ORIGINAL ARTICLE

Development a heat-pulse sapflow sensor to continuously record water use in fruit trees

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Abstract

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The prototype of a heat-pulse sapflow sensor (PSU-TTSF) was developed for continuous recording of sapflow. The efficiency of the measurement of PSU-TTSF was evaluated by comparing with the Greenspan Sapflow Sensor (a commercial equipment). The 10-year old longkong trees were used as the test plants. The results showed that both equipments could be used for continuously automated records. The accuracy of the measurement was evaluated, and it was found that the sap flow values measured by PSU-TTSF exhibited high relationship with those values measured by Greenspan Sapflow Sensors. The sap flow measured by PSU-TTSF tended to be lower, and the difference was approximately 16%. To reduce the error of measurement, the method of installing PSU-TTSF probe set needs to be improved by using a drill guide.

Key words : Greenspan Sapflow Sensors, heat-pulse sapflow sensors, longkong trees, PSU-TTSF, sap flow

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การพัฒนาหัววัดการไหลของน้ำแบบพัลส์ความร้อนเพื่อวัดการไหลของน้ำอย่างต่อเนื่องในต้นไม้ผล

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ได้พัฒนาและประเมินประสิทธิภาพของเครื่องต้นแบบของหัววัดการไหลของน้ำแบบพัลส์ความร้อน(PSU-TTSF) เพื่อวัดการไหลของน้ำอย่างต่อเนื่องในต้นไม้ผล โดยเปรียบเทียบการวัดโดยเครื่อง Greenspan Sapflow Sensors ซึ่งเป็นเครื่องทางการค้า ในงานวิจัยนี้ได้ใช้ต้นลองกองอายุ 10 ปี เป็นพืชทดลอง ผลปรากฏว่า เครื่องทั้งสองสามารถบันทึกข้อมูลอัตโนมัติอย่างต่อเนื่อง จากการประเมินความเที่ยงตรงพบว่าค่าวัดการไหลของน้ำที่วัดโดยเครื่อง PSU-TTSF มีความสัมพันธ์กับค่าที่วัดจากเครื่องเปรียบเทียบ ค่าที่วัดได้จากเครื่อง PSU-TTSF มีแนวโน้มต่ำกว่าและมีความแตกต่างกันประมาณ 16 เปอร์เซ็นต์ เพื่อลดการคลาดเคลื่อนน่าจะมีการปรับปรุงการติดตั้งหัววัด PSU-TTSF โดยการใช้ตัวนำการเจาะ

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Water is very important in the agriculture sector, particularly with fruit production where the farmer tries to enhance yield and quality of fruits. However, the influence of climatic change also causes a marked fluctuation of rainfall. For example, an impact of drought on agricultural production occurred because of El Niño during 1997-1998(Agricultural Economic Office, 1998). This led to an unpredictable rainfall in Southeast Asia, and severe droughts also caused a disaster of fruit production in Thailand. Therefore, the farmer realizes that an effective irrigation management is necessary in fruit production.

The measurement of water use from individual plants is an effective method in irrigation management. Smith and Allen (1996) suggested that sapflow measurement by heat-pulse method in fruit-trees holds important advantages over other techniques. It is easily automated, so continuous records of plant water use with high resolution can be obtained. Therefore, Limsakul *et al.* (1996) developed a prototype of heat-pulse sapflow sensor as PSU-NECTEC1 to determine water use of fruit-trees. A comparative study between PSU-NECTEC1 and Greenspan sapflow sensor was made, and it was found that the measurement of PSU-NECTEC1 was reliable (Sdoodee *et al.*, 2000). Hence PSU-NECTEC1 will be improved as practical equipment. This equipment will be possibly developed as a commercial product in Thailand in order to reduce imports.

Material and Methods

According to the efficiency of PSU-NECTEC1 sapflow sensors in the measurement of sapflow of fruit trees (Sdoodee *et al.*, 2000), it was introduced for use in an investigation. However, it could not be used for continuously automated records. With this limitation, it needs to be improved. Hence, there were 2 parts in this research : 1) Design of equipment improvement and 2) Testing the measurement under fruit orchard conditions.

1. Prototype Design

1.1 Hardware Design

The prototype of sapflow sensor was designed in order to have 2 sets of sensor probe. Figure 1 shows the block diagram of hardware of sapflow sensor.

Each part was developed as follows:

1) Thermistor with R_o 4700 Ω was used as the lower and upper temperature probes

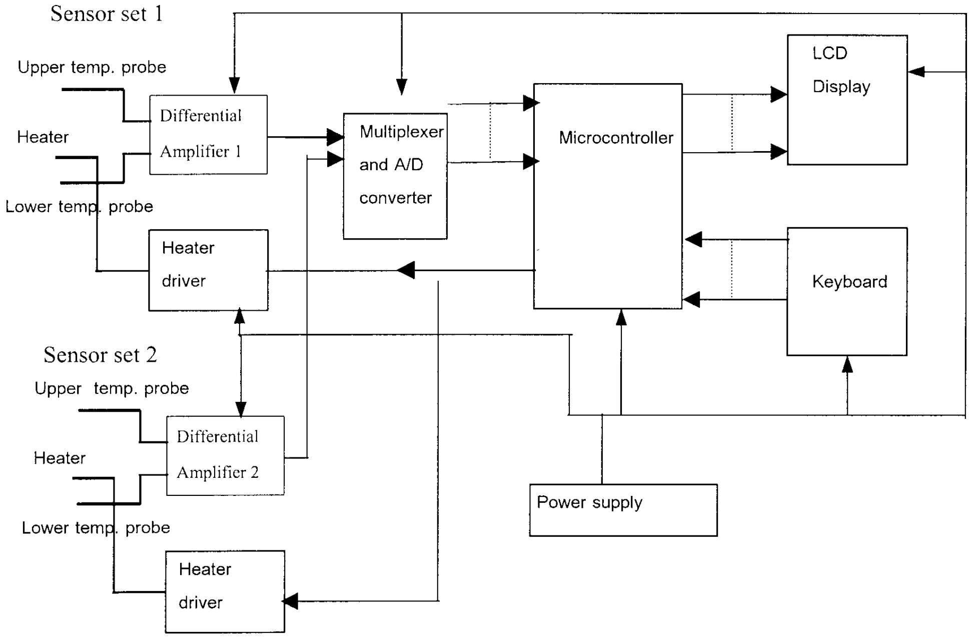

Figure 1. Block diagram of hardware of sapflow sensor.

for measuring the temperature above and below the heater. Each thermister was packed in a stainless tube of 3 mm diameter and 8cm length (Figure 2).

2) The heater of 13 ohms resistance was packed in a stainless tube of 3 mm diameter and 9 cm length. This heater supplied the heat pulse when the transistor 2N2222 was turned on (Figure 3).
3) LP324 was used as a unity gain differential amplifier to amplify the different voltage between two thermisters (Figure 2).
4) ADC 0808 A/D converter 8 bits was used to multiplex signal 8 channels and convert the analog signal to a digital signal (Figure 2). The conversion was controlled by a microcontroller every 1 sec. The real time clock was generated by MN5369 (Figure 4).
5) Figure 5 shows the circuit diagram of microcontroller AT89C52 was the central processor unit with internal memory of 8 Kbytes. It controlled the function of the A/D converter, keyboard, LCD display and delay time measuring.
6) The 32 Kbytes data memory (IC 24LC256) was used to store the delay time (Figure 4).
7) LCD display (16 characters × 4 rows) was the display unit (Figure 4).
8) Keypad 3 × 4 was the keyboard for interfacing to the user (Figure 4).
9) Transistor 2N2222 was the heater driver. The function of this transistor was controlled by the microprocessor (Figure 3).
10) The main power supply was a 12V 40Ah rechargeable battery. 12 V was converted to 5V, 9V and -5 V (Figure 3).

1.2 Software design

The assembly language MCS-51 was implemented. Figure 6 shows the program flowchart. When the equipment is turned on, the user should specify the duration of heat pulse, the sampling period (Ts) and the number of measurements (M). Then the equipment starts to count time (to) and apply current to the heater and measures the initial value of different temperature between two

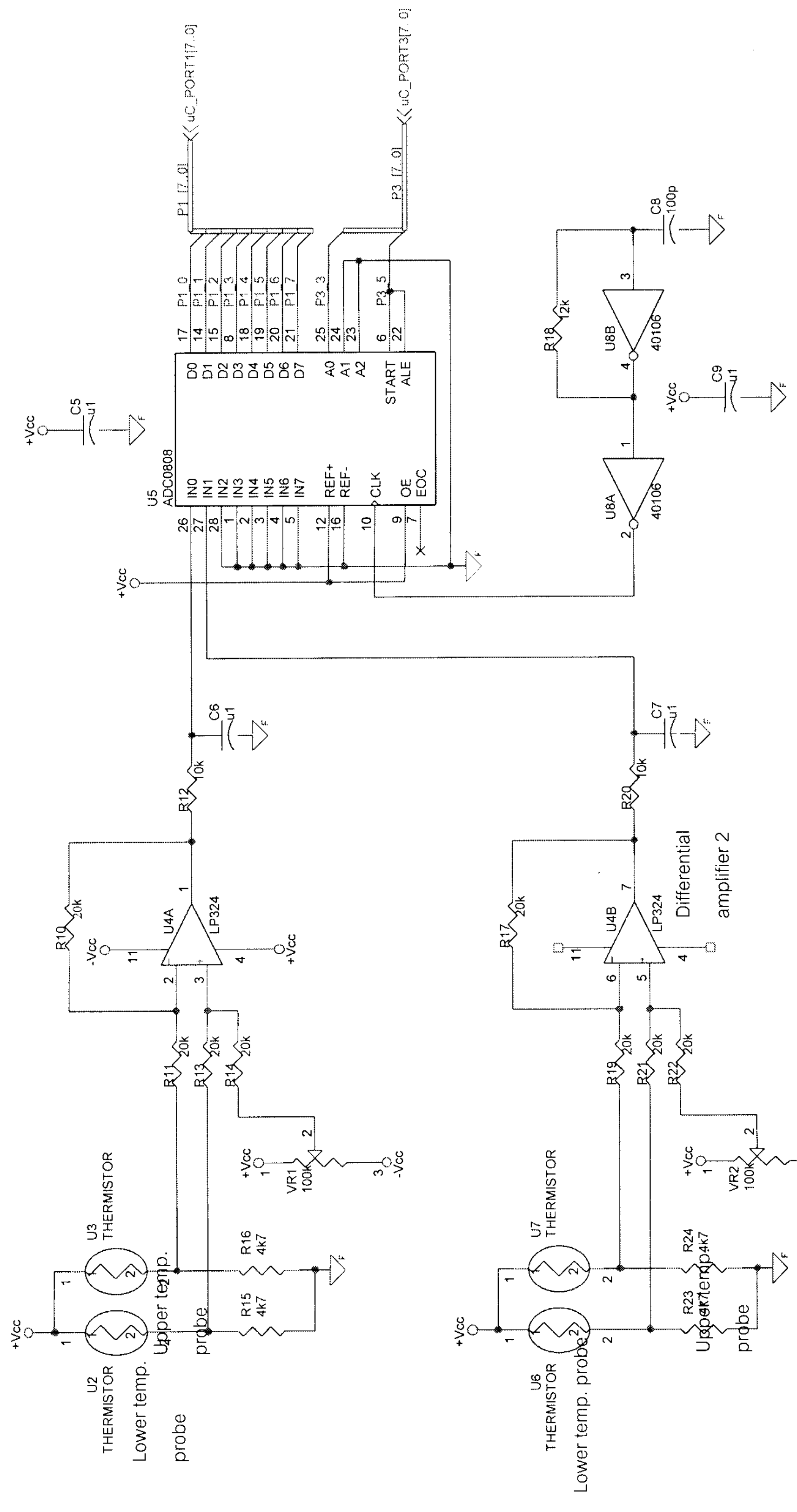

Figure 2. Circuit diagram of differential amplifier and multiplexer and A/D converter

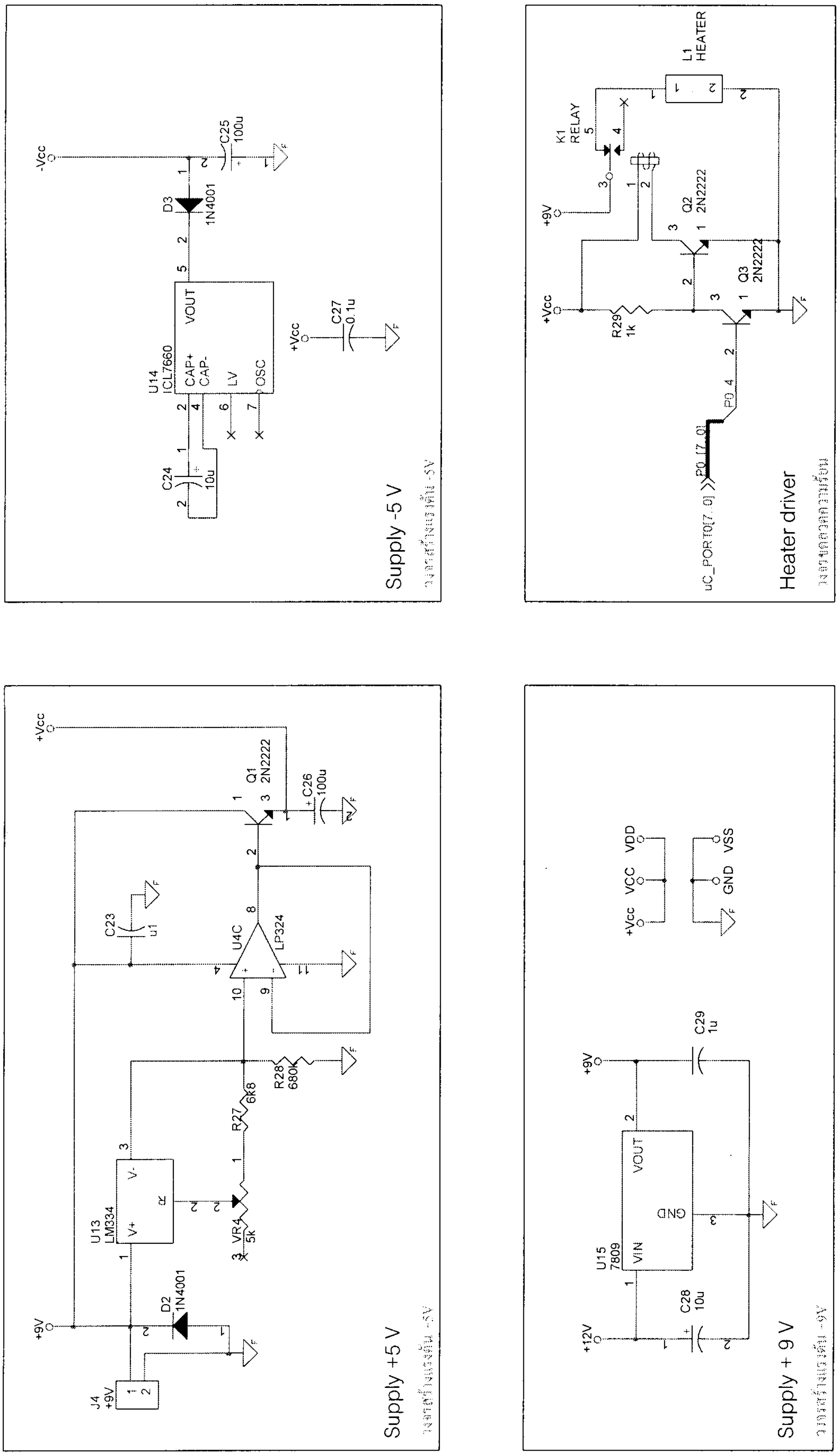

Figure 3. Circuit diagram of power supply and heater driver

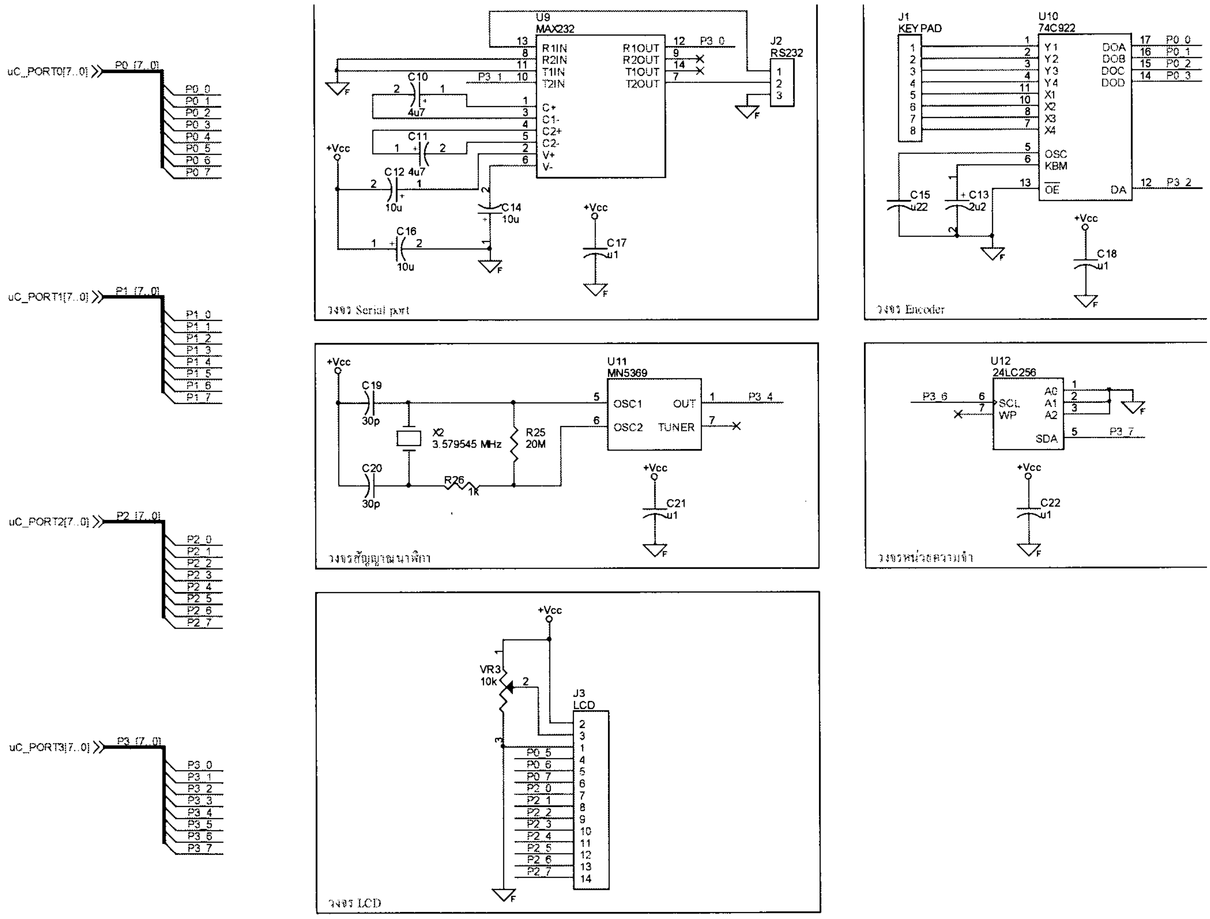

Figure 4. Circuit diagram of peripherals

temperature probes (Told). After ten seconds the different temperature is measured again (Tnew). If Tnew < Told, the error of measuring occurs. If Tnew > Told, the different temperature is measured every 1 sec until Told > Tnew and the equipment stops counting time and records the delay time in memory. The cycle of measuring is started again when the cycle of sampling period occurs. The measuring is done continuously until the number of measurements is reached.

2. Testing the measurement under fruit orchard condition.

An experiment was established at the experimental plot of fruit orchard at the Department of Plant Science, Faculty of Natural Resources, Prince of Songkla University. Longkong was the tropical fruit tree that was chosen as a test plant and four 10-year-old trees were used. Diameter, radius of hardwood and sapwood and bark thickness of each tree were recorded and volume fraction of wood was also determined (Ormsubsin, 2000). Then, the parameters were calculated to access volume flux by the method of Green and Clothier (1988).

$$V = (Xu - Xd)/2to \qquad (1)$$

Xu is the distance from upstream sensor probe that is located 5 mm below the heater probe

Xd is the distance from downstream sensor probe that is located 10 mm above the heater probe

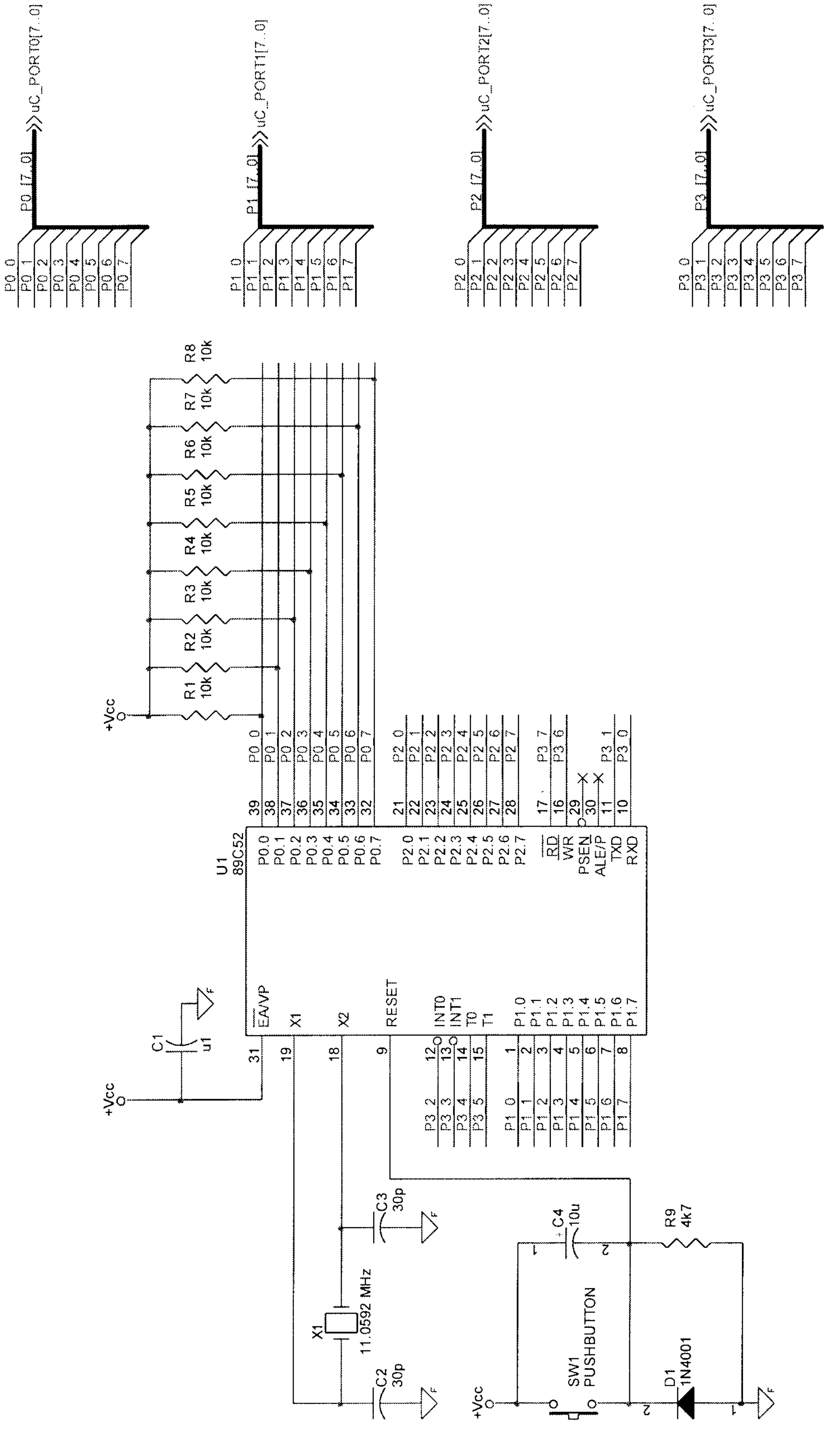

Figure 5. Circuit diagram of AT89C52

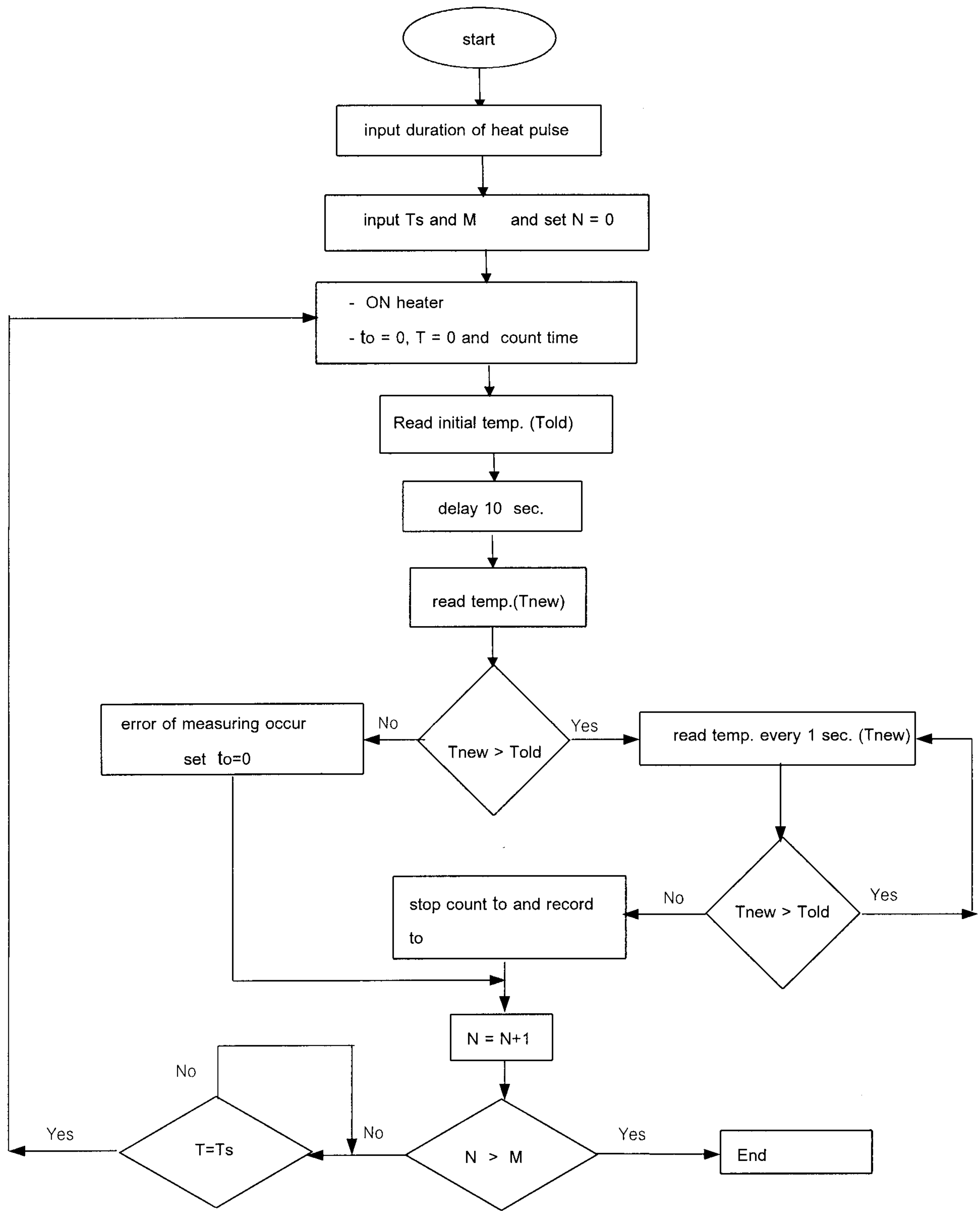

Figure 6. Flowchart of the program

Sap flux density (J)

$$J = P(0.33+M)\,V \quad (2)$$
P = sapwood thickness
M = water content of wood

Volume flux (Q)

$$Q = \int_{H}^{R} 2\pi(r)dr \quad (3)$$
R = radius of sapwood or the distance between bark and hardwood

The probes of PSU-TTSF (Figure 7A) were implanted on the trunk of longkong tree (Figure 7B) at 2.5 cm depth from bark (Wongwongaree, 2001). At the period of sap flow measurement, the diurnal changes of light intensity, leaf water potential and stomatal conductance of the plants were concurrently determined.

Results and Discussion

Average volume fraction of wood of longkong was determined as water content of fresh wood (0.57) and wood density (0.43).

Figure 8 illustrates the data of sapflow rates that were continuously recorded by PSU-TTSF, and they concurrently changed with the light fluctuation during the day. Diurnal changes of sapflow rates also synchronized with the changes of stomatal conductance. This response indicated that sapflow rates increased with the increases of transpiration (Lertsiriworakul, 1993). Besides, it was found that water loss by transpiration through stomata caused the decreases of leaf water potentials. The plants exhibited high water-uptake or high sapflow rate during midday to replace water loss. This is a physiological response of fruit trees during the day; stomatal aperture usually begins in the morning, and stomatal closure occurs in the evening (Sdoodee and Singhabumrung, 1997).

It was found that changes of sap flow I measured by Greenspan Sapflow Sensors were synchronized with those of sap flow II measured by PSU-TTSF (Figure 9). However, the sap flow II trended to be lower than sap flow I during the peak of sapflow around midday. Comparison of sap flow determined in terms of 15-minute record interval by both equipments, showed that there was a close relationship between sap flow I and sap flow II (Figure 10). The values of sap flow II were lower than those of sap flow I values. From

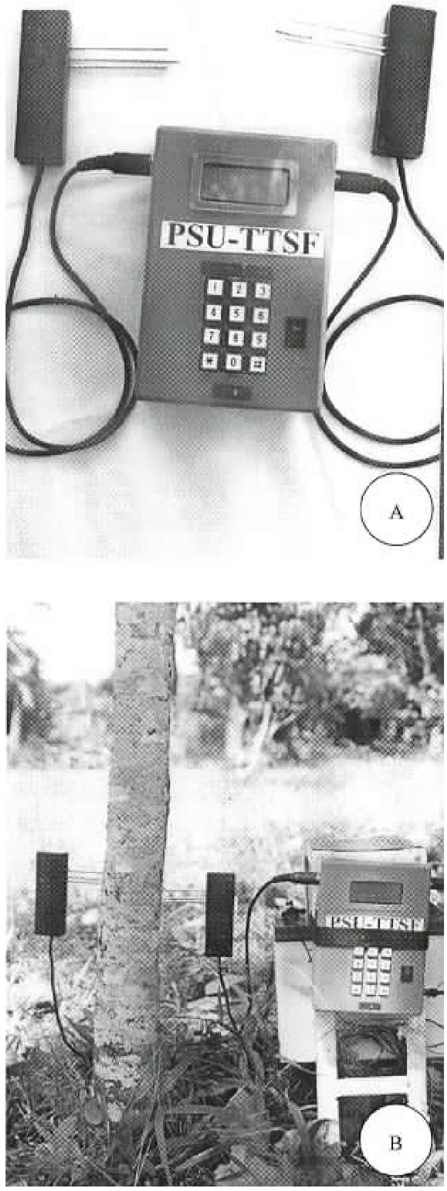

Figure 7. A. The prototype of PSU-TTSF.
B. Installation of the equipment on the longkong tree in the experimental plot.

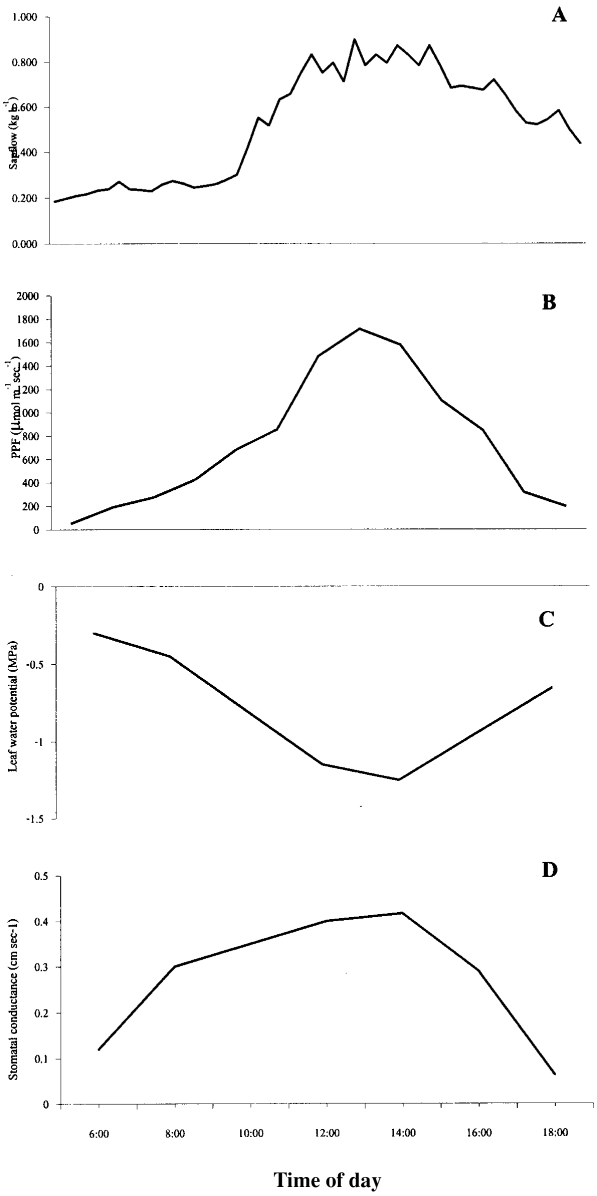

Figure 8. Diaurnal changes of sap flow (A), PPF (B), leaf water potential (C) and stomatal conductance of the longkong tree (D) on DOY 27 in 2001.

the linear regression equation, sap flow II was 0.84 of sap flow I. It indicated that there was a difference 16%. Therefore, calibration curve has to be developed for correction as reported by Sdoodee *et al.* (2000). Besides, the method of installing the probe set of PSU-TTSF needs to be improved to reduce the error of measurement. Adopting the method of installing Greenspan Sapflow Sensor by using a drill guide (Anonymous, 1992) could prevent excessive tearing of wood fiber along the length of the holes. This led to a proper position of attachment between the probe and wood surface. In the case of drilling without using the drill guide for installing of PSU-TTSF, the hole was not drilled properly. This caused the tearing of wood fiber inside the hole, and the probe did not fit with the hole. This might result in poor transfer of heat, and lead to an increase of the delay time or t_o. When calculated by the equation (1), the values of velocity would be lower. Hence, it is necessary to improve the method of installing PSU-TTSF probe sets by using the drill guide.

With the capacity of PSU-TTSF in providing a continuous automated record, it is possible to develop the equipment to be a commercial product. Then, the software for data analysis needs to be developed further.

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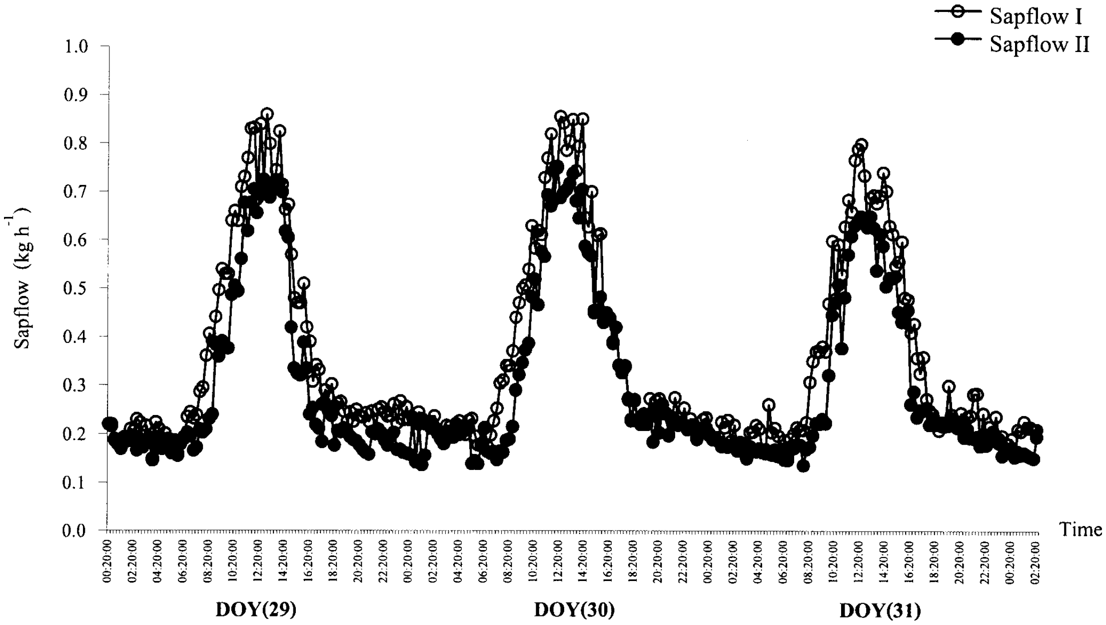

Figure 9. Diurnal changes of sap flow determined by Greenspan Sapflow Sensor (Sap flow I) and PSU-TTSF (Sap flow II) in the longkong tree during DOY 29-31 in 2001.

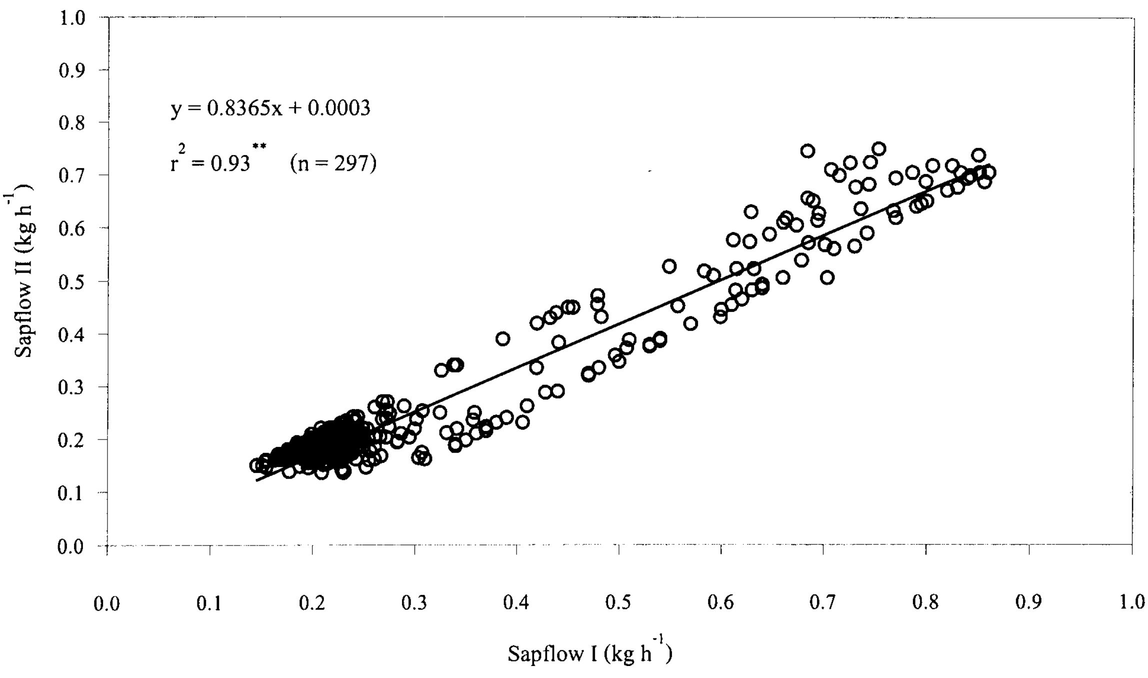

Figure 10. Comparison of the sap flow determined by Greenspan Sapflow Sensor (Sap flow I) and PSU-TTSF (Sap flow II) in the longkong tree during DOY 29-31 in 2001. Each point represents 15 - minute interval record during the 3-day period.

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