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A Smart Manufacturing Execution System

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Abstract: *This paper presents a novel design of a smart and efficient Manufacturing Execution System (MES) to acquire data from the shop floor in a factory. With increasing complexities in the production process, improving industrial productivity using production information systems is a challenge for all industries in the world. Manufacturing Execution Systems (MES), since their introduction in the factory environment, are gaining popularity due to their ability to control and monitor production process using integrated data. However, employers/managers are still confronting with many complications in understanding huge information on the production process and reacting quickly based on such information. In this paper, we propose the design of NIRMAN Factory Information System (FIS)-A Smart MES to enable the control and monitoring of multiple factors of the production process like assembly line, personnel, quality control, safety, etc. NIRMAN FIS, a MES based on Android Smartphone, presents data about factory environment and factory operations on the manager's smartphone screen and helps him to react and take important decisions quickly and flexibly.*

Index Terms: *Sectional Efficiency, Factory Efficiency, Assembly Line, Threshold Limit, Productivity, Morale, Factory Environment, Data Acquisition, Analysis, Automatic and Manual Control, Bluetooth, Arduino, Android, Remote Monitoring*.

I. INTRODUCTION

Production Managers share a significant task in the production process. They continuously monitor the factory operations and are involved in optimizing the operations so as to escalate factory efficiency. However, monitoring factory operations and production status is not an easy task.

Many existing computer based industrial automation systems help managers towards accomplishment of his objectives. However, these systems, being bulky, are not portable and information is not available to the manager unless he makes use of computer [3]. Hence, updates about production process are not conveyed to manager when he is away from the system and this may delay some important decisions related to production.

This drawback necessitates development of new Manufacturing Execution System (MES) which can be portable and can provide information about factory operations whenever required without physical presence of manager before the system.

Smartphones are the best portable devices capable of providing enormous information. Single click on the smartphone can fetch enormous information for the user. We cannot deny that the use of smartphones in daily activities is making human life easier and faster than ever. The concept of using smartphones if extended to industrial and commercial world can help manager to acquire data about his industry or business from anywhere in the world.

The ever-increasing use of Android Smartphones and various applications that run on it led to evolution of NIRMAN Factory Information System (FIS)-An Android based MES that not only monitors important safety parameters in a factory but also provides information about production status and quality. NIRMAN FIS provides real time production status, calculates production efficiency, plots real time graphs and provides many other features for efficient analysis of data.

II. PROPOSED SYSTEM

Data Acquisition System of NIRMAN FIS consists of 4 important blocks i.e., Factory Power Control, Production Status, Factory Environment and Bluetooth Module. Details of Data Acquisition System will be discussed in the later part of the paper. Arduino Uno Microcontroller Board [11] acquires data about production process and factory environment to process and convert it into required form.

A Data String Pattern is designed to send this data to Android Application of NIRMAN FIS using HC-05 Bluetooth Module [20]-[21]. With a Data Refresh Rate of 1 minute, android application continuously displays and monitors various parameters of the factory. The android application also communicates with the web server [8]-[10] to receive some commands and then conveys these commands to Arduino through bluetooth module so as to enable Arduino to take appropriate action to ensure safety inside factory and thus, control factory operations.

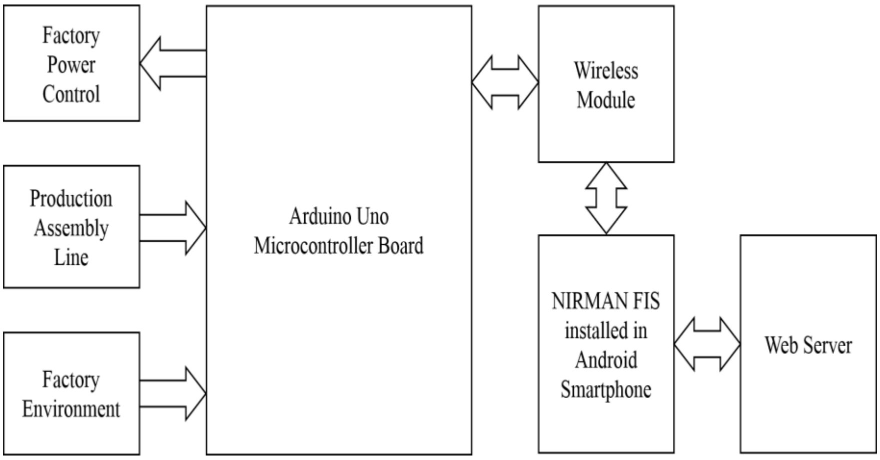


Fig. 1. Block Diagram of NIRMAN FIS

III. WORKING OF THE SYSTEM

Data received from the Data Acquisition System of NIRMAN FIS is fragmented inside android application to display appropriate data in the respective section of android application. The login screen and primary interface of android application is shown in Fig. 2.

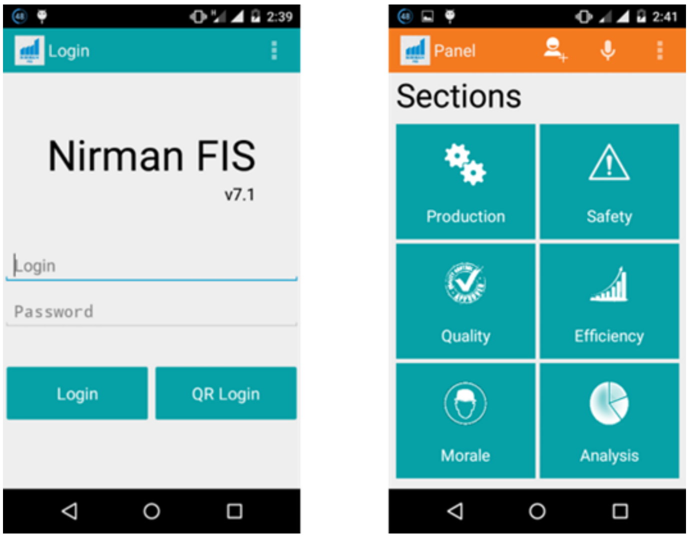


Fig. 2. Login Screen and Primary Interface of Android Application in NIRMAN FIS

A. Assembly Line Efficiency

Production Process for any product consists of number of stages. A product, before completion, has to pass through all stages. Thus, an Assembly Line is divide into appropriate number of stages depending upon the requirements of the production process. For simplicity, let us consider a factory has 3 stage/section assembly line as follows:

1. Stage/Section I- Primaries, where raw steel is converted into machine parts.
2. Stage/Section II- Paint, where machine parts are painted.
3. Stage/Section III- Post Paint, where the machine parts are actually assembled.

The production status of a product in all the above mentioned stages is monitored in NIRMAN FIS. When the product passes through Stage I, the count of products completing stage I of production process is incremented by 1 and displayed in the Production Section of android application. A product is completely manufactured when it passes through Stage 3 of the assembly line. NIRMAN FIS tracks the efficiency of each stage by considering actual and expected production.

The count of expected production for each stage is incremented by 1 after a predefined standard time required for a product to pass through that stage. Presently, this time is set as 1 minute for each stage and hence, at the end of 3 minutes, each stage is expected to complete 3 products as shown in Fig. 3. However, based upon the actual production, efficiency for each stage is calculated and is displayed in the application. For e.g., from Fig. 3, actual and expected production for Stage I is 2 and 3 respectively. Hence, efficiency for Stage I is calculated as (2/3)*100=66.66 %.

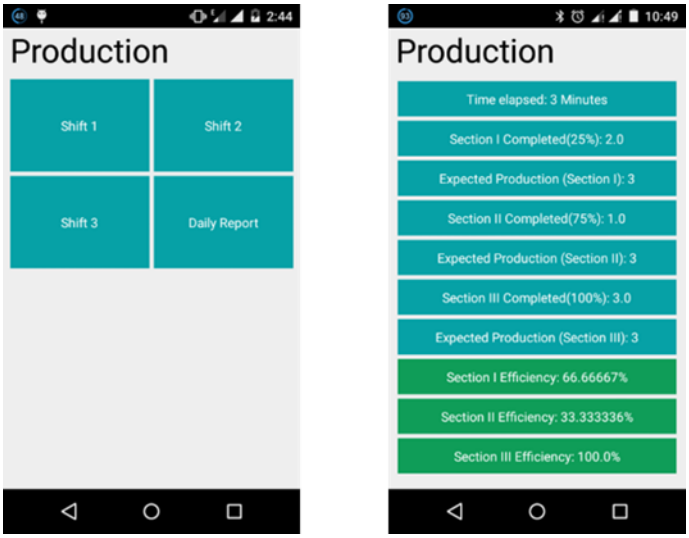


Fig. 3. Production Details displayed in Android Application of NIRMAN FIS

Shift wise data for each stage is made available in Production section of android application. As shown in Fig. 3, each stage is allotted with percentage i.e. 25% for stage I, 75% for Stage II and 100% for stage III. This indicates partial manufacturing of a product. For e.g., Say, at the end of the day, 50, 45 and 30 products have passed through stage I, II, and III respectively. This means that 50, 45 and 30 products have completed 25%, 75% and 100% of the total production process respectively. Thus, at the end of the day, a manager can know the count of products that are partially manufactured and the count of completely manufactured products.

We can also track the number of products that are available for delivery from Stage I to Stage II or from Stage II to Stage III or from Stage III to Shipping.

B. Factory Environment

For complex industrial processes that are automated by process management systems, disruptions or short-term interruptions of workflows cause high failure costs, in the worst case, even danger to people or the environment. Hence, the factory environment should be constantly monitored to check some vital parameters like temperature, air quality, pressure, humidity, light intensity, etc. because factor of safety is directly related with these parameters.

NIRMAN Factory Information System acquires factory conditions using various sensors (to be discussed later). For safety parameters like temperature, air quality and pressure, we can set Threshold Limit using NIRMAN FIS as shown in Fig. 4. When these parameters cross their threshold limits, following actions are generated by the system:

1. The power supply to the factory is cut-off.
2. Auxiliary power supply turns ON the light for emergency exit path.
3. The tile of the corresponding parameter turns red.
4. Emergency situation is notified to all workers in the factory using an alarm.

When entered into section of Safety, tiles for four zones will give details of various parameters like temperature, pressure, humidity, air quality and light intensity as shown in Fig. 5. Thus, NIRMAN FIS monitors and ensures safe working conditions in the factory.

The sensors used in the system to procure the above mentioned safety parameters consists of:

1. Temperature and Pressure - BMP180 [5][19]
2. Air Quality - MQ135 [17]
3. Humidity - DHT 11 [18]
4. Light Intensity - LDR [2]

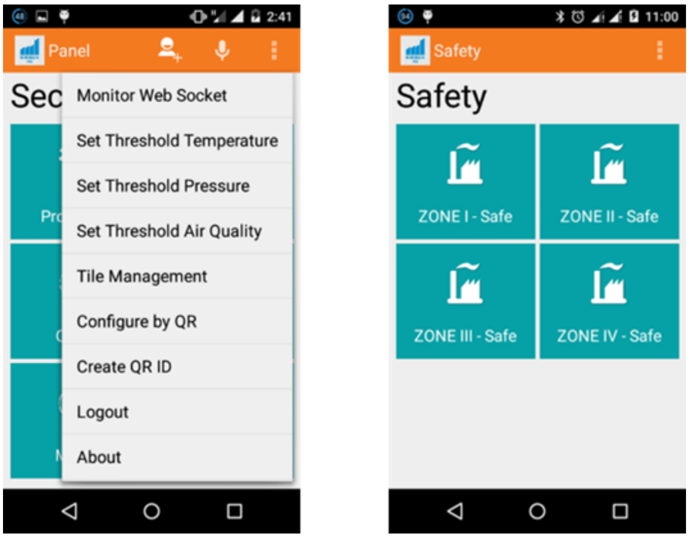


Fig. 4. Safety Section in Android Application of NIRMAN FIS

C. Automatic and Manual Power Control

If the temperature inside factory exceeds Threshold Limit due to fire, the tile of the zone will turn red to indicate an emergency situation inside factory as shown in Fig. 5. When clicked on that zone, the tile of temperature is found to turn red. When temperature crosses its Threshold Limit, android application communicates with Arduino through bluetooth module and instructs the microcontroller to shut down the main power supply to prevent further damage.

Sometimes, automatic control of the system might introduce a delay in conveying information about an emergency situation or might even fail due to some technical problems. At such times, if an emergency situation is visible before the eyes of a manager, he can use Power ON/OFF to manually cut-off the power supply to the factory as shown in Fig. 5. Similarly, Buzzer ON/OFF option can be used to notify workers about an emergency situation in the factory. When we click on the Power OFF button, the system will automatically turn ON an auxiliary power supply as discussed earlier and generate an alarm.

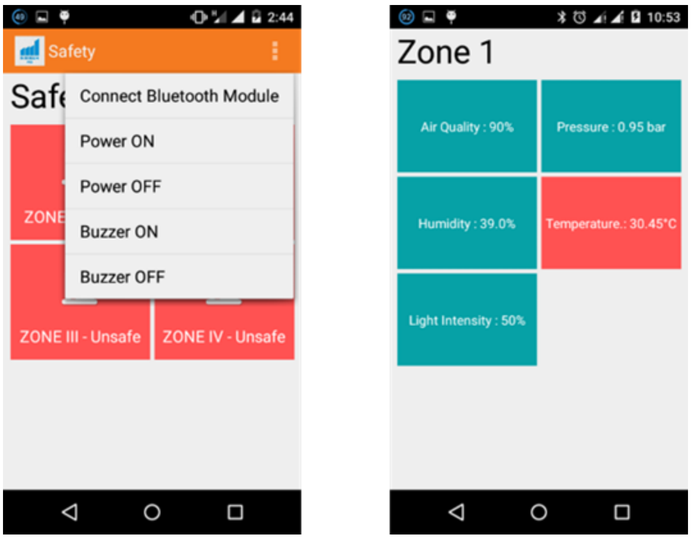


Fig. 5. Safety Parameters displayed in Android Application of NIRMAN FIS

As shown in Fig. 6, when a safety parameter is below its threshold value, power is continuously supplied to the factory. This is indicated by Green LED in the system. When a safety parameter exceeds threshold value, the android application instructs Arduino to make its pin 3 High [16]. This pin is connected to the base of transistor Q1 (BC 547).

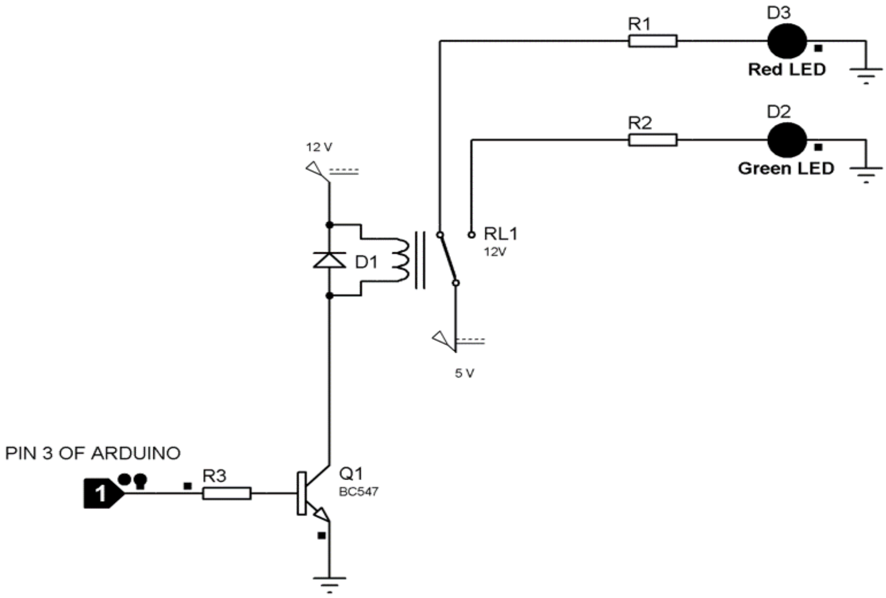


Fig. 6. Power supply to factory turned OFF when a parameter exceeds Threshold Limit

When it goes high, transistor turns ON and causes the relay to switch [1], turning OFF the Green LED connected to relay, thus, indicating that the power supply is cut-off. As indicated by Red LED, an auxiliary power supply is turned ON to light evacuation path.

D. Paperless Factory

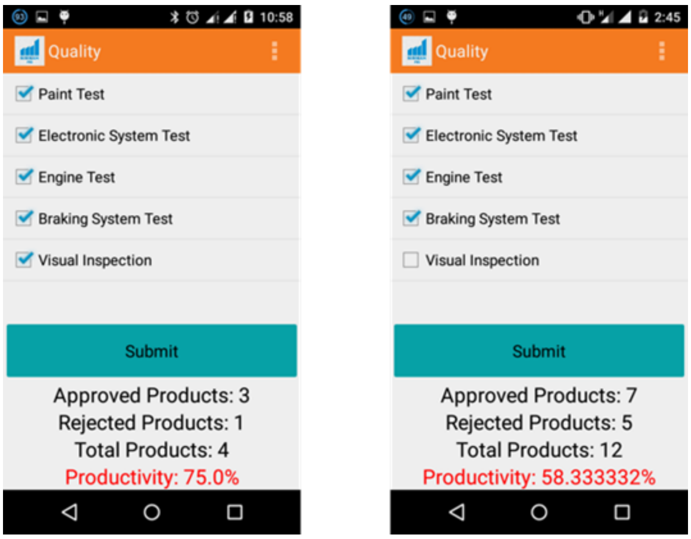


Fig. 7. Productivity displayed in Android Application of NIRMAN FIS

Customer Satisfaction is the basic objective behind every manufactured product. Quality of the product determines the level of influence of the product on the customers. Hence, Quality Testing of products is essential to before the manufactured product is delivered to customer. A manufactured product is approved for delivery to customer only if it passes all quality tests. For large products like cars or tractors, quality testing involves documentation of many parameters of the product. It undergoes many tests the results of which are recorded on papers. Thus, quality testing consumes many papers. NIRMAN FIS aims towards minimization of paper usage and promotes Green and Paperless Factory.

A list of quality control parameters is prepared in the android application of NIRMAN FIS as shown in Fig. 7. When a product passes the test for that parameter, we place a Correct Mark on that parameter. The procedure is repeated for all the parameters of a single product and pressing Submit button when all parameters for a product are correct will increment the count of Approved Products by 1. When any of the parameters is not correct, pressing Submit button will increment the count of Rejected Products.

Productivity of the factory is calculated by using formula:

$$Productivity = \frac{Approved\ Products}{Total\ Products}\ x\ 100\ \%$$

As an extension to above features, if parameter is being tested by a machine, then output from that machine can also be fetched to place a correct mark on that parameter automatically.

E. Personnel Morale

The morale of the employees will play an important role in determining the production capacity of the factory. Morale and working capabilities of the workers are affected by the factory conditions. More favorable the factory conditions, higher will be productivity. Each employee can be provided with unique Radio Frequency Identification (RFID) [7][4] tags. When an employee wants to enter factory premises, RFID tag will serve as an entry ticket and at the same time sensors will record his attendance that can be fetched by the application. The application can keep a track of absent employees. Shift wise data will be collected to draw some important conclusions related to employee morale.

Fig. 8. Personnel Morale in Android Application of NIRMAN FIS

As shown in Fig. 8, the application will continuously keep a track of expected workers and present workers in the factory. The factory conditions like temperature, humidity and light intensity which effect physical abilities of the workers will be procured from the sensors installed in the factory. With proper analysis of the relation between these conditions and productivity, we can conclude the most favorable conditions when the workers can perform at their best level. Maintaining a pleasant factory environment will increase the output from workers, thus, resulting in increased productivity and efficiency.

F. Factory Efficiency

The data available from three shifts will be collectively analyzed to generate a report. If actual period for which machines are active is greater than expected period, either machine efficiency or worker efficiency has been decreased and should be addressed immediately. This will increase the energy consumption and increase the overall production cost. The final goal is Increase Efficiency, Reduce Costs.

The efficiency shown here is Factory Efficiency and considers 2 factors:

1. Average efficiency of 3 sections
2. Productivity

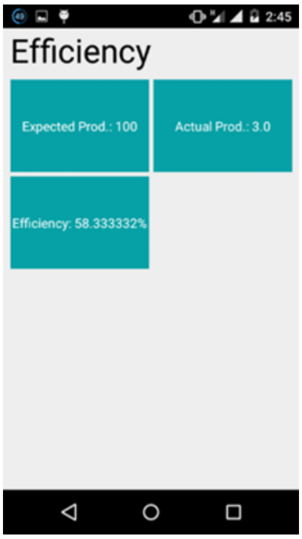


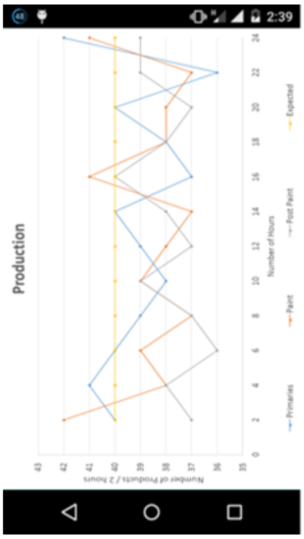
Fig. 9. Factory Efficiency displayed in Android Application of NIRMAN FIS

It is calculated by taking average efficiency of 3 sections and then multiplying the obtained average with productivity to get answer in percentage. The formula used is as follows:

$$Factory\ Efficiency = Average\ \ efficiency\ of\ 3\ stages\ x\ \frac{Productivity\ in\ percent}{100}\ \%$$

For e.g., if average efficiency of 3 sections is 70 % and productivity is 50 %, then the actual efficiency of the factory is 35 %. It calculates the efficiency based on the number of approved products. Thus, even though the average efficiency was 70 %, the actual efficiency is only 35 % because only 50 % of the total products were approved.

G. Data Analysis



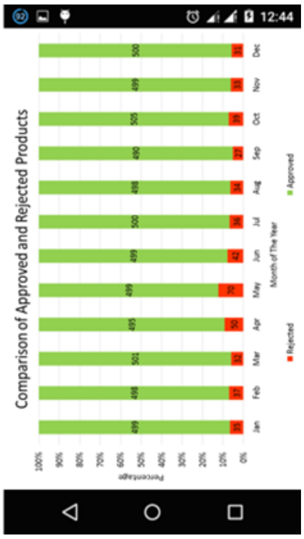


Fig. 10. Graphical Analysis for Production from 3 Stages of Assembly Line

Data available, if analyzed properly, can reveal many important facts about factory performance and can help managers to take proper actions for improving its performance. NIRMAN FIS generates real time graphs based on the data acquired from Data Acquisition System.

Line graph of Fig. 10 shows the number of products manufactured in each stage per 2 hours. Considering the expected number of manufactured products per 2 hours to be 40 (indicated by Yellow Line in the graph), we can track the actual production for the entire day i.e. all 3 shifts. The duration when production goes down can be tracked and appropriate measures can be taken.

Bar graph of Fig. 10 is the result of Quality Testing of the product. The number of Approved and Rejected products can be tracked in each month. It is seen that rejected products are more during month of May. Factory conditions in the month of May can be reviewed to find the cause for increase in rejected products.

Fig. 11 is a speedometer that will generate a rating for factory performance based on Factory Efficiency discussed earlier. For example, if Factory Efficiency is 91%, Performance Rating is 9.1 and the factory performance is Outstanding.

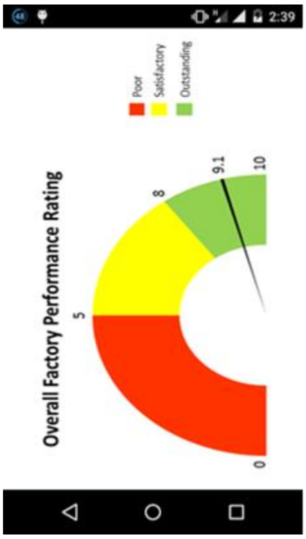


Fig. 11. Graphical Analysis for Overall Factory Performance

IV. DATA ACQUISITION SYSTEM

Data Acquisition forms the heart of NIRMAN Factory Information System. Data about various parameters is fetched from the sensors located in the factory environment. Arduino Uno, being the central processing unit, processes the acquired data and transmits it serially [12] to Bluetooth Module.

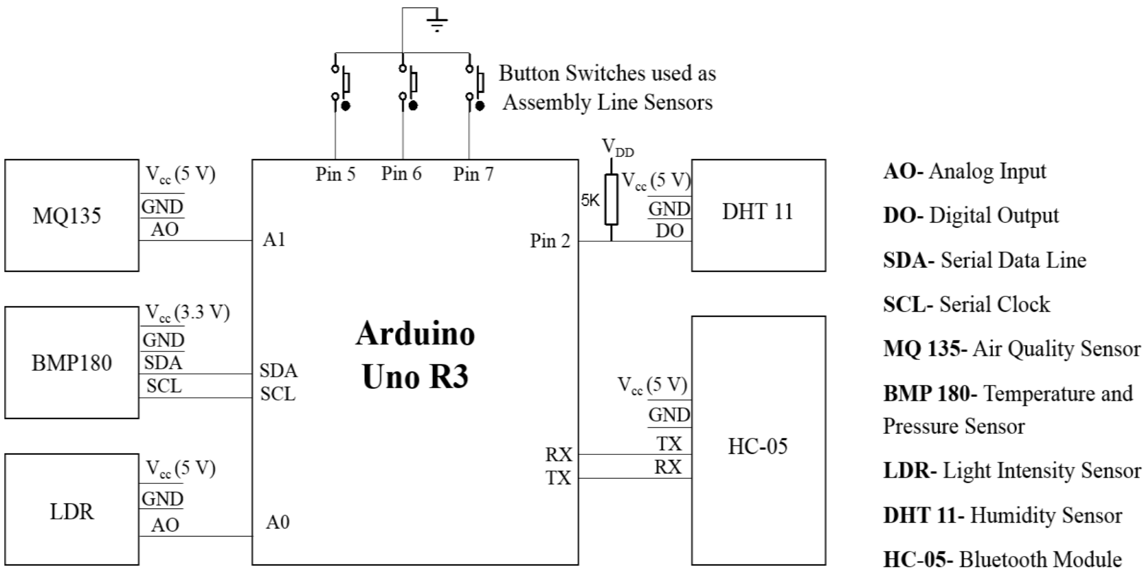


Fig. 12. Data Acquisition System of NIRMAN FIS

The composition of string in the transmitted serial data will be discussed later. The acquired data is refreshed every second so that live updates about factory status are conveyed to the manager. Fig. 12 simplifies the idea about the interface of various sensors with Arduino Uno.

To get acquainted with each block, we'll discuss about the parameters fetched by Arduino. These parameters include temperature, pressure, humidity, air quality, light intensity and production status. A constant length string is formed using these parameters to simplify the communication of data between Bluetooth Module and Android Application.

A. Data String Pattern

As shown in Fig. 12, HC-05 [20] is connected to Arduino using TX and RX pins. The values serially transmitted by Arduino are received by bluetooth module and transmitted to android application using wireless bluetooth connection. Fig. 13 shows the string pattern generated by Arduino in NIRMAN FIS.

Parameter	Production	Time	Humidity	Pressure	Temperature	Air Quality	Light
String	010	002	34.59	0.95	37.89	5	9
No. of characters	3	3	5	4	5	1	1

Fig. 13. String Pattern generated by Arduino for Serial Transmission

The string pattern and the length of the string is kept constant so that application on receiving the data through bluetooth connection can divide the string and allot those values to respective parameters. This string is sent every 1 sec by Arduino to bluetooth module. For example, if transmitted string is 01000234.590.9537.8959, it actually consists of data blocks as shown in Fig. 13.

Fig. 14. Hardware Implementation of Data Acquisition System in NIRMAN FIS

B. Air Quality

MQ135 is used as the air quality sensor. Arduino Uno has 6-channel 10-bit ADC. The analog output of MQ135 is connected to channel 1 (A1) to get digital output [14] varying from 0 to1023. Here, lower values of digital output [17] indicate clean air while higher values indicate polluted air.

Using mapping function in Arduino Uno (i.e. map(AirQuality, 0, 1023, 9, 0)) [13], the values for air quality from 0 to 1023 are mapped between 9 and 0. Thus, as a simplification to human understanding, higher values between 0 and 9 will now indicate clean air and polluted air will be represented by lower values. Since the values between 0 and 9 are used to specify air quality, it consumes only one character of the entire string pattern.

C. Temperature and Pressure

BMP180 [5] requires DC power supply of 3.3 V and is interfaced with Arduino Uno using Serial Data (SDA) and Serial Clock (SCL) pins i.e. Inter Integrated Circuit (I2C) protocol [6]. It delivers pressure and temperature values in bar and °C respectively [19]. For example, pressure=0.95 bar and temperature=34.89 °C. It, therefore, consumes 9 characters in the transmitted string (dot is also considered as a character). The measurement ranges are as follows:

1. Temperature: -40 to 85 °C
2. Pressure: up to 10,000 hPa

D. Humidity

DHT11, Temperature and Humidity Sensor, features a temperature and humidity sensor complex with a calibrated digital signal output. By using the exclusive digital signal acquisition technique and temperature and humidity sensing technology, it ensures high reliability and excellent long-term stability. This sensor includes a resistive-type humidity measurement component and an NTC temperature measurement component and connects to a high-performance 8-bit microcontroller offering excellent quality, fast response, anti-interference ability and cost-effectiveness.

Although, DHT11 provides, both, temperature and humidity values, we use only the latter part. Single-bus data format is used for communication and synchronization between Arduino and DHT11 sensor [18]. As shown in Fig. 12, digital output of DHT11 is connected to pin 2 of Arduino and requires a pull-up resistor of 5 kΩ. DHT11 measures humidity between 20-90% RH. Humidity consumes 5 characters in the transmitted string. For e.g., humidity in a factory is 38.59 %.

E. Light Intensity

LDR is used to measure light intensity. The circuit diagram is shown in the Fig. 15. As the resistance of LDR varies with light, the voltage available at the analog input A0 of Arduino changes. The digital output [14] has values from 0 to 1023. These values are mapped [13] between 0 and 9 in Arduino.

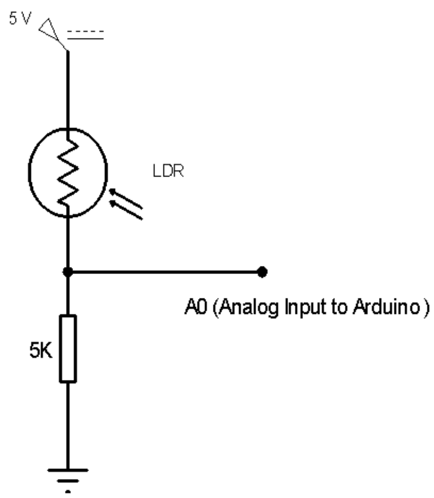


Fig. 15. LDR Connection Diagram to measure Light Intensity

When light falls on the LDR [2], its resistance decreases and analog input to A0 increases resulting in higher values of light intensity between 0 and 9. Similarly, when no light falls on the LDR, its resistance increases and analog input to A0 decreases giving lower values of light intensity. Light Intensity consumes only 1 character in the string as it has values between 0 and 9.

F. Production Status

The production status of 3 stages in supervised by the system. For the same, 3 sensors can be installed at the end of each stage. To demonstrate the working of production section, 3 button switches as used as

Assembly Line Sensors as shown in Fig. 12. These 3 switches which represent 3 stages of the assembly line are connected to pins 5, 6 and 7 of Arduino respectively (Refer Fig. 12).

An active low signal is given to Arduino pins when the switch is pressed. Pressing a switch is equivalent to product passing from one stage to another stage in an assembly line. This active low signal is detected [15] by Arduino to send 1 when the switch is pressed and send 0 when switch is not pressed. 3 characters are used, one for each stage, whose value will be either 0 or 1 depending upon the condition of the switch. Thus, production status consumes 3 characters in the transmitted string.

In practice, a pair of light source and photodiode [2] can be used at the end of each stage of assembly line to detect the movement of products as shown in Fig. 16. When no product passes through a stage of assembly line, the light emitted by light source will continuously fall on photodiode. The presence of product will obstruct the light beam falling on photodiode that can be detected by properly interfacing photodiode with Arduino.

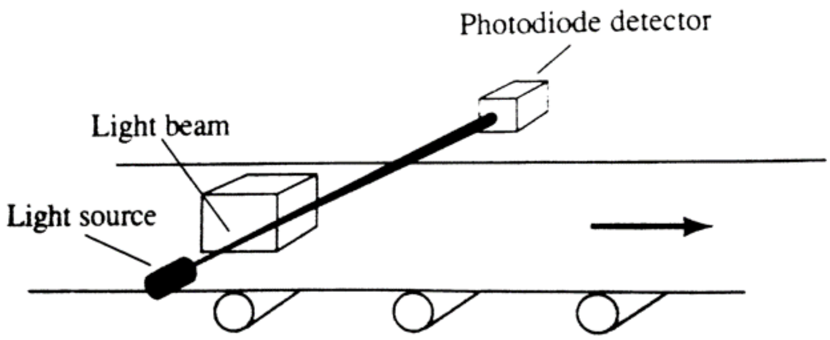


Fig. 16. Use of Photodiodes to detect a product passing through a stage of assembly line

Thus, each time a product obstructs the light beam, the count of products passing through a stage will be incremented by 1 and displayed in the android application of NIRMAN FIS.

V. REMOTE MONITORING

By using NIRMAN FIS Web Portal or NIRMAN FIS Companion, it is possible to monitor and control all factory operations remotely. When a manager wants to have a manual control over factory operations while he is not physically present in the factory, he can use Remote Monitoring methods. The user has to authenticate his account while using any of these methods. Using internet connectivity, he, can send commands to android application which is connected to NIRMAN FIS using bluetooth.

Table I: Commands Used In Remote Monitoring

Command	Function
141	Turn ON Buzzer in the factory
142	Turn OFF Buzzer in the factory
143	Turn ON Power Supply of the factory
144	Turn OFF Power Supply of the factory

The android application on reception of commands will instruct Arduino to take appropriate action. These commands can be configured based on user requirements. The option of Web Socket Monitoring in the android application must be turned ON to use remote monitoring methods. The 4 basic commands used in the prototype are given in Table I.

A. NIRMAN FIS Web Portal

NIRMAN FIS Web Portal is a website connected to android application of NIRMAN FIS. After user authentication on Login Screen, control panel is displayed as shown in Fig. 17 and Fig. 18.

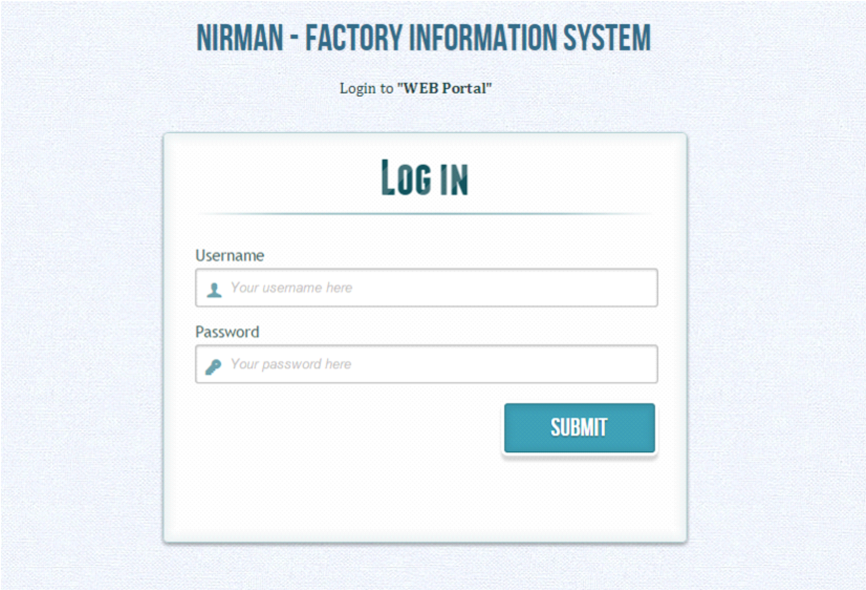


Fig. 17. NIRMAN FIS Web Portal-Log In

The user must enter appropriate command in the Command Box of control panel and press Submit button. This will push the command on android application of NIRMAN FIS which is also connected to internet. Web portal uses Google's Cloud Messaging Service [8]-[10], which is web based push messaging service, to push the command on the android application of NIRMAN FIS.

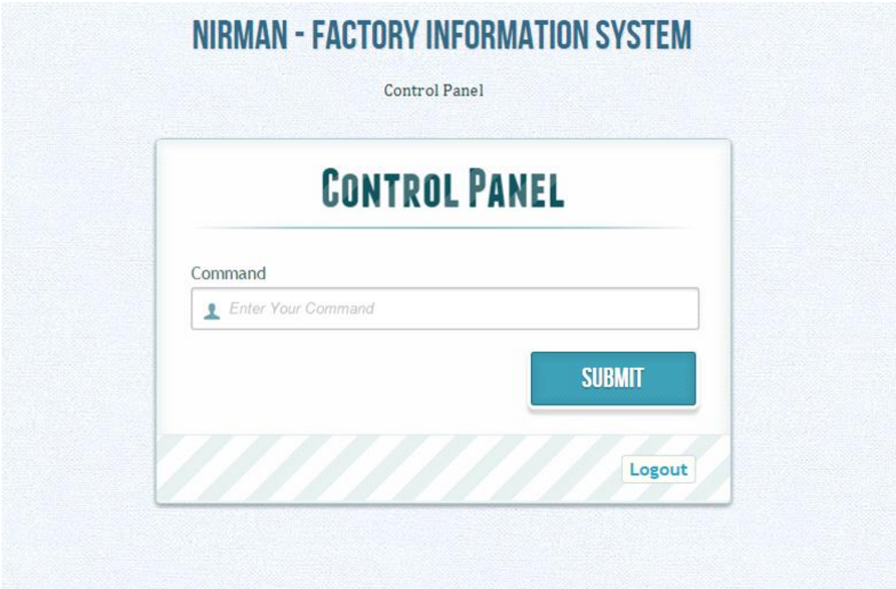


Fig. 18. NIRMAN FIS Web Portal-Control Panel

B. NIRMAN FIS Companion

NIRMAN FIS Companion can be launched through android application as shown in Fig. 19. By installing android application on another android smartphone and launching the Companion, a user can send commands to the primary android application which is connected to Data Acquisition System using bluetooth in the factory.

Thus, android application of NIRMAN FIS in one smartphone can control the same android application installed in another smartphone using internet connectivity.

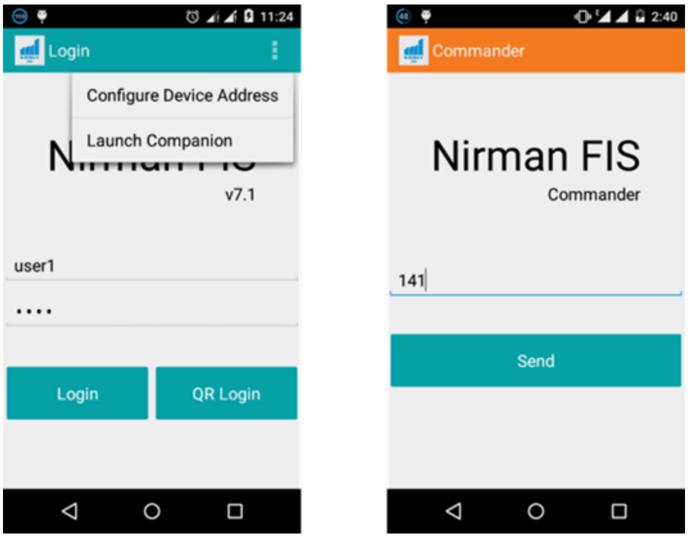


Fig. 19. NIRMAN FIS Companion

VI. ADDITIONAL FEATURES

Android Application of NIRMAN FIS incorporates many other features like SMS Notifications, Voice Recognition, Adding a user account, etc.

A. Configure Device Address

NIRMAN FIS Android application is connected with hardware using Bluetooth module. In order to establish a connection, Media Access Control (MAC) address of the bluetooth device needs to be configured by the application. The MAC address of the targeted device after encrypting in a QR code will be scanned by the application to establish a connection.

Using this feature, an old bluetooth device can be easily replaced with new one without any major alterations in the existing system. Configure Device Address is available on the login screen of android application as shown in Fig. 19.

B. Adding a User Account

The administrator or manager of the factory can add a user account for his subordinate in the android application as shown in Fig. 20.

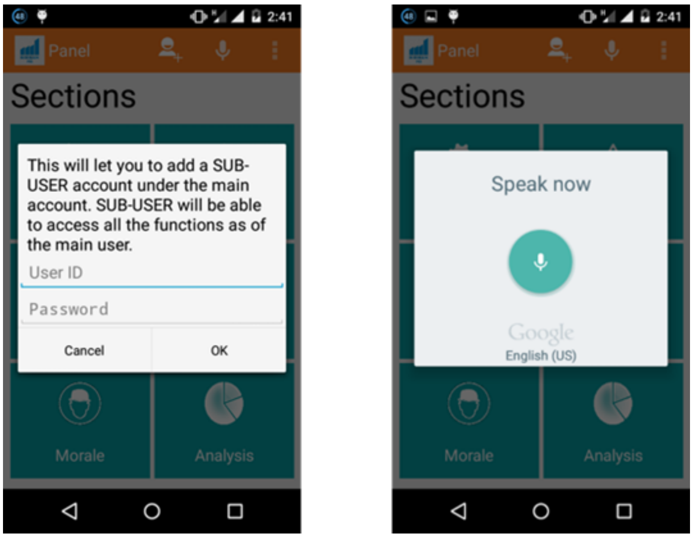


Fig. 20. Adding a User Account and Voice Recognition in Android Application of NIRMAN FIS.

C. Voice Recognition

Voice recognition allows the user to control application using simple voice commands. For example, if manager says, Open Production, the application will receive the voice command and open production section of the NIRMAN FIS. Voice recognition enables hands-free operation of the application. However, it requires internet connection to be enabled on the smartphone.

D. SMS Notifications

The critical parameters in the factory are informed to manager by NIRMAN FIS through SMS notifications. For example, if the manager is not present in the factory and temperature exceeds threshold value, an SMS is sent to manager by the application.

Fig. 21. SMS Notifications in Android Application of NIRMAN FIS

The manager needs to save his mobile number in the application as shown in Fig. 21. When SMS notification system is turned on, the saved mobile number is used by the application to send critical updates to the factory manager.

VII. CONCLUSION

NIRMAN FIS is the most reliable solution for Integrated Data Recording and Performance Monitoring in real time. Short-term and Long-term analysis for a factory is, therefore, possible in a more efficient manner.

Manual Data Recording can be reduced to a great extent by implementing NIRMAN FIS. This results in a reduced time outlay because it is the system which takes care of recording important parameters like production status, efficiencies, etc.

NIRMAN FIS aims towards Paperless Factory. Since the system reduces manual data recording to a great extent, the use of paper for recording data is also reduced.

The system provides machine workers with real time information needed for orderly production. Reducing human efforts to collect data, therefore, increases employee productivity in taking important decisions. The production status in the assembly line is accurately tracked by the system. The estimated time for the completion of order can be calculated and can be conveyed to a client.

Unacceptable deviations are recognized immediately by the real time monitoring of all influencing parameters in a production process and measures can be taken accordingly. This is equivalent to real time cost control as the system takes care about safety inside factory.

The present system works with a Bluetooth Module. The same system can be easily made compatible with Wi-Fi Module. The use of Wi-Fi Module can increase the range of accessibility and allow multiple mobiles to get connected to the system. The concept of Internet of Things [7] can be used to locate, identify and remotely configure the objects using RFID, Near Field Communication (NFC) or optically readable barcodes. A new feature can be included such that whenever a machine has a problem, the machine itself will call for help that will be notified to the user in the application. A User Interface (UI) that supports all major OS platforms like Android, iOS, and Windows can be developed for making interaction with system easier than ever.

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