# VELOCITY FIELD VISUALIZATION, MEASURED WITH 3D ULTRASONIC ANEMOMETER

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**ABSTRACT.** The advance in technology development makes it possible to use state of the art devices for 3D measurements such as ultrasonic anemometers. These devices are able to acquire great amounts of data which need to be further processed. By adding a GPS device and SD card storage the data can be analysed by engineers in offline mode or can be accessed wirelessly through Bluetooth connection. The above mentioned improvements are presented in this paper in their final version. A very important point in the overall practical application of the device is the visualization of the obtained velocity vector field. Several possible ways of visualization with the aid of different software packages such as Surfer and Grapher are discussed. A real 3D velocity vector field, measured with ultrasonic anemometer MODEL 81000 by R.M. YOUNG COMPANY, USA is presented in the paper along with cross sections in the xy, yz and xz planes.

**Keywords:** ultrasonic anemometer, velocity field measurement and visualization, data logging

**ВИЗУАЛИЗАЦИЯ НА ВЕКТОРНО ПОЛЕ, ИЗМЕРЕНО С 3D УЛТРАЗВУКОВ АНЕМОМЕТЪР**

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**РЕЗЮМЕ.** Развитието на технологиите прави възможно използването на съвременни устройства за тридименсионни измервания като например ултразвуковите анемометри. Чрез тези устройства се получават голям обем измерени данни, които чрез GPS позиционираща система и запис на SD карта посредством безжична връзка са на разположение на инженерните специалисти в електронен вид. Усъвършенстванията на уреда са реализирани от авторите и са представени в окончателния си вариант. Важно продължение на работата е визуализация на векторното поле. Статията представя няколко начина за визуализация с използване на приложните софтуерни продукти Surfer и Grapher. Представено е реално измерено 3D векторно поле и разрези по xy, yz и xz равнините.

**Ключови думи:** ултразвуков анемометър, скоростно поле, измерване, визуализация, регистриране на данни

## Introduction

Real time velocity field measurement is a valuable and highly useful technique in many spheres of aerodynamics and ventilation (Francia V. at. all, (2016)). In the Report of Project MTF 159/2017 and in the paper (Dinchev Z., Gorbunov Y., 2017) the main features of the ultrasonic 3D anemometer are presented, together with the possibilities for instrumentation improvements in the following aspects: automation of measurements by implementing a data logging device with a possibility for storing on a SD card, automatic location registration via GPS, addition of a Bluetooth connection for easing mobile data transfer and for user convenience. Other authors also present modernization and special approaches in measurement technique with ultrasonic anemometers (Hietanen J. 2010).

This paper presents the ultimate realization of these device modernizations. The great amount of acquired data in the process of measurement needs specific treatment in order to get the output in applicable engineering presentation in a plane, surface and volume. Special attention is paid to the methodology for visualization of velocity fields by utilizing different software products.

## Connecting the anemometer with the data logging device

A general overview of the setup is given in Fig. 1. As a main controller unit an 8-bit MCU-based Arduino platform is used. It represents an open software and open hardware project and provides short development times and easy programmability at a rational price. Programming is performed in the Arduino IDE via built-in libraries. The source code of the program is given in Appendix 2 of Report of Project MTF 159/2017, while the description of the included components is in Appendix 3 of the same project.

The anemometer has battery power supply of 12-24V which is further reduced by a DC-DC converter down to 3.3V. Such voltage is required by the Arduino system and the attached GPS, SD card (Elecrow Model MCS01107S) and Bluetooth. The anemometer communicates with the controller via the four provided analog voltages for the U, V, W and T vectors. The MCU reads the GPS data, adding coordinates to measured values of velocity vectors in the x, y and z directions. Next, it records the full information about the measured values and coordinates on the SD card.

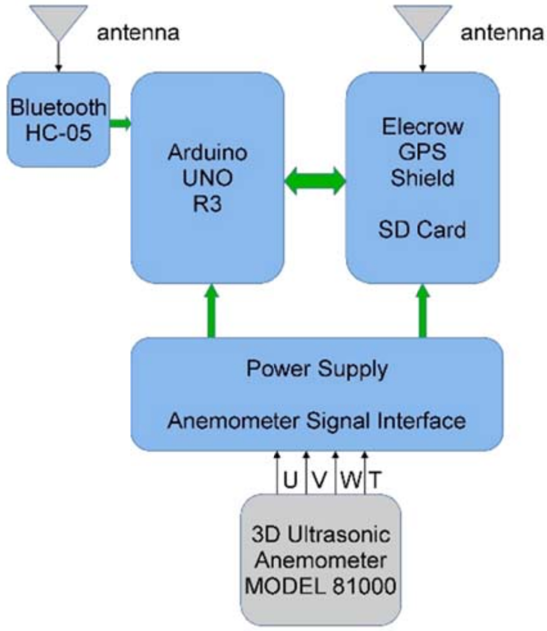


Fig.1. A general overview of the system

In Fig. 2 the final view of the controller is shown.

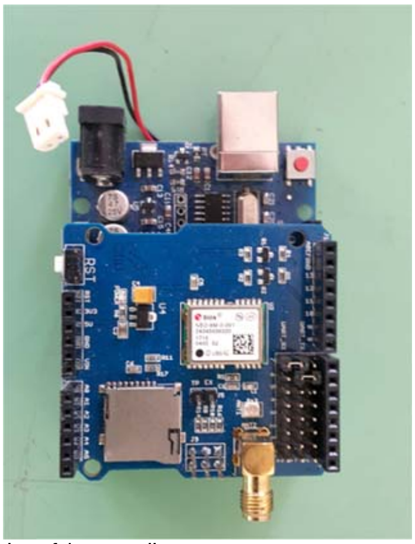

Fig.2. Final view of the controller

The Arduino board is located into a secure plastic box, which is mounted on the anemometer stand – see Fig.3. The external GPS antenna and the Bluetooth receiver placed inside the box are not shown.

Fig.3. Anemometer with the attached controller box

## Performed measurements with MODEL 8100

First, it is important to place and orient the anemometer in the right position (fig. 4) – ideally facing the north geomagnetic pole or in the position that is along the tube. After this step the anemometer performs synchronization of devices for link to GPS and Bluetooth and initiates measurement. A new file in the comma-separated (CSV) format is created for every measurement cycle and the data is saved every second. The content of the file has the structure given in Table 1:

Table 1.

| GPS_ LAT | GPS_ LON | GPS_ DATE | GPS _TIME | U [m/s] | V [m/s] | W [m/s] | T ['K] |
|---|---|---|---|---|---|---|---|
| | | | | x | y | z | |

where:
GPS_LAT – latitude, deg
GPS_LON - longitude, deg
GPS_DATE – data in format dd/mm/yyyy
GPS_UTC_TIME –time of record, UTC hh:mm:ss
U [m/s] – velocity vector, m/s (orientation east / west) – Fig. 4;
V [m/s] – velocity vector, m/s (orientation north/ south) –Fig.4.;
W [m/s] - velocity vector, m/s (orientation down/up), Fig. 5 m/s
T['K] – temperature of air flow, °K.

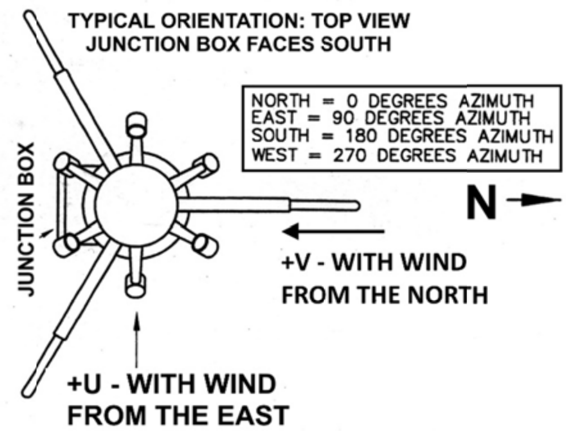


Fig.4. Orientation of the anemometer device

In case if no GPS connection is available (for instance underground) or the measurement is performed in a restricted area where the latitude and the longitude in different points are negligible, a close spare scenario is developed. The GPS data is switched off by a hardware button. Then the user inputs unique coordinates in the measuring points.

The orientation shown in Fig. 4 and 5 is used when performing measurements outdoor. When measurements are being taken indoor, the device orientation is the following: the direction north should coincide with the ordinate Y, thus receiving data in XY coordinated system – 2D surface velocity field. Changing the orientation allows 2D visualization in all planes (XY, XZ, YZ). Using three coordinates (X - GPS_LAT , Y - GPS_LON , Z – height) it makes it possible to achieve 3D visualization of the vectors – this is called the volumetric velocity field. Special attention is paid to data transformations, depending on specific application of results (Walker Ian J., 2004). Different approaches are possible to perform graphical visualization in the chosen view. Further presented in the paper are 2D and 3D visualizations with specialized software products of Golden Software company – Grapher and Surfer, as well as with MatLab.

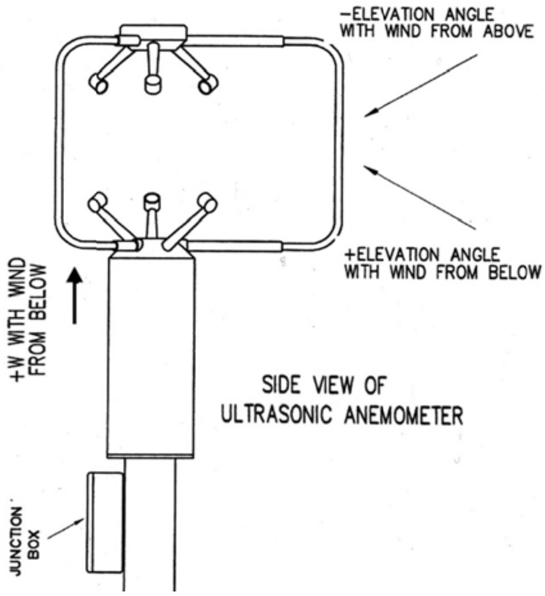


**Fig.5. Side view of the anemometer device**

The collected data from the file is transformed into EXCEL columns, representing vectors in three dimensions, thus giving a chance to calculate velocity scalar – Table 2.

Table 2.

| tau | u | v | w | скорост |
|---|---|---|---|---|
| 1 | -0.3 | -0.2 | 0.86 | 0.932523 |
| 2 | -0.7 | 0.28 | -0.3 | 0.811419 |
| 3 | -1.18 | 0.96 | 0.68 | 1.666253 |
| 4 | -0.8 | 0.48 | 0.58 | 1.098544 |
| 5 | 0.68 | 0.08 | 0.48 | 0.836182 |

## Velocity field visualization

### *2D Visualization*

The 2D visualization requires selection of surface in which velocity field needs to be drawn - XY, XZ or YZ. To do so additional transformations of measured data are fulfilled. The purpose of these transformations is to locate each vector direction, value and azimuth angle. As stated above, the planes for visualization and data required for each of them are:

- for plane XY – U and V
- for plane XZ –U and W
- for plane YZ – V and W).

The approach for each plane is similar to the one presented hereafter for plane XY. Vector's scalar mXY is:

$$mXY= \sqrt{U^2+V^2} \quad ,m/s \qquad (1)$$

The azimuth angle is defined depending on the vector position, bearing in mind that the anemometer measures the direction from where the wind flows, while the picture should visualize the direction of the vector. Following the structure given in Table 1, the value of U follows the East-West direction, while the value of V follows the direction Nord-South. Which means that if U<0 and V<0, the azimuth angle is in I[st] quadrant, i.e. $0^\circ < \theta < 90^\circ$. The azimuth angles *θ*, representing the values of U and V are defined in the following way:

- if U<0 and V<0 $an = \theta = \arctan|U/V|$ - angle is in I[st] quadrant;
- if U<0 and V>0 $an = \theta = 180 - \arctan|U/V|$ - angle is in II[nd] quadrant;
- if – U>0 and V>0 $an = \theta = 180 + \arctan|U/V|$ angle is in III[rd] quadrant;
- if U>0 и V<0 $an = \theta = 360 - \arctan|U/V|$ - angle is in IV[th] quadrant.

The velocity vectors on other planes are drawn in similar way, changing measured data for V and W (YZ) and for U and W (XZ) respectively.

Table 3 shows an EXCEL file, which is used by the software applied by authors to draw the velocity field.

Table 3.

| x | y | z | u- dx | v-dy | w-dz | V-xy | angle |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | -0.3 | -0.2 | 0.86 | 0.36 | 56.31 |
| 2 | 0 | 0 | -0.7 | 0.28 | -0.3 | 0.75 | 111.80 |
| 4 | 0 | 0 | -1.18 | 0.96 | 0.68 | 1.52 | 129.13 |
| 0 | 2 | 0 | -0.8 | 0.48 | 0.58 | 0.93 | 120.96 |
| 2 | 2 | 0 | 0.68 | 0.08 | 0.48 | 0.68 | 263.29 |
| 4 | 2 | 0 | 0.08 | 0.78 | 0.18 | 0.78 | 185.86 |
| 0 | 4 | 0 | 0.28 | 0.48 | 0.38 | 0.56 | 210.26 |
| 2 | 4 | 0 | -0.1 | -0.6 | 0.18 | 0.61 | 9.46 |
| 4 | 4 | 0 | 0.28 | 0.38 | -0.1 | 0.47 | 216.38 |
| 0 | 6 | 0 | 0.38 | 0.58 | 0.58 | 0.69 | 213.23 |
| 2 | 6 | 0 | -0.2 | 0.86 | 1.06 | 0.88 | 166.91 |
| 4 | 6 | 0 | 0.38 | 0.68 | 0.6 | 0.78 | 209.20 |

Visualization, after the above presented modification (Tabl.3) of measured data, is presented by Grapher and Surfer. Both ways are discussed below. Grapher software makes 2d and 3D visualization without interpolation between measuring points – i.e. it only registers the measurement. Surfer software makes interpolation between measured points and its velocity field is more fluent, but it can make only 2D plots. Very useful product of the same company (Golden Software) is Voxler, which creates 3D grid and surface diagram of isolines of equal velocities.

### *Visualization with GRAPHER*

Fig. 6b shows 12 vectors in the XY plane, achieved by the data transformation shown in Table 3. Starting from the point of origin (X,Y), then taking into account angle (an) and scalar value mXY, vectors are drawn in the plane with size, representing measured area. Parts of GRAPHER's properties are shown in Fig. 6a, while the diagram itself – in Fig 6b.

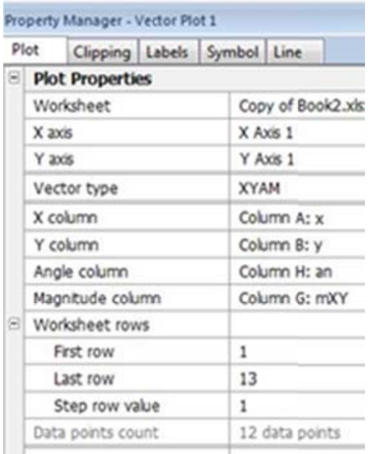


Fig. 6a. Golden Software Grapher properties

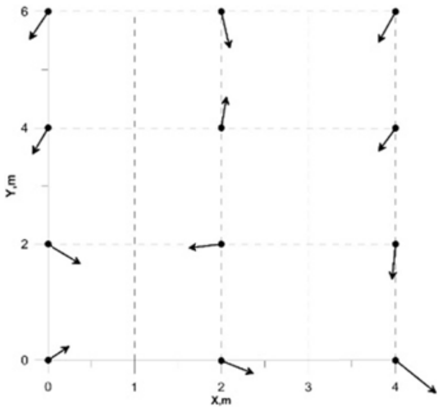


Fig. 6b. Golden Software Grapher plot of 12 vectors

### Visualization with SURFER

This software generates 2D velocity field by interpolation between measured single vectors in a chosen plane (XY, YZ or XZ). If selecting „2 – Grid Vector Map" from the program menu two interpolation grid files with extension GDR are created. First of them holds information about the initial coordinates of the vector in the plane (XY) and the azimuth angle, while the second one contains the coordinates and scalars. The two files are created sequentially by „Surfer", taking as an input file the one, shown in Table 3. Fig. 7a shows part of the positions in Surfer, while Fig 7b shows the velocity field in the XY plane.

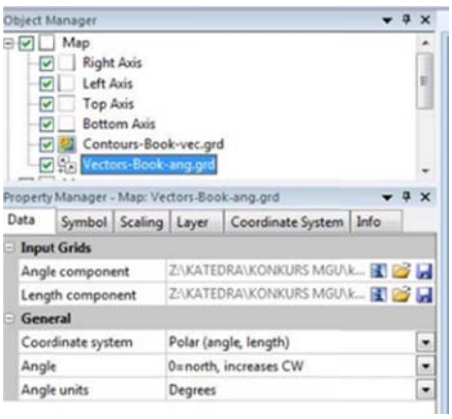


Fig. 7a. Golden Software Surfer Object Manager screen

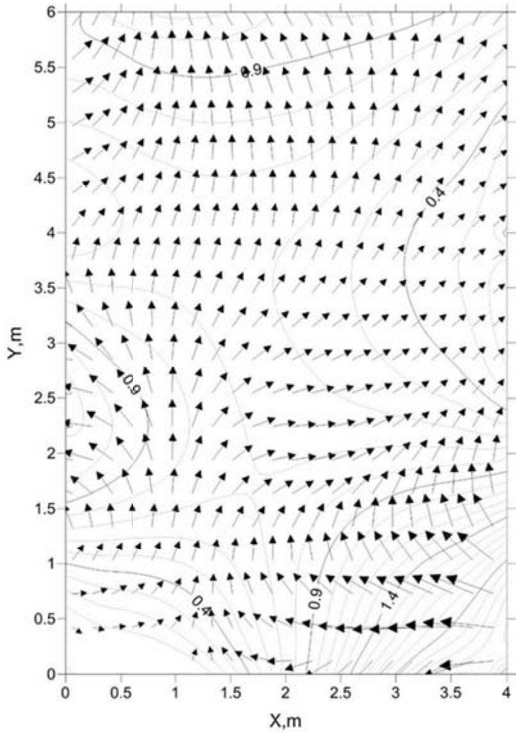


Fig. 7b. Golden Software Surfer velocity field plot in the XY plane

### 3D Visualization with GRAPHER

3D visualization with "Grapher" is performed by using the function "XYZ vector plot". The diagram may be in two different views according to the available data:

- absolute coordinates given by the GPS device of origin point of vectors (X, Y, Z) in the measured region and vector projections on three axes (dx, dy, dz) or relative coordinates given by the user when the GPS is switched off;
- evaluation of vector's end (X2, Y2, Z2) coordinates based on vector's origin (X1, Y1, Z1) and azimuth angle. This approach is complicated, because it requires numerous mathematical transformations, but when the location is important it may be used for special purposes.

Fig. 8a shows part of the Grapher parameters used in function "XYZ Vector Plot", while Fig 8b – the 3D velocity field.

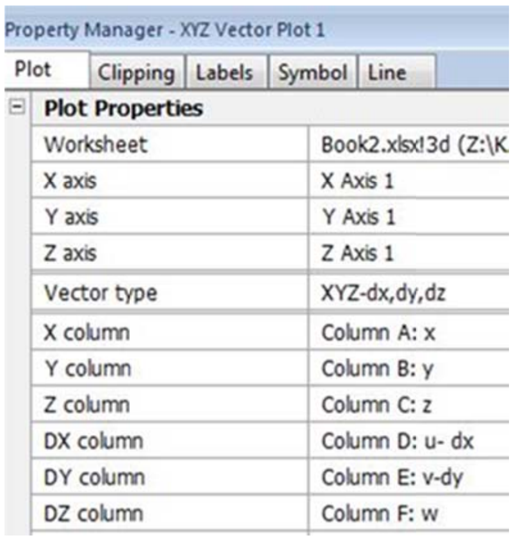


Fig. 8a. Golden Software Grapher XYZ vector plot settings

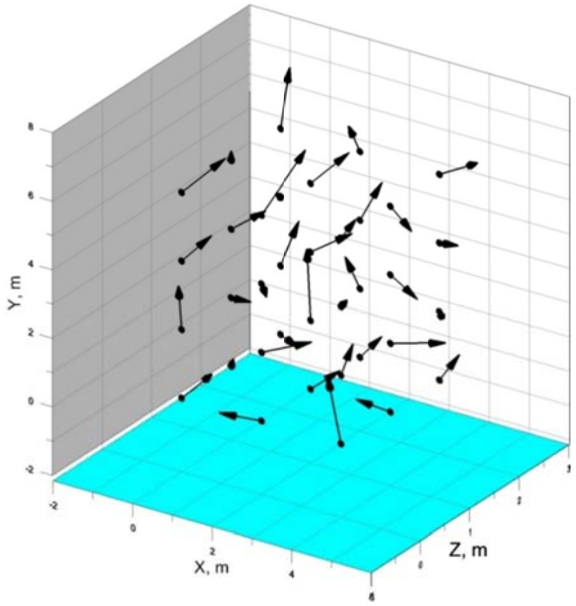


**Fig. 8b. Golden Software Grapher 3D velocity field plot**

### *3D Visualization with MATLAB*

A 3D data visualization can be performed with the aid of the MathWorks Matlab matrix laboratory mathematical package. This visualization is performed by Matlab's function "quiver3" with the following syntax:

```
quiver3(x,y,z,u,v,w)
quiver3(z,u,v,w)
quiver3(...,scale)
quiver3(...,LineSpec)
quiver3(...,LineSpec,'filled')
quiver3(...,'PropertyName',PropertyValue,...)
quiver3(ax,...)
h = quiver3(...)
```

A velocity field plot obtained by using the "quiver3" function is shown on Fig. 9.

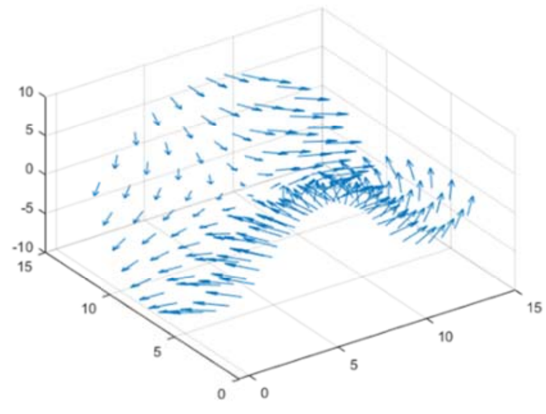

**Fig. 9. Velocity field plot obtained by using the 'quiver3' function**

## In situ experiment

Fig. 10 shows the experimental measurement setup, which is performed in a restricted space with dimensions: L= 30 m, W= 2,7 m. An axial fan, located 10 meters away from measurement points, is connected to a flexible duct. The 3D anemometer is consecutively located into 20 points, at three levels:

- $Z_0$=1.1 m below center axis of the pipeline;
- $Z_1$=1.55 m along the center axis of the pipeline;
- $Z_2$=1.8 m above the center axis of the pipeline.

The points create a regular mesh in rows and columns. The space between the points in a row is 0.54 m, while the row to row distance is 2 m.

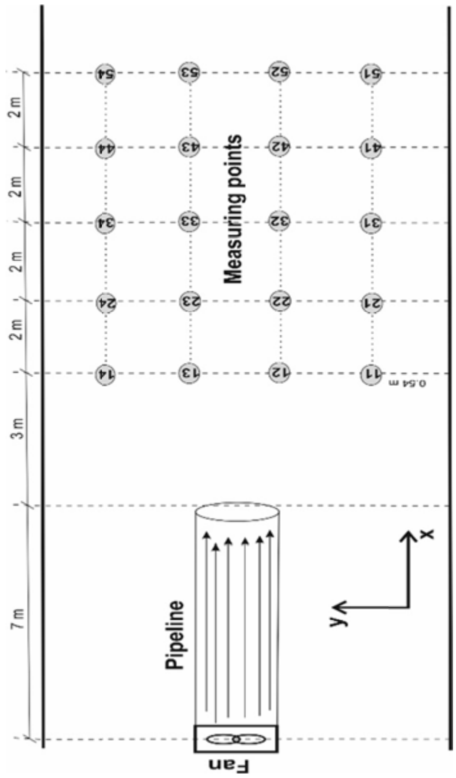


**Fig. 10. The experimental measurement setup**

As the anemometer measures 32 values per second, the measurement in each point has a duration of 1 min and data is saved into a file with a unique name. The results of the measurements are saved into 20x3=60 data files. Then, following the methodology explained above, velocity vectors in each point can be evaluated and different visualizations can be performed.

Fig. 11 shows the XY velocity vectors and lines of equal velocities for two elevations:

- for Z=1.1 m on fig. 11a;
- for Z=1.55 m on fig. 11b.

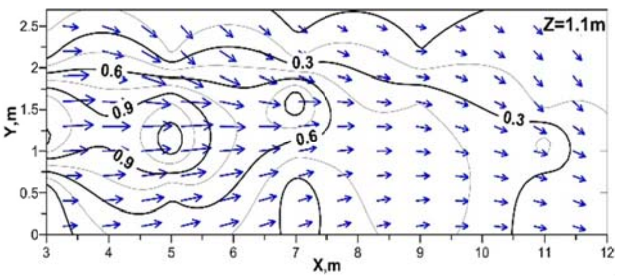


**Fig. 11a. The XY velocity vectors and the isolines for Z=1.1[m]**

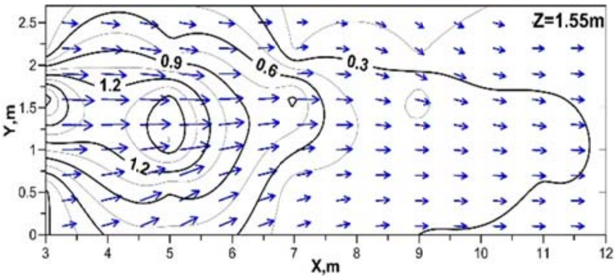


**Fig. 11b. The XY velocity vectors and the isolines for Z=1.55[m]**

The elevation Z=1.55 m is in plane, parallel to the main flow current from the pipeline. There velocities are higher, compared to Figure 11a. They are within a range of 1.2 m/s to 0.3 m/s, while on the lower level maximum velocity is 0.9 m/s. Another interesting point is that at the lower level wall the effect is bigger and can be observed in Fig. 11a.

Fig. 12 shows velocity field with vectors and scalars in plane XZ for two Y locations:

- For Y=1.1 m in fig 12a – i.e. in the middle of the space in Y direction;
- For Y=0.54 m on fig 12b – close to the wall.

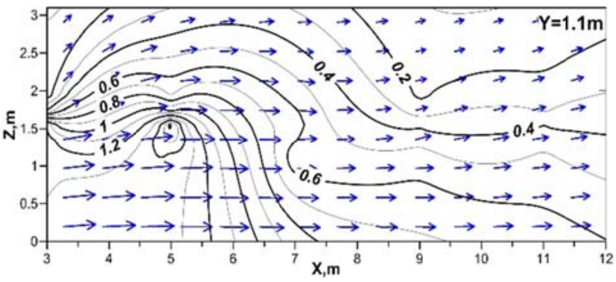


**Fig. 12a. The XZ velocity vectors and the isolines for Y=1.1[m]**

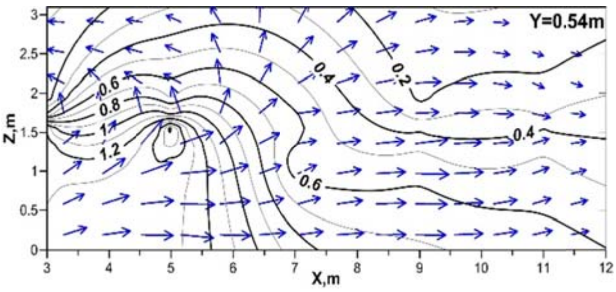


**Fig. 12b. The XZ velocity vectors and the isolines for Y=0.54[m]**

The wall effect is perfectly observed in Fig. 12b, leading to recirculation of the current. In Fig. 12a one can notice well developed flow in the middle of the area with minimum fluctuations toward walls and nearly missing recirculation.

## Conclusion

The 3D anemometer, being a modern measuring device, is capable of collecting great amounts of data when performing flow velocity measurements. However, its ability to measure so many values – 32 measurement per second, raise the necessity of special data treatment in order to present the measured velocity field in practically applicable view. This paper shows several approaches which can be applied.

In general, measurements with 3D anemometer have several very practical applications:

- point measurement may serve as a tool to define coefficient of turbulence;
- as seen from Figures 11 and 12, wall effect can be seen and also the recirculation along it;
- it is also highly important to see how far from the end of a pipeline, the influence of the fan can take place.

All that directions will be explored in future work.

## Acknowledgements

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