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Multisensor data fusion using Elman neural networks

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ABSTRACT

The paper presents a navigation system based on Elman Artificial Neural Network (ANN). The task of data fusion from different sensors is realized by trained ANN. Determining position in space is an issue of nonlinear hence. Not every type of ANN is used for such a task. Choice of Elman ANN was dictated by its construction and successfully applications to nonlinear problems requiring prediction. Elman network is composed of three layers. Comprises a layer of hidden layer units context which is connected to the hidden layer. Context-sensitive layer allows for store the values of previous hidden units. With this layer prediction is possible in sequential order. This is the effect of contextual memory where information is stored about what it was before. This kind of functionality is not able to provide any other standard neural network unidirectional. The system consists of MEMS (Micro Electro-Mechanical Systems) sensors, which are based on IMU (Inertial Measurement Unit). IMU is composed from gyroscopes, accelerometers and magnetometers which provide three dimensional linear accelerations and angular rates. This is a classic set of sensors for determining the position in space. The study presents the results of the implementation of algorithms for determining the position in space using trained Elman ANN. The data samples to train ANN were collected during the test flight of Quadrocopter. Paper presents the performance for different configurations of Elman ANN. Presented system provides easy addition of other sensors e.g. GPS/GLONASS receiver.

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1. Introduction

The precise location in space plays an important role in many fields such as robotics [1,2], navigation [3,4], human motion analysis [5] and human-machine interface [6]. The sensors are used to accurately map the movement of the object in space. However, the sensors are not universal and not each of them is suitable for every task. Often, multiple sensors are used to measure various physical values such as: linear acceleration, angular acceleration and the magnetic field. Data collected from these sensors must be combined in order to obtain complete information on the position of the object in space.

Most of the values used in determining the position are expressed by a vector. The position is defined as a displacement between the two coordinate systems. The first one can be the ground or the starting point of the sensor calibration. The second one is the navigation object e.g. quadrocopter. Variables such as direction, speed, acceleration and movements can be easily calculated from based on the change of position [7,8]. Such calculations are performed as multiplying the vector representing the position of one coordinate system to another by a 3×3 rotation matrix. This representation is referred to

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as a representation of direction cosines or DCM (Direction Cosine Matrices). The conversion of the angular position between the Euler angles and DCM representation given by the rotation Matrix R

$$R = \begin{bmatrix} \cos\theta\cos\psi & \sin\phi\sin\theta\cos\psi - \cos\phi\sin\psi & \cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi \\ \cos\theta\sin\psi & \sin\phi\sin\theta\sin\psi + \cos\phi\cos\psi & \cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi \\ -\sin\theta & \sin\phi\cos\theta & \cos\phi\cos\theta \end{bmatrix} \tag{1}$$

where:

ϕ - Roll; θ - Pitch; ψ - Yaw.

Another, often used method to define position of the object in space is to use a quaternion math. Quaternion is a four-dimensional complex number that can be used to represent the orientation of a rigid body or coordinate frame in three-dimensional space.

Data connections are made by using mathematical transformations describing the position in space using quaternions. Quaternion q can be written in the following form:

$$q = q_0 + iq_1 + jq_2 + kq_3 = (q_0, q_1, q_2, q_3) \tag{2}$$

$$i = \begin{bmatrix} i & 0 \\ 0 & -i \end{bmatrix} \quad j = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} \quad k = \begin{bmatrix} 0 & i \\ i & 0 \end{bmatrix} \tag{3}$$

where:

i, j, k are special quaternion matrixes, q_0, q_1, q_2 are the vector components, q_3 is the scalar component of the quaternion, and:

$$\begin{aligned} q_0 &= e_x \sin\left(\frac{\vartheta}{2}\right) \quad & q_1 &= e_y \sin\left(\frac{\vartheta}{2}\right) \\ q_2 &= e_z \sin\left(\frac{\vartheta}{2}\right) & q_3 &= \cos\left(\frac{\vartheta}{2}\right) \end{aligned} \tag{4}$$

where:

e_x, e_y, e_z are the principal axis ϑ is the principal angle.

Transforming the quaternion to the Euler representation of angles is simple and is done with the following formulas:

$$\phi = \tan^{-1}\left(\frac{2(q_1q_2 + q_0q_3)}{q_3^2 - q_2^2 - q_1^2 + q_0^2}\right) \tag{5}$$

$$\theta = \sin^{-1}\left(-2(q_0q_2 + q_1q_3)\right) \tag{6}$$

$$\psi = \tan^{-1}\left(\frac{2(q_0q_1 + q_3q_2)}{q_3^2 - q_2^2 - q_1^2 + q_0^2}\right) \tag{7}$$

2. Multisensor data fusion

To train the ANN we used Euler angles calculated with the AHRS algorithm. Designed ANN has nine inputs representing the various axes of each of the sensors, while at the output there are three signals corresponding to the description of the position in space of Euler angles (Roll, Pitch, Yaw).

To record samples from the sensors we have built a special equipment showed in Fig. 1. We used Atmel IMU module ATAVRSBIN1 features a three-axis accelerometer, three-axis gyroscope and three-axis magnetometer. To read and store the data we used development board STM32F4-Discovery.

The connections between components have been implemented using custom PCB containing an additional power block, communication via Bluetooth and SD card slot. Samples from the accelerometer and gyro were recorded at a frequency of 50 Hz while frequency of magnetometer was 10 Hz. Collected data was recorded on SD Card, then ripped to a PC where all data were processed with use MATLAB environment.

Attitude Heading and Reference Systems are able to provide a complete measurement of orientation relatively to the direction of gravity and the Earth's magnetic field. An orientation estimation algorithm is a fundamental component of any IMU system. It is required to join together the separate sensor data into a single, optimal estimation of orientation.

Typical sensors used to form an AHRS are accelerometers to measure the proper acceleration along the three axes of the UAV body coordinate, gyroscopes to provide the three-axis angular rates and magnetometers to capture the magnet values of the three axes (Fig. 2) [9,10].

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