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Development open source microcontroller based temperature data logger

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Abstract. This article discusses the development stages in designing, prototyping, testing and deploying a portable open source microcontroller based temperature data logger for use in rough industrial environment. The 5V powered prototype of data logger is equipped with open source Arduino microcontroller for integrating multiple thermocouple sensors with their module, secure digital (SD) card storage, liquid crystal display (LCD), real time clock and electronic enclosure made of acrylic. The program for the function of the datalogger is programmed so that 8 readings from the thermocouples can be acquired within 3 s interval and displayed on the LCD simultaneously. The recorded temperature readings at four different points on both hydrodistillation show similar profile pattern and highest yield of extracted oil was achieved on hydrodistillation 2 at 0.004%. From the obtained results, this study achieved the objective of developing an inexpensive, portable and robust eight channels temperature measuring module with capabilities to monitor and store real time data.

1. Introduction

Agarwood is a resinous, fragrant and highly valuable heartwood. Healthy agarwood is relatively light and pale colored. Occasionally the heartwood gets contaminated by a parasitic ascomycetous mold, haeoacremonium parasitical. As a reaction, the tree produces a resin high in volatile organic compounds that aids in suppressing or retarding the fungal growth [1]. There are numerous grades of agarwood, and the most astounding quality wood is extremely expensive [2]. Indeed, the first grade agarwood is one of the costly natural product on the planet, with costs up to $13,000 per pound. However, the finest grade of agarwood is produce from naturally occurring fungal infection which happens gradually and rarely. There are also several technique to produce the resin such as inoculation of grown agarwood with the fungus as well as purposeful harming of the tree to urge fungal infection [3-5]. However, resin harvested in this way is considered to be optional quality and has inferior market value contrasted with naturally harvested agarwood resin.

Agarwood resin and its oil are valuable for their use in medicine, perfumery and other aromatic products [6]. They are volatile oils, generously odorous, which occur in certain plants or specified parts of plants, and are recovered by accepted procedures, such that the nature and composition of the product is, as nearly as practicable, unchanged by such procedures [7, 8]. It specifies clearly that the nature and composition of the oil must be unchanged by the process of extraction. Currently, there are a few conventional and modern methods of extracting essential oils such as by hydro-distillation, supercritical fluid extraction and microwave extraction. Hydro-distillation is the oldest and most common method of extracting essential oil since it is economically viable and safe. During hydro-distillation the essential oil components form an azeotropic mixture with water. The extraction period influences not only the yield but also the extract composition. Hydro-distillation can be achieved by one of the two methods which are Clevenger or steam distillation.

In both methods the vapours of the volatile components are carried by the steam to a condenser. On condensation oil-rich and water-rich layers are formed. Clevenger distillation generates steam continuously and on a large scale. Controlling the boiling process is extremely difficult, it is a highly nonlinear process, its dynamics vary with load and it is strongly multivariable. It is also inherently unstable due to the integrator effect of the drum. Boiler for distillation process is different to boiler for energy generation, where the boiler in energy generation is commonly operated at maximum capacity [9], whereas the boiler for essential oil distillation process must consider the critical temperature that may potentially degrade the thermolabile bioactive components [10]. However, both boiler systems have process parameters that are strongly dependent on load. The process parameters drift over time for a number of reasons such as the build-up of soot on heating surfaces, actuator wear and variations in raw materials quality. It may be necessary to continuously update the controller parameters [11, 12].

The yield, taste, flavour and chemical composition (amount and ratio of components) of essential oil depends on a number of parameters, such as plant variety, season, soil, environmental conditions, drying procedure, storage conditions, method of distillation, and the analytics used for identification of the compounds [13, 14]. Despite of the generally successful practical hydro-distillation technology used to extract essential oils, there is still a need to consider a procedure or method in detail that would enable the production of essential oils at an optimum output [15]. Up to now many investigators have studied the thermolability and thermostability of the fragrant components when the plant material is under distillation process [10, 16]. They conclude that optimum temperature should be determined to avoid losses of volatile and thermolabile substances during extraction of the essential oils.

Automatic data acquisition systems are currently used in wide variety of applications which include environmental monitoring, renewable energy, medical and many significant fields. With numerous benefit of automated measurements, data are collected continuously throughout the practice with minimal human intervention. Systems based on microcontrollers have been widely used for the monitoring of general physical parameters [17] and, in particular, for solar energy applications research and weather data acquisition [18-22]. Such systems enable the use of complex control strategies and can improve significantly the energy efficiency of solar thermal facilities [23-27]. Fuentes et al. [28], following a slightly different approach, have developed a data logger for a photovoltaic system in compliance with the standard of the International Electrotechnical Commission (IEC) IEC 61724:1998 [29].

The aims of this work is to develop stand alone, inexpensive, reliable, portable and easily-programmable control systems and monitoring, oriented to temperature data acquisition research in general and temperature management of agarwood extraction process in particular. From the acquired temperature variation data, recommended temperature variations have been outlined for the purpose of managing optimum mixture temperature of hydrodistillation and improving the cooling system effectiveness. In-situ temperature control of traditional hydrodistillation is highly needed to ensure the high yield and consistent quality of producing agarwood essential oil.

2. Materials and Methods

The proposed control system is based on the Arduino electronic platform, which is an open source electronic prototyping platform based on ATMEL microcontroller[30]. It offers several products such as boards, modules, shields and also Integrated Development Environment (IDE) software to program them. Because of its uncomplicated programming and economical features, this platform has already taken a significant role in recent data acquisition research application [31-35].

2.1. Data logger hardware

The presented control system of data logger has been designed and built to measure and record real time temperature readings as an improvement of previous simpler prototypes (Figure 1)[36], and it is based on the Arduino Mega 2560 model due to the enhanced features offered. This second version of the temperature data logger (Figure 2) is able to register and monitor up to eight channel temperature variable in real time format. Then it records the acquired data in Secure Digital (SD) card attachedi to the system, in order to retrieve the temperature variation data on the targeted application. The acrylic exterior case also has been fabricated using laser cutter machine to meet the robust and portable design criteria.

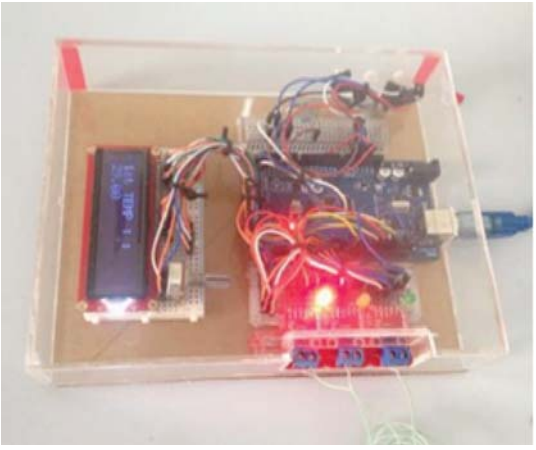


Figure 1. Previous prototype version of temperature data logger system

Figure 2. Latest version of temperature data logger system

The latest version of the temperature data logger system that has been develop for this study consists of the following parts.

2.1.1. Microcontroller board. An Arduino Mega 2560 board equipped with a powerful and inexpensive ATMega 2560 microcontroller [37] is used as the system mainboard. This board works with a 16 MHz clock and has 256 KB of flash memory, 54 digital Inputs and Outputs, of which 15 provide Pulse Width Modulation (PWM) [38], and 16 analog inputs. This board is the main core of the system managing all sensors, actuators and shields. It can be programmed, from the Arduino IDE, with the desired control algorithm from a PC by means of a USB port. All the other module boards must be connected to it, since it controls the whole system.

2.1.2. Sensor shield. The Arduino MEGA has many more Input/output (I/O) pins (54 Digital pins and 16 Analog pins) than a standard Arduino. This shield has connectors specifically for some external devices like an SD Card, Radio communications (Bluetooth and others). It also has an option to power the voltage (V) pins on all the Digital I/O 3-pin groups from an external power supply instead of the Arduino +5V. Using an external supply allows more current than the Arduino or Mega can supply, such as current for control of many sensors and other attached modules.

2.1.3. SD Card module. This module is in charge of saving the experimental data in a secure digital (SD) memory card to be analyzed later. The SD card module makes use of the Serial Peripheral Interface (SPI) bus [39] in order to communicate with the microcontroller board.

2.1.4. Real time clock (RTC) module. The RTC chip [40], employed in this module to put data time stamp in the data log file, it uses the Inter-Integrated Circuit bus (I2C) [41] for communication with the Arduino board. The RTC module is also equipped with a battery backup device to keep the time and date going even when the Arduino is disconnected from the power supply.

2.1.5. LCD module. An Adafruit Character LCD board with I2C module is used as a display interface. It makes use of a 20×4 Liquid Crystal Display (LCD) [42] which shows information about the monitoring temperatures. Since this shield uses the I2C bus to communicate with the Arduino board, it requires only a two digital pins connection.

2.1.6. Temperature sensor module. Maxim Integrated MAX6675 digital thermocouple amplifier [43] are used. The MAX6675 performs cold-junction compensation and digitizes the signal from a type-K thermocouple. The data is output in a 12-bit resolution, these amplifier carry out the analog to digital conversion directly and make use of the Serial Peripheral Interface (SPI™)-compatible [39], read-only format via digital pin of the Arduino board. This converter is able to measure temperatures values in range of 0°C to 1024°C with a maximum resolution of 0.25°C, and since their power supply range goes from 3.0 V to 5.5 V, they can be powered directly from the Arduino board data line. The selected k-type thermocouple sensor are most applicable to avoid moisture and water-related problems [34].

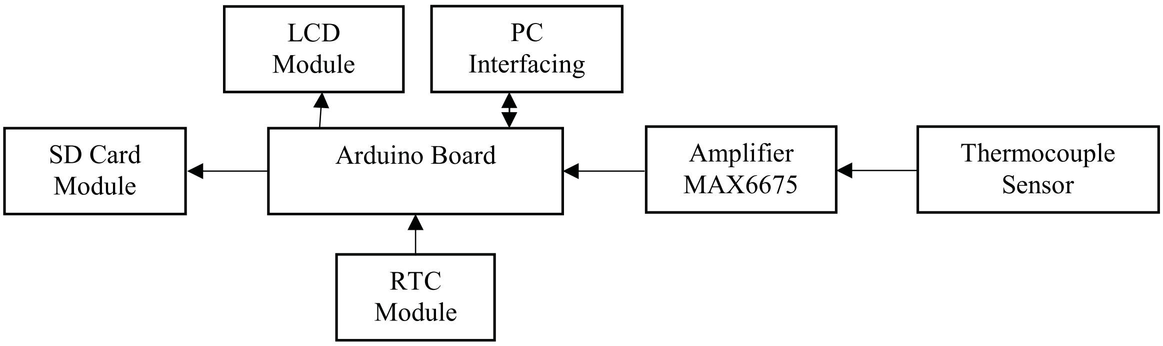


Figure 3. Block diagram of the control system

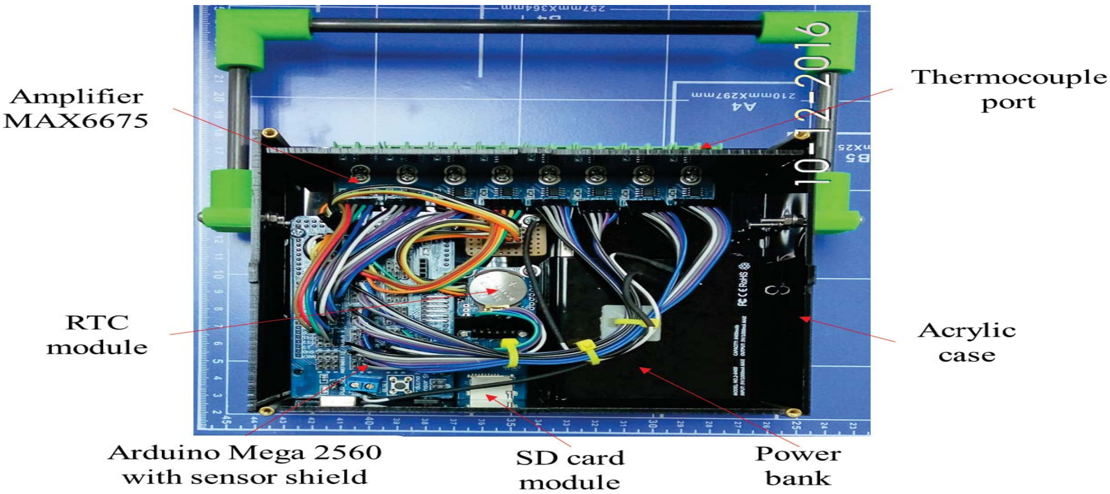


Figure 4. Latest version prototype-detail view

A block diagram of the control system is shown in Figure 3, while detail view of the latest prototype version and a wiring diagram of the temperature data logger are shown in Figure 4 and Figure 5 respectively.

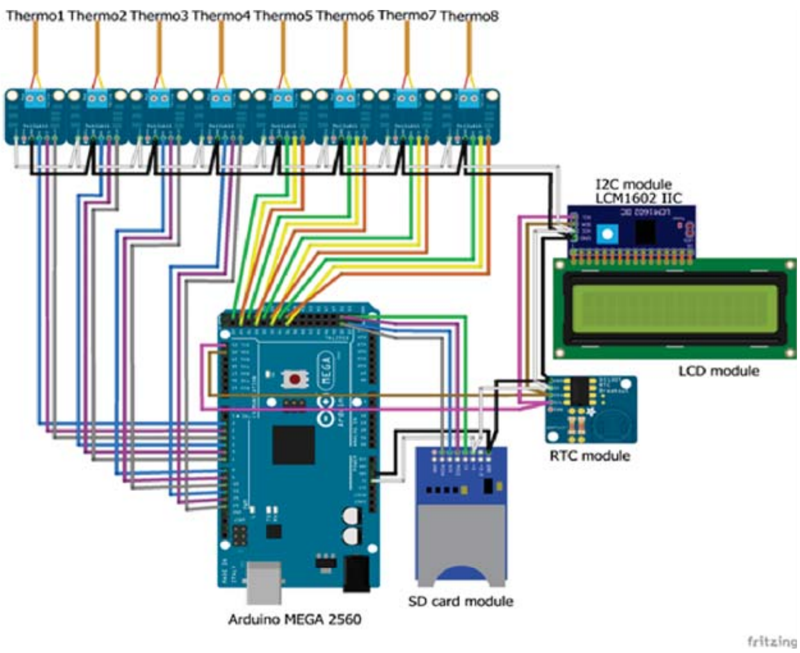
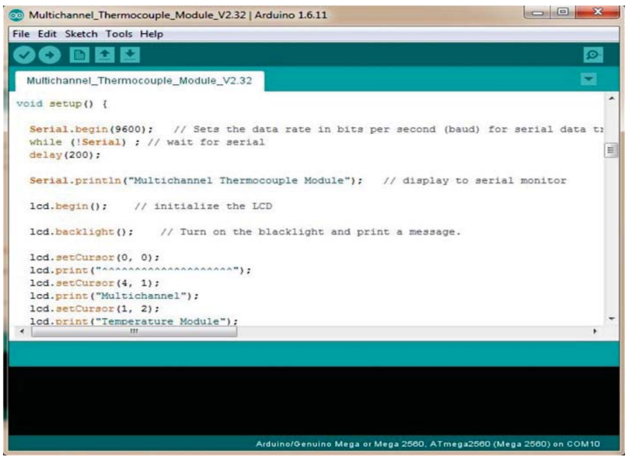


Figure 5. Latest version prototype-wiring diagram

2.2. Software programming

The control algorithms are coded in the Arduino C/C++ subset language combined with the AVR Libc library [44] using the Arduino IDE in a PC (Figure 6). Then they are uploaded to the Arduino board by means of a USB cable. The serial interface employed allows also to receive data from the board to the PC. Thus, the monitored data can be optionally shown on the Arduino IDE Serial Monitor on a PC at the same time the control system is working. The sequence of steps followed in a typical programming code to perform the desired actions. After this common structure, the selected control algorithm included in the loop function runs indefinitely for continuous data acquisition and monitoring function.



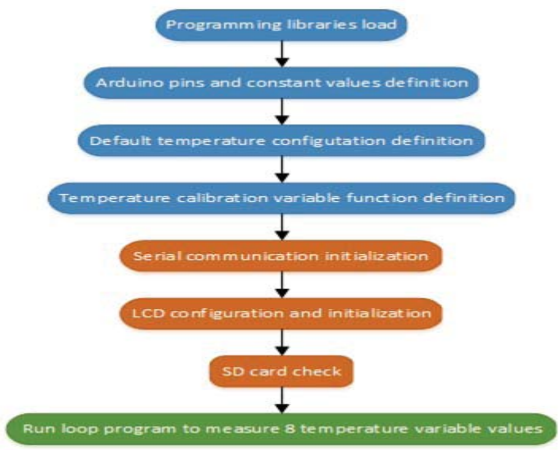


Figure 6. Arduino IDE software

Figure 7. Arduino code step sequence

Data acquisition structure. The control system is in charge of managing the temperature data measurement and storage. The flowchart presented in Figure 8 illustrates the working structure of temperature data gathering on this data logger. The program is divided into three procedure; the initialization, measurement, recording.

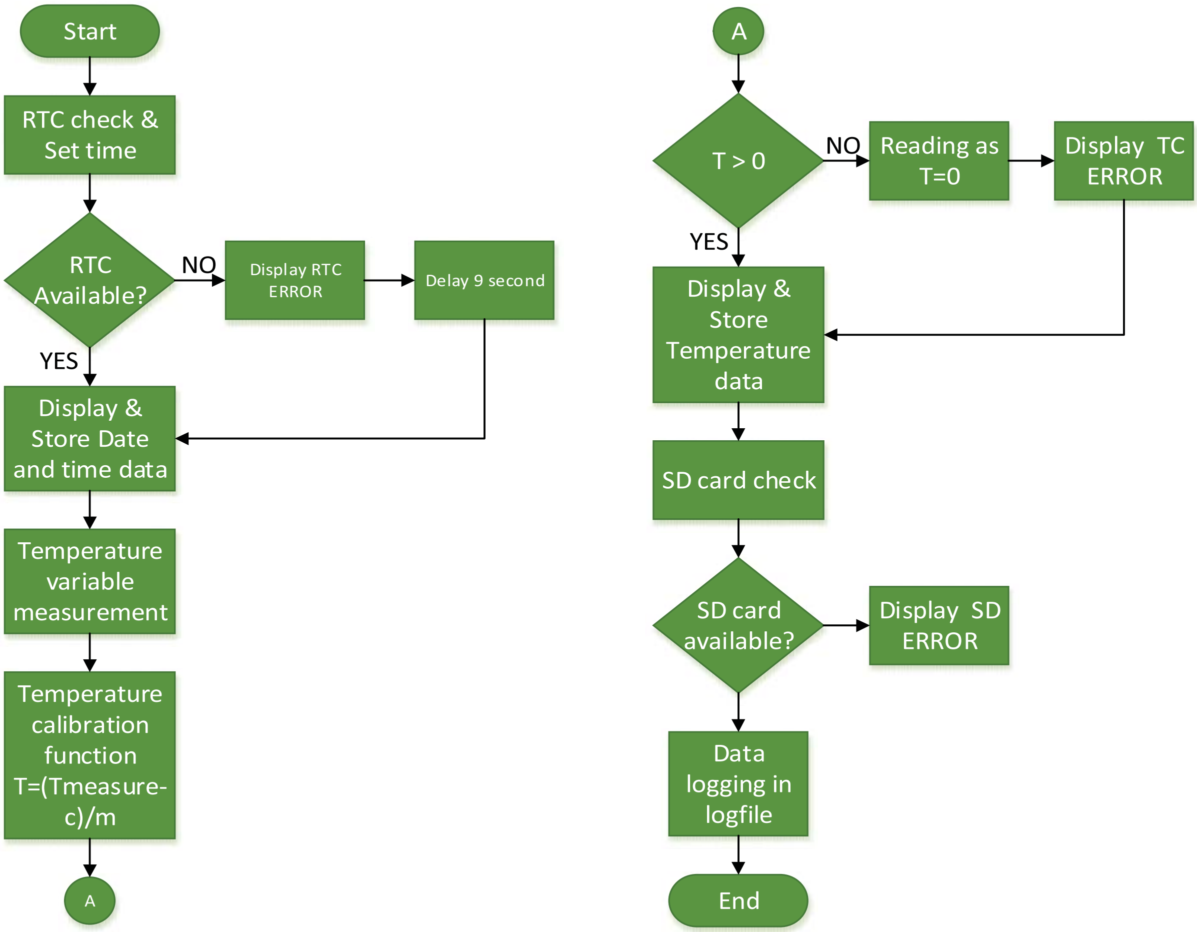


Figure 8. Data acquisition structure flowchart

2.3. Experimental setup
The developed data logger has been used in the monitoring process of agarwood oil extraction using conventional hydrodistillation method. The process started with immersion of agarwood chips in distilled water for 14 days at room temperature (30°C) and then hydrodistillation was conducted with variations of heating temperature between 150°C and 250°C. Temperature measurement at five different points of two hydrodistillations were taken in real time for 24 hours using k-type thermocouples that were connected to in-house built data logger and the produced oil yields from both distillation systems were compared.

2.3.1. Raw material. Inoculated agarwood (Aquailaria agallocha) plant sample for this research was cultivated by artificial method to stimulate the resin production. This agarwood was purchased from R&Z Agarwood's plantation in Sungai Udang, Melaka, Malaysia. Observation of sample composition ratio between resinous wood and non-resinous is about 80:20. The sample then ground into approximately 2 mm chips after drying. 30 kg of grinded agarwood chips were then immersed in distilled water for 14 days at ambient temperature (about 30°C). After 14 days, soaked chips were filtered manually to remove the excessive water and weighed before hydrodistillation process. Hypothetically, soaking process caused the degradation of wood cell wall which enlarges the agarwood pore size to improve yield of extracted oil [45].

2.3.2. Hydrodistillation system. Conventional hydrodistillation technique was used as extraction method in this study. The hydrodistillation apparatus consists of boiler, evaporator, condenser and glass container with overflow. The boiler is a custom design stainless steel with the capacity of 250 L. The condenser of Clevenger apparatus was also fabricated using stainless steel. Recycled water from coolant tank was used as heat exchanging medium of the condenser. The hydrodistillation and its apparatus were shown in Figure 9. Using distilled water as a solvent, the ratio of agarwood chips to distilled water was 1:10 (kg/L). Extraction process was conducted continuously at boiling temperature of water for 24 hours on two separate hydrodistillation systems with 15 kg chips in each boiler. Liquid propane gas (LPG) stove was used to supply heat. The gas flow rate for heating was set instinctively by experienced operator for entire experiment to ensure constant heating of 100°C inside the boiler.

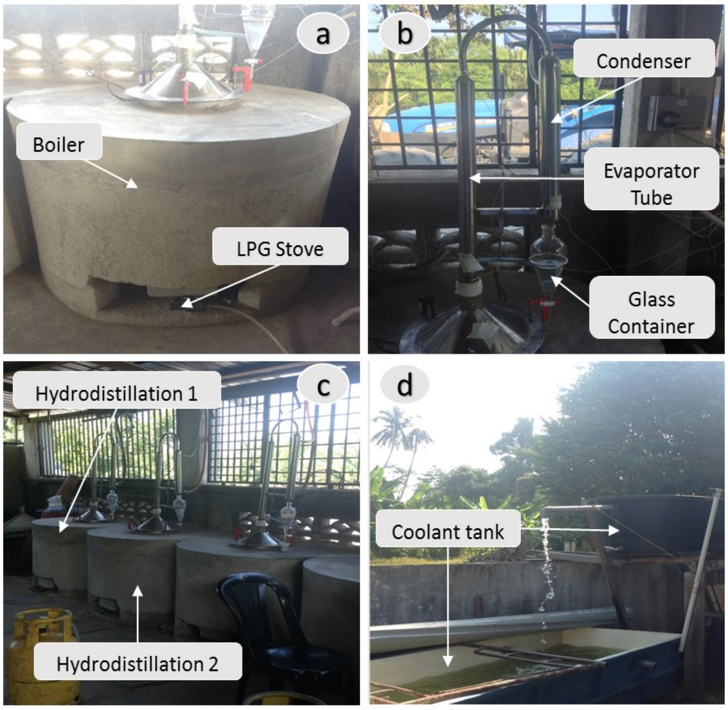


Figure 9. (a) Hydrodistillation boiler inside concrete design is heated using LPG stove. (b) Custom stainless steel apparatus. (c) Extraction facilities setup. (d) Reservoir tank to supply coolant water to condenser of hydrodistillation.

2.3.3. Temperature measurement. The temperature measurement of hydrodistillation setup was monitored by attaching thermocouples at several points and signals from the thermocouples were acquired by in-house built eight channel thermocouple data logger controlled by Arduino microprocessor. The thermocouples were aimed to measure four locations in the hydrodistillation setup for 24 hours. The locations include mixture temperature, vaporize temperature as well as condenser's inlet and outlet temperature (Figures 10 and 11). Then, data will be logged in real-time format and can be retrieved from an 8 Gigabyte memory card although the size of the log file is just in kilobyte. Instant temperatures were also showed on a LCD display of the data logger as depicted in Figure 10(d). The sampling rate was set at 0.3Hz which recorded one sample every 3 seconds.

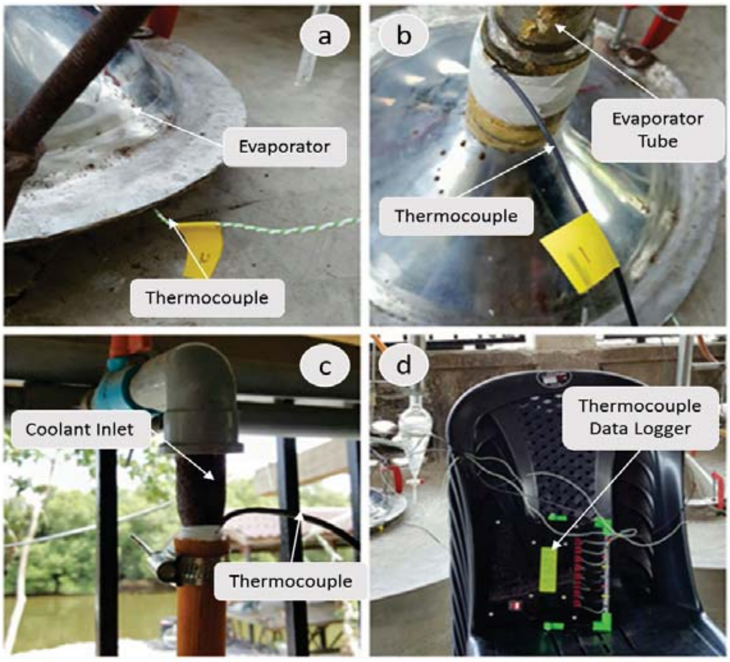


Figure 10. (a) Thermocouple arrangement to measure mixture temperature inside the boiler. (b) Thermocouple arrangement to measure vapour temperature at evaporator. (c) Thermocouple arrangement to measure coolant temperature at condenser. (d) All thermocouples are attached to multichannel temperature data logger.

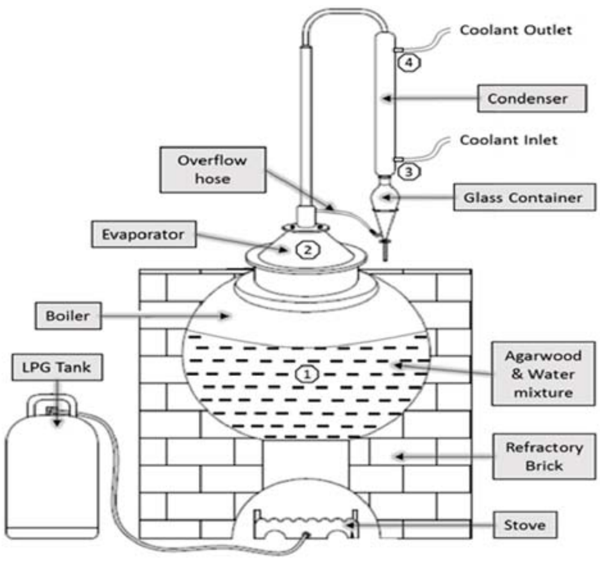


Figure 11. Schematic diagram of custom made traditional hydrodistillation system (1) Mixture temperature measuring point (2) Vapor temperature measuring point. (3) Coolant inlet temperature measuring point. (4) Coolant outlet temperature measuring point

Yield of extracted oil. After 24 hours of hydrodistillation process, mixture of agarwood oil and water collected in container flask were separated into 3 mL bottle. Then, the bottle was weighed to determine the yield of oil. The yield of oil extracted was calculated using following formula.

$$\text{Yield of Oil (\%)} = \frac{\text{agarwood oil (g)}}{\text{agarwood chips (g)}} \times 100\% \quad (1)$$

3. Results and discussion

The result presented the current progress from DAQ module deployment test at industrial facilities. The main objective is to emphasizes on the temperature distribution as a process control for standard operation procedure by the industry for the extraction process towards better control of the yield, and quality of the extracted essential oil.

3.1. Temperature profile of hydrodistillation system

The extraction process was executed for 24 hours to monitor the temperature profile on four (4) points of two hydrodistillation system respectively. It is observed from Figure 12 that both hydrodistillation systems were able to achieve higher mixture temperature (more than 100°C) at evaporator point. Boiling point of water at normal room temperature and atmospheric pressure is 100°C. The higher boiling temperature than the water's suggests that addition of agarwood into the system increases the mixture boiling points. The addition of the agarwood chips became impurities in the water and elevates the boiling points. According to Pornpunyapat, J. (2011) [46], the temperature of distillation should not reach beyond 120°C because it may burn out the plant material. As observed in Figure 12, both hydrodistillation system does not exceeding 120°C and hence met the condition criteria.

Figure 12 also shows that both hydrodistillation system have similar temperature profile patterns. The graphs show extraction process has archived its temperature stability after approximately 4.5 hours and continue to maintain for the rest of the time. The average of recorded temperature was calculated with the standard deviation and summaries in table 1. The heat supplied for the extraction process was less utilised for breaking the cell wall but consumed more energy for vaporizing the volatile compounds. The amount of energy required for the both processes depend on the hydration process of the agarwood chips [47]. The compounds were then carried by the steam along the condenser and finally collected as distillate.

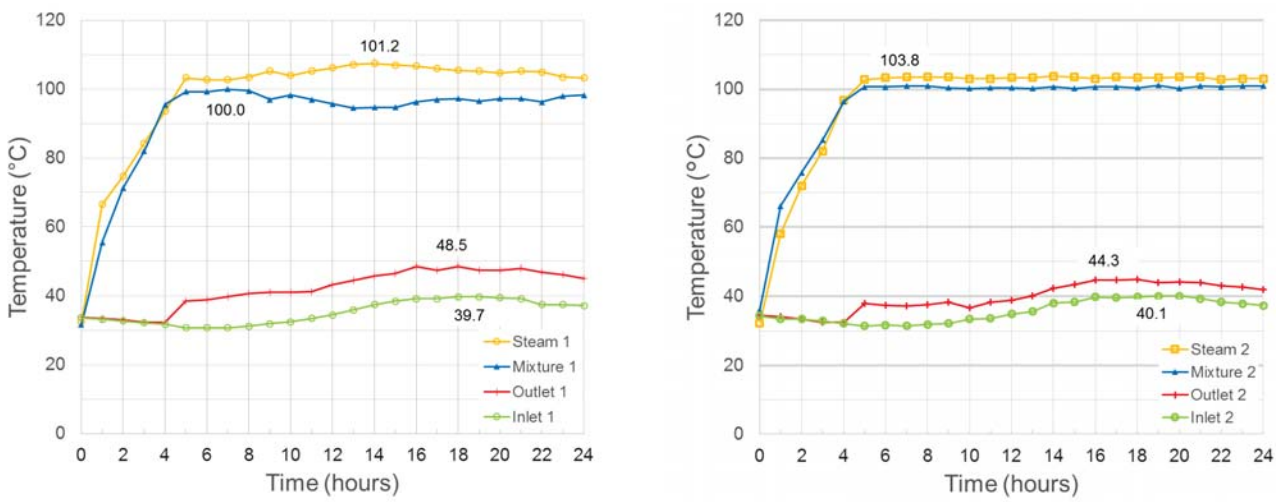


Figure 12. Temperature profile on **(a)** hydrodistillation 1 and **(b)** hydrodistillation 2. The numeral shows the highest temperature reading for each point.

Table 1. Comparison of average temperature on both hydrodistillation system after 4.5 hours.

	Hydrodistillation 1		Hydrodistillation 2	
	Steam	Mixture	Steam	Mixture
Average Temperature (°C)	104.889	97.256	103.206	100.665
Standard Deviation (°C)	1.580	1.606	0.355	0.313

3.2. Yield of extracted oil

Both hydrodistillation setup shows similar outcome based on yield of agarwood oil extracted using conventional hydrodistillation as shown in Figure 13. Higher yield was obtained from hydrodistillation 2 which is 0.004% compared with hydrodistillation 1 samples as summaries in table 2. Our findings seemed contradicts with other researchers who found that the yield of essential oil derived from agarwood soaked in water was between 0.03 and 4.43% [48, 49]. However, the difference results presented in Wetwitayaklung, Thavanapong and Charoenteeraboon [48] and Tajuddin and Yusoff [49] due to the laboratory setup might be the reason of the contradiction with the yield obtained in this study.

Table 2. Yield of extracted agarwood oil.

	Hydrodistillation 1	Hydrodistillation 2
Yield of oil (%)	0.0036	0.0040

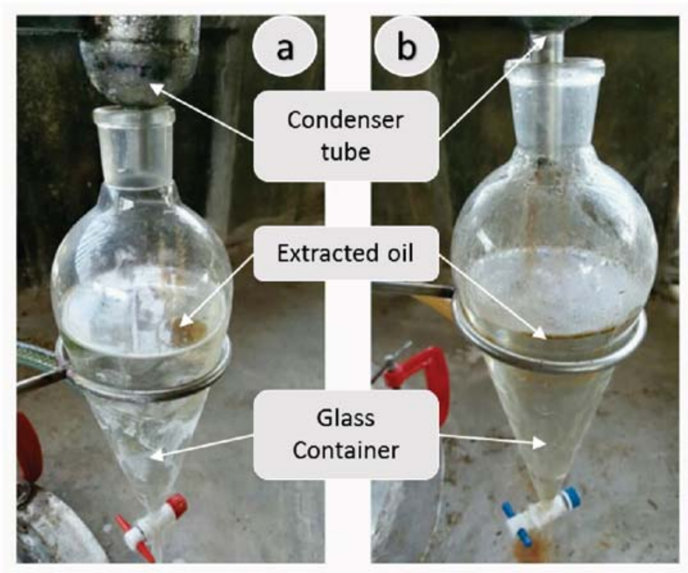


Figure 13. Yield observation of extracted agarwood oil on (a) hydrodistillation 1 and (b) hydrodistillation 2.

4. Conclusions

As a vital part of any systematic studies nowadays, data logger has to be developed with minimum power consumption but yet able to acquire data accurately from multisensors. Taking open source Arduino microcontroller-based data logger for monitoring temperature distribution in hydrodistillation systems, this article established an architecture of software and hardware to provide datalogging functionalities for real time process monitoring that requires durability for long term operation in rough environment. Furthermore, the deployment in the real industry application can also correlate the measurement taken to the quality and quantity of extracted essential oil from the process. Distinction research findings from this research that should be paid attention are that both hydrodistillation showed similar temperature profile pattern with stable readings after 4.5 hours, mixture temperature for both hydrodistillation achieved the average stable temperature of 97.26 °C to 100.66 °C. Whereas, steam temperature shows small difference between both hydrodistillation setup. Higher yield of extracted agarwood oil achieved 0.004% on hydrodistillation 2 compare to hydrodistillation 1 with 0.0036%. From the obtained results, this study achieved the objective of developing an inexpensive, portable and robust eight channels temperature measuring module with capabilities to monitor and store real time data.

Acknowledgement
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