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DEVELOPMENT AND IMPLEMENTATION OF A SENSOR NETWORK TO MONITOR FERMENTATION PROCESS PARAMETER IN TEA PROCESSING

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Abstract- Fermentation is extremely a crucial process which is primarily responsible for tea quality. It is an oxidation process where tea leaves change colour and smell. Relative humidity (RH) and temperature are two important physical parameters which play a crucial role in producing good quality tea. This work is an attempt to develop and implement a monitoring system for fermentation room of tea factory. Due to the larger dimension of the fermentation room, it requires several numbers of monitoring point for estimating average condition. Sensor node at each monitoring point is connected via RS 485 network which works with a protocol developed for this purpose. Each sensor node consists of sensors, signal conditioning, controller and RS485 transceiver. All these nodes are calibrated and the voltage level of RS 485 system is converted to RS 232 voltage level to make compatible with the COM port of the PC. Data acquisition software is developed with the help of NI Lab VIEW.

Index terms*:* Tea Fermentation, Relative Humidity, Temperature, RS 485 Network.

I. INTRODUCTION

Tea is a major agricultural and export item of Assam and it plays an important role to the economic growth of India in general and Assam in particular. Almost 2500 numbers of tea gardens are there in Assam producing almost 51 % of total tea production of India. But the proper monitoring and control of different tea process parameters like temperature, relative humidity, moisture content at different level is done by manual means and guesswork. In rare cases where modern measurement methods are implemented, but due to lack of proper expertise in operation and maintenance they are not effectively utilized. As a result the quality of product and efficiency of operation suffer badly, affecting the performance of the industry (1, 2). Black tea processing is performed through a few sequential operations: (a) plucking, (b) withering, (c) pre-conditioning, (d) cut–tear–curl (CTC), (e) fermentation and (f) drying as shown in Fig. 1. (3)

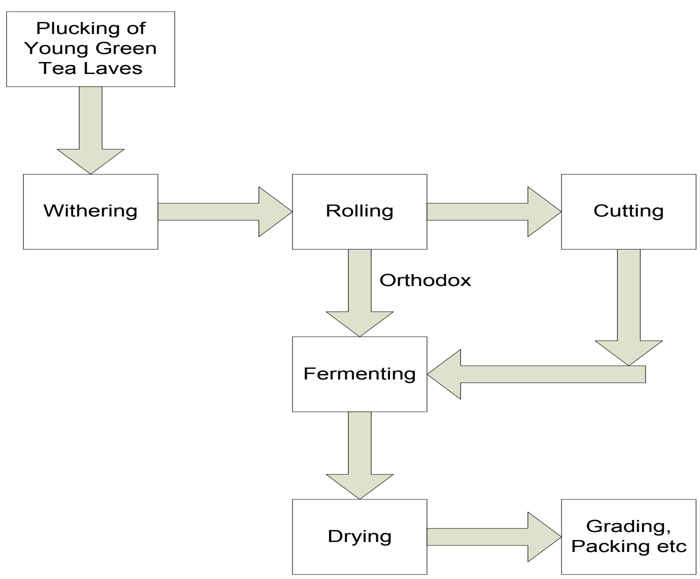


Fig 1: Block diagram of the tea processing stages

Among all these processes fermentation is one of the most important process where tea leaves change colour and smell. It is a complex chain of biochemical reactions those take place during the fermentation process and once such changes reach their optimum point, the process should be stopped (4). The physical parameters that affect the fermentation process are i) Relative Humidity ii) Temperature. Thus control of these physical parameters will be very useful to maintain proper fermentation condition to have desired quality of tea (5).In this study they have experimented with electronic nose based system in 81 fermentation cycle and by using different statistical tools, they are able to correlate the electronic nose based results with colorimetric test as well as human panel test to find out the optimum fermentation time. Bhattacharya et al. [6] used electronic nose based technique to monitor the fermentation process of black tea and successfully correlated these data with the results of colorimetric tests and human expert evaluation. Tudu et.al. [7] studied different optimization technique for black tea classification by using electronic nose which comprises of a gas sensor array.

Sarma et al. developed a system for monitoring RH and temperature of fermentation room [8, 9]. In these studies, a capacitive RH sensor with on chip signal conditioner is taken as RH sensor and a temperature to digital converter (TDC) is used for ambient temperature monitoring which are interfaced with an 8051 microcontroller. Online temperature correction for RH measurement, calibration and field installation has been done and studied. In [8] the system is calibrated using conventional dry and wet bulb method where as in [9] the system is calibrated using standard saturated binary salt solutions. Moghavvemi et al. [10] also developed a relative humidity and temperature measurement instrument with built-in sensing circuitry. A pioneering work had been done by Dey et.al.[11]where a low cost RH and temperature monitoring system is devised using two identical thermistor and its performance was studied by simulation. But networking capability is not incorporated with these systems and need individual central monitoring and data logging system. As the fermentation room is larger in dimension, so network based system is the prior need for monitoring these parameter simultaneously with a central monitoring system. So an instrument with on line central monitoring and data logging feature having networking capability for Fermentation process is expected to be helpful for controlling these parameters and thus quality improvement.

This paper describes development and implementation of an electronic instrumentation to monitor the parameters mentioned above and logging of the data in desired form. The system comprises of several smart sensor nodes. Each sensor node has sensor, signal conditioner, A/D converter and network interface to communicate with central monitoring system. The system has features like online temperature correction for humidity, monitoring and data logging of ambient RH and temperature at different places of fermentation room simultaneously at an average rate of 10 data per minute.

II. SYSTEM DESCRIPTION

A customized instrumentation set-up has been developed to monitor the fermentation room of the tea factory. Block diagram of the complete instrumentation set-up is given in Fig 2. Four sensor nodes are placed to monitor the temperature as well as R/H of the fermentation room. An R/H to voltage converter [132] and temperature to voltage converter [13] type sensor is used to develop the R/H and temperature monitoring sensor node. The block diagram and the completed view of the sensor node is given in Fig 3 and Fig 4.

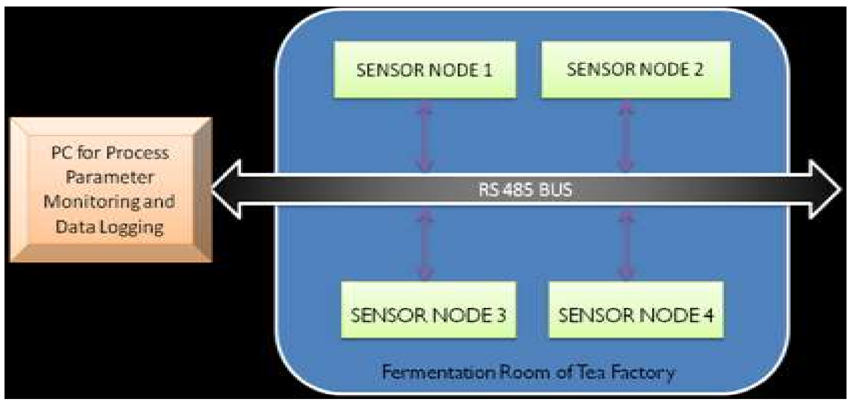


Fig2: Block diagram of the instrumentation set-up for fermentation room

The temperature is sensed by the temperature to voltage converter type sensor and the voltage is read by the 10 bit built in ADC of PIC microcontroller [14]. The analog signal from the R/H sensor is fed to the same microcontroller and analog to digital conversion is done by another 10 bit built in ADC. The system is calibrated and the digital data is converted to its corresponding temperature and humidity. These values are sent to PC via RS485 communication network [15]. The reason of choosing RS 485 based network is its sufficient reliability for the stated purpose and relatively low cost over wireless sensor network. The voltage level of RS 485 system is converted to RS 232 voltage level to make compatible with the COM port of the PC. All these correction and communication is done by the application algorithm embedded in the microcontroller. The transceiver for RS 485 communication is MAX 485[16]. The flowchart of the firmware embedded in the microcontroller is given in Fig 5. The function of the firmware developed is as follows-

i. Initialize ADC and serial port

ii. Wait for receiving address of the node.

iii. If the address is matched, ADCs connected with the sensors are read.

iv. Raw digital data is sent to PC.

v. Go to step (ii) after completion of sending data.

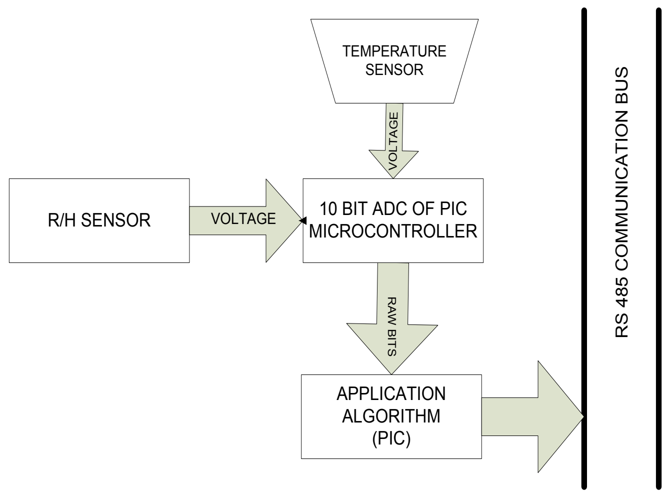


Fig 3: Block diagram of R/H and temperature monitoring system

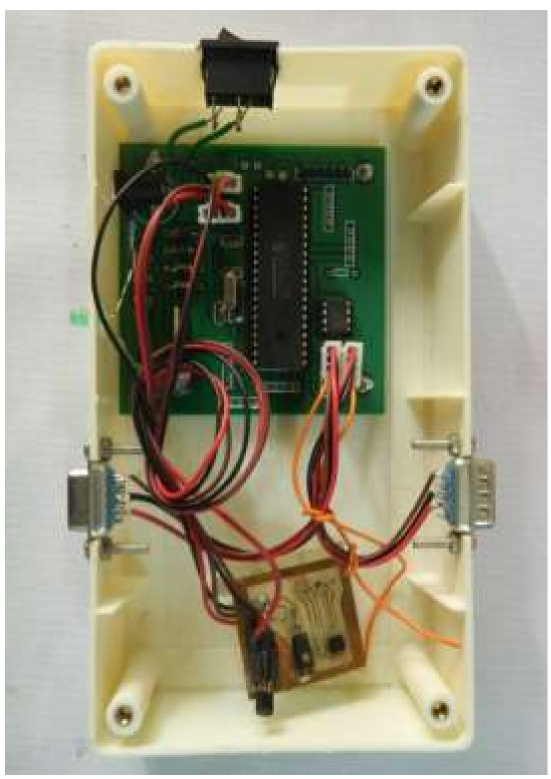


Fig 4: View of the Sensor Node

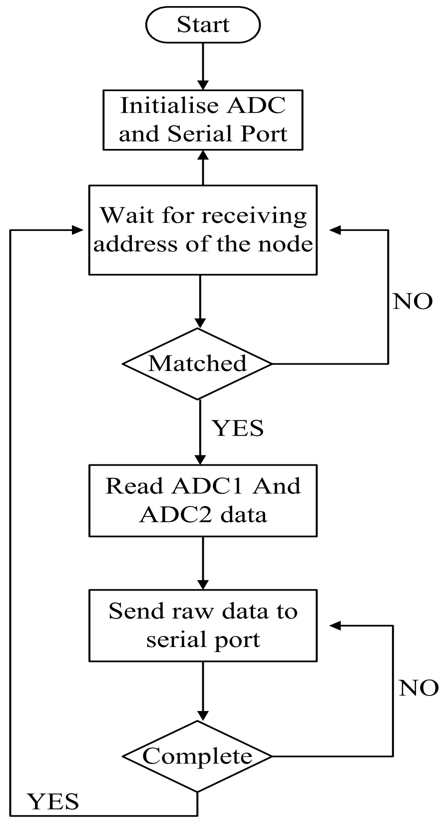


Fig 5: Flowchart of the firmware embedded in the microcontroller

THE SENSORS:

For sensing temperature LM35D is used. It is an IC temperature sensor which gives 10mV/ ^{0}C output. It is calibrated in ^{0}C with the accuracy of 1.5 ^{0}C and rated temperature range is -55 to 150 ^{0}C. The circuit schematic is given in Fig 6 [13].

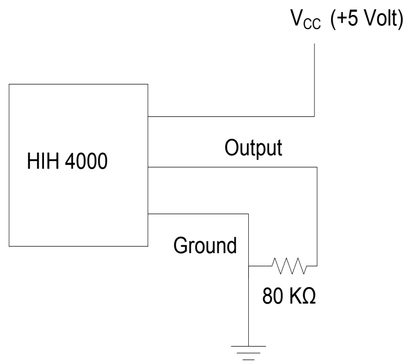
For sensing Relative humidity, low power RH to voltage converter (HIH 4000) is used. It is basically a LASER trimmed, thermoset polymer capacitive type sensing element with on chip integrated signal conditioning. The accuracy of the sensor is ±3.5% at 25 ^{0}C with 5 Volt DC supply. The output voltage (V_{OUT}) and RH can be expressed typically at 25^{0}C as [9, 12, 17]:

$$RH = \left(\frac{V_{OUT}}{V_{SUPPLY}} - .16\right) \times 61.29\ \%$$ ------- (1)

Temperature compensated RH is given in equation (2)

$$True\ RH = \frac{\text{sensor RH}}{1.0546-(0.00216\times T)}$$, T in ºC ------- (2)

The circuit for measuring the RH is given in Fig 7



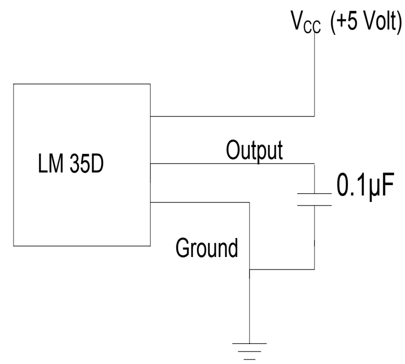


Fig 6: Circuit schematic for RH sensor

Fig 7: Circuit schematic for temperature sensor

THE DATA ACQUISITION SOFTWARE:

The software required at PC to send and receive data serially using the protocol RS 485 is developed in Lab VIEW. The raw digital data is converted to temperature and humidity in this software. The format of the signature sent by the PC is shown in Fig 8 and the format of the data received by the PC is in Fig 9 (a) and 9 (b). In Fig 8 the data frame comprises of the address of the sensor node with one start bit and one stop bit. In Fig 9 (a), the data sent from the sensor node consisting of total seven bytes and significance of each byte is shown there. Each byte comprises of one start bit and one stop bit and eight data bits as shown in fig 9 (b). Flowchart of the software is given in Fig 10. A screenshot of a portion of the LabVIEW program is given in Fig 11.

Start Bit (1 bit)	Address of the node (1 byte)	Stop bit (1 bit)

Fig 8: Format of the signature sent to sensor node from PC

Signature of the parameter (1 byte)	Signature of the Sensor node (1 byte)	Raw hexadecimal data (5 byte)				

Fig 9 (a): Format of the data sent to PC from sensor node

Start Bit (1 bit)	Raw hexadecimal data (1 byte)	Stop bit (1 bit)

Fig 9 (b): Format of each byte shown in Fig 9 (a)

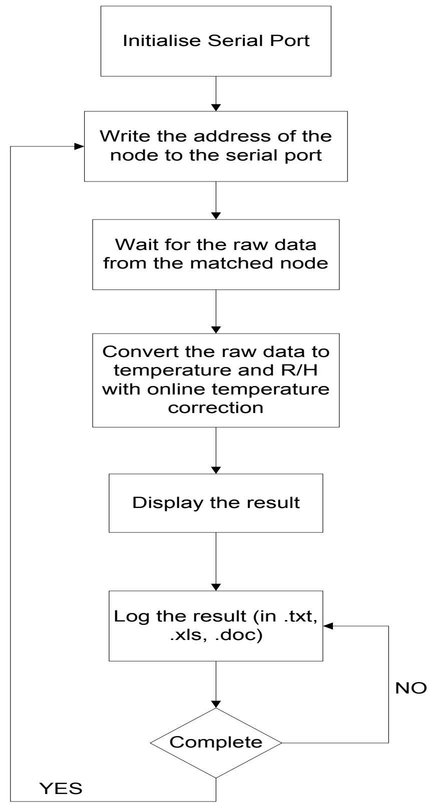


Fig 10: Flowchart of the data acquisition software.

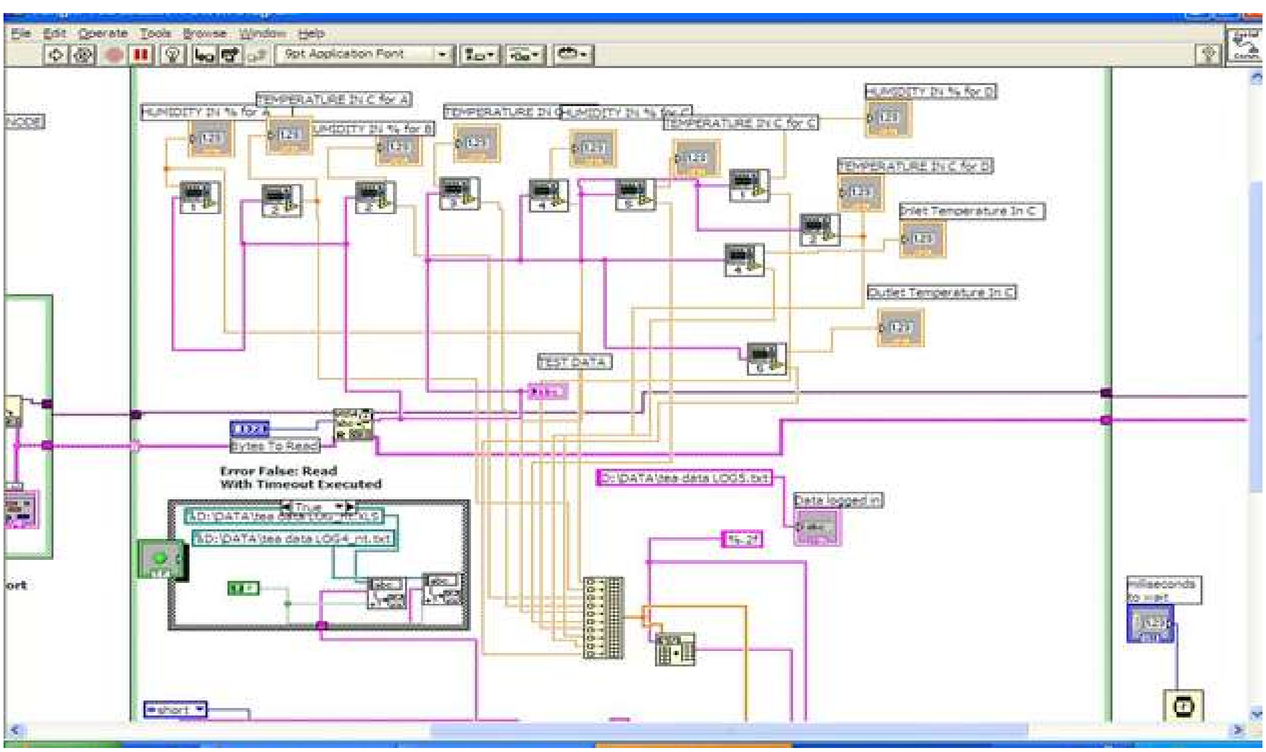


Fig 11: Screenshot of a portion of the LabVIEW program

III. CALIBRATION

The system is calibrated [9,17] for RH in constant temperature. The system is calibrated using 4 standard saturated binary salt solutions at 25^0C. The corresponding RH values for the selected binary salts are shown in Table 1[18]. The solutions are prepared according to OIML R121 [19]. Distilled water is selected as solvent. The sensing part is inserted in the hygrostat which is a closed vessel containing the hygrostatic solution. The pictorial view of calibration setup is given in Fig 12. The variation of RH is monitored in a PC. When system shows a stable value of RH for 30 minutes, 100 readings are recorded using on line data acquisition facility of the system. The resolution of the system is 1% for relative humidity and 1ºC for temperature is found. The experiment was carried out in a temperature controlled environment where temperature was kept constant at 25^0C and the system was also showing the controlled temperature without any deviation at the time of experiment. Table 2 represents the calibration data with % error for RH. Fig 13 shows the comparison between the RH measurement of the system and the standard RH. The observational error pattern for the RH measured by the system is shown in fig 14.

Table 1.The selected binary salts with standard RH [18]

Sample	Standard RH at 25^0C
S1: Potassium Hydroxide	8.23 ± 0.72
S2: Magnesium Nitrate	52.89 ± 0.22
S3: Sodium Chloride	75.29 ± 0.12
S4: Potassium Sulphate	97.30 ±0.45

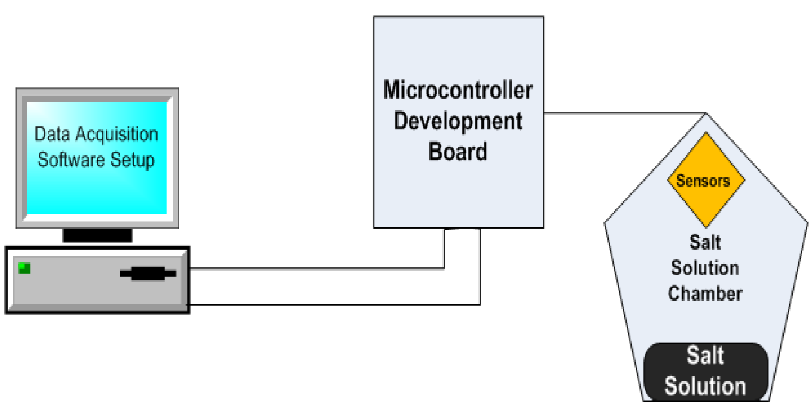


Fig 12: Pictorial View of the calibration setup

Table 2. Calibration Data for RH

Sample	Temperature in ^{0}C	Standard RH in %	RH measured by the system in %	% error for full scale output
S1	25	8.23 ± 0.72	8.5	0.27
S2	25	52.89 ± 0.22	52.14	-0.75
S3	25	75.29 ± 0.12	75.43	0.14
S4	25	97.30 ±0.45	97.27	-0.03

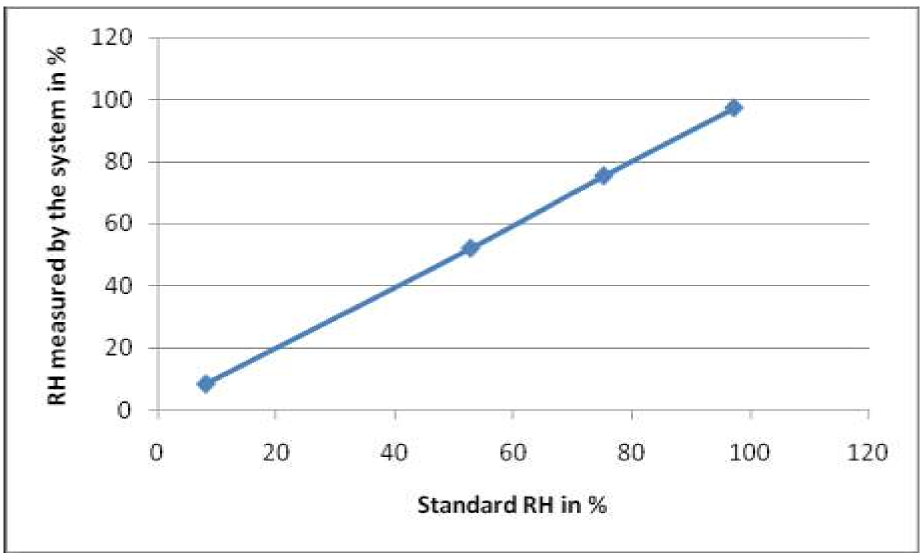


Fig 13: Comparision plot showing RH measured by the system vs standard RH in %

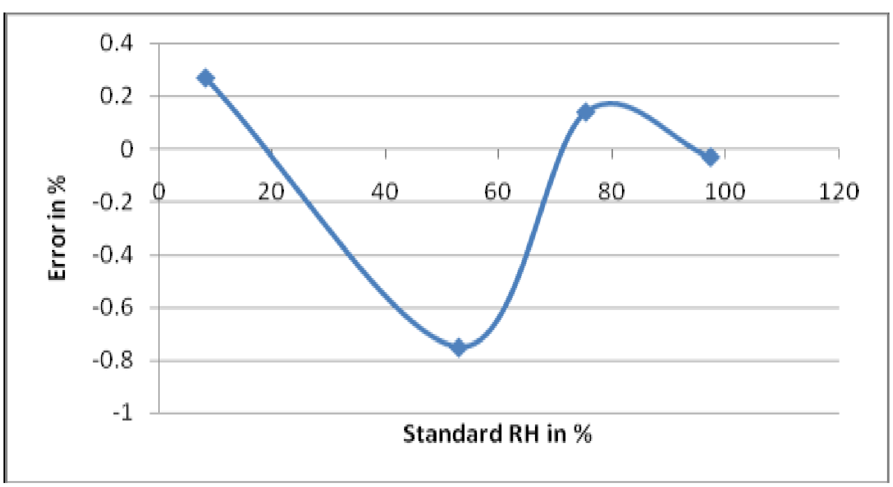


Fig 14: Observational error pattern for RH of the system in % at 25^{0}C

IV. FIELD INSTALLATION

The acquired data shows ±8% variation from the average in case of Relative Humidity and ±2.5 ºC variation in case of temperature for a particular day of the fermentation room of the tea factory during tea production. Analysis of data for several days during 26th July to 3rd December 2013 shows the average variation of Relative Humidity as 83% to 90% and temperature from 27 ºC to 32 ºC in the fermentation room. Screen shot of the logged data in .xls format is shown in Fig 15. Table 3 and Fig 16 represent variation of fermentation room parameters for the day of 2nd august, 2013. In Fig 16, HUM_1, TEMP_1, HUM_2, TEMP_2, HUM_3, TEMP_3, HUM_4, TEMP_4 are indicating the R/H and temperature of the four sensor nodes placed in different points of the fermentation room. Table 4, Fig 17 and Fig 18 represents variation of daily average RH and temperature of tea Fermentation Room for 15 days.

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	A	B	C	D	E	F	G	H	I	J
99104										
99105	08-07-2013	8:41 AM	89.6	28.8	95.8	27.3	89.6	26.8	93.3	27.8
99106										
99107	08-07-2013	8:42 AM	90.8	28.8	95.8	27.3	89.6	26.8	93.3	27.8
99108										
99109	08-07-2013	8:42 AM	90.8	28.8	95.8	27.3	89.6	26.8	93.3	27.8
99110										
99111	08-07-2013	8:42 AM	90.8	28.8	93.3	27.3	89.6	26.8	93.3	27.8
99112										
99113	08-07-2013	8:42 AM	90.8	28.8	93.3	27.3	89.6	26.8	93.3	27.8
99114										
99115	08-07-2013	8:42 AM	90.8	28.8	93.3	27.3	90.2	26.8	93.3	27.8
99116										
99117	08-07-2013	8:42 AM	90.8	28.8	93.3	27.3	90.2	27.3	93.3	27.8
99118										
99119	08-07-2013	8:42 AM	90.8	28.8	93.3	27.3	90.2	27.3	93.9	27.8
99120										
99121	08-07-2013	8:42 AM	90.8	28.8	93.3	27.3	90.2	27.3	93.9	27.8
99122										
99123	08-07-2013	8:42 AM	90.8	28.8	93.3	27.3	90.2	27.3	93.9	27.8

Fig 15: Screenshot of the logged data

Table 3: Variation of fermentation room parameters, Date: 02.08.2013

Time	RH in % from Sensor node 1	Temp* in ^{0}C from Sensor node 1	RH in % from Sensor node 2	Temp* in ^{0}C from Sensor node 2	RH in % from Sensor node 3	Temp* in ^{0}C from Sensor node 3	RH in % from Sensor node 4	Temp* in ^{0}C from Sensor node 4
6:00 AM	84.2	30.3	87.4	29.0	83.7	28.7	79.5	31.1
6:30 AM	84.0	30.6	86.8	29.4	84.3	28.6	80.0	31.3
7:00 AM	86.1	30.5	88.5	29.4	86.0	28.8	85.1	30.5
7:30 AM	86.3	30.4	89.0	29.3	86.3	28.7	86.3	30.3
8:00 AM	87.2	30.5	88.6	29.5	86.4	28.7	86.7	30.4
8:30 AM	86.6	30.4	88.0	29.6	85.4	28.8	85.7	30.2
9:00 AM	87.5	30.4	88.9	29.4	86.6	28.9	86.8	30.3
9:30 AM	87.8	30.5	89.3	29.5	86.9	28.9	87.8	30.3
10:00 AM	89.9	30.3	92.2	29.1	89.4	28.6	91.9	29.8
10:30 AM	90.5	30.2	92.6	29.1	90.8	28.2	92.7	29.4
11:00 AM	91.6	30.3	93.4	29.2	91.2	28.5	93.4	29.7
11:30 AM	90.7	30.2	93.1	29.0	90.7	28.3	92.0	29.5
12:00 PM	89.9	30.1	91.5	29.2	90.3	28.4	92.2	29.5
12:30 PM	90.4	30.3	92.4	28.9	90.1	28.7	92.8	29.7
1:00 PM	89.9	30.7	88.3	32.3	88.7	30.1	90.6	31.4
1:30 PM	89.9	30.3	91.9	28.9	88.0	27.9	89.0	28.5
2:00 PM	88.5	30.6	89.2	30.2	87.2	29.3	91.0	30.1
2:30 PM	87.6	30.3	83.3	28.4	78.0	26.2	77.8	25.5
3:00 PM	86.1	31.1	83.7	29.8	72.8	25.8	81.9	29.0
3:30 PM	87.0	30.3	84.3	28.9	80.0	27.0	80.5	26.8
4:00 PM	86.0	31.1	84.9	30.8	84.8	29.5	88.6	30.5
4:30 PM	86.6	31.1	85.4	30.5	86.3	29.4	89.5	30.4

*Temperature

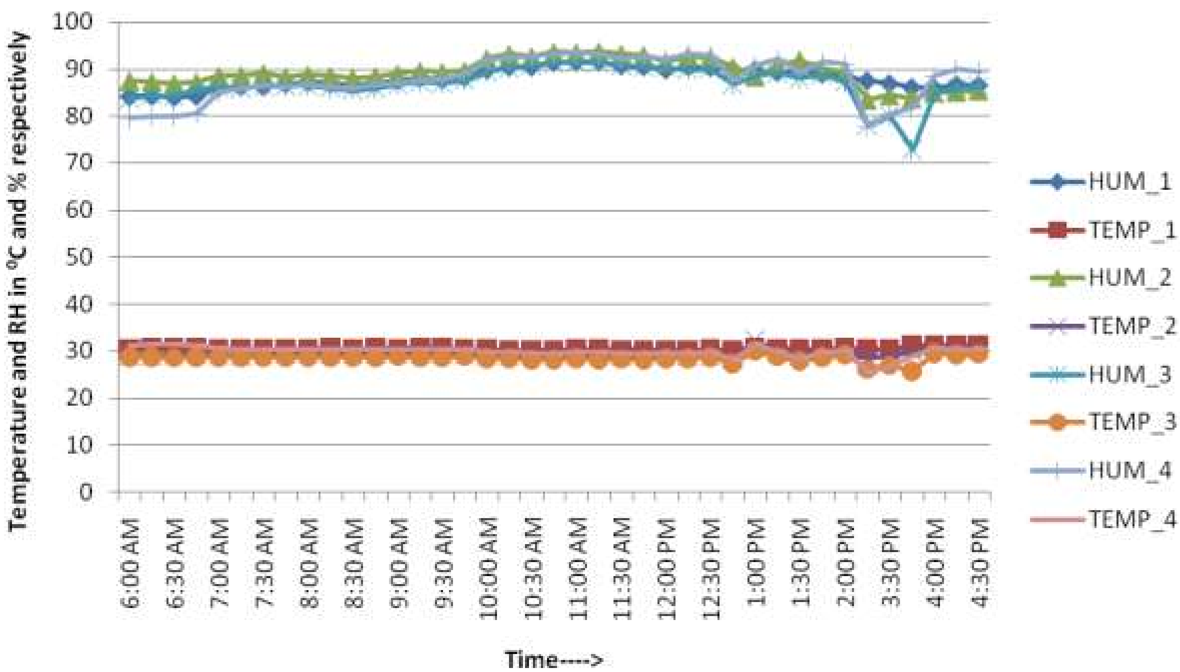

Fig 16: Variation of fermentation room parameters, Date: 02.08.2013

Table 4: Variation of daily average RH and temperature for tea fermentation room

Date	Average RH in %	Average temperature in ^{0}C
27/07/2013	88.7	28.9
28/07/2013	86.4	29.9
30/07/2013	86.7	31.8
31/07/2013	84.6	29.4
01/08/2013	83	29
02/08/2013	88.1	29.6
03/08/2013	89.2	30.2
04/08/2013	87.5	30.9
06/08/2013	88.4	28.2
07/08/2013	87.7	27.7
08/08/2013	87	29
09/08/2013	89.3	28.8
10/08/2013	89	28.7

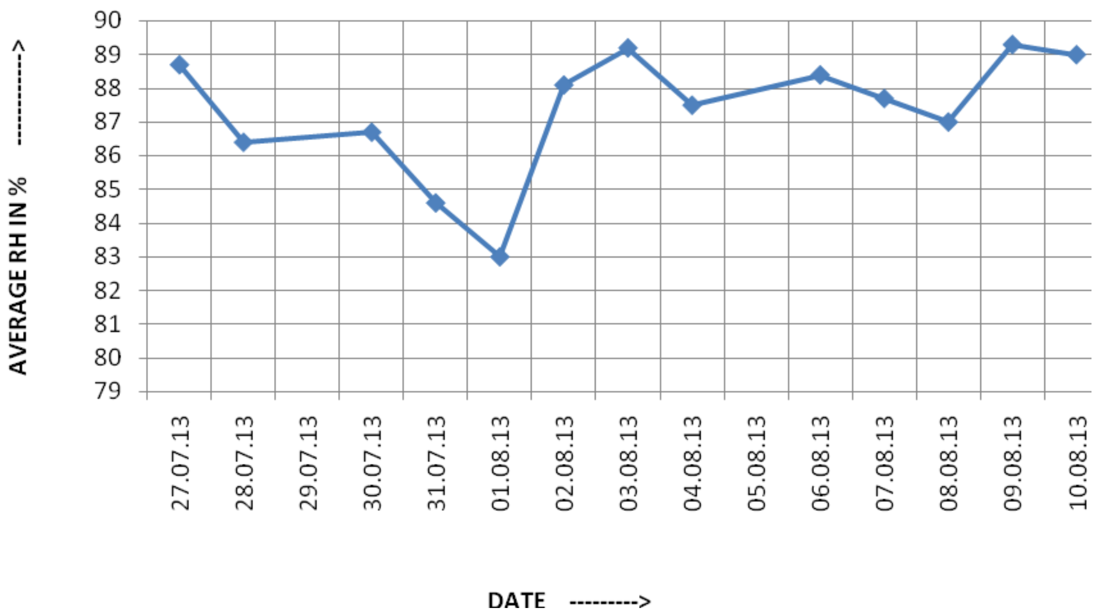

Fig 17: Variation of daily average RH of tea fermentation room for 15 days

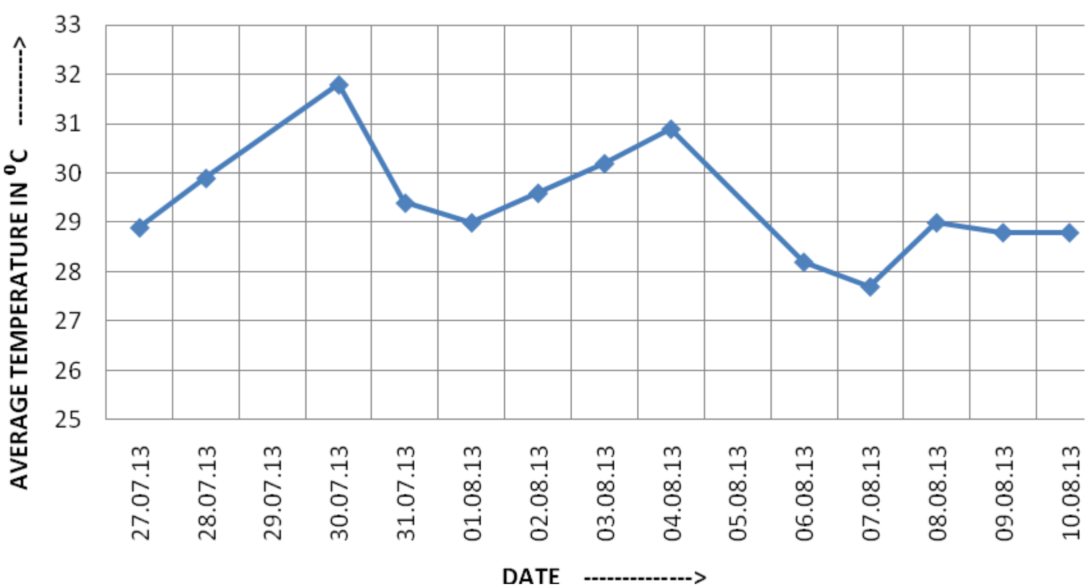

Fig 18: Variation of daily average temperature of tea fermentation room for 15 days

V. CONCLUSION

The system is undergoing test in the factory and it is working satisfactorily. It is observed that temperature and R/H varied from time to time with a maximum variation of ±2.5 ^{0}C for temperature and 8% for R/H. It is found that by proper control of R/H and temperature the quality of tea can be improved. The resolution of the system is found as 1% for relative humidity and 1ºC for temperature. The system is calibrated for RH in constant 25^0C temperature which gives ± 0.75 % accuracy on full scale. This system is useful for monitoring the fermentation process parameters which can be used for controlling the optimum process condition to get desired tea quality with slight upgradation. There are several merits of the developed system over the conventional system as under

- Low Cost
- Online temperature correction for RH
- Ease of installation & small hardware setup
- Data logging feature

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