx} = \frac{BD^3}{12}$$

$$I_{yy} = \frac{DB^3}{12} \quad (45)$$

According to Khurmi and Gupta (2012)

$$I = \frac{DB^3}{12} - \frac{db^3}{12}$$

$$I = \frac{679.6\ x\ 68^3}{12} - \frac{679.6\ x\ 66^3}{12}$$

$$I = 1525475.467\ mm^4$$

The area of the column section

$$A = BD - bd$$

$$A = BB - bb$$

$$A = (68\ x\ 68) - (66\ x\ 66)$$

$$A = 268\ mm^2$$

Radius of gyration is obtained using equation 46 as given by Vanamane and Pravin [25]

$$k = \sqrt{\frac{I}{A}}$$

$$= \sqrt{\frac{1525475.467}{268}} = 75.45 \quad (46)$$

The Slender ratio is obtained from equation 47 according to Khurmi and Gupta [22]

$$\text{Slenderness ratio,} = \frac{l}{k}$$

$$= \frac{length\ of\ column}{radius\ of\ gyration} = \frac{679.6}{75.45} = 9.01 \quad (47)$$

Therefore, the slenderness ratio is < 30; hence, no buckling takes place. The structure design is safe for the support frame.

4.10.3 Safe load on frame support

The safe load on the frame is calculated from Fig. 18

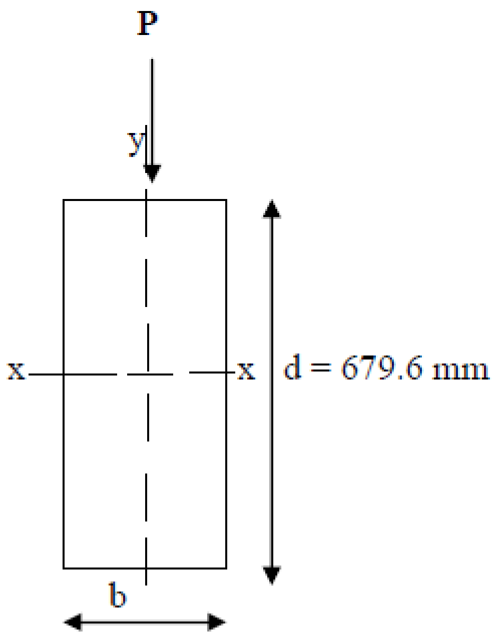


Fig. 18. Safe load on frame support

For short column, the safe load according to Khurmi and Gupta [22] is given by;

$$P = 6_C \text{ x } A \quad (48)$$

Where; $6_c = 320MPa$ (compression stress for steel column) A = Area of column =268 mm2

Then, $P = 320 \text{ x } 268 = 85760N$ (this is the maximum load the column can support, any value above this they will failure in the column)

The load on the support column is

$$= \frac{1}{2}\ weight\ of\ roller + load\ effect\ due\ to\ resultant\ of\ tension\ on\ belt\ \text{due to roller}$$

$$= 8.25\text{N} + 184.5\ \text{N} = 192.75\ \text{N}$$

The load on the support, 192.75N < 85760N (maximum load the column can support), therefore, failure of base support will not take place.

4.11 Summary of the Results Obtained from Design Analysis for the Development of a Mini- conveyor

Table 7 shows essential parameters obtained from design calculations shown in section 1.7 for the development of a mini-conveyor.

Table 7. Essential parameters used in the development of the conveyor

S/N	Essential design parameters	Values
1.	Conveyor length (CL)	1.2192 m
2.	Belt length (Lb)	2.41 m
3.	Centre to centre distance between pulleys/rollers (Lcd)	1.1252 m
4.	Belt width (Wb)	200 mm
5.	Belt thickness pulley/roller width (tb)	2.0 mm
6.	Pulley/roller width (RW)	230mm (minimum)
7.	Pulley/roller diameter (DR)	50.8 mm
8.	Chain length (L)	452 mm
9.	Belt mass (MR)	1.64 kg
10.	Angle of contact or wrap (α)	180 degree
11.	Mass of rollers (MR) x 2	3.3 kg
12.	Motor power (Pm)	10 Watts
13.	Motor speed (N1)	0.005 m/s
14.	Belt speed (Vb)	0.05 m/s
15.	Carrying side tension (TI)	379.4 N
16.	Return side tension (T2)	194.9 N
17.	Conveyor height (H)	0.8 m
18.	Driven sprocket number of teeth (NT2)	14
19.	Driving sprocket number of teeth (NT1)	24

4.12 Typical Mechanical Steps for Conveyor Fabrication Process

The methods of fabrication include following steps;

i. Measuring and sizing of parts
ii. Cutting (by sawing) and boring
iii. Joining parts (by welding, threaded fasteners (bolts and nuts) and riveting)
iv. Filling/smoothening (using abrasive electric filling machine)
v. Coating by spraying

The conveyor is made up of three sections; the base supported by four trolley wheels, the electronic/electrical control unit and the belt-roller unit. The frame of the conveyor is made up of Mild Steel Material. The two conveyor rollers are at the end of the fame with the help of end bearing. Chain and sprockets are used for transmitting motion from the electric motor to the belt conveyor driving roller shaft. The sketch of the designed conveyor machine structure using computer aided design (CAD) software Solid works is shown in Fig. 19a and b.

Fig. 19a. 3D Solid work design of mini-automatic conveyor after design calculations and before fabrication

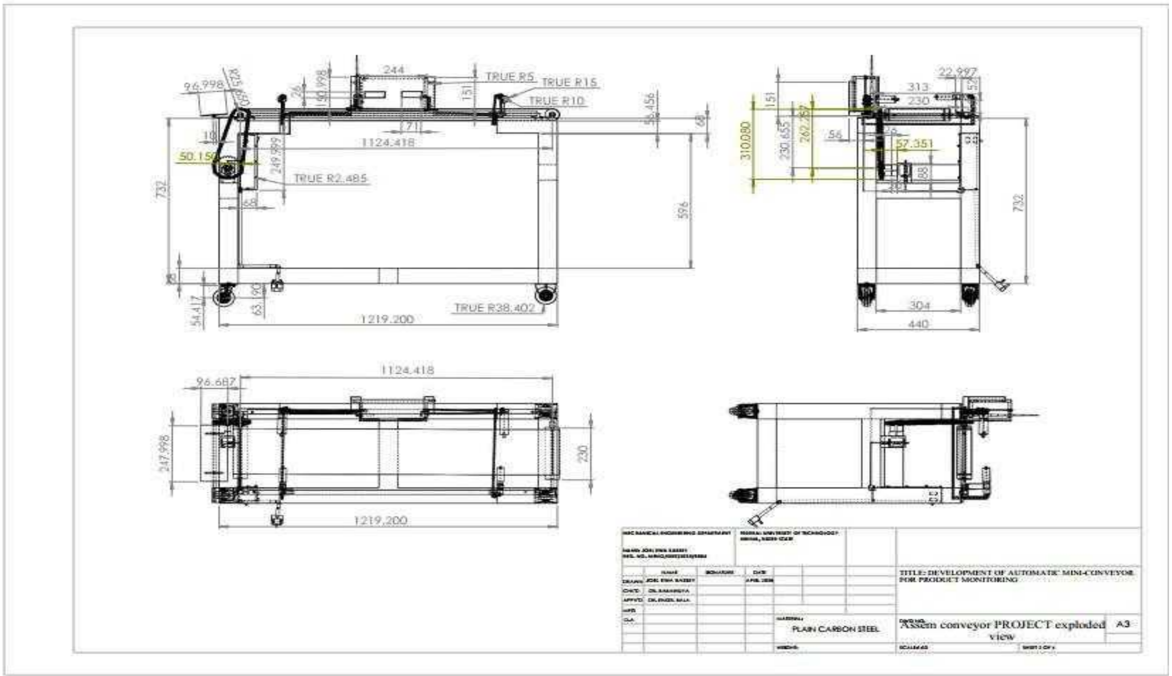


Fig. 19b. 2D Solid work design of mini-automatic conveyor after design calculations and before fabrication

The pictures of a fabrication operation, the parts used and fabricated mini-conveyor are shown in Plates III to VII.


a b

Plate III. a and b; cutting operation and a roller chain used


a b

Plate IV. a and b; fabricated rollers and drive roller with 14teeth sprocket

Plate V. Drive roller and the drive system

Plate VI. Fabricated mini-conveyor

Plate VII. Mini-conveyor after finishing

4.13 Sensors Analysis

4.13.1 Analysis of effect of distance between sensors on power density between sensors

Sensors distance analysis base on power transmitted and/or power density across sensors and magnitude of the incident current generated at the photodiode was carried out, considering Fig. 20.

The r value depends on the power rating of the sensors and the distance apart determines the responsiveness of the photodiode sensor to the light from the infra red sensor, this is determined through mathematical analysis as given by Adediran, [9] for charge carrying points, using the formula in equation 49;

$$P_d = \frac{P_t}{4\pi r^2} \tag{49}$$

Pt = is the power transmitted by the IR sensor, which comes with the manufacturer specification.
P_d= is the power density generated between the sensors.

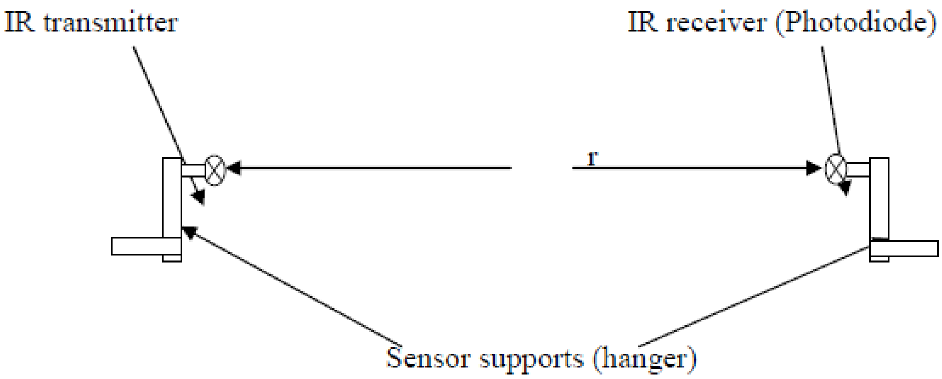


Fig. 20. Distance between sensors

This is used to evaluate effect of distance between sensors on power density of the received infrared light on the photodiode sensor used. Pt is the power transmitted that comes with the manufacturer specification. The distance r is measured with reference to the conveyor width.

4.14 Performance Evaluation of System units and the Mini-online Automatic Counting Conveyor Machine

4.14.1 The test procedure for the IR sensors functionality

In other to test if the IR sensor is functional is by connecting its terminal to a power source and then the emitted light is viewed using a mobile phone camera, because its emitted light is not visible with the human eyes.

Plate VII. Testing the functionality of the IR sensors

4.14.2 Automatic counting and signaling system hardware performance

The test on the system was carried out by first connecting the counting electronic box to a 9 volt power source. The sensors are connected to this box using flexible wires. The IR sensors and the photodiodes at the entrance and exit point are placed at certain distance apart. Using finger, fist and object, the sensing of the movement of the objects between sensors at the entrance and exit points where observed as a count displayed on LCD1 (orange coloured) for the entrance count and LCD2 (blue coloured) for the exit count respectively. Thereafter, the inter-connectivity between the sensor box the max232 modem was tested for response and functionality by turning the modem on and observing the response of the LED of the modem. When there is connectivity between the modem and the counting and signalling box the LED light is full and steady and when it is receiving data from the counting unit the LED light is full and slightly blinking.

4.14.3 Performance of the automatic mini-conveyor

The mini-conveyor is turned on as shown in Plate X, the sensors are adjusted for proper line in sight array, so that the photodiode will sense the light emitted from the IR sensor. Hand movement was carried across the sensors at the entrance and exit to test the alignment response of the sensors. The motor power was turned on and the product from the take off tray was taken by the moving conveyor belt. The time it takes the product to be conveyed between the entrance and exit sensors was measure using a stop watch. Also the effect of distance between IR and photodiode sensor on time of response to display on LCD was studied in other to the minimum distance between sensors that will give quick response to display time.

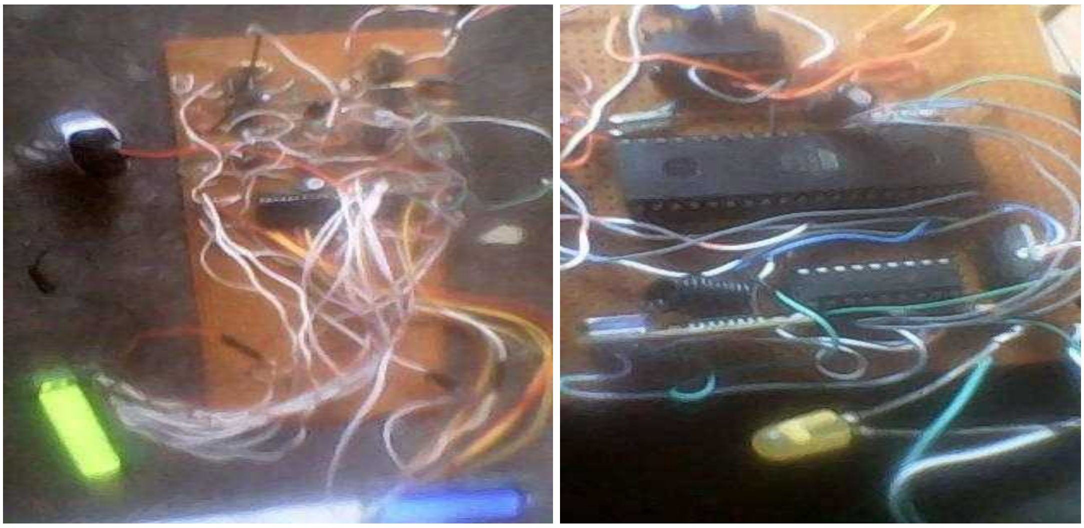


Plate IXa. Testing the performance of the automatic counting, signalling and wireless system and modem

Plate IXb. Testing the performance of the automatic counting, signalling and wireless system and modem

Plate X. Automatic Mini-Conveyor under test

4.14.4 Test distance

Fig. 21 shows a drawing which gives a brief view of the distance setup between conveyor machine and the computer monitoring system.

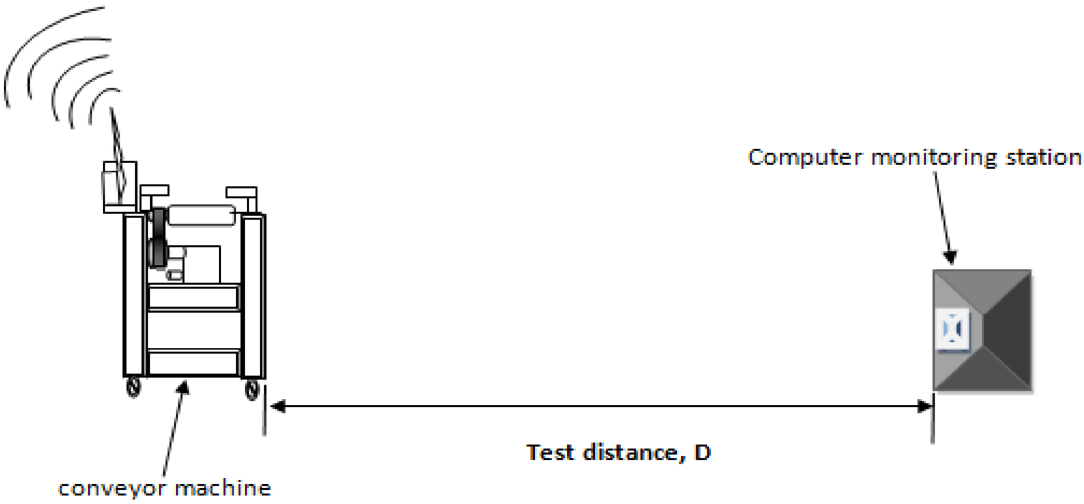


Fig. 21. Distance between conveyor machine and the computer monitoring system

During the test, the modem placed on the computer and connected to it was moved away from the conveyor machine and far away from the building in which the conveyor machine is stationed. The maximum distance at which there is loss of connection signal was measured using tape.

4.15 Simulation of Designed Circuit

Simulation was done on the ISIS professional animation platform, using a virtual circuit containing AT89C52 PLC microcontroller. The individual components in the circuit have been labeled as shown in Fig. 22. Assembly programming language was written and use to drive the simulation process and to examine how it will work in real time. The programming language written to execute the automated function is shown below (this is part of it);

Written Assembly Programming Language

```
  org 000h
tens_thousand equ 69h
thousand equ 71h
hundred equ 72h
tens equ 73h
ones equ 74h
;setb p3.5

start:
mov thousand, #30h
mov hundred, #30h
mov tens, #30h
mov ones, #30h
again:


setb tr1
call lcd_init
back:
......................
...............
jb p3.5, $
call delay
sjmp back
show:          inc ones
               mov a, ones
               cjne a, #3ah, show_exit
               mov ones, #30h
               inc tens
               mov a, tens
               cjne a, #3ah, show_exit
               mov ones, #30h
```

```
                mov tens, #30h
                inc hundred
                ……………………….
                ………………….
                cjne a, #3ah, show_exit
                mov ones, #30h
                mov tens, #30h
                mov hundred, #30h
                mov thousand, #30h
 show_exit:     call show_lcd
                ret
 show_lcd:      mov r1, #0cah
                call lcd_command
                mov r1, thousand
                call lcd_data
                mov r1, hundred
                call lcd_data
                mov r1, tens
                call lcd_data
                mov r1, ones
                call lcd_data
                ret

contac:
……………
……………………#30h

mov r1, a
mov p1, r1
call lcd_data
ret
lcd_init
……………………
……………
ret
lcd_command:
…………………………
………
delay:
mov r3, #20
ade:
mov r5, #220
jomn:
djnz r5, jomn
djnz r3, ade
ret
 end
```

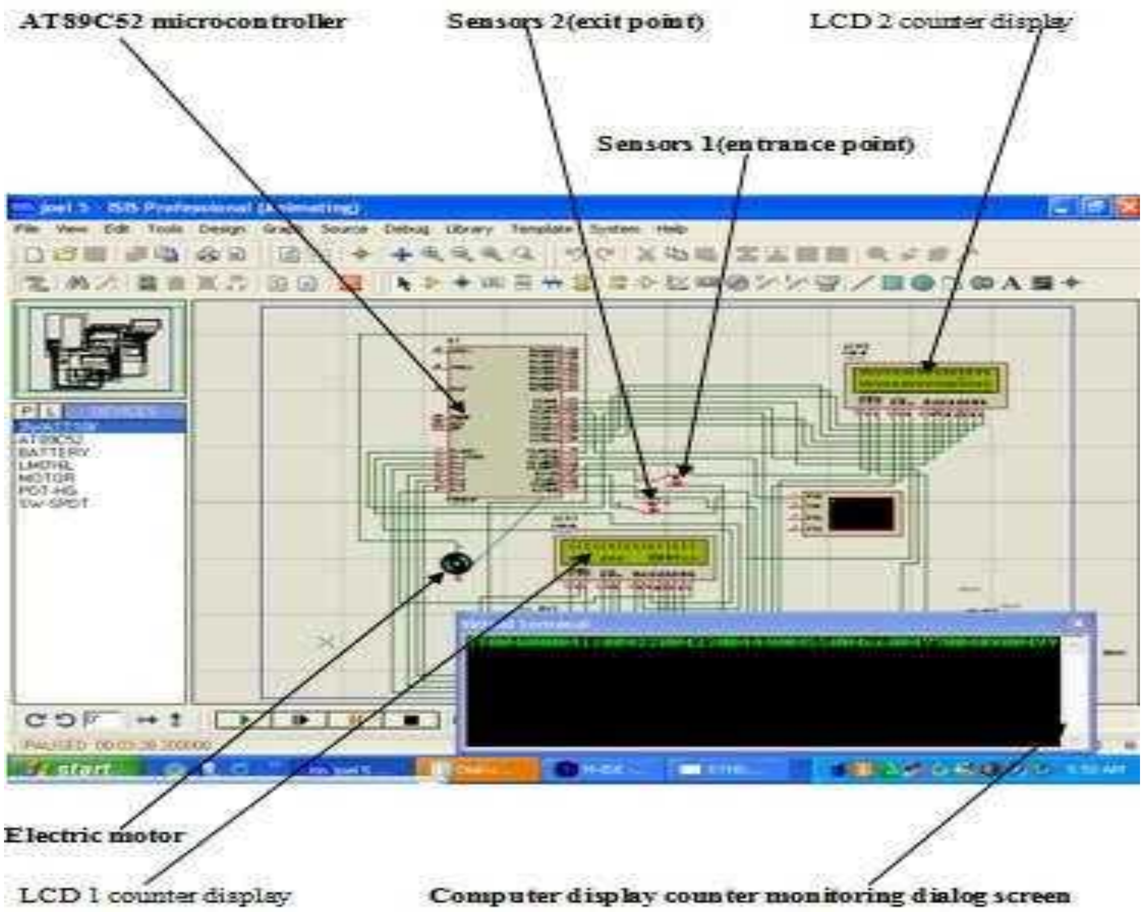


Fig. 22. Simulation layout (Products through first IR sensors (entry) on conveyor- system counting)

Fig. 23 shows the simulation layout of products passing in between the first sets of sensors at entry point on conveyor system. The simulation shows the count been displayed on the LCD 1 when the photodiode sensor power source is obstructed. This gives evidence as how it would perform in real life application.

Fig. 24 shows the simulation layout products passes between the second sets of sensors at the exit point on conveyor- system. The simulation show the count been displayed on the LCD 2 when the photodiode sensor power source is obstructed.

4.16 Hard Ware Developed

Plate XII, XIII and XIV shows the mini-on line conveyor with automatic counting, signalling and wireless system for monitoring products being conveyed through it. This has two sensors points at the part labeled II and IV, III is the automatic counting and signalling electronic box with two LCD (LCD 1, yellow coloured and LCD 2, blue coloured). A product I placed on the takeoff tray V, at the entrance point. When the switch on power control box VI is turned on, small switch for the automatic counting and signalling electronic box VII is turned on, the electric motor VIII, start up and conveyor belt rotates and the product is picked by the moving belt.

Plate XIII shows product between sensors at the entrance point, at this point the product block the photodiode from the light emitted by the IR sensor, this blockage is seen as an interruption by the photodiode sensing system and it is transformed into counting sequence by the micro- controller and is reflected as a number on the LCD 1(yellow coloured).

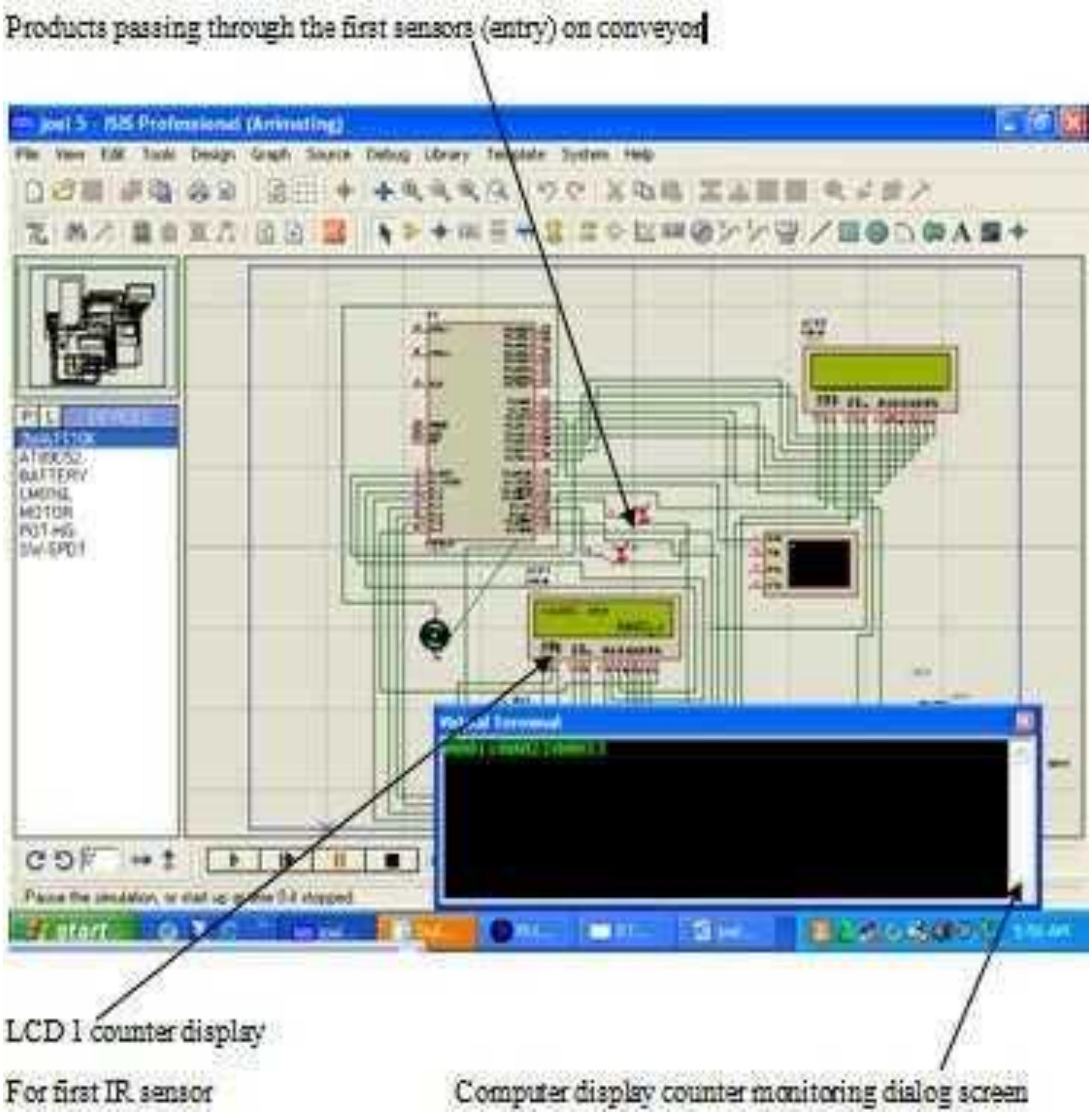


Fig. 23. Products through first sets of sensors (entry point) on conveyor system

Plate XIV shows the object or product in between the sensors at the exit point. At this point also, the product block the photodiode from the light emitted by the IR sensor, this blockage is seen as an interruption by the photodiode sensing system and it is transformed into counting sequence by the micro-controller and is reflected as a number on the LCD 2 (blue coloured). At this point the second microcontroller compares the count between the two sensors, and sends the count data or count imbalance error data (inform of a code number 5) through the data transmitting wireless signalling unit to the MAX 232 interfacing wireless data receiver modem, which is seen on the monitoring dialog box.

Plate XV shows that, the modem is connected to computer by means of a DB9 (COM 1 port) to USB conversion cable. The links that leads to the display of the monitoring dialog box on the telnet hyper terminal connectivity, on which the data received by the modem is displayed on the computer screen with window XP operating system, is shown below. Plate XVI shows the links and path taken to open the telnet hyper terminal connectivity dialog box.

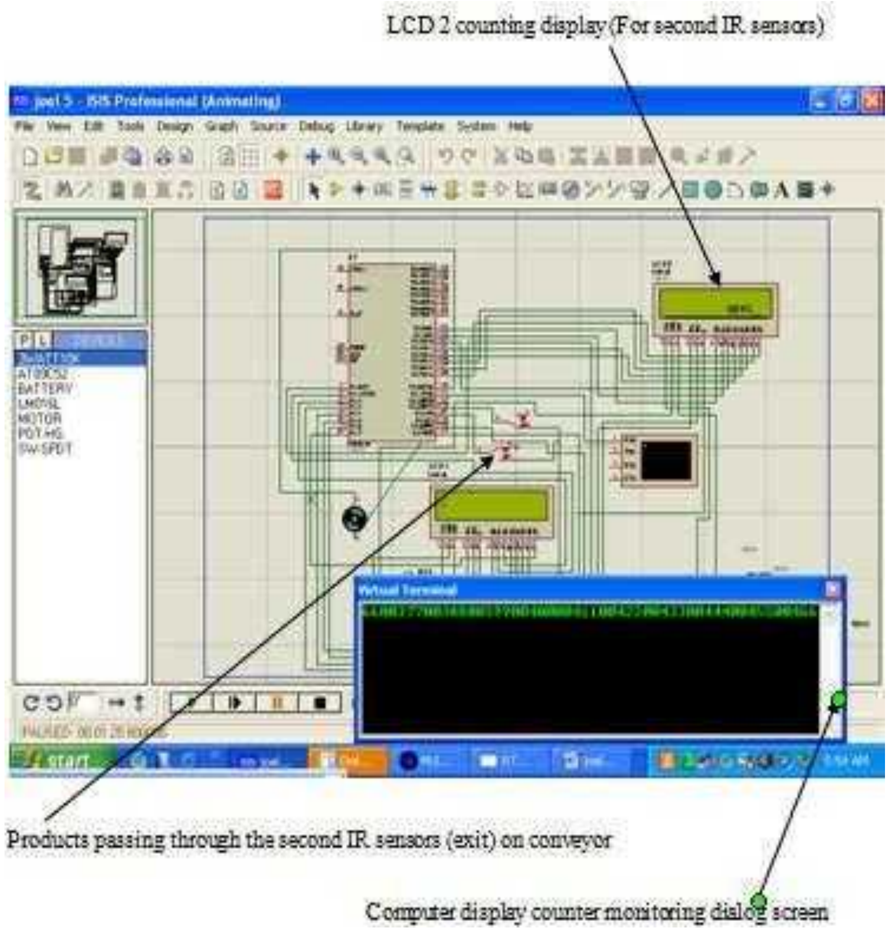


Fig. 24. Products through second sets of sensors (exit point) on conveyor system

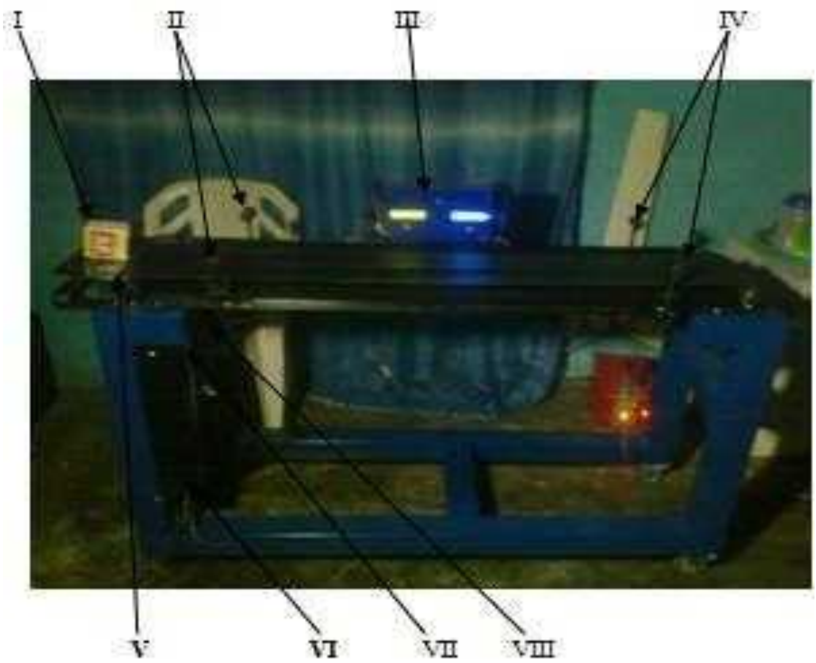


Plate XI. Product on takeoff tray on conveyor

Plate XII. Product between sensors at the entrance point

Plate XII. Product between sensors at the exit point

Plate XIV. MAX 232 data receiving wireless modem connected to a laptop

Taskbar → Start button → program → accessory → communication → hyper terminal

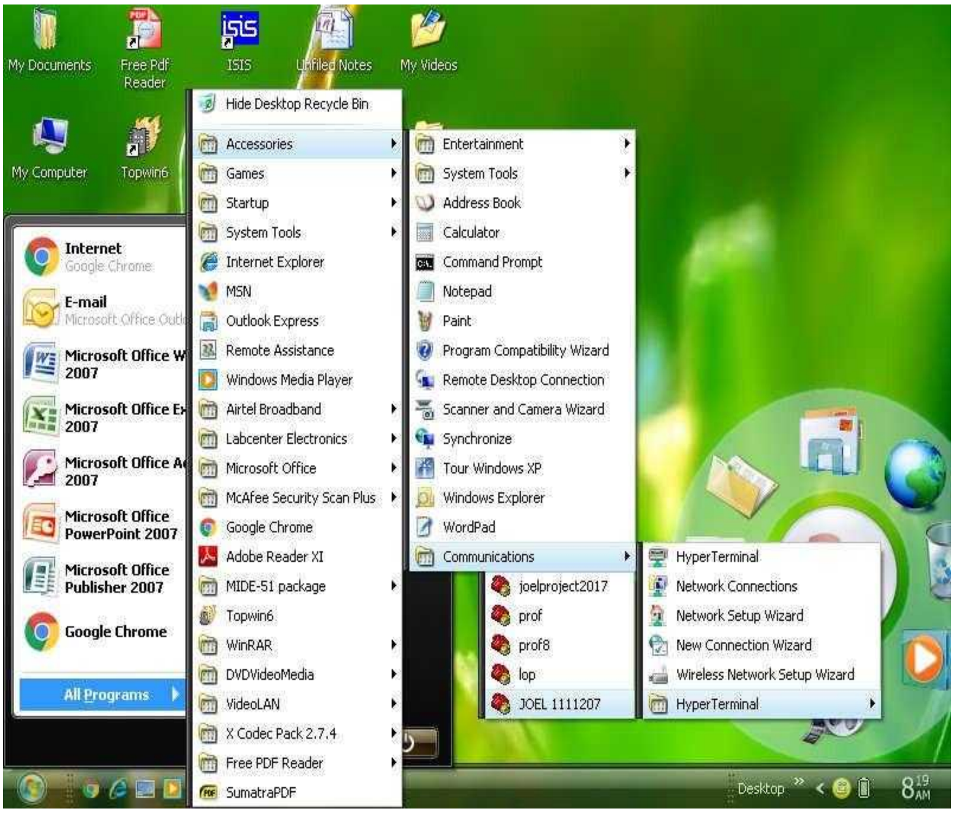


Plate XV. The links that leads to the display of the monitoring dialog box on the telnet hyper terminal connectivity

(a) **(b)**

Plate XVI. (a) The monitoring display dialog box initialized, (b) modem turned on

Plate XII (a), shows the monitoring display dialog box, appearing when the telnet hyper terminal links and setting is complete, (b) shows modem turned on and receiving data wirelessly when the coloured light indicator comes on, the monitoring display dialog box shows data sent to the computer system through the modem.

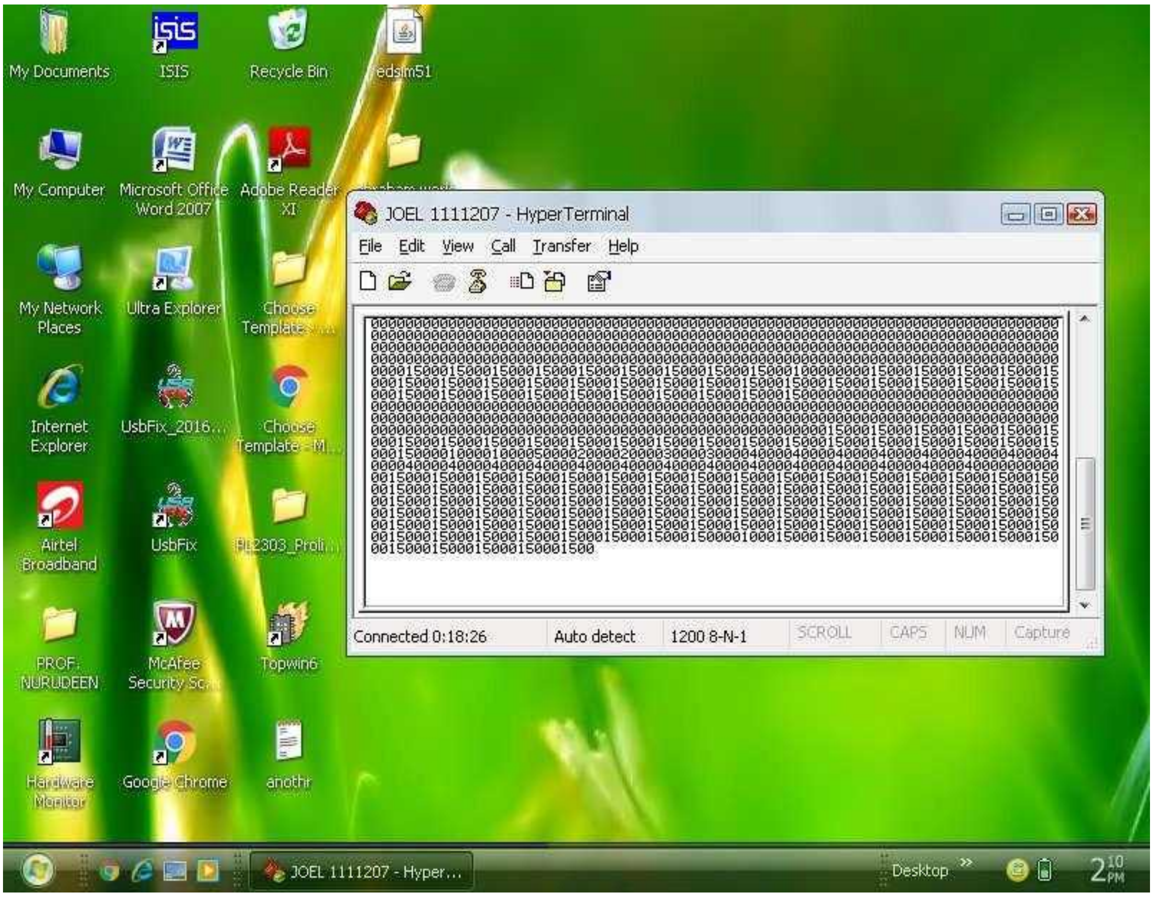


Plate XVII. Product monitoring display dialog box screen extracted from computer on plate XII (b)

000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
000000000000000000000000000000000000000000000000000000000000000000000

000001500015000150001500015000150001500015000150001500015000150001500015000150001500015000
150001500015000150001500015000150001500015000150001500015000000000000000000000000001500015

000010000100001000020000200002000030000300003000050000400004

000010000100001000010000100001000010000100001000010000200002000020000200002000020000200002
000020000200002000020000200002000020000200002000020000200002000030000300003000030000300004
000040000400004000040000400005000050000500005000050000500005000050000500005000050000500005
000060000600006000060000700007000070000700007000070000700007000080000800008000080000800008
00009000090000900009000090001000010000100001000010000100011000110001100011000110001100011

Fig. 25. Pre-count and count data display array

Plate XVIII. Computer screen showing enlarged monitoring display dialog box

The pattern of data display on the product monitoring display dialog box is shown in Fig. 25. The 00000 count is displayed when the modem is turned on and it is not receiving data or information from the signalling system on the conveyor. Immediately the modem connects wirelessly to the conveyor system, connection code 15 is displayed continuously on the monitoring dialog box, but immediately product or object passes between the sensors, the actual numbering begins, such as; 000010002000030000400005006 etc, as shown in Fig. 25. The computer receives this information on a telnet wireless protocol, on baud rate of 1200. The baud rate 1200 is the frequency at which the computer receives information and displays it.

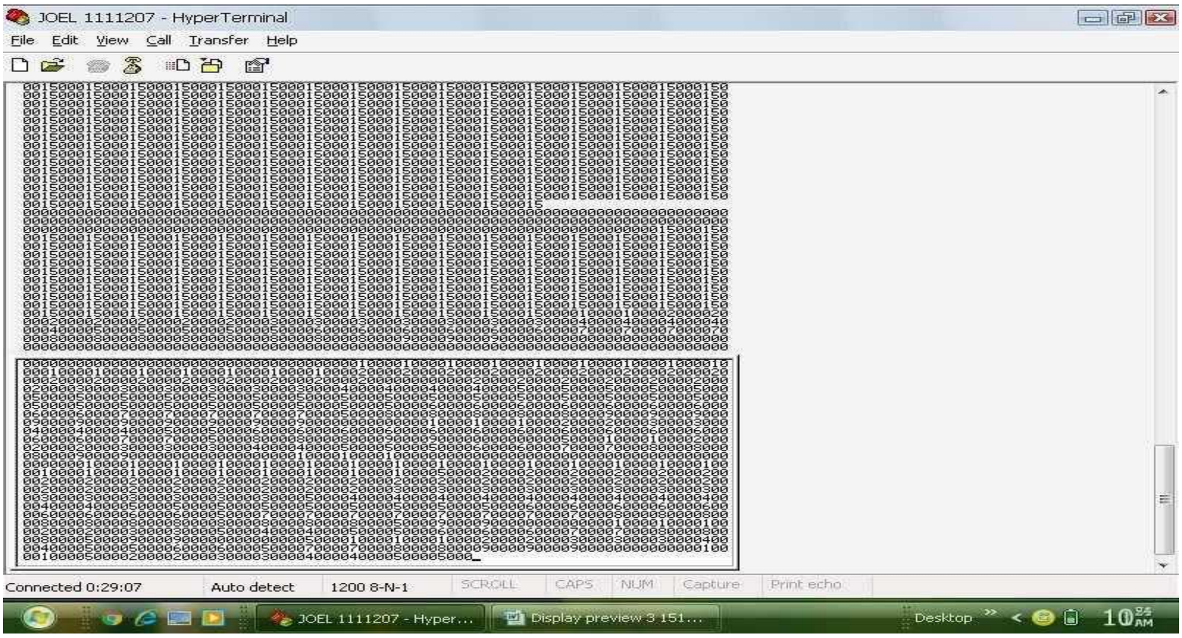


Plate XIX. Screen print of enlarge monitoring display dialog box

Plate XIV and XV shows that the monitoring display dialog box can be enlarged. This enables wider view of the data and also previously generated data in the last production period or schedule can be accessed. Production takes place on a shift bases, 8 hours to another 8hours for an instance and in each period of production, data are generated. Therefore, an effective and efficient production management system would be one that has very effective material handling and inventory system.

5. EXPERIENTIAL RESULTS AND DISCUSSIONS

5.1 Effect of Distance between Sensors on Power Density

The effect of the distance between the sensors on the power density between sensors was investigated and it was analyzed using mathematical model presented in equation 3.56. Tape was used to measure the distance between sensors, as the sensors position was varied with reference to the width of the conveyor and the belt. The data obtained was tabulated, in Table 8 and graph was plotted using MATLAB software as show in Fig. 25.

Table 8. The effect of distance between sensors on power density

Power transmitted Pt (mW)	distance between sensors, r (m)	r^2	$\frac{1}{r^2}$	power density (P_d)
8	0.10	0.0100	100.0	63.66
8	0.15	0.0225	400.0	28.29
8	0.20	0.0400	25.0	15.92
8	0.25	0. 0625	16.0	10.19
8	0.30	0.0900	11.1	7.07
8	0.35	0.1225	8.2	5.20
8	0.45	0.2025	4.9	3.14

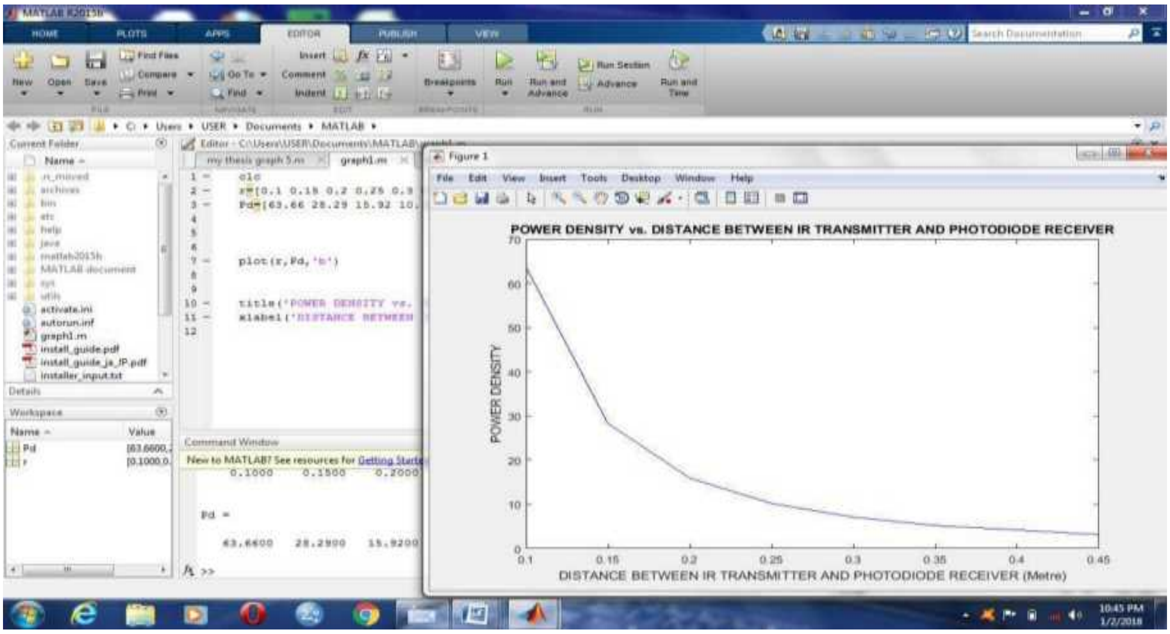


Fig. 26. Graphical plot 1 using MATLAB software

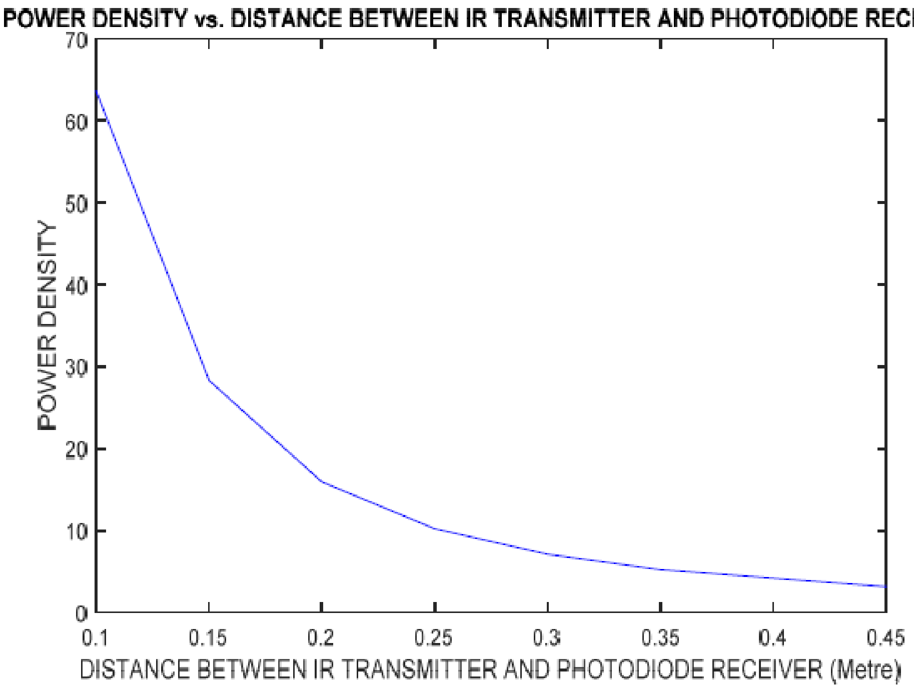


Fig. 27. A graph of Effect of distance between sensors on power density

The graph obtained reveals that as the distance between sensors increases the power density decreases. This result gives a guide as to how far apart the sensors must be positioned in order to obtain optimum sensitivity when placed in their line of sight. This analysis adequately gives an insight into how the relative distance between the sensors affects the power density and how power density between sensors affect the incident current generated. The positioning photodiode sensor at certain distance away from the IR sensor affect it's sensitively to the light emitted by the IR sensor. Although, the responsivity of the photodiode is constant as the stated by the manufacturer, it is dependent on the power density between sensors and the incident current generated at the IR detector (photodiode sensor). According to Panos and Nickolay, [26], the responsivity is the parameter (applicable to all detectors) and can be defined as the output signal (typically voltage or current) of the detector produced when it response to a given incident radiant power falling on the detector.

5.2 Effect of Distance between Sensors on Response Display Time on LCD

The Table 9 shows the response display time on LCD obtained by varying the distance between the IR and photodiode sensor. The graph was plotted using MATLAB and is shown in Figs. 4.9. This result reveals that at the of 0.096m the time it takes the system to sense the object and display the count on the LCD is approximately 1.0 second. Also determined is the time it takes the product to move from sensor at entrance to sensor at exit point was measured to be between 15.7 sec to 16.3 sec depending on the power in the motor from the power source. The distance between the entrance sensors and the exit sensor is 0.8 m; it therefore means that the product is moving at the speed of 0.05 m/s. This is the speed at which the conveyor belt is moving.

Table 9. Distance between sensors and Response display time on LCD

Distance between sensors (m)	Response display time on LCD (second)
0.247	7.0
0.225	5.5
0.184	4.7
0.165	4.1
0.135	3.5
0.116	2.8
0.096	1.0

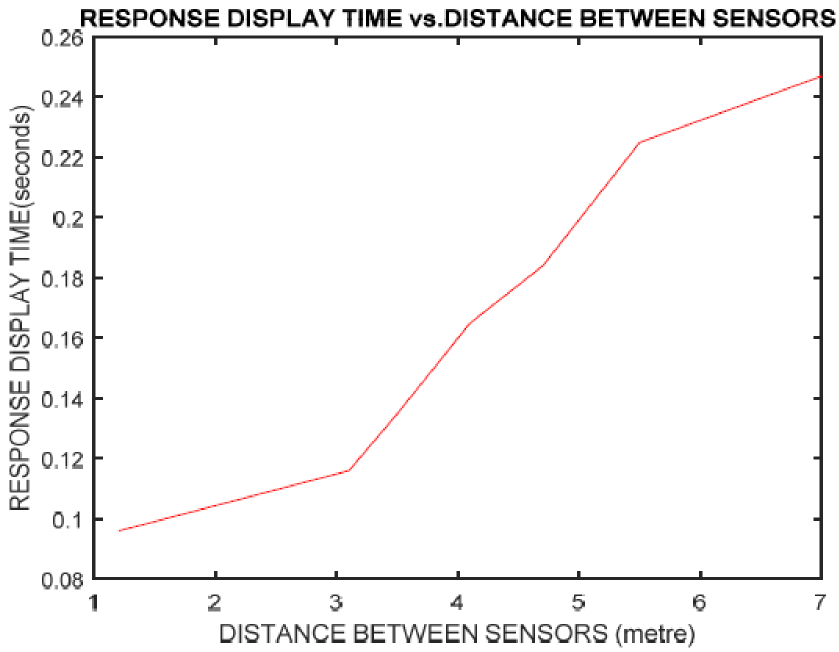


Fig. 28. A graph of response display time vs. distance between sensors

Table 10. Comparison between MCDA system and other data acquisition systems.

System Name	Embedded RFID and WSN	Web-basedsystem	Low cost	Automatic monitoring monitoring compared standard time, target	M2M wireless communication	Communication range	Flexible design, adding modification of software and hardware
SCADA	x	√	x	x	x	-	√
ABACUS	x	√	x	x	x	-	x
BARCO	x	x	x	x	x	15m	x
MCDAS	√	√	√	√	√	50m to 200m	√

Source: Zulkifili, Hassan, Ismail and Semunab (2015).

Table 11. Characteristics of X- system developed

System	Eembedded RFID and WSN	Web-based system	Low cost	Automatic monitoring monitoring compared standard time, target	M2M wireless communication	Communication range	Flexible design, adding modification of software and hardware
X-SYSTEM	√	√	√	√	√	22m to 27m	√

5.3 Communication Distance

The communication distance measured is 22m to 27m. This test reveals that, the wireless system developed will be operational at a maximum distance of at least 22 between the factory location and the management or administration departments were the monitoring and collection of production data is carried out.

5.4 Comparison of X-System Developed with a Typical MCDA System and other Data Acquisition Systems

According to Handersan, Kotz and Abyzov [27], and Zulkifili et al. [28], stated that, SCADA was developed on a protocol based on internet to enable monitoring and optimization of the process through the web system. However, major objective of implementing an internet based system is to improve to a certain extent than to replace computer based methods for control systems. Also, though SCADA and other systems shown in Table 10 are been used as solutions to control and manage processes for flow and optimization system within a broad range of industrial application. The X-system developed is a typical MCDA system and is more advantageous, because of the adoptability of an RFID module architectural structure with counter system in its wireless protocol design platform and is for a typical manufacturing based sector for monitoring, data acquisition and feedback, reduced error in human intervention, theft reduction and elimination. Table 11 shows the characteristic of the wireless system developed (tagged X-system), in comparison with other data acquisition systems including that of a typical MCDA system.

6. IMPLICATION OF FINDINGS TO THE RESEARCH STUDY

The implication of the findings from this study is that, it reveals that based on the responsivity of the IR detector, the relative distance between the IR emitter and IR detector affect the power density between the sensors and IR detector and consequently on the incident current generated at the IR detector unit. This is due to the fact that as the power density increases the incident current increases. Therefore, this guides the positioning of the sensors and the extent of their distance apart. The communication distance tested is 22m, about 7m greater than the communication distance recorded by Zulkifili et al. [28], for BARCO system in Table 10 and although the distance is less than that recorded for a typical MCDA system, it is still a typical MCDA system due to similarity in feature adaptation. This distance can be lengthened by adjustment and enhance of signal strength and range. This will serve as a guide for future modification to enhance greater performance.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Biography of author(s)

Joel Ewa Bassey
Mechanical Engineering Department, Federal University of Technology, Minna, Nigeria.

He was educated at the Federal University of Technology Owerri, where he obtained a bachelor degree (B.Eng) in Polymer engineering in 2008 and Federal University of Technology Minna, where he obtained a postgraduate diploma in mechanical engineering in 2015 and then master's degree (M.Eng) in mechanical engineering with specialization in industrial and production engineering. He is an educational instructor with a postgraduate diploma in Education (PGDE) from the National Open University of Nigeria (NOUN). He was a member of the Society of Plastic Engineers (SPE), Member of the Institute of Safety Professionals of Nigeria (ISPON), graduate member of the Nigeria Institute of Management (NIM), member of the Teachers Registration Council of Nigeria (TRCN) and also, a registered engineer of the Council for the Regulating Engineering in Nigeria, (COREN). He worked as production supervisor and then head, production department in Jackson Davos (Crown Carpet) Company at the export processing zone Calabar since 2011 to 2012. He has facilitated many academic research works and has publications in both national and international journals. His areas of interest are in industrial and production engineering systems, polymers, mechanical design analysis, CAD modeling, material handling systems, monitoring systems. He worked on the development of an automatic mini-conveyor system for product monitoring; which is geared at consolidating the knowledge on conveyor design analysis, wireless system monitoring and to solve relative industrial problems in material handling such as pilfering, inefficient supervision, monitoring, workmanship and inconsistency in production records and data inventory.

Katsina Christopher Bala
Mechanical Engineering Department, Federal University of Technology, Minna, Nigeria.

He is an Associate Professor of the Mechanical Engineering with specialization in industrial and production engineering of the federal university of technology Minna. He started his academic career as an assistant lecturer of the federal university of technology Minna in 1993 and since then has risen through the ranks to an associate professor since 2016 after obtaining a Doctor of Philosophy degree (PhD) in industrial and production engineering in 2012. He has supervised a great number of students at the undergraduate, postgraduate Diploma, masters and PhD levels. He has over 35 academic publications in both national and international journals, and has international journals and has attended several and conferences and workshops. Has served the university at various capacity such as examination officer, coordinator of postgraduate program of the mechanical engineering department, member of several university committees, senate member and was the director of centre for preliminary and extra-mural studies (CPES), FUT Minna. He is a registered engineer of the council for the regulation of engineering in Nigeria (COREN). He is a Member of the Nigerian Society of Engineer (NSE) and also a member of the Nigeria Institute of Mechanical Engineers (NiMechE). His research interest are in the areas of simulation of solidification, development of foundry materials in terms equipment, sand testing, manufacturing and characterization of casting materials.

Nurudeen Abdul
Physics Department Federal University of Technology, Minna, Nigeria.

He obtained diploma certificate in science laboratory technology from the federal University of Technology (FUT) Minna, Nigeria in 2006. He Possess a B-Tech degree in Physics (Electronics) from FUT Minna. He is currently working for the Federal Government of Nigeria in the Kaduna Polytechnic, under the body of program/embedded unit in Kaduna Polytechnic. His Area of interest is in the study of earth and plants to produce electronic components. He developed a semiconductor device from clay and other minor materials which got me a Federal Government prize award in the year 2002 by Federal Ministry of science and Technology. In 2010 the semiconductor device won a grant award. In 2015- 2017, he proved and developed the concept which shows that electromagnetic field was emitted only when acceleration of particle approaches zero. He has developed several electronic/digital systems such as; the fire brigade robot, radio receivers, solar digital system with oven, GSM Mobile Sensor and a local wireless modem to interact with both machine and computer. He has also developed a rechargeable battery from cement and starch (1998 – 2017), the project battery won grant award in the year 2018 and in 2019 it won a patent award. He has worked on and developed organic solar cell with spectrum sensitivity and operates at 750nm in 2020. These are but few of what he has achieved and contributed.

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