

## IMPROVEMENT OF MEASUREMENTS OF 3D AIR FLOWS IN FREE AND SEMI-RESTRICTED SPACE

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**ABSTRACT.** The enhanced requirements for safe, healthy and environmentally friendly workplace and ambience require highly specialized measurements of the air quality in indoor and outdoor workplaces. Many mining work areas have large volumes and in such sites, one-dimensional, directed air flows are rarely observed. It is common that the flows are equally sized in the three directions (x, y, z). In fact this is also the way the harmful particles are spread in the studied areas. Measurement and visualization of the fluid vector field in free and semi-restricted space can be successfully performed with a 3D ultrasonic anemometer. It permits the composition of a real flow speed field by making fast multiple measurements in all the three directions. A microcontroller device is proposed in the paper that enhances the capabilities of the 3D ultrasonic anemometer MODEL 81000 by R.M. YOUNG COMPANY, USA. This is done by reading the data from the standard RS-232 serial interface and logging it on a SD card. A GPS receiver is also added to the system thus making possible the precise capturing of geographic coordinates in open space. All this makes the anemometer much more flexible and portable. A proposal for future development is also presented which will make the anemometer accessible via wireless connection and a mobile platform in the field.

**Keywords:** ultrasonic anemometer, air quality, data logging

## УСЪВЪРШЕНСТВАНЕ НА ИЗМЕРВАНИЯТА НА 3D ВЪЗДУШНИ ТЕЧЕНИЯ В СВОБОДНО И ПОЛУОГРАНИЧЕНО ПРОСТРАНСТВО

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**РЕЗЮМЕ.** Повишените изисквания за безопасна, здравословна и екологична работна и околна среда изискват специализирани измервания за качеството на въздуха в работни места в затворени помещения и на открито. Немалка част от работните зони в минното дело са с големи обеми и при такива обекти едномерни, насочени въздушни течения, рядко се наблюдават. Твърде често теченията са с относително равнопоставени големина в трите направления (по x, y, z). Така се разпространяват и отделените вредности в изследваните зони. Измерване и визуализация на векторното поле на въздушно течение в свободно и полуограничено пространство е възможно да се осъществи с 3D ултразвуков анемометър. Това позволява съставянето на реално скоростно поле чрез бързо многократно измерване в трите направления. В статията е предложено микроконтролерно устройство, което разширява възможностите на 3D ултразвуков анемометър MODEL 81000 by R.M. YOUNG COMPANY, USA. Това е направено чрез прочитане на данните по стандартен RS-232 интерфейс и тяхното запазване върху SD картата. Освен това към системата е добавен GPS приемник, който позволява прецизно снемане на географски координати на открито. Всичко това прави анемометъра много по-преносим и гъвкав в употреба. Направено е предложение за бъдещо доразвиване на системата, чрез което анемометърът да стане достъпен през безжична мрежа от мобилно устройство в мястото на измерване.

**Ключови думи:** ултразвуков анемометър, качество на въздуха, регистриране на данни

## Introduction

Precise measurements of flow directions and distribution in many industrial areas is crucial for ensuring safe work atmosphere. It is even more important for many mining sites such as open pit mines, face ventilation (Timko, 2005), flows around fans. Other civil objects – tunnels entrances and exits, flows around buildings and typical meteorological measurements (Wilson, 2012) also require 3D velocity field. In such objects one-dimensional, directed air flows are rarely observed. It is common that the flows are sized in the three directions (x, y, z). In fact this is also the way the harmful particles are spread in the studied areas.

The technological development makes possible the utilization of up-to-date devices for flow measurements based on ultrasonic signals. These are ultrasonic anemometers (Fig.1). Their application and measurement results need additional processing for upgrading into a user friendly view. In order to get measured a 3D velocity field one needs a computer linked to the anemometer which is not appropriate in many sites. What is more, after uploading the data it should pass additional treatment, especially in sequencing between positions where the vector and its measured value are taken.

This paper presents one possible way to improve 3D ultrasonic measurements in the following directions: GPS positioning system and transfer of the measured vectors in the specified coordinates to the SD card.



Fig. 1

### Technical characteristics of 3D anemometer

The constant increase in computing capabilities enables the creation of ever faster and more powerful computing devices and practical implementation of increasingly sophisticated algorithms. This makes possible the existence of ultrasonic anemometers in which the three-dimensional flow velocity is based on the time of passing ultrasound acoustic signals. This paper is built around the 3D ultrasonic anemometer MODEL 81000 by R.M. YOUNG COMPANY, USA (fig.1).

The YOUNG Model 81000 Ultrasonic Anemometer is a 3-axis, with no-moving-parts, wind sensor (<http://www.youngusa.com>). The sensor features durable corrosion-resistant construction with 3 opposing pairs of ultrasonic transducers supported by stainless steel members. It measures wind speed in a range from 0 to 40 m/s, with resolution 0.01 m/s in all 360 degrees wind direction. The device has several serial outputs (one user programmable ASCII, RS-232 or RS-485) and 4 voltage outputs (from 0 to 5000 mV).

#### Serial Output:

- RS232 at 38400 Baud
- ASCII Text Serial String - Wind Speed - 3D (m/s); Direction (Deg); Elevation (Deg); Speed of Sound (m/s); Sonic Temperature (°C)

#### Analog Voltage Outputs:

- Channel V1: Wind Speed (3D) - 0-5000 mV = 0-50 m/s
- Channel V2: Wind Direction - 0-5000mV = 0-540 Deg
- Channel V3: Elevation - 0-5000mV = -60° to +60°
- Channel V4: Sonic Temperature -0-5000mV = 220K to 320K

### Operating principle of ultrasonic anemometer

Operating principle of ultrasonic anemometer can be described briefly in the following way (fig.2).



Fig. 2

The anemometer has 3 arms. The three pairs of transducers are displaced at 120 deg. Redundancy of the measurement is given to each path thus improving the sensor accuracy and reducing aerodynamic turbulence. The time taken for an ultrasonic pulse of sound to travel from one transducer to the diametrically opposite transducer (north to south) is measured, then it is compared with the time for a pulse to travel in the opposite direction (S to N) (Gill Instruments, 2017; Ultrasonic Anemometer, 2017). Simultaneously, times are compared between west and east and vice versa (E to W). If we have preliminary northern wind, then the time taken for the pulse to travel from N to S will be less than from S to N, whereas the W to E, and E to W times will be the same. The wind speed and direction can then be calculated from the differences in the times of flight on each axis. Sonic temperature is derived from the speed of sound which is corrected for crosswind effects. When the wind blows, it increases the time of flight for pulses travelling against it. The time of flight theory principle is illustrated in Fig. 3 with equations (1) to (4).

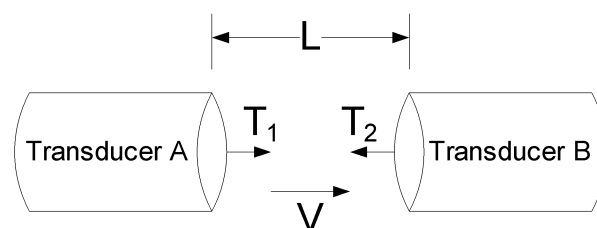


Fig. 3

$$T_1 = \frac{L}{c+V} \quad (1)$$

$$T_2 = \frac{L}{c-V} \quad (2)$$

$$V = \frac{L}{2} \left\{ \frac{1}{T_1} - \frac{1}{T_2} \right\} \quad (3)$$

$$C = \frac{L}{2} \left\{ \frac{1}{T_1} + \frac{1}{T_2} \right\} \quad (4)$$

where: L is the distance between the transducer faces,  
C is the speed of sound,  
V is the velocity of the fluid (the air),  
T1 and T2 are the propagation times of the ultrasound.

## Necessity for measurement improvement

Measurements with ultrasonic anemometer are performed and managed through Command Menu with the following structure:

```

COMMANDS (VERSION 7.0.05)
-----
R) REPORT
S) SETUP
X) EXIT TO OPERATE MODE
  
```

One can choose consequently positions R), S) or X) in order to set initial parameters according to Model 81000 Instructions. As seen from the passage below, many parameters should be set according to measurements which need to be performed.

```

SET PARAMETERS
-----
A) AVERAGING
B) BAUD
E) ERROR HANDLING
N) SCALING MULT
O) OUTPUT RATE
P) POLL CHARACTER (ADDR)
S) SER OUT FORMAT
T) THRESHOLD
U) UNITS
V) V OUT FORMAT
W) WAKE CORRECTION
X) EXIT TO MAIN MENU
  
```

Special attention is paid to position R) – report. If 3D speed is selected in order to have 3D vector field, the output file will consist of ASCII string, containing all measured data. This data is in mV for each analog channels outputs.

```

CURRENT SERIAL OUTPUT FORMAT:
-----
5) UVW
6) 2D SPEED
7) 3D SPEED
8) AZIMUTH
9) ELEVATION
A) SOS
B) Ts
C) CHKSUM
E) ERR CODE
V) INTERNAL VOLTAGE
  
```

Then special conversion should be performed as given below:

```

CONVERSION TO ENGINEERING UNITS
FOR UVW FORMAT:
U,V, OR W
WINDSPEED = [(SCALE X 2 / RANGE) X MV] - SCALE
EXAMPLE:
W CHANNEL OUTPUT VALUE = 2550 MV
SCALE = 25 M/S
RANGE = 5000 MV
SPEED = [(25 X 2 / 5000) X 2550] - 25 = 0.5 M/S
  
```

What is more, separate coordination of measurement points should be written down during experiments. All these problems need to be overcome in order to put the device in a user friendly mode. One solution is presented hereafter – a modem linked to the anemometer, to the GPS receiver and to the mV

converter which transfer measured data in a vector view to a SD card.

## Logging device

A NodeMCU ESP12-E is selected as the main controller because of its low price, easy programming and WiFi connectivity capabilities. NodeMCU is an open source IoT platform and includes firmware running on the popular ESP8266 Wi-Fi SoC from Espressif Systems. It can be programmed in the Arduino IDE which provides simplicity and pre-built libraries. A block diagram with all the main components of the controller is shown in Fig. 3.

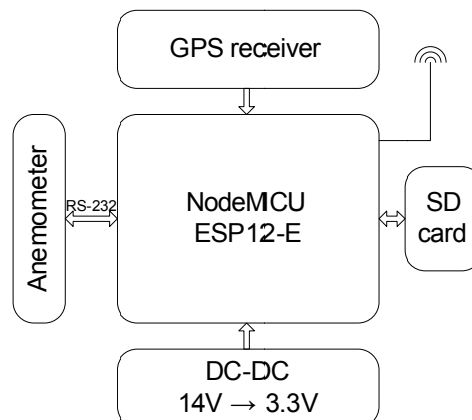


Fig. 4

The anemometer is powered by a 12-24V battery so there is a DC-DC converter to lower the voltage to 3.3V required by the NodeMCU. The anemometer communicates with the controller over a standard RS-232 serial port. The MCU reads the data from the GPS receiver and adds that data to the one from the anemometer and then continuously stores it on a SD card.

## Performed measurements with MODEL 8100

Illustration of capabilities and applicability of 3D flow measurements are presented hereafter. Fig. 5a shows schematic view of the stand with wind turbine, while Fig. 5b – the same stand with 3D anemometer (Z. Dinchev, 2014). The purpose of experiments was to measure velocity field flows around wind turbine.

The stand consists of the following elements:

- 1 – axial fan with regulation;
- 2 – flexible pipeline;
- 3 – regulation grid and diffusor;
- 4 – wind fan in two types (H225 and H150);
- 5 – anemometer;
- 6 – 3D supersonic anemometer;
- 7 – Laptop.

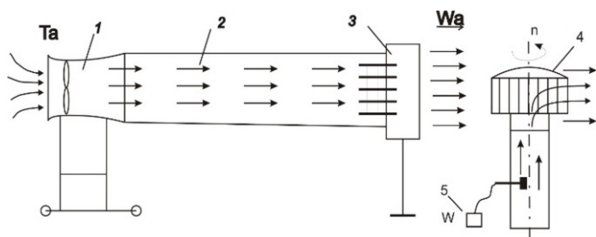


Fig. 5a

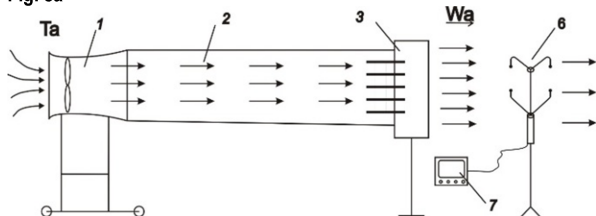


Fig. 5b

Measurement results are summarized in Table 1. They are obtained without a logging device and their final output was achieved with additional treatment of the registered data. As seen from the figures, the velocity field is uniform in plane XY. Very small fluctuations in Z and X direction are seen. That was the purpose of the experimental measurements – well targeted and constant flow towards the wind turbine. Applying such flow, the regime characteristics of the wind turbine were measured (Z. Dinchev, 2014).

Table 1.

U, m/s	V, m/s	W, m/s	3D, m/s	A, Azimuth, deg	E, Elevation, deg
-0.06	6.51	-0.08	6.53	359.4	-0.7
-0.02	6.53	-0.11	6.55	359.8	-1
-0.03	6.54	-0.02	6.56	359.7	-0.2
-0.05	6.48	-0.35	6.51	359.5	-3.1

### Future work

The selected NodeMCU ESP12-E main controller gives opportunity for future improvements that can provide additional flexibility. The core of this work includes the use of WebSockets. The WebSocket protocol is a TCP-based protocol. This protocol lowers the overhead in the interaction between a browser and a web server by providing a standardized way for the server to send content to the browser without being solicited by the client. This allows for messages to be exchanged while keeping the connection open.

The basic idea for the proposed improvement is shown in Fig. 6.

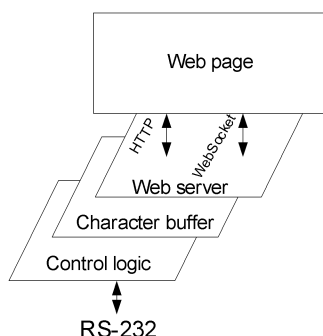


Fig. 6

The implementation of the proposed approach will give the opportunity to build a wireless serial terminal. Thus, a terminal of a convenient computer will be emulated by the NodeMCU via a webpage that can be read on any portable device with a web browser.

### Conclusion

Based on general knowledge of 3D measurements and utilization of ultrasonic anemometers one useful improvement of measurement technique is presented. After considering all ideas, researchers will have an intelligent device which can perform all type of three dimensional velocity field in different engineering sites.

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