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Design of an Arduino based digital psychrometric device

Arduino tabanlı dijital psikrometre tasarımı

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Ö Z E T / A B S T R A C T

Aims: In this study an Arduino based simple and cost-effective psychrometrics device was developed to determine psychrometrics properties of moist air and gather long-term data to be used for automation devices or other engineering designs related to environmental control systems.
Methods and Results: The device employs Arduino microcontroller card. This card has a cheap and high capacity microprocessor that can easily integrate different sensors. The device includes a temperature/relative humidity sensor and a digital barometric sensor. The measured temperature/ relative humidity and elevation are recorded by connecting to a remote database server through the Internet at the desired time intervals. All other pscyhrometrics properties are calculated within the database.
Conclusions: A device that costs 1,044.37 TL ($ 183.22) was developed. The design procedure and performance of the device is discussed in this study.
Significance and Impact of the Study: Considering the importance of gathering psychrometrics data in environmental control of agricultural production buildings, we concluded that the device which was developed might provide a native, easy to use and cost-effective method.

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INTRODUCTION

Environmental control in agricultural buildings means control of the psychrometric properties of an indoor air. Hence, the material of interest is moist air. Psychrometrics deals with properties of moist air at known and unknown states followed by a certain change from a known state (Albright, 1990). Therefore knowing the psychrometrics properties of indoor is essential to design and operate environmental control systems such as ventilation, heating and cooling (Lindley and Whitaker, 1996). The effectiveness of these systems can also be evaluated by psychrometrics functions of sensible and latent heat (Vitt et al., 2017). There are some equations and models available to calculate psychrometrics properties of moist air (ASHRAE, 2001; Nelson and Sauer, 2002; Bell et al., 2018). In most cases if two of psychrometrics properties are known, the remainder can be calculated using different equations. The psychrometrics properties and brief explanations of a moist air that should be determined are listed in Table 1 (Albright, 1990).
The best way to obtain data on psychrometrics properties is to use a simple temperature/humidity sensor. Even though there are such sensors available at little costs they only provide dry-bulb temperature (T_{db}) and relative humidity (RH). One should conduct numerous calculations to determine all other properties.

Therefore, there is a need for a cost effective, easy to use device that can measure these two parameters, calculate other properties, transfer data, and store for future or instant use.

Table 1. Psychrometrics properties of a moist air

Property	Definition	Symbol
Dry-bulb temperature	The temperature measured by a regular thermometer	T_{db}
Water vapor saturation partial pressure	The highest amount of water that can be held by dry air during saturation	P_{ws}
Relative humidity	The amount of water vapor present in air expressed as a percentage of the amount needed for saturation at the same temperature	RH
Humidity ratio	The ratio of the weight of water vapor in the sample air compared to the weight of the same air under dry conditions	W
Degree of saturation	The ratio of weight of water vapor in air at given conditions and at saturation under constant temperature	μ
Specific volume	The total volume of humid air per mass unit of dry air	v
Density	The inverse of specific volume	ρ
Dew point temperature	The temperature at which air is saturated with water	t_d
Enthalpy	The measure of the energy present in the moist air at a certain state	h
Wet-bulb temperature	The lowest temperature to which air can be cooled by the evaporation of water into the air at a constant pressure	T_{wb}

In this study, it was aimed to design a low-cost device that can measure, calculate and transfer the psychrometrics properties of air using Arduino and associated technologies. The proposed device requires sensors to gather data, electronics to transfer data, and a microcontroller to coordinate these sensors and electronics. Actually, the most important part of the device is microcontroller. Arduino is a low–cost, open source microcontroller that makes it popular to improve, build or expand new technologies in all disciplines (Varacha et al., 2012). The Arduino microcontroller can be programmed using C programming language. A number of input and output devices and sensors are available to be used with Arduino platform (Schultz and Vugt, 2016).

MATERIAL and METHODS

Psychrometrics procedure

Albright (1990) reported the equations that can be used to calculate psychrometics properties of ambient air. The method requires at least 2 known properties and elevation above sea level (EASL). The EASL value is required to calculate humidity ratio (W). The actual water vapor saturation pressure and atmospheric pressure at local elevation should be known to calculate EASL. Relationship between EASL and standard atmospheric pressure is shown in Fig 1. The regression equation that can be used to calculate standard air pressure was also shown in same figure.

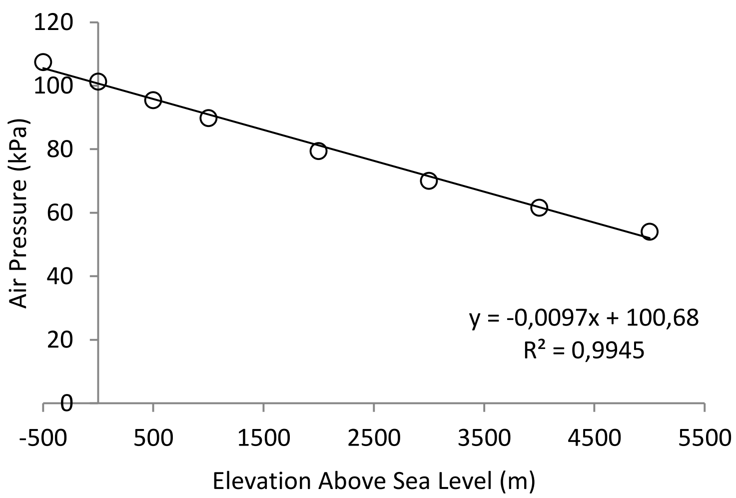

Figure 1. Linear relationship between EASL and standard air pressure (Albright, 1990).

One can easily calculate the remainder properties using simple equations. However, wet-bulb temperature (T_{wb}) is more complicated to determine. It requires an iterative procedure to find the solution. Stull (2011) published the following simple equation to calculate T_{wb} based on T_{db} and R

$$T_{wb} = T_{db} \times arctan\left[0.151977 \times \left(\sqrt{RH + 8.313659}\right)\right] + arctan(T_{db} + RH) - arctan(RH - 1.676331) + 0.00391838 \times RH^{3/2} \times arctan(0.023101 \times RH) - 4.686035 \quad \text{Eq. (1)}$$

Eq. (1) is an empirical inverse solution of a function that fits a graph plots the relationship between T_{wb} and wet-bulb depressions depending on different relative humidities at standard atmospheric pressure (101.3 kPA, and EASL of 0.0 m). Therefore this equation is not applicable to altitudes other than sea level. However, the difference between any T_{wb} calculated at an elevation of -500 and 5000 m is less than 1 °C for any combination of T_{db} and RH. Therefore, the error in the calculations was assumed to be negligible and Eq. (1) was used during the development of proposed device.

Electronics components used in device

In the design an Arduino Uno R3 microcontroller board was used, which employs an AT mega328 microprocessor (Fig 2). This microcontroller unit can be connected to a computer via USB port, or it can be powered with an AC/DC adapter or a battery can be used to operate it.

Technical properties of Arduino Uno R3 microcontroller is given in Table 2.

Figure 2. Arduino Uno R3 microcontroller (Anonymous, 2019)

Table 2. Technical specifications of Arduino Uno R3 microcontroller (Arduino, 2019)

Microprocessor	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7–12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by boot loader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

As discussed earlier, ambient temperature and relative humidity is measured using an Arduino adaptable sensor to calculate psychrometrics properties. In the device a SHT11 sensor was used, which can measure ambient temperature and relative humidity together (SENSIRION, Laubisruetistrasse Staefa ZH, Switzerland) (Fig 3). This sensor is also a low-cost technology with high accuracy. It can measure the temperature and relative humidity with ±0.4 °C and ±3 % accuracy, respectively.

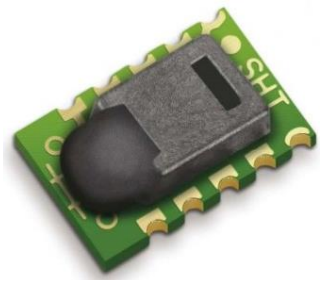

Figure 3. SHT11 temperature/relative humidity sensor (Anonymous, 2019)

Altitude of the location is measured via BMP180 Digital Barometric Pressure Sensor (Bosch Sensortec GmbH, Reutlingen, Germany) (Fig 4). This sensor measures the absolute pressure of the air. This pressure varies with altitude and hence the altitude can easily be calculated using Eq. (2), if the pressure is known.

Figure 4. Digital barometric pressure sensor (Anonymous, 2019)

$$EASL = 44{,}330 \times \left[1 - \left(\frac{P}{P_0}\right)^{1/5.255}\right] \qquad \text{Eq. (2)}$$

where:
EASL: elevation above sea level (m),
P: ambient air pressure measured by sensor (hPa),
P_0: air pressure at reference location which is sea level (1013.25 hPa)

Measured T_{db}, RH, EASL, and calculated other psychrometrics properties are sent to internet database. In the data transfer a Global System Mobile transfer (GSM) module is used (Fig 5). This module (GSM Shield–Simcom/Sim800C) (SIMCom Wireless Solutions Ltd., Shanghai, China) has a built–in antenna that prevents data from being processed when the network signal is weak.

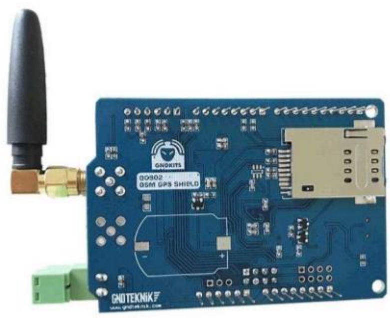

Figure 5. Global System Mobile transfer (GSM) module (Anonymous, 2019)

In order to visualize the most recent measured and calculated data, a Liquid Crystal Display (LCD) is employed. It is a 5–Inch Nextion HMI Touch TFT LCD Display (Nextion, Nanshan Dist., Shenzhen, GD, China) that is capable of communicating with Arduino microcontroller.

Software development

The software basically adapts sensors and other electronics into the system, calculates the psychrometrics properties based on the sensor data and uses codes to transfer calculated data. The Arduino technology provides a free of charge programming platform that makes the entire system low-cost, dynamic and accessible by others. The platform is based on C/C++ which is one of the most common languages used by programmers. The software enables users to change data collection interval down to 1 reading per minute. The collected data is recorded by connecting to a remote database server over the internet at desired time intervals. In this way, the data security is ensured and the data can be accessed from any place at any time via the database server. MySQL, a relational database, was used in the project. The flowchart of the entire procedure is given in Fig 6.

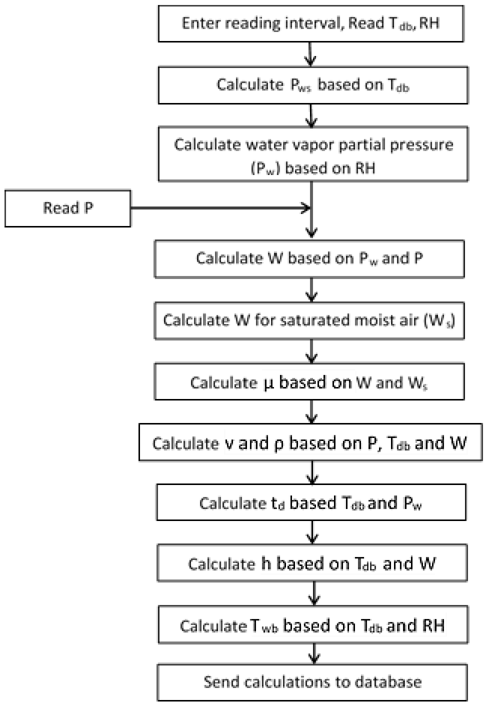

Figure 6. Flow chart of the data processing and transfer procedure.

RESULTS and DISCUSSION

An Arduino based digital psychrometrics device was developed using electronics that were compatible with microcontroller unit (Fig 7). The major components of the device are microcontroller, temperature/relative humidity sensor, GSM unit, and touchscreen. All these components are available at market with low costs. Cost of each piece and total cost in TL and USD are summarized in Table 3. The cost doesn't include GSM operator and internet server costs. A total cost of close to $185 is achieved which is affordable comparing to similar weather monitoring devices which have not same capacity.

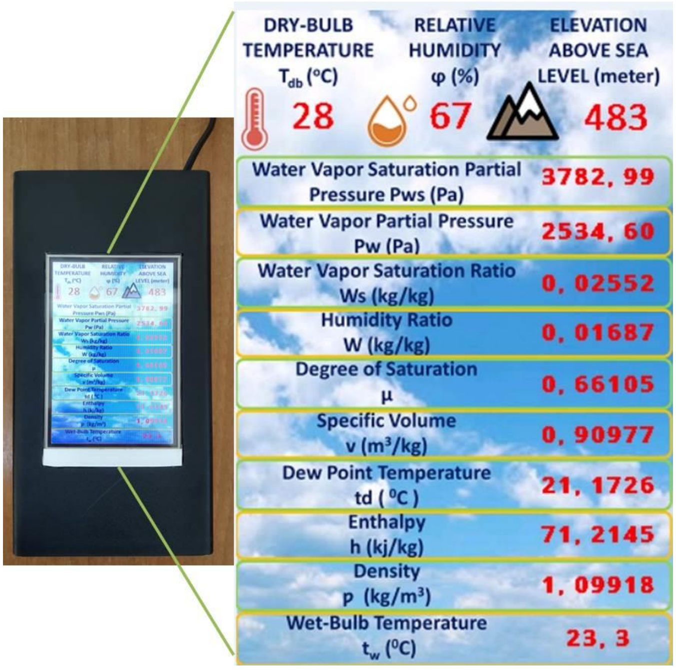

Figure 7. Psychrometrics device

Table 3. Total cost of psychrometrics device.

	Piece	Unit price (TL)	Total cost (TL)
Arduino Uno R3 (Microcontroller)	1	135.30	135.30
Arduino GSM Shiled-Simcom/Sim800C	1	402.85	402.85
DS1307 RTC (Real time clock module)	1	60.43	60.43
3.5 Inch Nextion HMI (Touchscreen display)	1	217.02	217.02
SHT11 (Temperature/relative humidity sensor)	1	127.57	127.57
HH8282 (85x155x60mm box)	1	17.93	17.93
BMP180 (Digital barometric sensor)	1	7.05	7.05
CR2032 (Lithium battery)	1	1.34	1.34
5V 1A (Power adapter)	1	18.80	18.80
Power connector	1	1.21	1.21
3.7V 1100mA 1S Lipo - (Battery)	1	34.38	34.38
(Micro USB Li Ion battery charge circuit Micro)	1	5.71	5.71
LM2596 (Adjustable voltage reducer)	1	4.70	4.70
MT3608 2A (Power booster)	2	5.04	10.08
		Total (TL)	1,044.37
		Total (USD)	183.22

In order to compare the cost and performance of the system a TFA 35.105 Wireless Weather Station (TFA–Dostmann GmbH & Co.KG Zum Ottersberg 12 D–97877 Wertheim/Reicholzheim, Germany) was used (Fig. 8). This device not only measures and stores T_{db} and RH it also measures indoor air pressure, wind speed/direction and precipitation. The cost of the system is $360 which is twice more expensive than the device developed in this study. Even though our device is not capable of measuring precipitation and wind data, with integration of related sensors it can measure and store these data as well. The total costs of wind and precipitation sensor kit is $108 that makes the cost of our device $291. Our device not only measures psychrometrics properties it also transfers data to an internet server and can automate environmental control devices. Therefore, it has more capabilities with smaller cost comparing to the commercial device.

Figure 8. Reference weather station device

As discussed above accuracies of SHT11 sensor are ±0.4 °C and ±3% for T_{db} and RH, respectively. Technical specifications of TFA 35.105 Wireless Weather Station are listed in Table 4.

Based on the table SHT11 is more accurate in both temperature and RH (±0.4 °C vs ± 1°C, and 3% vs 5%)

Table 4. Technical specifications of reference weather station

External temperature display range	-40°C–80°C
Internal temperature display range	-9.9°C–60°C
Operating temperature	-5°C–50°C
Storage temperature	-20°C – 70°C
Temperature accuracy	± 1°C
Temperature precision	0.1°C
RH display range	0%–99%
RH accuracy	±5%
RH precision	1%

The T_{db} and RH values that were acquired with both devices were recorded and stored under laboratory conditions. A 24–hour experiment is conducted. Temperature and RH values recorded to monitor the relationship between the designed device and reference commercial system. Both relations are shown in Fig 9. As can be seen from the figure, there is a strong relationship between measured and reference temperature values. Mean daily temperature values are 24.6 and 23.5 for SHT11 and reference, respectively. The slope of trend line and line of equality are similar which means both device yield similar temperature values during operation.

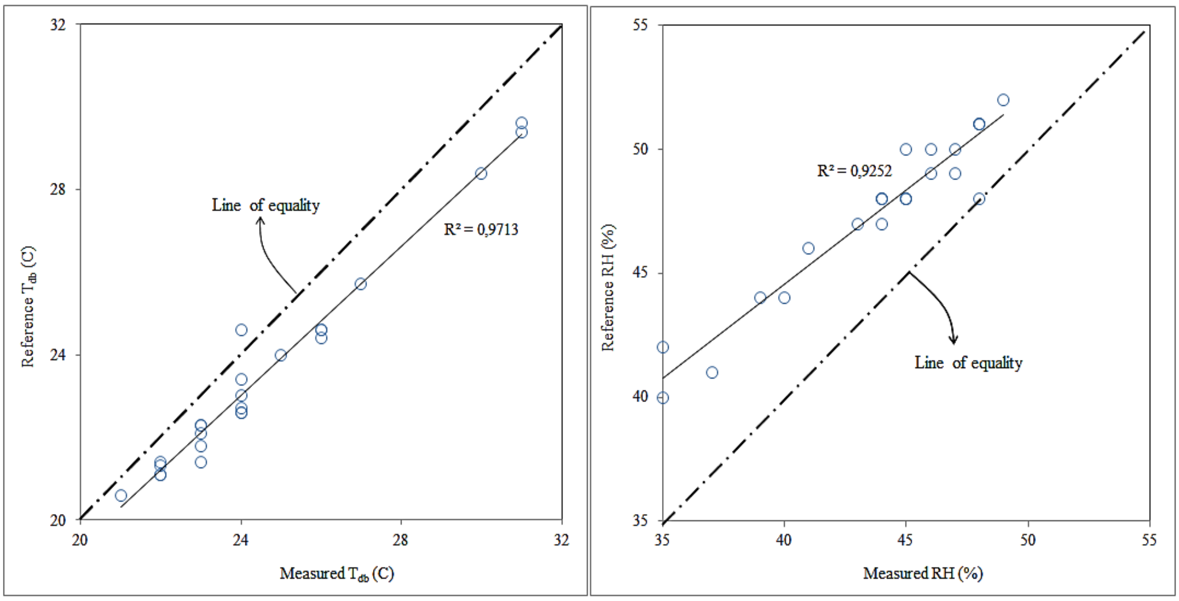

Figure 9. Comparison of measured and reference T_{db}, RH.

If we look at the relationship between measured and reference RH, there is a smaller R^2 value of 0.93 comparing to that relation of temperature (0.97). Also, the slopes of trend line and line of equality are different. This may be explained by smaller accuracies of both systems in the measurement of RH (3 and 5% for our device and reference system). Olgun (2016) reported that required RH ranges for cattle, sheep/goat, and poultry are 60–80%, 50–60%, and 60–75%, respectively. Therefore, in environmental control for agricultural buildings accuracy of up to 5% can be tolerated without causing any problem in operation. Mean daily RH values are 44 and 48% for SHT11 and reference device, respectively. There is a difference of 4% that is within the accuracy range of reference device.

CONCLUSIONS

As a result, in this study a digital psychrometer that can be used to measure, transfer, and record pschrometerics properties of a moist air was designed. Arduino microcontroller was used as a tool to coordinate required sensors and electronics to achieve the goal. As a result, it can be concluded that;

- Arduino, an open source microcontroller, can be used to design environmental monitoring and automation devices,
- The low cost, accessibility, and easiness of programing make this technology suitable for agricultural applications,
- Accuracies of related sensors are good enough comparing to other commercial technologies,
- Possibilities of integrating other sensors and electronics with Arduino also makes this microcontroller dynamic,

Integration of GSM technology into the system makes Arduino based devices ideal for applications in which data transfer and storage is critical.

ÖZET

Amaç: Bu çalışmada, nemli havanın psikrometrik özelliklerini belirlemek ve otomasyon cihazları veya çevre kontrol sistemleri ile ilgili diğer mühendislik tasarımları için uzun vadeli veriler toplamak amacıyla Arduino tabanlı basit ve uygun maliyetli bir psikrometri cihazı geliştirilmiştir.

Yöntemler ve Bulgular: Cihazda Arduino mikrodenetleyici kartı kullanılmıştır. Bu kart, farklı sensörleri kolayca entegre edebilen ucuz ve yüksek kapasiteli bir mikroişlemciye sahiptir. Cihaz, bir sıcaklık / bağıl nem sensörü ve bir dijital barometrik sensör içermektedir. Ölçülen sıcaklık / bağıl nem ve yükseklik, istenen zaman aralıklarında internet üzerinden uzak bir veritabanı sunucusuna bağlanarak kaydedilebilmektedir. Diğer tüm psikrometrik özellikler, veritabanında hesaplanmaktadır.

Genel Yorum: Geliştirilen cihazın toplam maliyeti 1,044.37 TL (183.22 $) olmuştur. Bu çalışmada cihazın tasarım prosedürü ve performansı tartışılmıştır.

Çalışmanın Önemi ve Etkisi: Tarımsal üretim binalarının çevresel kontrolünde psikrometri verilerinin toplanmasının önemini göz önüne alarak, geliştirilen cihazın yerli, kullanımı kolay ve uygun maliyetli bir yöntem sağlayabileceği sonucuna varılmıştır.

Anahtar Kelimeler: Psikrometri, çevre denetimi, otomasyon, Arduino, veri aktarımı

DECLARATION OF CONFLICTING INTERESTS

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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