Air Navigation Systems Department
National Aviation University

Unmanned Aerial Vehicle Positioning by data from Pocket Device Sensors

EIZHENA PROTSENKO
MYKYTA RUDENKO
IVAN OSTROUMOV

2019 IEEE
5TH INTERNATIONAL CONFERENCE
ACTUAL PROBLEMS OF UNMANNED AERIAL VEHICLES DEVELOPMENT (APUAVD-2019)
OCTOBER 22-24, 2019
KYIV, UKRAINE

CONTENT

- Methods of UAV Positioning
- Personal Pocket Devices (PPD)
- Research tasks
- Inertial navigation by PPD
- Error filtering
- Data exchange level
- Numerical demonstration
- Conclusion

METHODS OF UAV POSITIONING

- GNSS (GPS, GALILEO, GLONASS, Beidow)
  - the effect of different factors such as ionospheric and tropospheric errors ,the interference of radio waves or unintentional jamming of signals may degrade the performance of positioning at some particular part of airspace or may totally lock positioning system.
- INS (AHRS)
  - as disadvantage of inertial navigation we can consider additive error behavior.
- Positioning by a ground-based network of beacons (DME, VOR, ADF)
  - significant weight and size of sensors make impossible implementation of this positioning technique for small fly object.

PERSONAL POCKET DEVICES (PPD)

People are already used to the fact that gadgets have become an integral part of their lives. We constantly use devices that make our life easier and better. Common examples of the PPD are smartphones, tablets, watches, bracelets, glasses, and others.

SENSORS OF PPD

- Accelerometers

  (acceleration by X,Y, Z axes)

- Gyroscopes

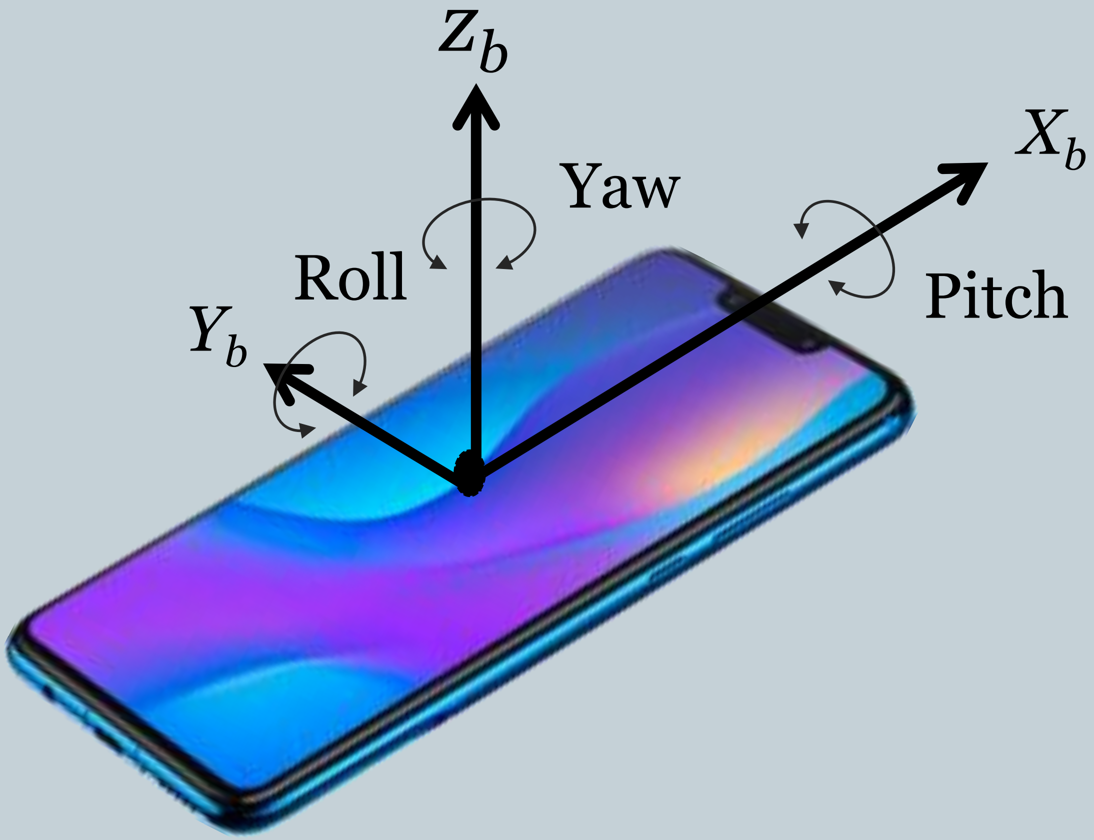
  (pitch, roll and yaw velocities, and angles)

- Magnetometers

  (intensity of magnetic field)

BODY COORDINATE SYSTEM

(ANDROID)

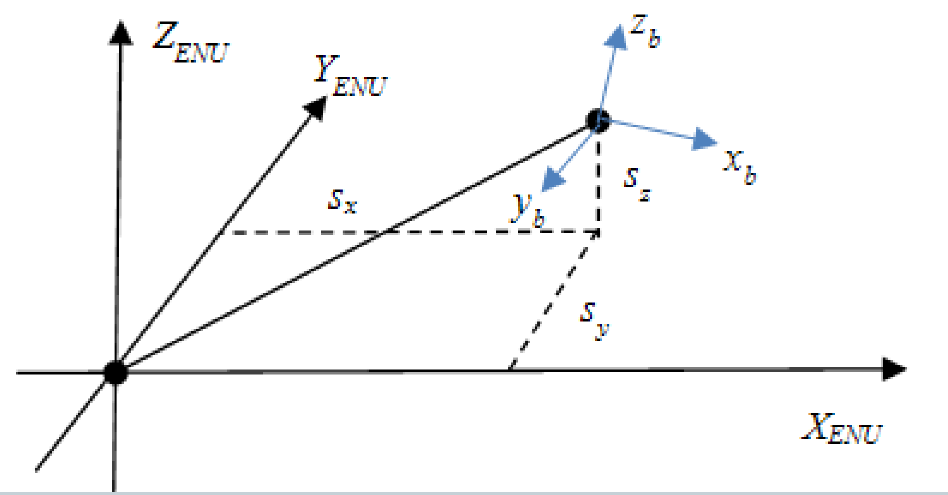


RESEARCH TASKS

We consider:

- application of the main personal pocket device sensors for UAV positioning.
- to use Alfa/Beta/Gamma filter in the form of Kalman filter for UAV coordinates filtering in order to improve accuracy of positioning.
- remote data processing
- *autopilot system in PPD (future work).*

INERTIAL NAVIGATION BY PPD



$$S(t_i) = \Delta t V_{ENU}(t_i) + + \frac{\Delta t^2}{2} A_{ENU}(t_i),$$

where $A_{ENU}=[a_x, a_y, a_z]$ is a matrix of accelerations by the axis of the reference frame;
$V_{ENU}=[v_x, v_y, v_z]$ is a matrix of velocities;
$\Delta t = t_i - t_{i-1}$ is a discretization time.

$$X_{ENU}(t_i) = X_{ENU}(t_{i-1}) + \Delta t V_{ENU}(t_i) + + \frac{\Delta t^2}{2} A_{ENU}(t_i),$$

where $X_{ENU}(t_{i-1})$ and $X_{ENU}(t_i)$ are coordinates of object location at previous and current iteration correspondently.

INERTIAL NAVIGATION BY PPD

$$A_{ENU}=TA_b\ ,$$

$$T =$$

$$\begin{bmatrix} \sin\psi\cos\theta & \cos\varphi\cos\psi+\sin\varphi\sin\psi\sin\theta & -\sin\varphi\cos\psi+\cos\varphi\sin\psi\sin\theta \\ \cos\psi\cos\theta & -\cos\varphi\sin\psi+\sin\varphi\cos\psi\sin\theta & \sin\varphi\cos\psi+\cos\varphi\cos\psi\sin\theta \\ \sin\theta & -\sin\varphi\cos\theta & -\cos\varphi\cos\theta \end{bmatrix}$$

where

A_b is a matrix of acceleration in the body reference frame;

T is a transformation matrix;

ψ is a yaw angle;

φ is a roll angle;

θ is a pitch angle.

ERROR FILTERING

The idea of error filtering is grounded on applying an object model and statistical analysis of measurements in order to predict investigated parameter value at time of the next measurement. Next measured and predicted values are used in filtering.

We consider usage of **α-β-γ** filter in the form of linear **Kalman** filter to reduce noise in distance and angle measurements.

$$X_i=\Phi_{i-1}X_{i-1}+w_{i-1}$$

where $\boldsymbol{X_i}$ is a state matrix at time t_i; $\boldsymbol{\Phi_{i-1}}$ is a transformation matrix from previous state i-1 to current state i; $\boldsymbol{w_{i-1}}$ is noise.

The state matrix $\boldsymbol{X_i=[x_i,v_i,a_i]^T}$ includes smoothed parameter $\boldsymbol{x_i}$, value of velocity $\boldsymbol{v_i}$, and acceleration $\boldsymbol{a_i}$. Also, we suppose that measurements are linearly connected with system state by the following model:

$$z_i=H_iX_i+v_i$$

where $\boldsymbol{H}$ is sensitivity matrix of measurement; $\boldsymbol{v_i}$ is an error of measurement.

We consider sensitivity matrix in the form: $\boldsymbol{H=[1,0,0]}$**,** because we measure $\boldsymbol{x_i}$ value and estimate velocity and acceleration.

ERROR FILTERING

The extrapolated system state can be obtained as follows:

$$X^e_i = \Phi_{i-1} X_{i-1},$$

$$\Phi = \begin{bmatrix} 1 & T & \frac{1}{2}T^2 \\ 0 & 1 & T \\ 0 & 0 & 1 \end{bmatrix}$$

where

$T=t_i-t_{i-1}$ is a time difference between measurements;

$X_{i-1}=[x_{i-1}, v_{i-1}, a_{i-1}]^T$ is a state matrix at time t_{i-1}.

A covariance error matrix of extrapolation is:

$$P^e_i = \Phi_{i-1} P_{i-1} \Phi^T_{i-1} + Q_{i-1},$$

$$P_{i-1} = diag([\sigma^2_x, \sigma^2_v, \sigma^2_a]),$$

where σ^2_x, σ^2_v and σ^2_a are dispersion of x, v and a estimation; Q_{i-1} is an intensity matrix of noise.

A state estimate observation update can be obtained as follows:

$$X_i = X^e_i + K_i[z_i - H X^e_i],$$

$$K_i = \begin{bmatrix} \alpha & \frac{\beta}{T} & \frac{2\gamma}{T^2} \end{bmatrix}^T$$

where K is Kalman gain matrix.

An updated covariance error matrix is :

$$P_i=[I-K_iH]P^e_i,$$

where I is ones matrix.

COEFFICIENTS OF α, β, γ

$\alpha=1-r^2$

$$\beta = 2(2-\alpha) - \sqrt[4]{1-\alpha},$$

$$\gamma = \frac{\beta^2}{2\alpha}$$

Damping coefficient:

$$r = \frac{(4+\Lambda) - \sqrt{(8\Lambda + \Lambda^2)}}{4}$$

Tracking index

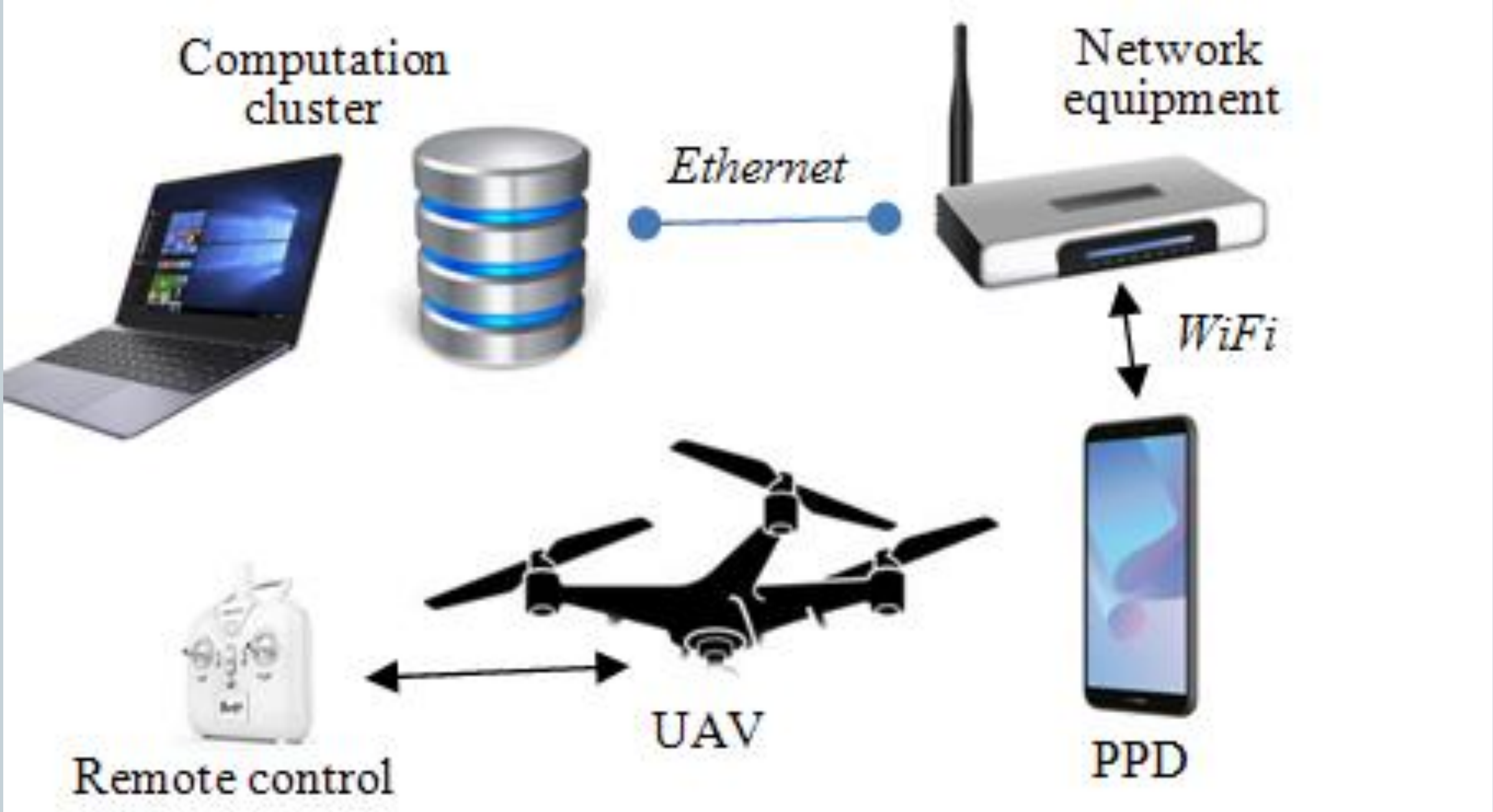
$$\Lambda = \frac{T^2 \sigma_g}{\sigma_x}$$

where σ_g *is* guidance error; σ_x *is* error of measurement.

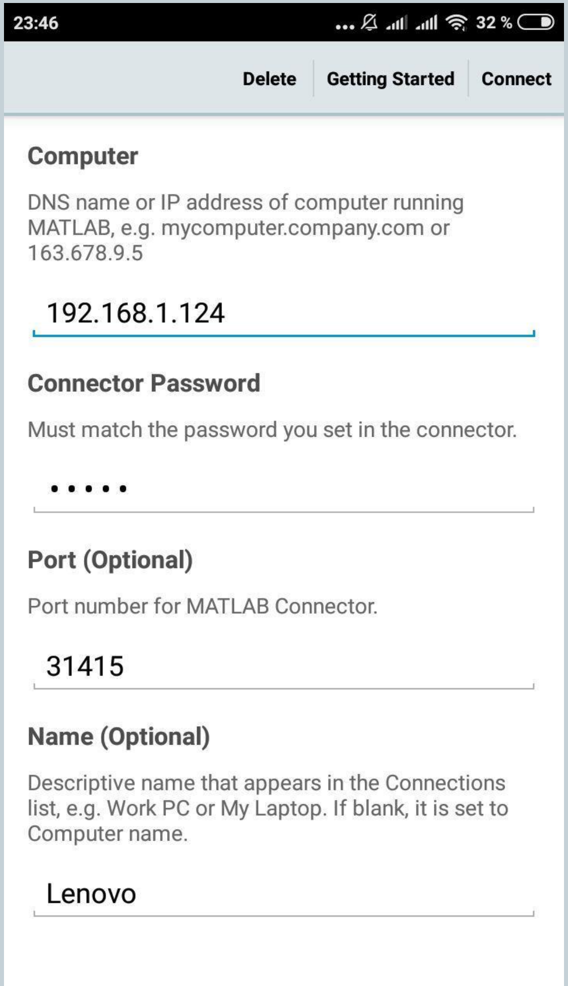
T. Jeong, A. W. Njonjo, and B. F. Pan. "A study on the performance comparison of three optimal Alpha-Beta-Gamma filters and Alpha-Beta-Gamma-Eta filter for a high dynamic target," TransNav: International Journal on Marine Navigation and Safety of Sea Transportation, vol. 11, issue 1, March 2017, pp.55–61.

L. Ting-En, J. Su, K. Yu, and K. Hsia, "Design of Adaptive Alpha-Beta-Gamma Filters with Fuzzy Systems." in The 17th National Conference on Fuzzy Theory and Its Applications, pp. 910-915, 2009.

DATA EXCHANGE LEVEL



MATLAB MOBILE



Computer

DNS name or IP address of computer running MATLAB, e.g. mycomputer.company.com or 163.678.9.5

192.168.1.124

Connector Password

Must match the password you set in the connector.

•••••

Port (Optional)

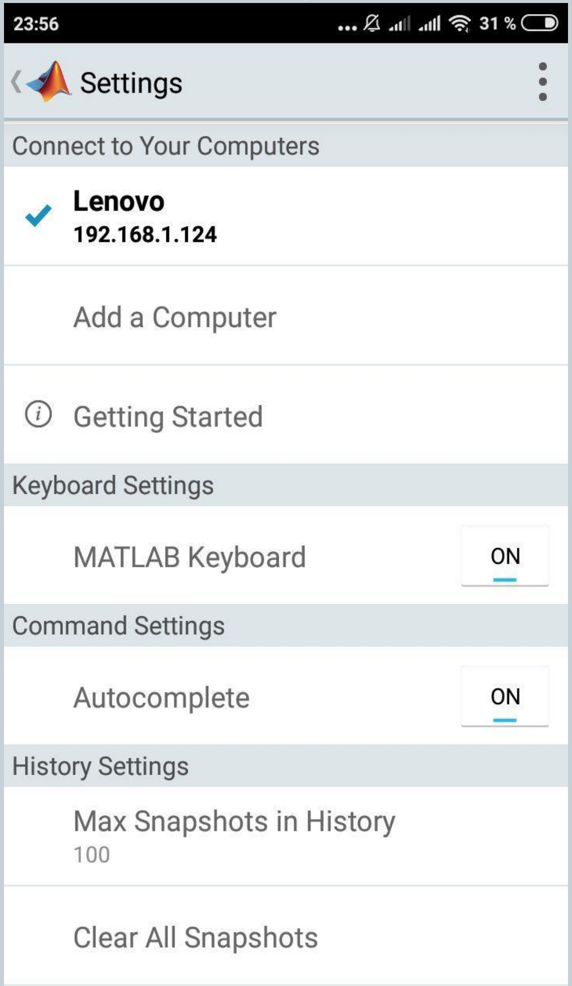
Port number for MATLAB Connector.

31415

Name (Optional)

Descriptive name that appears in the Connections list, e.g. Work PC or My Laptop. If blank, it is set to Computer name.

Lenovo



Connect to Your Computers

✓ **Lenovo**
192.168.1.124

Add a Computer

ⓘ Getting Started

Keyboard Settings

MATLAB Keyboard ON

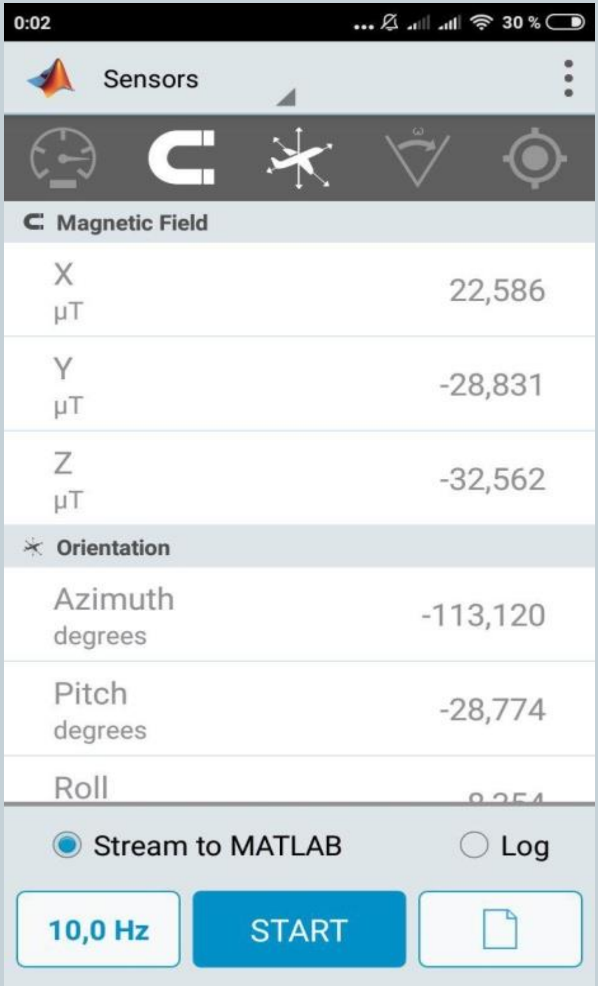
Command Settings

Autocomplete ON

History Settings

Max Snapshots in History
100

Clear All Snapshots



Magnetic Field

X μT	22,586
Y μT	-28,831
Z μT	-32,562

Orientation

Azimuth degrees	-113,120
Pitch degrees	-28,774
Roll	

● Stream to MATLAB ○ Log

NUMERICAL DEMONSTRATION

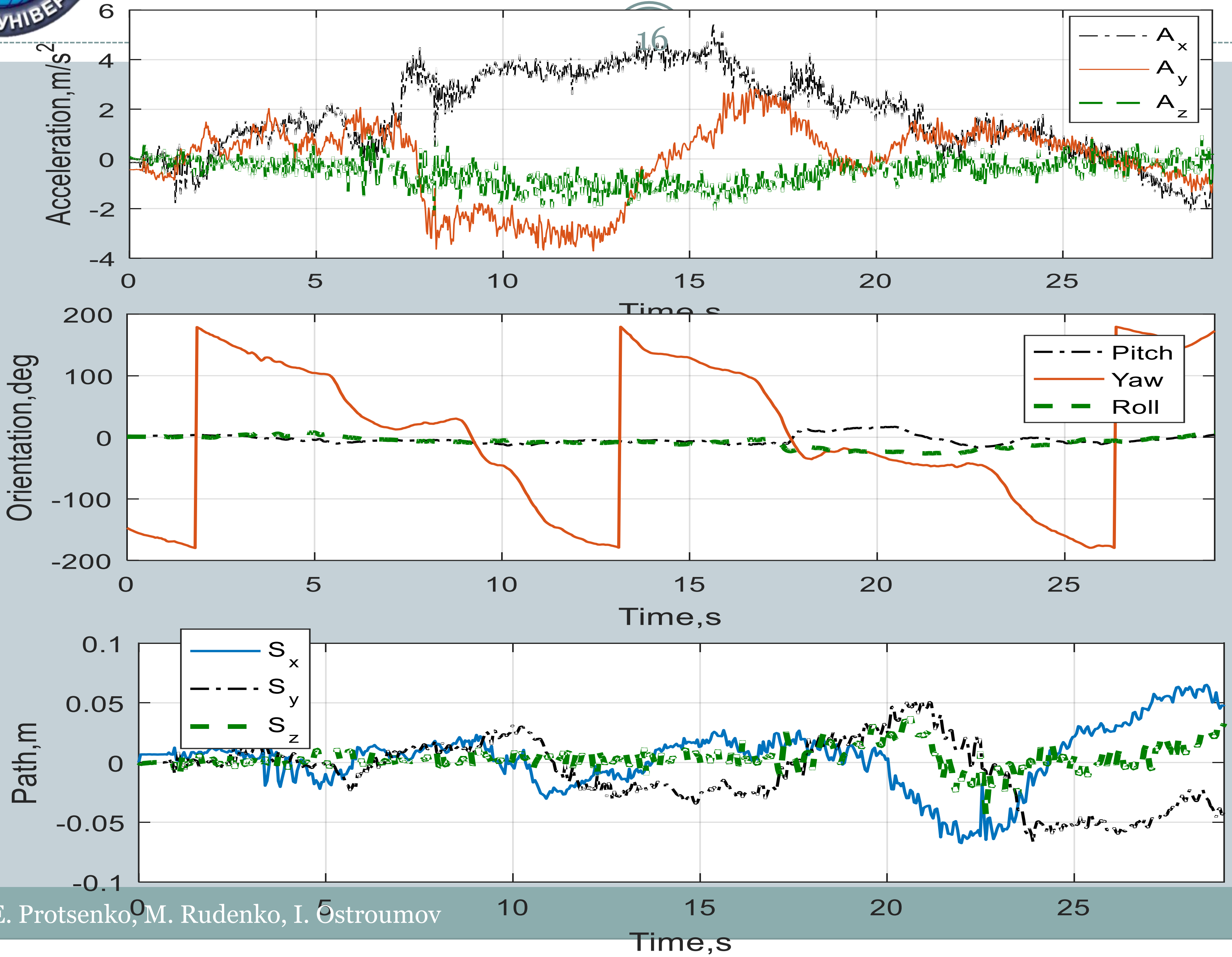
Quadrocopter “CTW A6” commercially available for imaging and filming production.

Smartphone “Xiaomi redmi 4x” (MIUI 10.3, Android 7.1.2) as a PPD.

Computation cluster at laptop “Lenovo G580” (i3-2328M CPU 2.20 GHz, 4GB RAM).

WiFi line was used for PPD connection to the network and wire Ethernet line for connection with laptop.

NUMERICAL DEMONSTRATION



NUMERICAL DEMONSTRATION

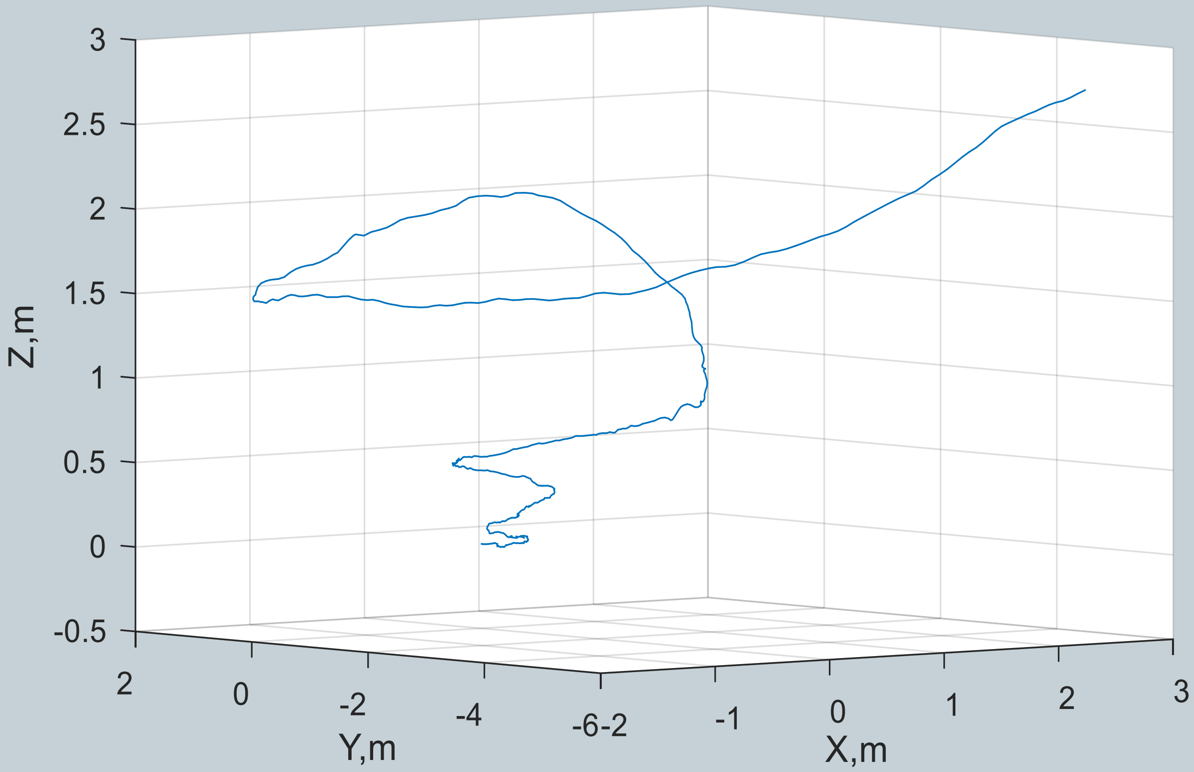


Fig. Filtered UAV trajectory in ENU reference frame

CONCLUSION

In our research, we analyze possibility to implement PPD in UAV application. In common way, PPD is equipped with various sensors. Moreover, at software level it is easy to get sensor data to provide positioning in airspace. Coordinates of UAV are estimated in ENU reference frame by inertial navigation relations. Unfortunately, errors of measurements degrade positioning accuracy progressively in time. Therefore, usage of inertial navigation is limited in time according to required performance level. Thus, considered approach may be implemented as a stand-by technique in case of GNSS lock. At upper level of trajectory data processing we use α-β-γ filter in the form of linear Kalman filter to reduce noise. Implementation of α-β-γ filter indicates optimal noice filtering for UAV with dynamic characteristics. In our future research we are going to consider group UAVs navigation with a set of various PPDs.