Sensor-Network based Instrumentation for monitoring of withering in black tea production

Nipan Das, Pradip Kumar Boruah, Utpal Sarma

Dept. of Instrumentation & USIC, Gauhati University
GNB Nagar,Jalukbari, Guwahati - 781014, Assam. INDIA.
nipan.das86@yahoo.co.in

Abstract: ***Proper level of withering plays an important role in overall quality of the produced tea. Withering is the first process in tea manufacturing and is considered the foundation of quality tea. In this paper, an in-situ instrumentation technique is proposed, which is validated experimentally for monitoring of parameters affecting the withering process of tea leaves in black tea production. In the proposed technique, distribution of relative humidity and temperature during withering process is monitored and recorded which would be useful for prediction of withering level using advanced soft computing tool. The implementation detail of a sensor network is presented in the paper. Using the sensor network, variations in the distribution of relative humidity and temperature in a withering trough is monitored and recorded.***

Keywords: Sensor Network, Relative Humidity, Temperature, Withering**.**

1. Introduction

Tea is the most popular beverage all over the world. The various types of tea are categorized based on their physical appearances and quality attributes. Different types of tea are produced by adopting different processing methods. Quality attributes of the same type of tea varies mostly due to variation of process controlling parameter such as temperature and relative humidity (RH) during the manufacturing process. Quality also depends on the cultural practice, leaf quality and the breed. Depending on the variations of manufacturing methods, tea can be classified into six different types, viz., green tea, yellow tea, white tea, Oolong tea, black tea and post-fermented tea. Amongst the various types, black tea is the highest consumed type all over the world.

Withering is an essential processing step in the manufacturing of black tea or CTC (crush, tear and curl) tea. In withering, the freshly plucked tea leaves are conditioned physically and chemically for the subsequent processing steps of tea manufacturing. In physical withering, the moisture content of the fresh leaf is reduced and the chemical withering contributes to the quality attributes of the produced tea. Withering of tea leaves is expressed in percentage, which is defined as the remaining weight reduced from 100 kg of leaf at the end of the withering process [1]. The range of withering level is in between 83%-74% for black tea. For chemical withering to be completed, it normally takes about 12-16 hours. Physical withering is regulated to proceed at a slow rate so as to facilitate completion of the chemical withering.

Immediately after plucking of tea leaves, the chemical withering starts and contributes to the quality attributes. It involves several chemical processes. Due to break down of larger molecules carbon dioxide and water releases. The process also involves changes in enzyme activity and partial break down of proteins to amino acids which act as precursors for aroma and increase in caffeine content. These activities contribute towards briskness and production of Volatile Flavour Components (VFC), some of which contribute to the grassy odour and others are responsible for the flowery aroma, reduction in chlorophyll content. The mentioned chemical changes are all inherent to the biochemical structure of the leaf. But the range and the extent of the reactions depend on the breed, cultural practices and physical parameters like temperature, humidity etc. The chemical changes contribute to the quality attributes of tea like the ‘body’ and ‘flavour’ [1].

Withering plays an important role and it has different aspects in achieving good quality in final product of tea. Influence of withering, including leaf handling, on the manufacturing and quality of black tea is reported by K. I. Tomlins & A. Mashingaidze [2]. The withering time duration plays a vital role which contributes to some biochemical properties and sensory quality attribute in final product [3]. It is found that chemical wither for a longer period produces liquor with better flavor quality and fuller cup characters [4]. The various biochemical processes that take place during withering of black tea production are reported by N. T. Omiadze et al. [5]. They reported the characteristics of phenol oxidase, i.e., the main enzyme of tea production and its hydroxylase and catechol oxidase activities responsible for the main transformation of phenol compounds determining the quality of the product and concluded that modified technologies excluding withering cannot provide high quality product.

The withering process is carried out by passing air through the leaves in withering troughs. There are two types of troughs- (a) open type and (b) enclosed type. In an open type trough the upper side of the leaf bed, where the tea leaves are loaded is open. For uniform withering, bidirectional air flow through the leaves is necessary. In an open type trough, the bidirectional of airflow is achieved by reversing the rotation of the specially designed fan. On the other hand in an enclosed type trough, both upper side above the bed and lower side below the bed are closed. Change of airflow direction is achieved by changing the position of damper arrangement in air inlet and opening and closing outlet window attached in the trough. In this case reverse rotation of fan is not necessary [6]. Attempts are going on for improvement of withering troughs. One of such attempts is reported by Divya Singh et al. [7], where the withering process was completed within 6 hours. But it leads to effect in biochemical pathway.

In determining the quality of produced tea, withering plays a major role. Therefore, lots of attempts has been made to measure the percentage of wither using various techniques. Gravimetric method or weight loss method is one of such techniques where a representative section of the withering trough was used for the measurement [8]. In microwave transmission technique for measurement of moisture content, the change in ratio of amplitude and phase shift is the determining parameter [9]. For detection of MC of tea leaves at its final stage capacitive fringe-field method is also used [10]. Drying rate is an important factor in estimation of the withering of tea leaves. Drying curves of withering thin layer are reported by Ghodke et al. [11], but in this experiment Relative Humidity (RH) was unreported. RH has a major impact on withering of tea leaves and is reported by W. S. Botheju et al. [12]. Andrew Chen et al. used temperature and humidity sensor for determining moisture content (MC) of Oolong Tea by Equilibrium Relative Humidity and Equilibrium Moisture Content [13]. To overcome the difficulties associated with the techniques mentioned above, in online and *in-situ* applicability for withering, a new technique is required. Since the mechanism of moisture release by tea leaves is very complex and a wide area trough is used for withering, it is very difficult to predict the percentage of withering. Generally, the end point of withering in the factory is determined by human experts.

In withering process, release of moisture from leaf is governed by many factors involving complicated mechanisms. The moisture released from the tea leaves are carried out by the air that flows through the leaves. Temperature, RH and air speed are more significant parameters compared to the other factors that govern the withering process of tea leaves. In the withering trough, air carries the released moisture and therefore (a) the RH in open side (the side from which air goes out) is more compare to that in the closed side (the side in which the air coming into) and (b) the RH of the air gradually increases towards the outlet of airflow path.

Before implementing a prediction technique for withering of leaves in production of black tea, an *in-situ* and online instrumentation technique is required that is necessary for observing the distribution patterns of RH and temperature in the trough. Using the proposed technique, the change in RH and temperature distribution in the trough during the withering process is monitored and recorded. The developed sensor network includes ten sensor nodes each of which can measure RH and temperature. Out of ten, five nodes are fitted in the upper side of the leaf bed and the remaining five in the lower side of the bed. The variations of RH and temperature are recorded in a personal computer (PC) connected to the sensor network.

2. Sensor setup in the enclosed trough

A representative diagram of enclosed type withering trough is shown in figure 1. The width of the actual trough where the experiment is conducted is 12 feet and the length is 105feet. Ten numbers of sensor nodes are placed in the trough. Out of ten, five nodes are placed in the upper side of the leaf bed and the remaining five in the lower side of the bed. Each sensor node has provision for networking and capable of measuring RH and temperature.

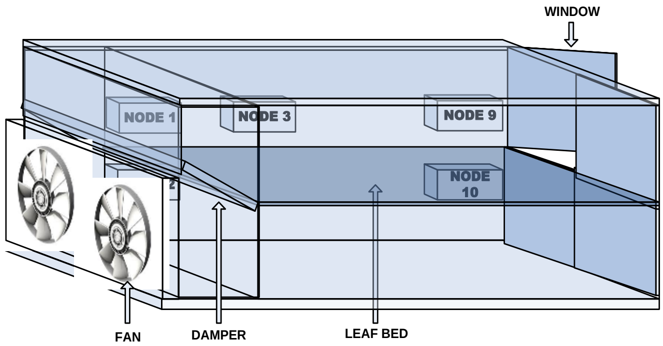

Figure 1: Sensor setup in withering trough

3. Instrumentation System

The instrumentation system comprises of sensing of distributed parameters through sensor nodes, data acquisition and logging in a personal computer (PC). The parameters of interest for sensing are temperature and RH distributed in the trough. To measure temperature and RH in the trough, ten sensor nodes are placed in the trough as shown in figure 1. In each of the sensor nodes, a microcontroller with built-in 10-bit ADC (Analog to digital converter) is used to read the voltage output values of attached temperature and RH sensor. The nodes are connected to PC by RS-485 network. RS-485 interface provides the facility of transferring small blocks of data over a long distance using balanced or differential signals. In RS-485 network, two wires carry the signal voltage and its inverse. The receiver detects the difference between the two. Since most noise that couples into the wires is common to both wires, it cancels out [14]. The block diagram of the system is shown in figure 2.

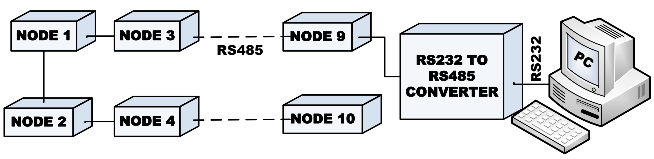

Figure 2: Block diagram of withering trough instrumentation

3.1. Sensors used in the system

In each of the sensor nodes, two sensors are used. LM35C [15] is used for measuring temperature and HIH5030 [16] for relative humidity. The accuracy of the temperature sensor, LM35C, is ±1.5 ºC and its operating range is -55ºC to +150ºC. The operating range of RH sensor, HIH5030, is 0%RH to 100%RH within the temperature range of -40ºC to +85ºC. The accuracy of RH measurement is ±3% in the operating range of 11% RH to 89% RH, where as ±7% in the range of 0% RH to 10% RH and 90% RH to 100% RH. The circuit schematic diagram is shown in figure 3.

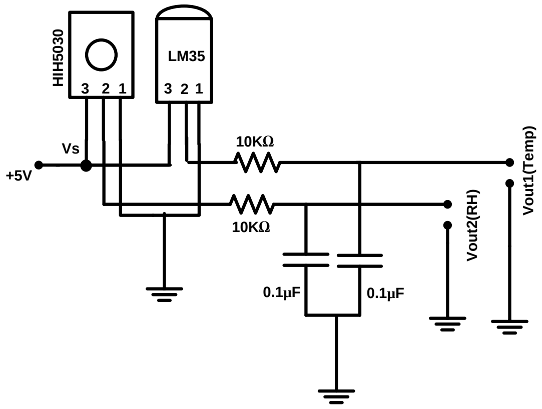

Figure 3: Circuit schematic of sensor module

The output voltage V_{out2} (RH) (figure 3) and RH is related by the following equation at 25 ^{0}C

$$RH = \frac{\frac{V_{out2}(RH)}{V_S} - 0.1515}{0.00636} \qquad (1)$$

The true *RH* requires temperature correction and is given by the following equation

$$True\ RH = \frac{RH}{(1.0546 - 0.00216\ T)}\% \qquad (2)$$

Where, T is the measured temperature in ˚C.

The RH sensor and temperature sensor are assembled close to each other to minimize the temperature gradient between them.

4. Data acquisition

In each node, the voltage outputs of the two sensors are connected to two channels of built-in 10-bit ADC of an ATmega8 [17] microcontroller. The microcontrollers are connected to a PC by RS485 network. An algorithm is developed for reading the output voltages of sensors, compensating the effect of temperature in RH measurement and finally sending the data to PC in proper format through the network. The developed algorithm is implemented in ATmega8 microcontroller by writing suitable C-code in Atmel Studio4 IDE (Integrated Development Environment) [18]. The temperature compensation is done using the equation (1& 2). To control the communication in the sensor network and record the received data in PC, a program is written in C language. Data are stored in PC in .XLS format along with records of date and time. Figure 7 & figure 8 show the flowchart of developed algorithms that are implemented in microcontroller and PC respectively.

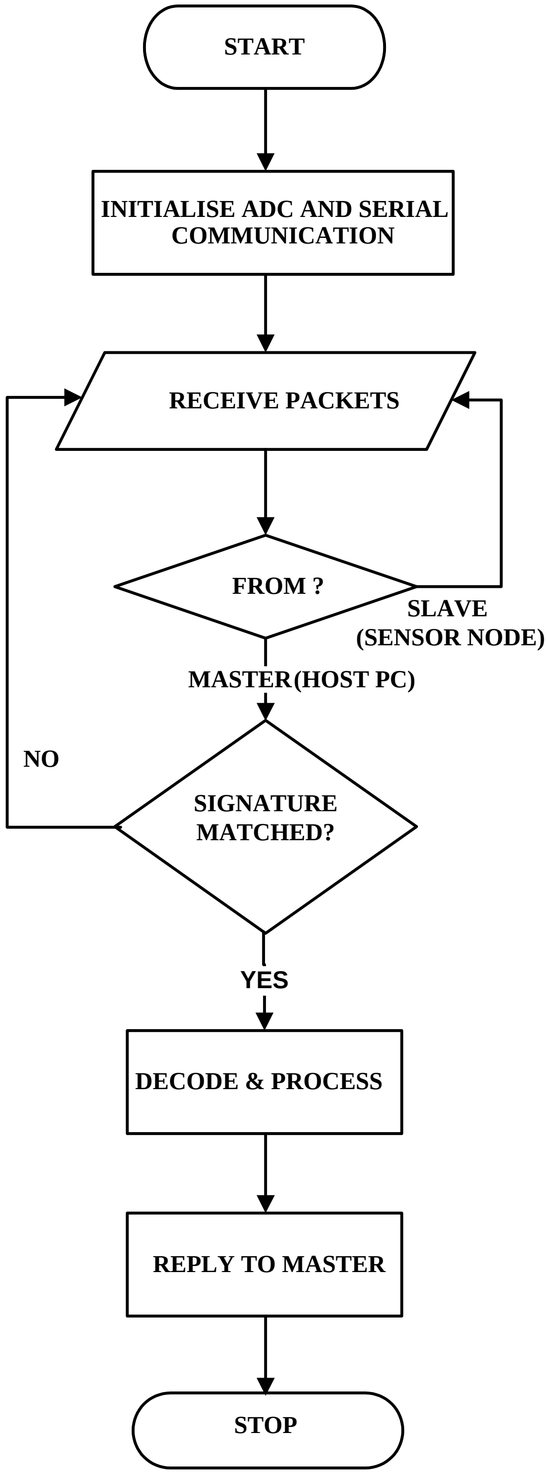

Figure 4: Flowchart for the implemented algorithm in sensor node

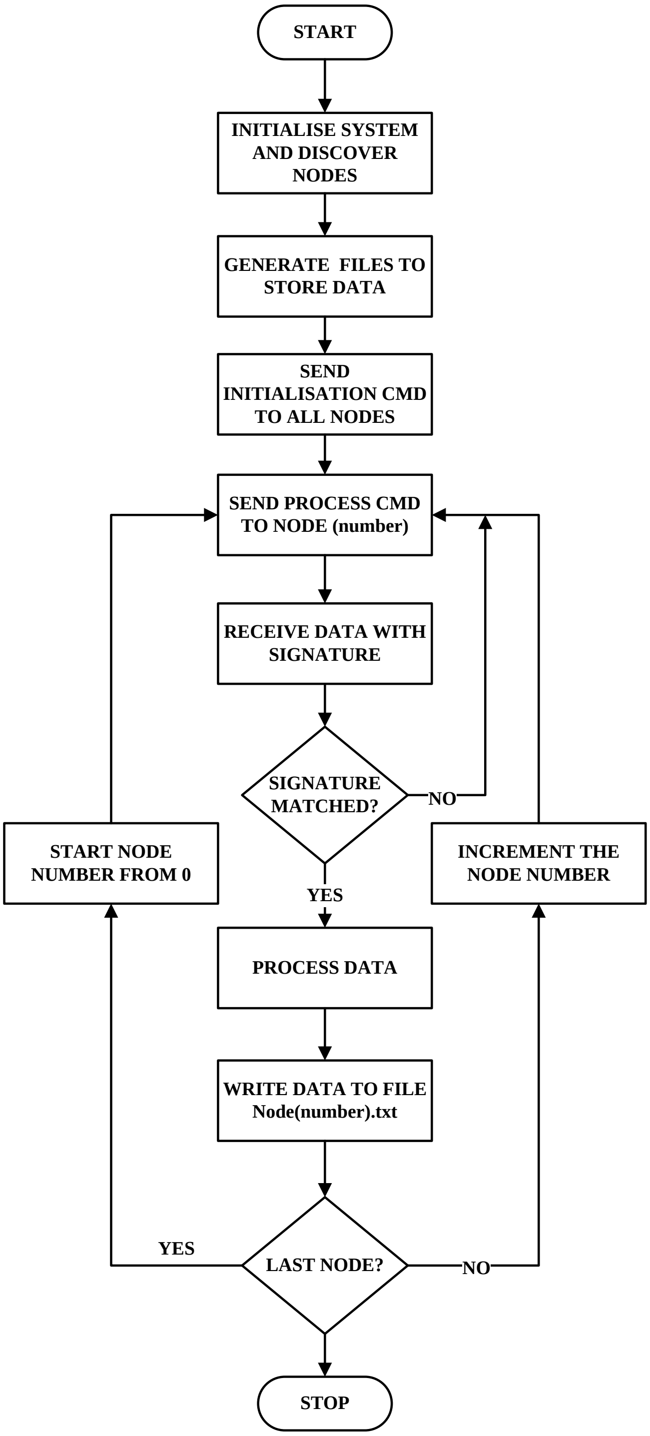

Figure 5: Flowchart for the implemented algorithm in PC

The information content passing through peer-to-peer connection is packed in a very simple structure containing four separate fields.

Table 1: Fields of the communication packets

Field-1	Field-2	Field-3	Field-4
Head string (1 byte)	Code identifier (1 byte)	Info-field (24 byte)	Terminator string (1 byte)

Head string contains the signature of the nodes and PC (host or master). *Code identifier* contains the necessary instruction code which is to be decoded by the nodes for required action. The *Info-field* contains the data and *terminator string* indicates the completion of transmission.

5. Result and discussion

For analyzing the data recorded during the withering process, the ten sensor nodes are considered into five pairs. Node 1 and 2 constitutes the first pair. Similarly node 3 and 4 constitutes second pair, node 5 and 6 constitutes third pair, node 7 and 8 constitutes fourth pair and finally node 9 and 10 constitutes fifth pair.

The variations of difference in RH in each pair of nodes are shown in figures 6 to 10. Average temperatures in the pair of nodes are also shown in the figures 6 to 10.

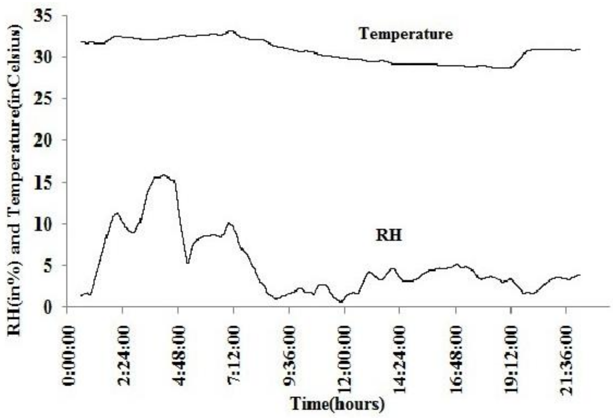

Figure 6: Variation of RH and Temperature in pair-1 (Node 1 &2)

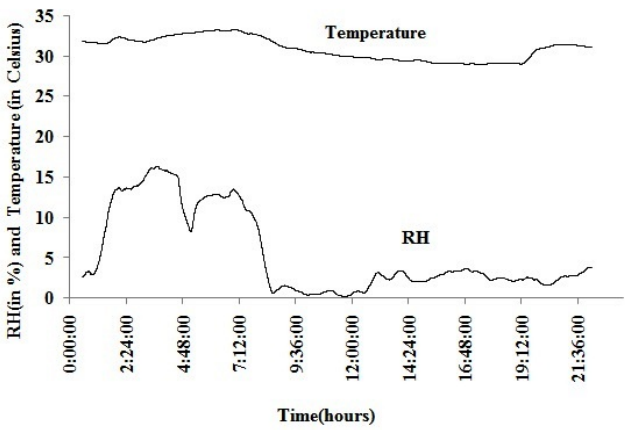

Figure 7: Variation of RH and Temperature in pair-2 (Node 3 &4)

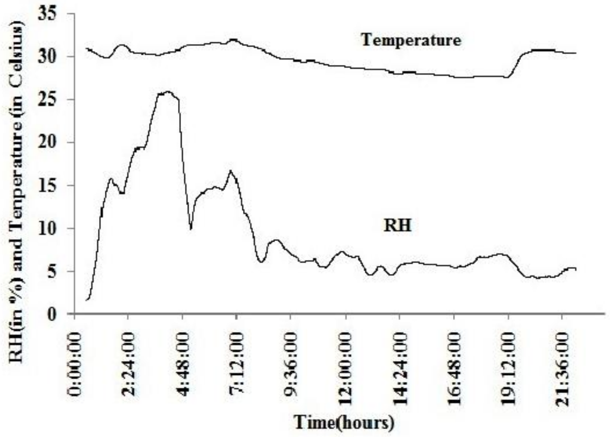

Figure 8: Variation of RH and Temperature in pair-3 (Node 5 &6)

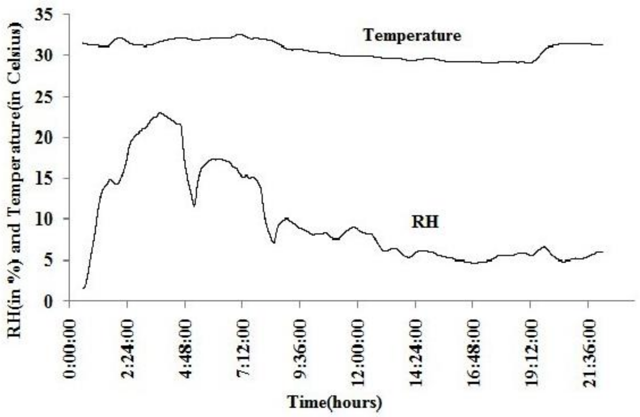

Figure 9: Variation of RH and Temperature in pair-4 (Node 7 & 8)

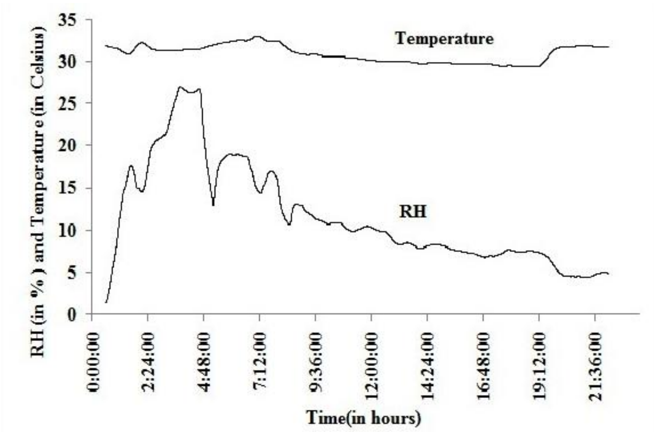

Figure 10: Variation of RH and Temperature in pair-5 (Node 9 &10)

From the variations it is observed that the RH variation towards the air outlet of the trough is more prominent compared to that of the air inlet. Temperature is almost constant throughout the trough. At the starting of withering, the RH difference increases, reaches a maximum and starts decreasing. The increase in RH difference at the initial stage of withering is due to the surface moisture of the tea leaves. After completion of surface moisture, the internal moisture from the leaves starts releasing which is a slow process. Therefore in the observed results, the RH difference slowly decreases after time duration of around 2 to 3 hours in the process of withering.

6. Conclusion

The developed sensor network is suitable for use in tea industry. Since amount of data to be transferred in tea industry is small, RS485 network is a preferred choice compared to other existing network infrastructures such as Local Area Network (LAN), Zigbee etc. From the point of cost and implementation difficulties also RS485 is preferable compared to other type of network. Also the network is easily expandable in the sense that number of sensing parameters can be increased in each node by adding suitable sensor or the number of sensor nodes can also be increased in the network.

In the withering process, when the air passes through the leaves air carries moisture from leaves resulting increase in RH at the outgoing side compared to that of incoming side. Difference of RH decreases as withering process continues. From the information of variation of RH and temperature in the course of withering time duration, the level of withering can be predicted using soft computing tool. From observation it is seen that that variations are highly nonlinear, Artificial Neural Network (ANN), based on structure of biological neural network and a data driven model would be a suitable tool for prediction.

References

[1] Withering. *Tea Research Association (TRA).*Available: http://www.tocklai.net/activities/tea-manufacture/withering/

[2] K. I. Tomlins, A. Mashingaidze. (1997, Dec.). Influence of withering, including leaf handling, on the manufacturing and quality of black teas - a review. *Food Chemistry*, 60(4), pp. 573-580. doi:10.1016/S0308-8146(97)00035-6

[3] F. Soheili-Fard, H. R. Ghassemzadeh and S. B. Salvatian. (2015). Impact of withering time duration on some biochemical properties and sensory quality attributes of black tea. *Biological Forum – An International Journal.* 7(1), pp.1045-1049 Available: http:/*/www.researchtrend.net/bfij/bf12/165%20FARSHAD%20SOHEILI-FARD.pdf*

[4] D. Baruah, L. P. Bhuyan, M. Hazarika. (2012). Impact of moisture loss and temperature on biochemical changes during withering stage of black tea processing on four Tocklai released clones. *Two and a Bud*, 59(2), pp. 134-142. Available: http://tocklai.net/wpcontent/uploads/2013/07/TwoBud59220 12/Impact%20of%20moisture%20loss%20and%20 temperature.pdf

[5] N. T. Omiadzea, N. I. Mchedlishvilia, J. N. Rodrigez_Lopezb, M. O. Abutidzea, T. A. Sadunishvilia, and

N. G. Pruidzea. (2014, Jul). Biochemical processes at the stage of withering during black tea production. *Appl Biochem Microbiol*, 50(4), pp. 394–397 doi: 10.1134/S0003683814040103

[6] M. G. Hampton, “Production of black tea” in *Tea: Cultivation to consumption*, Editor: K.C. Wilson and M.N. Clifford. Chapman & Hall, London. pp: 472-474

[7] D. Singh, T. Samantal, S. Das, A. K. Ghoshl, A. Mitra and B. C. Ghosh. (2012). Development of a customized trough to study withering of tea leaves. *Two and a Bud* 59(2), pp. 143-147. Available: http://www.tocklai.net/wp-content/uploads/2013/07/TwoBud5922012/Development%20of%20a%20customized%20trough.pdf

[8] M. Bhuyan, “Measurements in food processing” in *Measurement and control in food processing*”, CRC Press, Taylor & Francis Group, New York, 2007,pp.125-126

[9] S. Okamura, Y. Zhang , N. Tsukamoto.(2007). A new microstripline-type moisture sensor for heavily wet tea leaves. *Meas. Sci. Technol*. 18, pp. 1022–1028, doi:10.1088/0957-0233/18/4/009

[10] D. Hazarika, S. Laskar, A. Sarma, and P. K. Sarmah. (2006, Oct.) PC-based instrumentation system for the detection of moisture content of tea leaves at its final stage. *IEEE transactions on Instrumentation and Measurement*, 55(5), pp.1641-1647. doi: 10.1109/TIM.2006.881031

[11] H. M. Ghodake, T. K. Goswami, and A. Chakraverty (2006) Mathematical modeling of withering characteristics of tea leaves. *Drying Technology*, 24(2), pp.159–164. doi: 10.1080/07373930600558979

[12] W.S. Botheju, K.S.P. Amarathunge and I.S.B. Abeysinghe (2011). Simulation of trough withering of tea using one dimensional heat and mass transfer finite difference model. *Tropical Agricultural Research*, 22 (3), pp. 282 – 295.doi: http://dx.doi.org/10.4038/tar.v22i3.3701

[13] A. Chen, H.Yu. Chen ,C. Chen (2014,Aug). Use of temperature and humidity sensors to determine moisture content of oolong tea. *Sensors*, 14, pp. 15593-15609 doi:10.3390/s140815593

[14] Jan Axelson, (June 1999, June), Designing RS-485 Circuits, *Circuit Cellar,107,pp.20-24*

[15] Datasheet of LM35.Available: http://*www.ece.usu.edu/ece_store/spec/lm35dt-3p.pdf*

[16] Datasheet of HIH5030. Available: *https://sensing.honeywell.com/index.php?ci_id=49692*

[17] Datasheet of Atmega8. Available: http://www.atmel.com/.../Atmel-8159-8-bit-AVR-*microcontroller-ATmega8A_datasheet.pdf*

[18] Atmel Studio4. Available: http://*www.atmel.com › Products › Microcontrollers › AVR 8- and 32-bit MCUs*

Authors Profile

Nipan Das, received the M. Sc. degree in Instrumentation from the University of Gauhati, India, in 2009, and the M.Tech degree in Electronics Design and Technology in 2011 from Tezpur University, Tezpur, India. He is currently a Research Scholar in the Dept. of Instrumentation and USIC, Gauhati University. His current research interests include Embedded System Design, Signal Conditioning and Processing, Process Instrumentation.

P. K. Boruah received the Ph.D. degree from Gauhati University in 1980. He was a scientific officer and head in Instruments Division under Forensic laboratory, Govt. of Assam for a period of 17 years. He also served as a Research and Development Manager, Assam Electronics Development Corporation for a period of 3 years. He retired as a Professor from the Dept. of Instrumentation and USIC, Gauhati University in 2012. His research interests are Experimental Cosmic Ray Physics, Detectors and Instrumentation, Signal Processing and development of Smart Transducer Instrumentation and Sensor Networks.

Utpal Sarma, received the M. Sc. degree in Physics from the University of Gauhati, India, in 1998, and the Ph.D. degree in 2010 from the University of Gauhati.

In 1999, he joined the Department of Physics, B. Borooah College, Guwahati, as a Lecturer. He joined University of Gauhati in 2007 as an Assistant Professor where he is currently working as Associate Professor. His current research interests include embedded system for agro industries, sensor instrumentation, and micro-energy harvesting devices.