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Microcontroller-Enabled Embedded System for Assessing Jute Retting Water Quality Parameter

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Jute (Corchorus sp.) globally recognized as 'golden fibre' is one of the best natural fibre in the world used for various textile and non-textile applications for over 150 years due to its high tensile properties, low extensibility, high thermal insulation, biodegradability and environment friendliness (Ray et al. 2022; Ramesh et al. 2017; Ramesh and Deepa 2024). India is the paramount producer of raw jute in the world with a share of 49.7 % in 2021, closely followed by Bangladesh with 48.6 % (Anonymous, 2023a). It is cultivated primarily in West Bengal, Assam, Bihar, Odisha, Andhra Pradesh and Meghalaya states of the country. In the year 2022-23, approximately 93.56 million bales (1 bale = 180 Kg) were produced from 0.66 million ha of cultivated land with an average productivity of 2.63 tonnes/ha (Anonymous, 2023a). Production of jute fibre having excellent quality to meet global requirements is an important concern in the context of its application in the diversified area, which is mainly controlled by the retting process. In the jute fibre production process, retting is the foremost vital process in jute cultivation which rules the quality of jute fibre (Das et al. 2011).

In leading jute-growing countries i.e. India and Bangladesh, 'water retting' is conventionally performed by the farmers through the submergence of 2-3 layers of jute plants in water bodies by overlaying banana pseudo-stem and mud on the surface of plants for 20 to 25 days (Ray et al. 2015; Sarkar and Sengupta 2015; Ray et al. 2022). The efficiency of retting depends on several factors viz. plant age, fertilization, retting water quality, and activators (Bera et al. 2009). Among these, water quality predominantly influences the production of high-quality fibre. Prevailing studies revealed that water quality parameters such as temperature, pH, total dissolved solids (TDS), and turbidity can directly correlate with the level of retting of fibre (Ali et al. 2022). It was reported that temperature in the range of 34 to 36°C (Sarkar and Sengupta 2015), pH in the range of 6.0 to 8.0, (Broker, 2007; Majumdar et al. 2019), turbidity and TDS in the range of 210 to 595 mg/l (PPM) and 165 - 195 NTU (Paridah et al. 2011), respectively play a crucial role in efficient completion of retting. Periodic measurement of these parameters is pertinent to establish a correlation amongst them for the prediction of a critical endpoint of retting of jute stems. It is necessary to extract fibre at this endpoint to obtain the quality fibre having economic significance. In practice, the determination of this critical endpoint of retting is often difficult and overlooking this point may result in either under or over-retting. In case of under-retting, gummy, and pectic materials are not completely removed thus resulting in the production of unspinnable low-grade fibre whereas over-retting causes degradation of fibre cellulose (Ahmed and Akhter 2001; Ray et al. 2015).

Furthermore, sporadic rainfall and shifting of monsoon in Eastern India (a major jute growing region), have caused a diminishing of natural water bodies resulting in a shortage of availability of water during the peak season of post-harvest retting operations. Thereby, farmers are compelled to perform the retting operation in polluted local ditches, road-side water bodies, canals and ponds. Retting in such water bodies yields a poor quality of fibre as there is no control over the water quality and temperature (Guha, 1999). Subsequently, the retting operation further pollutes the stagnant water which becomes the breeding ground of mosquitoes and thus affects the local environment and makes that unsuitable for fish farming and vegetable cultivation. Hence, assessment of pre and post-retting water quality parameters is one of the prime requirements for researchers to determine the suitability of water for retting operation.

Generally, water quality parameters are assessed by collecting, testing and analyzing the samples by using high-end sophisticated instruments dedicated to the determination of individual parameters in the laboratory. These operations are time-consuming, skill-oriented and also prone to human error as the samples are to be carried from the actual arena to the laboratory for testing. Currently, several individual instruments for assessing temperature, pH, total dissolved solids (TDS), and turbidity are available in the market ranging from low to high cost based on accuracy. A very few integrated instruments are available in the market to measure all the mentioned parameters simultaneously, mostly limited to the determination of water quality parameters in domestic and industrial applications. However, to date, no study has been conducted to develop a microcontroller-enabled system for assessing the quality parameters of water used in jute retting. Currently, farmers assess the efficiency of retting by manual inspection, which requires frequent attention and efficient knowledge about the fibre production process. Hence, a system that can measure water quality in relation to retting could prove valuable for farmers in determining the fiber's retting stage. Therefore, a low-cost, microcontroller-enabled embedded system to assess the quality of retted water was developed.

Multi-sensor-based integrated water quality measurement system

For assessing jute retting water quality parameters, an embedded system was developed. The system comprised a DS18B20 temperature sensor, TECH1861-0001 pH sensor, KS0414 turbidity sensor TECH1218-000 TDS sensor, ATmega 2560 microcontroller, LCD, microSD storage board, and a power supply. The developed system can acquire, display and store the data of the mentioned sensors simultaneously. All sensors were integrated with an Arduino ATmega 2560 microcontroller through wire connections according to the circuit diagram as depicted in Fig. 1.

The microcontroller processed analog output of the sensors and converted into the desired form. For this purpose, algorithms developed for measuring the output value of individual sensors were integrated into one algorithm and uploaded to the microcontroller.

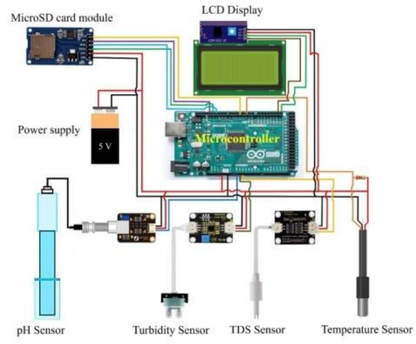

Fig. 1: Circuit diagram of the developed integrated system

For real-time display of sensors output, an LCD was also interfaced as well as programmed to the microcontroller through I2C connection. For storing various sensor outputs a MicroSD card was also integrated with the microcontroller. At last, for storing various sensor outputs a microSD card module was also integrated with the microcontroller through serial communication. the hardware of the water quality monitoring system is presented in Fig. 2.

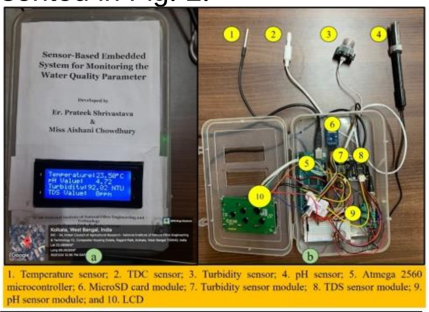

Fig. 2: Hardware of the developed integrated system; (a) outside view and (b) inner side view

Validation of the developed system

After successful validation in the laboratory condition, the developed system was also tested to examine the pre and post-retting water quality parameters in actual conditions. Retting of jute plants was conducted in the bricks and masonry-based artificial retting tanks (Fig.3) during July-August 2023.

For this study, jute plants cultivated through JRO 524 (Naveen) variety were used whereas regular tap water having the temperature, pH, turbidity and TDS as mentioned in Table 2 was used. For experiment purposes, 50 kg of jute plants in a plant: water ratios of 1:20 with three replications were retted in the tank.

Fig. 3: Retting of jute plants in artificial tanks and pre as well as post-retting water analysis

Test results showed that before and after retting, water quality parameters have changed significantly. The SE mean and MAPE in temperature of retting water measured by the developed system and commercial thermometer were observed as ±1.9° and 3.15 %, respectively. The test results further indicated a non-significant (Independent Sample T-test, $F_{42,1}$= 1.052, P =0.480) interaction between the measured and actual values of temperature. The pH of post-retting water (Actual pH Vs measured pH: 5.95 and 6.05) samples was observed considerably low compared to the pre-retting water samples (Actual pH Vs measured pH: 7.48 and 7.87). This drop in pH of water was observed may be due to the release of various organic acids i.e. acetic acid, butyric acid, lactic acids, etc. during microbial degradation of sugars, pectins, and hemicelluloses of the jute plant. The SE mean and MAPE between the measured and actual values of pH of post-retting were observed as ±0.50 and 2.34 % respectively whereas a non-significant difference (Independent Sample T test, $F_{42,1}$= 1.116, P =0.297) between the measured and actual values of pH was established at the 95% level of confidence interval.

The turbidity in retting water was found to be 10.83 to 17.00 times higher in post-retting water (195-204 NTU) as compared to pre-retting water (12-18 NTU). Correspondingly, total dissolved solids (TDS) values were 4.40 to 5.67 times higher in post-retting water (340-346 PPM) as compared to pre-retting water (60-64 PPM). The SE mean of turbidity and TDS between the measured and actual values was observed as ± 14.15 NTU and ± 19.46 PPM whereas MAPE was observed as 7.67% and 6.55% respectively. Statistically analysed results also revealed a non-significant difference between the measured and actual values of turbidity (Independent Sample T test, F42,1= 0.084, P =0.774) and TDS (Independent Sample T-test, F42,1= 0.116, P =0.992) at the 95% level of significance.

Based on field evaluation, it was observed that at the end of retting, temperature, pH, turbidity and TDS were varied in the range of 33 to 34°, 5.95 to 6.05, 195 to 205 NTU and 340 to 346 PPM, respectively. These limits of the individual parameter were selected as the permissible limit and based on that, the developed water quality assessment system was upgraded. By using these limits of permissible values, a new algorithm was developed to predict the endpoint of retting and uploaded on the microcontroller. The upgraded system (Fig. 4.a) was also provided with two LEDs i.e. green for ‘In progress’ (Fig. 4.b) and red for ‘completed’ (Fig. 4.c) and a buzzer to alert a person about the status of retting of jute plants. The algorithm was programmed in such a way that, until and unless all four parameters would not lie within the permissible limit of individual parameters, the developed algorithm displays the retting as ‘in progress’. Once the water quality parameters lie within the permissible limit the programme will display the retting as ‘completed’.

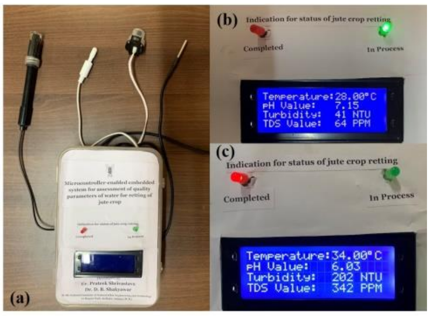

Fig. 4: (a) Upgraded embedded system along with visual and audible indicating system; (b) indication for retting in progress; (c) indication for retting is completed

After upgradation, developed embedded system was further evaluated for retting of jute plants using the regular tap water in the artificial retting tank during August 10, 2023 to September 01, 2023. It was observed that, on the 22nd day after submerging the jute plant in rettingett tank, developed system indicated the retting as ‘completed’ while through manual inspection it was observed that the retting was completed on 21st day. These results informed that the developed system was able to measure the quality of water and predict the end-point of retting within the range of ± 5% error.

Conclusion

The developed microcontroller-enabled embedded system is easy-to-build, easy-to-use and cost-effective for the determination of water quality parameters as well as the end-point of retting and may be helpful for research and academic purposes. Field level validation in artificial retting tank, established a non-significant difference between the actual and measured values of temperature (Independent Sample T test, F42,1= 1.052, P =0.480), pH (Independent Sample T test, F42,1= 1.116, P =0.297), Turbidity (Independent Sample T test, F42,1= 0.084, P =0.774) and TDS (Independent Sample T test, F42,1= 0.116, P =0.992) at the 95% level of significance. The developed embedded system was also provided with two LEDs for i.e. green for ‘In progress’ and red for ‘completed’ and a buzzer to alert a person about the status of the retting of jute plants. This development may also render an avenue for controlled retting of jute in natural conditions, which may help the farmers to produce high-quality fibres.