Chapter 4

Hardware Implementation of Fault Detection and Fuzzy Diagnosis

4.1 Introduction

The Textile Industry has reached at a highly resourceful stage in manufacturing of different types and qualities of fabrics. The fabric formation process of late is fully automated with the help of Electronic Technology and can be controlled to the lowest level down to each cross of warp and weft. Today Textile Industry is having Electronic Systems to ease the operation of different types of machines and plays an imperative role in the automation. Multiple sections and departments of fabric development process are interconnected to form a network which will lead to the centralized monitoring and can control the process from remote location. Continuous operation of the machines is therefore accomplished and eventual machine breakdowns can be reported instantly to the central station. Embedded Systems played a vital role in the formation of the network of these systems. The individual node in the embedded network can collect the information of various faults detected from the machine in Textile Mill. The fault information accumulated by the different nodes will then be sent to the centralized location in message format. However the noise factor in the Textile Mill is high enough to alter the fault signals throughout the communication between the faulty machine and the Centralized Fault Detection System. In the developed system the Controller Area Network (CAN) protocol has been implemented for the communication purpose. The CAN protocol is highly immune to noise and designed purely for the industrial environment where noise susceptibility over communication medium is higher.

The message information gathered will then be passed over to the Personal Computer called ‘host’ where the information must need to be analyzed to determine-

- The exact fault condition,
- Behavior of the fault,
• Reason of the fault,
• Damages to the machine due to fault and
• Possible remedial action for the particular fault condition.

Generally the fault occurrence behavior is uncertain and unpredictable in nature, and it can be arise due to single or multiple conditions those can be non-repeatable and therefore the remedies for such faults can be different depending upon the fault occurrence behavior. The number of different solutions or remedies can be therefore being worked out on trial-and-success base by the fault handling Engineers. This makes difficult to generalize the fault condition and may lead a Fault Diagnosis System be ill-defined and complicates the task for conventional fault diagnosis and fault processing algorithms. This tenders a space to exploit the fault diagnosis system using underlying principles of Fuzzy Logic. The Fuzzy Expert System (FES) and Fuzzy Logic Control (FLC) are the two avenues where fuzzy logic has been practically exploited to a great extent [1]. This is mainly due to success of traditional Expert Systems and conventional controls in past. FES is based on the semantic manipulation and approximate reasoning in the process of inferring conclusions. It can prioritize the conclusions provided by the different Experts to solve the fault condition. FES has ability to handle the situations where similar fault can occur with different condition by rule base approach where rules pervaded with ambiguity. It processes the imprecise information and has ability to reason. In other words FES is computer-based system that emulates the reasoning process of a human Expert within a specific domain of knowledge using the apparatus of Approximate (Fuzzy) Reasoning.

The architecture of the system having different kinds of machines of multiple sections/departments of the Textile Industry interconnected to each other within the network is shown in Fig. 4.1. There are different sections in the Textile Industry. However Spinning Department and Weaving Department have been chosen for the implementation of Fuzzy based Fault Diagnosis System. These departments are equipped with very high speed, fully automated
systems to gain the maximum throughput with respect to time and are made to run for twenty four hours to produce finest quality products. The process stages
in these two departments are dependent on each other and need to work in perfect synchronism for maximizing the produce. The breakdown in one process stage can therefore halts the total production line following it and an immediate solution is required to regain the synchronism, otherwise can results in to calamitous financial losses. The system is therefore required to attend with priority and an immediate remedy to be initiated circumventing the breakdown condition or it requires call for an Expert Engineer to seek the solution. The intelligent system instigating the alert before happening of undesirable breakdown and capable of taking initiating multiple remedies to choose from the Superior rather than waiting for an arrival of an Expert could be highly appreciable.

The system shown in the architecture (Fig.4.1) is intends to monitor multiple machines and their behavior according to the change in the input electrical and/or mechanical parameters and capture any anonymous behavior which can cause a fault. The change in behavior of the machine is then identified for possible condition of fault. Different kinds of faults generated by the different machines are acquired by an appropriate signal conditioning units. The fault information accumulated by the local controller is then send to the central controller by the means of high speed CAN network. The central node then prioritizes the fault information and send them to the processing unit i.e. PC where a Fuzzy Inference System designed in MATLAB analyses the faults according to the machines and evaluates the fault condition to provide a timely and veracious solution to recover the system from faulty condition.

As there are multiple causes of faults, there exist multiple remedies to resolve them. These remedies can be derived straight forward from manual, or from the experienced Operators or from the different Experts working with same systems or can be from the Researchers doing progressive investigations to find the better and better solution. The system presented here is able to provide the optimal among these multiple remedies prioritized by the ease of implication of the solution to save the time and cost.
4.2 Fault Collection Unit

The basic fault collection unit aims the gathering of electrical states as information which is then identified as fault if any outbound condition may happen to halt the machine functioning. The identified faults are categorized according to their electrical behavior as Digital faults and Analog faults. The outbound condition can be different for different machine according to its role in the process, but the electrical means of change can be distinguished by the state of its electrical data. Change in voltage, current and physical parameters etc. can be identified by the means of analog sections whereas logical change is classified in digital information which can be sensor failure, emergency stop, automatic machine breaking etc.

The Fault collection unit performs the role of watchman of the system which collects the status of the information, converts it to the meaningful form and sends to the central system periodically. It is mainly responsible to congregate correct status information of the particular machines by means of analog and/or digital signal conditioning system to get transformed in to the meaningful form. The general block diagram of fault collection unit containing various sensors and associated signal conditioning unit is shown in Fig. 4.2. To suite the parameter state for the acquisition, the analog sensors providing analog output employed in the system are connected to the analog signal conditioning section that can be an amplifier or attenuator. The analog output is then provided to the different channels of the ADC built-in in the microcontroller which encodes the analog data to the digital form. The digital states of the machines are acquired through the digital conditioning section which can be level shifter and/or inverter according to the electrical parameter state.

The collected information is stored in the microcontroller temporarily and sent to the central unit through the high speed CAN bus. A CAN transceiver is attached to microcontroller to form a communication link between the Fault collection unit and Central unit from which data information
can be exchanged. The provision for optional local display is made to ease viewing/debugging the machine states to the Operator/Engineer.

### 4.3 Environment Fault Collection

Many properties like weight, tensile strength, elastic recovery etc. of textile materials vary considerably with moisture regain, which in turn affected by the ambient Relative Humidity (RH) and Temperature. Therefore the measurement and recording of Temperature and Humidity at test locations either continuously or at regular intervals is anticipated. The block diagram of Environment fault collection unit is shown in Fig. 4.3. Both Temperature and Humidity sensor in the block diagram gives the analog output going through signal conditioning built using high gain operational amplifier. The inbuilt ADC in the intelligent microcontroller converts the sensor’s output in digital form for further processing. Temperature and Humidity data is then calibrated.
and displayed on local display and finally transferred to the Central Unit through CAN communication bus for fault analysis purpose.

4.3.1 Temperature Measurement

The atmospheric conditions with respect to temperature and humidity play very domineering part in the manufacturing process of textile yarns and fabrics. Mechanical properties of fibers and yarns also depend on the surrounding temperature conditions to which these are exposed during the textile process. Due to high heat dissipation from spinning as well as weaving and knitting equipment there is a significant increase in temperature particularly in the vicinity of the machinery and their driving motors.

The natural wax covering cotton fibers softens at these raised temperature conditions, thereby adversely affecting the lubricating property of wax for controlling static and dynamic friction. Increase in temperature beyond the design limit also reduces the relative humidity condition near the processing elements of the machinery. Hence textile air-engineering design has
to take care of controlled air flow within the textile machinery for dissipating heat generated at the source and it is customary to carry the waste heat along with the return air to the return air trench. The quantity of return air going to exhaust or recirculation is regulated for controlling the inside design conditions. Modern spinning equipment is designed to operate at high spindle speed. However, high ambient temperature always tends to curtail the operation speed of the machine. Moreover, the sophisticated electronic controls in modern textile machinery also require that the inside temperature in the department should not exceed 33°C or so.

It is also necessary to limit the range of temperature to which the textile machinery is exposed, since the structure of the machinery containing many steel and aluminum parts which expand at different rates with temperature rise (due to difference in co-efficient of thermal expansion) will be subjected to mechanical stress. Hence, along with maintenance of stable relative humidity conditions recommended for different textile processes, it is equally desirable to maintain the temperature level within a range, without much fluctuation.

Recommended temperature values are from 20 to 25°C for different material cotton, wool, linen, ribbons, knitwear, carpets for different applications like carding, spinning, weaving. For nylon/perlon the recommended temperature values ranges from 20 to 27°C. The Integrated Circuit Temperature Sensors offer another alternative to solving temperature measurement problems. The advantages of integrated circuit silicon temperature sensors includes the user friendly output formats and ease of installation in the PCB assembly environment. The LM35 is precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature [2].

4.3.2 Humidity Measurement

The environmental conditions with respect to temperature and humidity play very central part in the manufacturing process of Textile Industry. Many
properties of textile materials vary considerably with moisture regain, which in turn affected by the ambient Relative Humidity (RH). Therefore Humidity sensors have attracted a lot of attention in Textile industrial field. Different methods are used for measurements humidity, e.g., changes in mechanical, optical, and electrical properties of the gas water vapor mixtures [3]. Three types of humidity sensors feasible for present measurement could be:

1) Resistive humidity sensor,
2) Thermal conductivity humidity sensor,
3) Capacitive humidity sensor.

Resistive humidity sensors measure the change in electrical impedance of a hygroscopic medium such as a conductive polymer, salt, or treated substrate. The impedance change is typically an inverse exponential relationship to humidity. The response time for most resistive sensors ranges from 10 to 30 seconds for a 63% (RH). The impedance range of typical resistive elements varies from 1 KOhms to 100MOhms. In residential and commercial environments, the life expectancy of these sensors is greater than 5 years, but exposure to chemical vapors and other contaminants such as oil mist may lead to premature failure. Another drawback of some resistive sensors is their tendency to shift values when exposed to condensation if a water-soluble coating is used.

Thermal conductivity humidity sensors measure the absolute humidity by quantifying the difference between the thermal conductivity of dry air and that of air containing water vapor. An interesting feature of thermal conductivity sensors is that they respond to any gas that has thermal properties different from those of dry nitrogen, this will affect the measurements. Absolute humidity sensors are commonly used in appliances. In general, absolute humidity sensors provide greater resolution at temperatures >200°F (93°C) than do capacitive and resistive sensors, and may be used in applications where the other sensors would not survive.
Capacitive relative humidity sensors are widely used in industrial, commercial, and weather telemetry applications. They consist of a substrate on which a thin film of polymer or metal oxide is deposited between two conductive electrodes. The sensing surface is coated with a porous metal electrode to protect it from contamination and exposure to condensation. The substrate is typically glass, ceramic, or silicon. The incremental change in the dielectric constant of a capacitive humidity sensor is nearly directly proportional to the relative humidity (RH) of the surrounding environment. The change in capacitance is typically 0.2-0.5 pF for a 1% RH change, while the bulk capacitance is between 100 and 500 pF at 50% RH and 25°C. Capacitive sensors are characterized by low temperature coefficient, ability to function at high temperatures (up to 200°C), full recovery from condensation, and reasonable resistance to chemical vapors. The response time ranges from 10 to 60 s for a 63% RH step change [4].

Recommended temperature and humidity values for various textile applications are from 50 to 90 % RH for Spinning. For weaving section the humidity requirement is changes accordingly the types of cloths. For example cotton requires 60 to 70 % RH, wool requires 55 to 65 % RH, and linen requires 70 to 75 % RH. According to survey the humidity should be between 50 to 80 % RH for weaving purpose. For carding or combing machine the recommended humidity is somewhat high up to 85%. Textile manufacturing process involves the following sequence.

Raw cotton $\rightarrow$ Fiber making $\rightarrow$ Yarn making (spinning) $\rightarrow$ Fabric making (weaving/knitting)

The sequential steps during the processes of fiber making, yarn making and fabric making in the production of textiles along with the required relative humidity conditions to be maintained at each stage of processing in the textile process are discussed in the following sections. From 'carding' till 'roving', the loosely bound fibers are vulnerable to static electricity in dry and brittle condition due to static and dynamic friction. This also creates dust and fiber fly (fluff). Higher moisture content lowers the insulation resistance and helps to
carry off the electrostatic charge. Hence relative humidity (being related to moisture content) needs to be maintained above the lower limit of relative humidity range, specified for various textile processes so as to avoid the problems of yarn breakage in dry and brittle condition and also minimize the buildup of static charge so as to reduce dust and fiber fly (fluff).

At the high moisture limit (i.e. above the upper limit of relative humidity for the process) fibers tend to stick and lead to form the laps on the rolls which disrupts the production process. Removal of laps involves a manual activity and hence time consuming process. Weaving rooms for cotton fabric making are designed to maintain high relative humidity of 80% to 85% at the warp sheet level i.e. at 'loom sphere' as high humidity helps to increase the abrasion resistance of the warp. It is required to maintain the general humidity condition in the room at around 65% RH. Knitting operation also requires a stable relative humidity condition at 55% ± 5% for precise control of yarn tension. Hence it is vital to maintain stable relative humidity conditions within the prescribed tolerance limits at all steps of textile processing.

SY-HS220 [5] is humidity sensor with the analog output and has to be connected to the A/D convertor pin of the microcontroller with intermediate stage of Op-Amp buffer to avoid loading on the microcontroller port. It operates at 5V with the minimal current consumption less than 3.0mA and sensing range spreads over 30% to 90% of relative humidity with 5% of accuracy. The humidity sensor module comes with temperature compensation circuit with internal linearly calibrated output in the form of voltage.

The full circuit diagram of the Environmental Fault Collection Unit is shown in the Fig. 4.4.
Fig. 4.4: Circuit Diagram of Environment Fault Collection Unit
4.4 Motor Fault Signal Collection

AC Induction Motors are used as actuators in many industrial processes [6]. Although induction motors are reliable, they are subjected to some undesirable stresses and cause faults resulting into failure. Monitoring of induction motor is a fast emerging technology for the detection of initial faults. It avoids unexpected failure of Textile process. Though the probability of breakdowns of Induction motors is very low, the fault diagnosis has become almost indispensable for industry. Particularly when they are working in sophisticated automated production lines. To decrease the machine down time and improve stability the on-line diagnostic features are to be necessarily incorporated with the drives. In modern Textile Industry lots of machines depend on mutual operation and the cost of unexpected breakdowns figures out to be very high. Thus condition monitoring techniques comprising of fault diagnosis and prognosis are of great concern in industry and are gaining increasing attention. From the foregoing analysis it is clear that the appearance of various faults is simply determined by the stator current values. In general stator currents and voltages are preferred because the sensors required are usually present in the drive considered. The block diagram of Motor fault collection unit is as shown in Fig. 4.5. The Current Transformer (CT) is used as the current sensor and the Voltage Transformer (VT) is used as the voltage sensor. The frequency is measured using the Zero Crossing Detector (ZCD) circuit. With the help of waveforms from ZCD, the microcontroller measures the time period for one cycle and hence the frequency. The current, voltage and frequency values are gathered through the microcontroller and the calibrated data is transferred to the Central unit via the CAN bus.

4.4.1 Current Measurement

The measurement of instantaneous, peak, or average values of the voltage and current signals are necessary to monitor for protecting or
controlling the electrical systems. Hence, accuracy of current measurement plays an essential role in the dynamic performance, efficiency, and safety of an electrical system. Application of current sensing in motor control forms the significant part of Motor Fault Detection. There are different techniques used for current sensing as described in following sub-sections.

### 4.4.1.1 Current Measurement: Series Resistance Method

A low valued resistance placed in the current path of a circuit translates the current into a voltage. This voltage signal is a representation of the current, which can be easily measured and monitored by control circuitry. The sense resistor - the resistor used for current measurement must have low resistance to minimize its power consumption [7]. Resistive-based current sensors are acceptable where the power loss, low bandwidth, noise and non-isolated measurement are acceptable. These sensors are not used in high power applications where isolation is required. Solution to these problems could be electromagnetic-based current sensing techniques.
4.4.1.2 Current Measurement: Electromagnetic Based Current Sensing

Sensing the magnetic field surrounding a conductor provides information about its current. Electromagnetic-based techniques based on this phenomenon provide galvanic isolation between the control and power stages, higher bandwidth, and lower power losses. The lower power dissipation of electromagnetic-based current sensors allow much higher signal level, significantly improves the signal-to-noise environment of the control system [7]. It is mainly divided into two different segments based on the core material used to wound the coil. First type is nothing but a Current Transformers that utilizes ferrite or iron material as core for the coil, whereas second type uses air as core and known as Rogowski Coil.

4.4.1.3 Current Measurement: Using Current Transformers

A current transformer (CT) is similar to a transformer, except that the primary input is a current. CT is used with low range ammeters to measure currents in high voltage circuits. In addition to providing insulation from the high voltage side, CT steps down the current in a known ratio. Their physical basis is the mutual induction between two circuits linked by a common magnetic flux. A CT consists of two inductive coils, which are electrically separated but magnetically linked through a path of low reluctance, as shown in Fig.4.6. If one coil is connected to an ac source, an alternating flux is set up in the core, most of which is linked with the other coil in which it produces mutually induced electromotive force (EMF) according to Faraday’s law of electromagnetic induction. The first coil is called the primary coil, and second coil is called the secondary coil of the CT. If the secondary of the CT is closed, electric energy is magnetically transferred from primary to secondary.
For an ideal transformer with no load, the induced secondary EMF is same as the secondary terminal voltage (V_S). The relationship between the primary and secondary voltages, currents, and number of turns is given by (4.1).

\[
\frac{V_P}{V_S} = \frac{I_S}{I_P} = \frac{N_P}{N_S}
\]  

(4.1)

Where V_P and V_S are primary and secondary terminal voltages, I_P and I_S are primary and secondary winding currents, and N_P and N_S are the number of primary and secondary turns, respectively. The maximum input current of a CT can be increased by varying the ohms of the burden resistor. Lowering the ohms of the burden resistor will increase the maximum input of the CT, but it lowers the resolution. Also, the accuracy of the output voltage depends on the accuracy of the burden resistor. The burden resistor should never be used for more than 55% of its wattage capacity, and thermal concerns of the surrounding materials should be considered to prevent over heating damage. For circuits requiring very accurate outputs, the CT should only be used up to 50% of saturation line of core. In our work we utilized the Ring type CT having a Ferrite core. The specifications of the CT used are listed in table 4.1.
### Table 4.1 Electrical Specifications of Current Transformer

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<table>
<thead>
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<tbody>
<tr>
<td>1</td>
<td>Type</td>
<td>Ring</td>
</tr>
<tr>
<td>2</td>
<td>Sub Type</td>
<td>Tape insulated ring type</td>
</tr>
<tr>
<td>3</td>
<td>Primary Current</td>
<td>30 Amp</td>
</tr>
<tr>
<td>4</td>
<td>Secondary Current</td>
<td>3 Amp</td>
</tr>
<tr>
<td>5</td>
<td>Burden</td>
<td>5VA/ 10VA/ 15 VA.</td>
</tr>
<tr>
<td>6</td>
<td>Frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>7</td>
<td>Operating Temp.</td>
<td>- 10 deg. C to 65 deg. C.</td>
</tr>
</tbody>
</table>

#### 4.4.1.4 Current Measurement: Using Air Core

The performance of a CT is often limited by the characteristics of its magnetic core material (hysteresis, non-linearity, losses, saturation, remanence (residual flux) therefore, the design of an air core or coreless transformer is often considered. The challenge with air core current measurement techniques is to achieve measurement sensitivity and to be insensitive to external magnetic fields. The Rogowski Coil is a simple, inexpensive and accurate approach for current measurement. Structure of a Rogowski Coil is similar to a CT. However, instead of an iron core, Rogowski Coil is based on air or ironless bobbins with hundreds or thousands of turns, as shown in Fig. 4.7. The Rogowski Coil has an air core, so it will never get saturated and its output of remains linear for high current measurement [8-10].

![Rogowski Coil current](image)
4.4.2 Line Voltage measurement

Voltage transformers (VT) operate under the principle of electromagnetic induction between two electric circuits by means of a mutual magnetic flux. The standards establishing the performances of the voltage transformer is an instrument transformer in which the secondary voltage is substantially proportional to the primary voltage and differs in phase from it by an angle which is approximately zero for appropriate direction of the connections. The VT usually consists of two electric windings (the primary and secondary circuits), both wound around a magnetic core as shown in Fig. 4.8. The number of turns of each winding characterizes both circuits: \( N_1 \) is the number of turns of the primary circuit, and \( N_2 \) is the number of turns of the secondary circuit. The operation principle of a V.T. [11] is based on the Faraday Induction Law. In accordance with this law, when the primary winding is connected in parallel with the alternative high voltage to be measured as indicated in Fig. 4.9, a magnetic flux is created as indicated in the equation (4.2)

\[
u_1(t) = N_1 \times \frac{d\phi_1(t)}{dt} = N_1 \times \frac{d\phi_2(t)}{dt} \tag{4.2}
\]

This magnetic flux is guided by the magnetic core, which links the primary and secondary windings, and induces a secondary voltage given by equation (4.3).

\[
u_2(t) = N_2 \times \frac{d\phi_2(t)}{dt} \tag{4.3}
\]

Thus, it is possible to measure the primary high voltage \( u_1(t) \) by means of the secondary voltage, \( u_2(t) \), which is proportionally reduced and galvanically insulated from the high voltage part. The relationship between the primary voltage and the induced secondary voltage (transformation ratio) is given in equation (4.4)

\[
u_2(t) = u_1(t) \times \frac{N_2}{N_1} \tag{4.4}
\]

The secondary voltage causes a current \( i_2(t) \) to flow in the secondary circuit when a load is connected. The current \( i_2(t) \) is determined by the total impedance of the secondary circuit (ideally, for the load). The current in the primary is also depending of the load and can be obtained considering that
power in both sides is kept constant (no losses).

\[
\begin{align*}
P(t) &= u_1(t) \cdot i_1(t) = u_2(t) \cdot i_2(t) \\
i_1(t) &= i_2(t) \cdot \frac{u_2(t)}{u_1(t)}
\end{align*}
\]

For instance, the main criterion behind choosing the primary and secondary winding gauges is the limitation on errors (i.e., reduction of voltage drops) in the case of voltage transformers. The capacity or burden of the VTs is very low, and size is determined by the system voltage on which the VT is to be used. The exciting current of a VT will also be much larger relative to the burden. The accuracy depends on the leakage reactance and the winding resistances which determine how the errors vary as the burden on the secondary increases. The permeability and the power dissipation of the core affect the exciting current and hence the errors at zero burden. Standards for voltage transformers specify errors that must not be exceeded for various classes of accuracy. Limitation in errors leads to limits of watt loss and magnetizing current. The effect of this is to reduce the working flux density of the voltage transformer as compared to the power transformer. Care must also be taken in designing the winding, as the winding resistance and reactance affect errors.
4.4.3 Line Frequency Fault Measurement

The frequency of a power system is an important operational parameter for the safety, stability and efficiency of the power system. Reliable frequency measurement is prerequisite for effective power control, load restoration and system protection. Therefore, there is a need for fast and accurate estimation of the frequency of the power network using voltage waveforms.

Several digital methods for the frequency measuring have been proposed in the past few decades. The use of the zero crossing detection and calculation of the number of cycles that occur in a predetermined time interval [12] is a simple and well-known methodology. Measurement of frequency turns out to be more complicated and involves two main issues, one is obtaining an isolated sample of the line voltage and another is measuring the frequency. For safety reasons, it is essential to isolate the measuring electronics circuit from the power line. Isolation methods, such as a transformer, or optical couplers are available among which the Voltage Transformer is used for sampling the line voltage. The frequency measurement circuit shown in Fig. 4.9 generates an output square wave to use with TTL logic (0 to +5V range) from an input wave of any amplitude up to 100 volts. R1 combined with D1 and D2, limits the swing to 0.6V to +5.6V approximately. Resistive divider R2-R3 is necessary to limit negative swing to less than 0.3 V, the limit for LM358 comparator. R5 and R6 provide hysteresis, with R4 setting the trigger points symmetrically about ground. The input impedance is nearly constant, because of the large R1 value relative to the other resistors in the input attenuator [13].

4.5 Oil Tank Fault Collection

Every mechanism needs the lubrication in one or another form. But outside of the spinning frame no other class of machinery claims so much attention from the lubricant standpoint as looms. To withstand the continuous wear and tear process it is therefore necessary to ensure the fiber an optimum elasticity and a more efficient lubrication than that ensured by the batching oil.
It is therefore indispensable to have an efficient monitoring the lubrication oil
tank’s condition with the help of its quantity and pressure of oil. The two main parameters for oil to consider are oil level and pressure. The Fig. 4.10 is the block diagram of oil tank fault collection unit. The congregated data from the sensors are first amplified and applied to ADC channel of microcontroller. The intelligent microcontroller calibrates the sensor data, display on local display unit and the data collected is then transmitted over to Central Unit through CAN bus for analysis of fault condition.

4.5.1 Oil Pressure Measurement

Mechanical methods of measuring pressure have been known for centuries. The first pressure gauges used flexible elements as sensors. As pressure changed, the flexible element moved and this motion was used to rotate a pointer in front of a dial. In these mechanical pressure sensors, a bourdon tube, a diaphragm, or a bellows element detected the process pressure and caused a corresponding movement. A bourdon tube is C-shaped and has an oval cross-section with one end of the tube connected to the process.
pressure. The other end is sealed and connected to the pointer or transmitter mechanism. To increase their sensitivity, Bourdon tube elements can be extended into spirals or helical coils. This increases their effective angular length and, therefore, increases the movement at their tip, which in turn increases the resolution of the transducer [14]. Because of the inherent limitations of mechanical motion-balance devices, first the force-balance and later the solid state pressure transducer were introduced. The first unbonded-wire strain gauges were introduced in the late 1930s. In this device, the wire filament is attached to a structure under strain, and the resistance in the strained wire is measured. This design was inherently unstable and could not maintain calibration. Also there were problems with degradation of the bond between the wire filament and the diaphragm, and with hysteresis caused by thermoelastic strain in the wire [15]. The potentiometric pressure sensor provides a simple method for obtaining an electronic output from a mechanical pressure gauge. The device consists of a precision potentiometer, whose wiper arm is mechanically linked to a Bourdon or bellows element. The movement of the wiper arm across the potentiometer converts the mechanically detected sensor deflection into a resistance measurement, using a Wheatstone bridge circuit [15]. Potentiometric transducers can be made small and installed in very tight quarters, such as inside the housing of a 4.5 in. dial pressure gauge. They also provide an output that can be used without additional amplification. This permits them to be used in low power applications. They are also inexpensive. Potentiometric transducers can detect pressures between 5 and 10,000 psig (35 kPa to 70 MPa). Their accuracy is between 0.5% and 1% of full scale. The resonant-wire pressure transducer was introduced in the late 1970. In this design, a wire is gripped by a static member at one end and by the sensing diaphragm at the other [16]. An oscillator circuit causes the wire to oscillate at its resonant frequency. A change in process pressure changes the wire tension, which in turn changes the resonant frequency of the wire. A digital counter circuit detects the shift. Because this change in frequency can be detected quite
precisely, this type of transducer can be used for low differential pressure applications as well as to detect absolute and gauge pressures. The most significant advantage of the resonant wire pressure transducer is that it generates an inherently digital signal, which can be sent directly to a stable crystal clock in a microprocessor. Limitations include sensitivity to temperature variation, a nonlinear output signal, and some sensitivity to shock and vibration. The piezoresistive pressure sensor elements consist of a silicon chip with an etched diaphragm and, a glass base anodically bonded to the silicon at the wafer level. The front side of the chip contains four ion-implanted resistors in a Wheatstone bridge configuration. The resistors are located on the silicon membrane and metal paths provide electrical connections. When a pressure is applied, the membrane deflects causing to change in resistance of piezoresistors which results in unbalancing the bridge. Therefore voltage developed across bridge is proportional to the applied pressure [17]. The piezoresistive sensors have excellent electrical and mechanical stability that can be fabricated in a very small size and hence been widely used for industrial and biomedical electronics [18].

While selecting the pressure sensor in Textile Industry, good repeatability often is more important with accuracy. If process pressures vary over a wide range, transducers with good linearity and low hysteresis are the preferred choice. Ambient and process temperature variations also cause errors in pressure measurements, particularly in detecting low. In such applications, temperature compensators must be used. Keller Series 21 MC sensor [19] fulfills these requirements. These piezoresistive silicon pressure transmitters are produced on the new Keller automatic brazing lines, making possible the mass production of high quality pressure transmitters at low cost. This new technology allows the crack free construction of the pressure port without using seals or O-rings. In the brass sensor line (Series 21 MC), a steel insert and a nickel diaphragm is brazed into brass housing. The header with the silicon pressure sensor and glass lead through pins is welded to the steel insert
underneath the oil filling. The tiny chip-on-board amplifier (weight ≈ 1 gram) with the Keller-specific “PROGRES” circuit is mounted directly on the glass feed-through pins. It is then encapsulated in silicone compound for humidity and vibration protection.

The main features are as follows:

- For Industrial applications
- Compact version
- Pressure range 5 Bars
- Max overload pressure range 10 Bars
- Output 4-20 mA
- Operating temperature -25 to 80 °C
- Accuracy 1% F.S. and
- Sensitivity ± 0.04% /oC

![Fig. 4.1: Pressure Transmitter](image)

### 4.5.2 Oil Level Measurement

There are different techniques for measure the level of oil. Some techniques are available like magnetic principle based ultrasonic based and resistive float type. The magnetic and ultrasonic sensors are somehow difficult to mount with oil tank, therefore in oil tank unit the simple resistive type sensors are selected here. The oil level sensor unit is nothing but a variable resistor. The sensor unit is positioned in the oil tank of the machine. The typical float level sensor is shown in Fig. 4.12. It consists of a float, usually made of foam, connected to a thin, metal rod. The end of the rod is mounted to a variable resistor. In an oil tank, the variable resistor consists of a strip of resistive material connected on one side to the ground. A wiper connected to the gauge slides along this strip of material conducting the current from the gauge to the resistor. The wiper slides up or down with the oil level in the tank rising or falling respectively. The sensor unit operating nominally between 0 Ω and100 Ω corresponding to tank being Full or Empty. There are several ways of capturing signal from sensor unit and convert it into an equivalent digital
code. With one approach, the small signal from sensor is amplified and converted into digital code. When the resistance is at a certain point, it will also turn on a "Low Level" indicator. When the tank level reaches to its top limit the maximum current flows and the display unit indicates a “Full Level”.

The full circuit diagram of oil tank fault collection unit is shown in the Fig. 4.13.

4.6 Other Fault Collection

There are several other fault conditions which can halt the production line. Majority of them are of digital type which represents the different mechanical position sensors, detection sensors, emergency stop buttons etc. In case of weaving machine it is necessary to keep a keen eye on the every thread which is crossing each other. Failure to detect the thread damage or thread spool finish results in the downgraded cloth production. Optical sensors

Fig. 4.12: Float Level Sensor
provides a vital role with their ease of implementation, small size and fast response and hence are first choice of selection in the detection process.

Fig. 4.13: Circuit Diagram of Oil Tank Fault Collection Unit
Several optical sensors with some mechanical arrangements are implemented on the machine to detect the fault or safe states. In fully electronic controlled machine a reference starting position call home position is marked and can be checked frequently before starting the new operation. Failing to reach at home position can alter the reference point and hence the overall program positions.

Some of the faults can be treated as on the highest priority faults and needs to be resolved very quickly. Some emergency breaking systems or emergency switches are also provided on the machine to stop the operation on any critical circumstances and needs immediate attention. These are also considered as faults and having strong appeal in defining the machine health. Frequent emergency stops show the poor performance of the machine or the machine operator.

**Fig. 4.14: Block Diagram of Other Fault collection**

Several optical sensors with some mechanical arrangements are implemented on the machine to detect the fault or safe states. In fully electronic controlled machine a reference starting position call home position is marked and can be checked frequently before starting the new operation. Failing to reach at home position can alter the reference point and hence the overall program positions.

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4.6.1 Optical Sensor

Fig. 4.15: Stop mechanism with optical sensor; (a) Work Position, (b) Yarn Breakage Position, (c) Out Position

Fig. 4.16: Yarn Break Detection (Optical) Sensor [20]
Warping is aimed at preparing the weaver’s beam to be set up on the weaving machine. Moreover the warper systems are equipped with yarn breakage monitoring systems with optical sensor as shown in Fig. 4.15. During warping the thread supports the drop pin and the light beam are not interrupted (Fig. 4.15a). At thread breaking or marked thread loosening, the drop pin, being no longer supported hence rotates and shades the light beam (Fig. 4.15b). The idle threads are cut by pushing the relevant keys: the drop pins take up a position which does not interrupt the light beam, thus enabling the working of all other threads (Fig. 4.15c). The actual sensor array used for detection of yarn breakage is shown in the Fig. 4.16.

The detailed circuit diagram of digital fault collection unit is shown in the Fig. 4.17. The circuit consists of the arrangement for the attachment of sensors of various operating voltage range of 3V to 30V. The inputs from these sensors are optically isolated so as to protect the digital sensing logic and the controller. The system has its own power supply built on it and the local display for the purpose of debugging and indication of sensor states. The system updates sensor states to the control unit through the CAN communication bus. The algorithm of the sensing system is shown in the Fig. 4.18.

The software algorithm of the sensor units for analog as well as digital fault sensing is similar. There is a constant cycle of reading the fault information from the various sensors and converting them to the user understandable form by calibrating the binary data to the standard measurement units. These converted measurements of various parameters are then sent periodically to the central unit for the analysis process. In case of emergency faults the system flow skips the wait period and transfers the fault data immediately to the central unit. Otherwise the cycle keeps on repeating the same process and runs as long as the machine is functioning.
Fig. 4.17: Circuit Diagram of Digital Fault Collection Unit
Fig. 4.18 Flowchart of the Sensor Unit
4.7 The Central Unit

4.7.1 Block diagram

The block diagram of Central unit is shown in Fig. 4.19. The microcontroller is main intelligent device from this unit. The CAN transceiver is used for CAN bus communication. The LCD is used for display the sensor parameters like temperature, pressure etc. The RS232 interface is for PC serial COM port interface. The all sensor parameters are sent through the RS232 interface for further process diagnosis.

As shown in the Fig. 4.20 the Central unit consists of a PIC18F2480 microcontroller with a built-in CAN module and MCP2551 transceiver chip. The microcontroller is operated from 4MHz crystal. The MCLR input is connected to an external reset button. The CAN outputs (RB2/CANTX and RB3/CANRX) of the microcontroller are connected to the Txd and Rxd inputs of the MCP2551. Pins CANH and CANL of the transceiver chip are connected.
Fig. 4.20: Circuit Diagram of Central Unit

to the CAN bus. LCD16X2 is connected to PORTC of the microcontroller to display the sensor parameters. Fig. 4.21 shows the process flowchart of the
central node which gathers the fault data from various sensing nodes and passes them to the PC.

![Flowchart of the Central Unit](image)

**Fig. 4.21 Flowchart of the Central Unit**

### 4.8 CAN Node

For CAN-bus based designs, it is easier to use any microcontroller with a built-in CAN module. PIC, ARM, AVR are the popular microcontrollers having built-in CAN module. As shown in Fig. 4.22, such devices include
built-in CAN controller hardware on the PIC microcontroller. All that required to make a CAN node is to add a CAN transceiver chip.

Communication between CAN Nodes

The following is a simple two-node CAN bus communication. The block diagram is shown in Fig. 4.23. The system is made up of two CAN nodes. One node (called Central node) requests to another node after certain interval like second and displays the received parameters on an LCD. This process is repeated continuously. Central node sends all parameters to Personal
Computer for further analysis. Personal Computer is having fuzzy diagnosis system. The other node (called SENSOR node) reads the pressure and proximity from an external pressure sensor and proximity sensor respectively. If any major deviations or any fault occurs SENSOR node sends the parameters to Central node through CAN bus immediately.

**4.8.1 CAN Transceiver MCP2551**

The MCP2551 CAN transceiver [28] from Microchip is interfaced with PIC18F2480. Typically, each node in a CAN system must have a device to convert the digital signals generated by a CAN controller to signals suitable for transmission over the bus cabling (differential output). It also provides a buffer between the CAN controller and the high-voltage spikes that can be generated on the CAN bus by outside sources (EMI, ESD, electrical transients, etc.). The MCP2551 is a high-speed CAN, fault-tolerant device that serves as the interface between a CAN protocol controller and the physical bus. The MCP2551 provides differential transmit and receive capability for the CAN protocol controller and is fully compatible with the ISO-11898 standard, including 24V requirements. It will operate at speeds of up to 1 Mb/s.

![Fig. 4.24: Interfacing Microcontroller with MCP2551](image)

The CAN module uses port pin 24 RB3/CANRX and port pin 23 RB2/CANTX for CAN bus receive and transmit functions respectively. These pins are connected to the CAN bus via an MCP2551-type CAN bus transceiver chip.
Chapter 4 Hardware Implementation of Fault Detection and Fuzzy Diagnosis

Fig. 4.25: Circuit diagram of the CAN Communication between two different nodes

The circuit diagram of CAN Node is given in Fig. 4.25. Two CAN
nodes are connected together using a twisted pair cable, terminated with a 120-ohm resistor at each end. Both nodes are controlled by intelligent device microcontroller PIC18F2480 [21]. Microcontroller is having inbuilt CAN controller, so no external CAN controller is needed.

4.9 Laboratory Work

The experimental setup for Motor parameter measurement is shown in Fig. 4.26 and Fig. 4.27. The experimental setup includes the embedded circuit board which is made from PIC18F2480 having inbuilt CAN controller, power supply section, signal conditioning for Current transformer (CT) and three phase motor of 440 V, 1 Amp. The CT used is of 30/30mA specification. CT is specially used for measuring the current of motor because it gives total isolation. Each phase R, Y and B are attached with individual CT for current measurement. The voltage transformers are used to monitor the present voltages of the respective phases. The line frequency of the supply is monitored using the zero crossing detector circuit.

![Experimental setup for Measurement of Motor Parameters](image_url)

**Fig. 4.26: Experimental setup for Measurement of Motor Parameters**
With this experimental setup we generated some faulty conditions those can occur in the real time environment. The faults such as single phasing, overload and low and high voltage were tested with the FIS. The results are shown in the results section (Chapter V).

4.10 Graphical User Interface (GUI)

The success of any system mainly depends upon easiness in the operation and clear understanding of it to the system operator. To ease the handling of different fault conditions and to follow the respective remedies
suggested by the system to the operator we have designed a GUI of the total system. It is divided into several screens depending upon the different sections of the system. The main front end navigation GUI is shown in the Fig. 4.28 from where user can access every section of the system. GUI has been designed in MATLAB [23-25] software.

**4.10.1 GUI for Weaving Section**

Weaving section shows summery of two different parts - first is the Machine health Determination and second - the Machine Environment Determination. Machine health determination section includes Motor Condition, Lubricant Oil Tank Condition and Emergency Faults Detection. The
detailed parameters generated by the FIS models from the data acquired can be seen in the individual views.

![GUI for Motor Condition Determination](image.png)

**Fig. 4.29: GUI of Weaving Section**

**4.10.2 GUI for Motor Condition Determination**

The Fig. 4.30 shows the GUI window of Motor Condition determination. The motor parameters such as Phase Currents, Phase Voltages and the operating frequencies are continuously monitored. The motor condition depends mainly on stator current of motor. The GUI also indicates the present motor health condition. On any uneven change in rated parameter the system shows the possible causes of the problem occurred and also the available remedy there upon. The motor conditions like ‘Overloaded’, ‘Critically Overloaded’, and
‘Open Phase’ etc. can be seen in the Cause window which aids the operator to quickly understand the underlying problem.

4.10.3 GUI for Environment Condition Determination

The Fig. 4.31 shows the GUI window of Environment Condition determination. The environmental parameters like Humidity and Temperature play a vital role in the quality production and in the smooth operation of the machine. The machine health is also depends on the correct operating conditions and failing to maintain can cause frequent breakdowns to the machine and hence hamper the production process. The GUI includes the present state of environment, temperature in degree Celsius, humidity in %rh, and possible causes of fault if any. The Environment State ‘Good’ is always expected for smooth operation.
4.10.4 GUI for Lubrication Oil Tank Condition Determination

To keep the machine running smoother it requires the frequent lubrication. In case of high speed machine those are presently running in the Textile Industry needs a continuous oil circulation for the lubrication and cooling of several frictional parts. The constantly pressurized oil supply hence installed with every machine and the pressure and quantity of the oil needs to be monitored continuously. The Fig. 4.32 shows the GUI window of Oil tank Condition determination where the oil pressure and Oil level/Quantity are measured and displayed. The possible faults such as low oil pressure and low oil levels are continually monitored for any failure pertaining to tank condition.
4.10.5 GUI for Emergency Fault Condition Determination

There are several sensors installed in the machine for the proper working of each segment of the machine and to get the present state of the machine operations. These sensors can be mechanical, electromechanical or optical. It is very necessary to keep these sensors functioning all the time to get reliable operation of the machine. The failure of these sensors is considered as machine fault and their weightage is decided according to their function and consequence on the particular machine. There are some optional buttons also provided to stop the machine immediately on the serious events. These buttons have highest priority and marked as serious faults to get the immediate attention. The Fig. 4.33 shows the GUI window of Emergency Faults.
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4.11 Controller Area Network (CAN)

The Controller Area Network (CAN) is a serial bus communications protocol developed by Bosch (an electrical equipment manufacturer in Germany) in the early 1980s. Thereafter CAN was standardized as ISO-11898 and ISO-11519, establishing itself as the standard protocol for in-vehicle networking in the auto industry [26]. In the early days of the automotive industry, localized stand-alone controllers had been used to manage various actuators and electromechanical subsystems. By networking the Electronics in vehicles with CAN, however, these subsystems could be controlled from a central point- the engine control unit (ECU) thus increasing functionality, adding modularity and making diagnostic processes more efficient.

Fig. 4.33: GUI of Emergency Faults

![Emergency Faults](image.png)
Early CAN development was mainly supported by the vehicle industry, as it was used in passenger cars, boats, trucks, and other types of vehicles. Today the CAN protocol is used in many other fields in applications that call for networked embedded control including industrial automation, medical applications, building automation, weaving machines, and production machinery. CAN offers an efficient communication protocol between sensors, actuators, controllers, and other nodes in real-time applications, and is known for its simplicity, reliability, and high performance.

The CAN protocol is based on a bus topology, and only two wires are needed for communication over a CAN bus. The bus has a multimaster structure where each device on the bus can send or receive data. Only one device can send data at any time while all the others listen. If two or more devices attempt to send data at the same time the one with the highest priority is allowed to send its data while the others return to receive mode.

The CAN protocol is based on CSMA/CD+AMP (Carrier-Sense Multiple Access/Collision Detection with Arbitration on Message Priority) protocol, which is similar to the protocol used in Ethernet LAN. When Ethernet detects a collision, the sending nodes simply stop transmitting and wait a random amount of time before trying to send again. CAN protocol, however, solve the collision problem using the principle of arbitration, where only the highest priority node is given the right to send its data [27].

4.11.1 Message frames in CAN

To communicate between different nodes of the system the CAN communication bus is implemented which provide better noise immunity to the industrial noise and transfers the data at very high data rates. The communication between the central node and the fault collection node happens in the form of frames. The list of frames used in the communication and their priority on the CAN bus is listed in the Table 4.2.
Table 4.2 CAN Communication Frames

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Frame Description</th>
<th>Frame Length</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Emergency Fault</td>
<td>8 Byte</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Warp/Weft Break</td>
<td>8 Byte</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Motor Overload</td>
<td>8 Byte</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Motor Single Phase</td>
<td>8 Byte</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Oil Pressure Low</td>
<td>8 Byte</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>Humidity Level Low</td>
<td>8 Byte</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>Humidifier Failure</td>
<td>8 Byte</td>
<td>7</td>
</tr>
<tr>
<td>9</td>
<td>Temperature High</td>
<td>8 Byte</td>
<td>9</td>
</tr>
<tr>
<td>10</td>
<td>Temperature Low</td>
<td>8 Byte</td>
<td>10</td>
</tr>
<tr>
<td>11</td>
<td>Motor Voltage Change</td>
<td>8 Byte</td>
<td>11</td>
</tr>
<tr>
<td>12</td>
<td>Motor Frequency Change</td>
<td>8 Byte</td>
<td>12</td>
</tr>
<tr>
<td>13</td>
<td>Oil Level Low</td>
<td>8 Byte</td>
<td>13</td>
</tr>
</tbody>
</table>
4.12 References

12. A. Phadke, J. Thorp, and M. Adamiak, A new measurement technique for tracking voltage phasors, local systems frequency, and rate of


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