ADVANCED DISPLAY AND POSITION ANGLES MEASUREMENT SYSTEMS

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Abstract

In this article we introduce a patented and a completely new concept of airplane orientation angles measurement system which is furthermore referred as a pressure reference system. The authors also propose an arrangement of a magnetometer unit with multiple sensors that perform online calibration of hard iron and soft iron distortions. These systems are mutually connected to a WiFi network with other modules, head-down and head-up displays. There is also description of common avionics system units and sensors and their relation to the new proposed system.

General aviation accounts for about 77 percent of the total flight hours while the rest are routinely scheduled flights. General aviation operations range from short-distance flights in single engine light aircraft to long-distance international flights in private jets, aero-medical operations and flying for fun. Electronics onboard of the airplane nowadays costs around one third of the airplane total price which vary with the precision and capabilities of the electronics system. Demand for the more precise but low-cost navigation which could improve some safety issues is being solved by data fusion of different sets of low-cost micro-mechanical sensors. Mainly signals provided by global position system and triads of inertial measurement sensors are being investigated and tightly coupled. This combination is capable to provide position of the airplane and its orientation angles. This article presents a new system that provides new information about orientation angles which can be used within data fusion algorithms to increase precision of the displayed information.

1 Avionics System

General aviation airplanes [1] include wide variety of types whose mechanical and electronic systems (avionics) [2][3] are designed according to their intended use with regard to ambient conditions [4]. The systems are divided according to visual meteorological conditions (VMC) and instruments meteorological conditions (IMC) capable avionics which differs mainly in presence of an attitude indicator that provides information about horizon. The simplest avionics system is composed from mechanical instruments that are old, hard to interface with other systems, but reliable. The amount of electronics that is incorporated in the instrument allows us to divide instruments into the following maturity types:

- Type 1: mechanical or simple electromechanical instruments, e.g. rotating gyroscope based attitude indicator or a volt meter used to indicate exhaust gas temperatures.
- Type 2: simple electronic instruments with a digital information display, e.g. an altimeter with numerical output.
- Type 3: advanced display system with embedded graphic computer

Because type 1 instruments are long time available on the market they are also reliable, but difficult to manufacture and calibrate. Type 2 instruments provide just simple numerical information which is not ergonomically optimized, e.g. it takes time to interpret the displayed value and its changes [5]. The disadvantage of type 3 is the difficulty of their certification process but manufacturers and mainly users like the possibility to extend functionality of the system.

General aviation airplanes use all the three instrument maturity types. In modern installations, types 1 and 2 are used as a backup instruments and type 3 as the main source of information that combines engine, flight and navigation data. The latest development effort is aimed to add a smart guidance or a virtual assistant to these systems in order to improve flight safety [6][7][8][9][10].

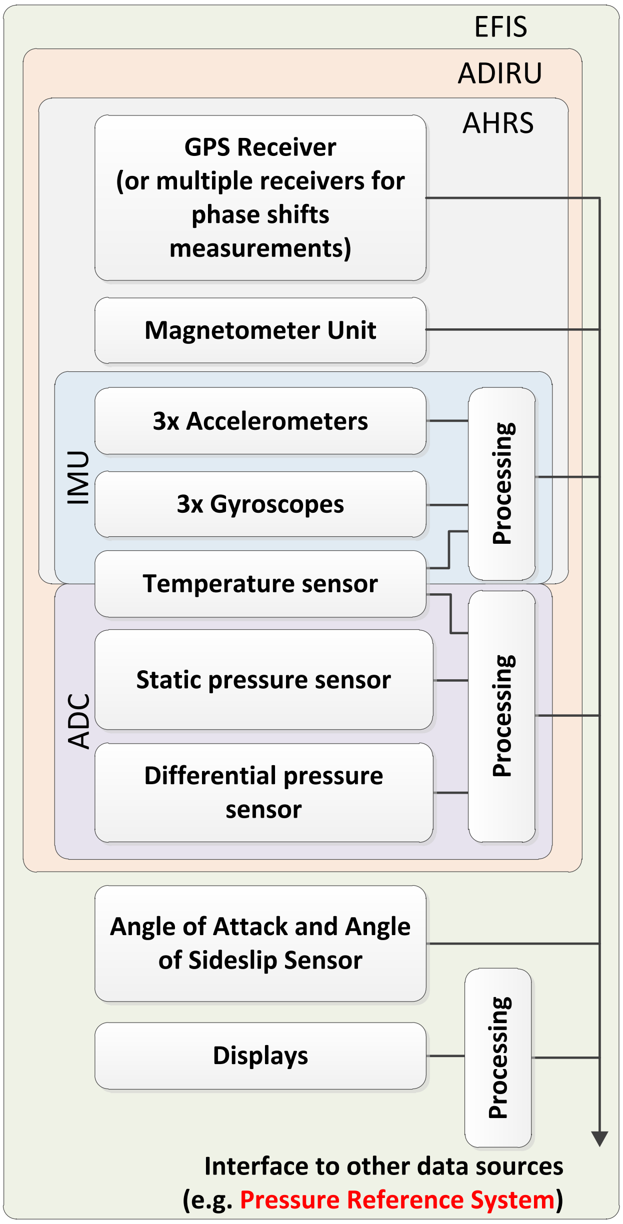

Fig. 1. Avionics System Sensors with Possibility to Interface Other Data Sources

1.1 Sensors and Systems

Reliable information [11] is necessary for safe airplane guidance during flight time and also during taxiing [12]. There are different principles being used that measures ambient environment around the airplane, its motion changes [13] and receives signals from different sources [14]. Pilots interact with dashboard gauges and control items. The past systems used independent data sources and display instruments. With electronics advancements the independent systems became replaceable electronic blocks that are able to distribute data [15] to other systems [16]. This concept is known as federated avionics and the blocks are called Line Replaceable Units (LRU).

The latest development of the modern avionic systems integrates all the sensors and processing modules into a network that allows data sharing [17]. Task of the LRUs, which contains electronics and software, has changed. In the new concept software functions performs tasks which were intended for single LRUs before. This approach is called Integrated Modular Avionics which is used mainly on brand new airliners. With rapidly increasing infrastructure available onboard of the airplane there arise new problems with safety [18][19] which were not present before and for which there are no certification guidelines.

The certification process [4][18] also changes with changing approaches for avionics development [20]. In the area of flying for fun airplanes, the development of avionics system is the most progressive because there is no demand for time consuming and costly certification. The avionics development for these airplanes is driven mainly by customer demand.

There are multiple systems commercially available for very low prices. The low price often means also low precision of the measurement system that is based on Micro-mechanical System (MEMS) sensors. Accelerometers, angular rate sensors, pressure sensors and temperature sensors are often used. In order to improve performance of the overall system different data fusion algorithms are used [21] within an electronic unit that contains all the necessary sensors which is called an Electronic Flight Instrument System (EFIS) [6] (see the block diagram in Fig. 1). These EFIS systems include a powerful processor and all the necessary sensors that are usually used with Air Data and Inertial Reference Units (ADIRU) [22].

As it was mentioned the sensors used within these systems requires calibration before it is possible to use them for different data fusion algorithms. It is possible to update calibration data during the flight which is usually based on a signal from a sensor that provides, in a specific state of the flight [6], more precise information [21][23]. The sources of information and sensors used for data acquisition are described in the following chapters where we describe single modules used in an airplane that are depicted in Fig. 1 within one EFIS instrument.

1.1.1 *MEMS Challenges*

Nowadays there is demand for systems based on low-cost micro-mechanical (MEMS) sensors [24]. These systems are not precise [25] because their precision depends on characteristics of used sensors that are in case of MEMS sensors highly dependent on the ambient environment. Despite continuous improvement of the material characteristics [26], the environment still influences linearity, scale factor, offset and hysteresis of the sensor, long term stability, their response on overloading, output value change caused by exposition to boundary temperature, etc. It is possible to correct all the long term changes with help of a polynomial function or a table whose coefficients were acquired from a set of demanding and often repeated measurements of all the sensor's characteristics. Another approach is to employ natural characteristics of redundant sensors.

Natural characteristics of sensors can be used to remove their dependence on the ambient environment [27]. First approach is to use multiple sensors of the required quantity and use them to improve precision of the output value, e.g. sensors with different measurement ranges and sensors that are used just to determine outside influences effecting on the sensor. To use a sensor just to measure ambient environment influences requires isolating it from the measured media. In case of pressure sensors, a blinded one can be used to measure outside temperature effects and also aging of the sensing element. In case of blinded sensor the isochoric process behavior can be used to extract sensors temperature dependences. What will rest after isochoric process subtraction is the temperature influence and aging effects. Another approach is to use a feedback system which in a loop periodically adjusts the correction coefficients of the sensors based on external information [25]. For example, the external information for an accelerometer sensor can be provided by the absolute pressure sensor which measures constant output value which means there is no vertical acceleration and so the actual offset of the acceleration sensor can be measured and stored for future use.

When MEMS sensors are used for precise measurements they are no longer low-cost. For example Air Data Computer uses sensors measuring absolute and relative pressures, see Fig. 3, where the required precision of the measurement is given by safety standards. For this special application it is possible to use sensors which were specially and carefully manufactured, tested, pre-selected, provided with a polynomial expression [28] describing its behavior with regard to temperature and fulfilled procedures required by Civil Aviation Authorities (CAA).

1.1.2 *Sensor Calibration*

Sensors used within Air Data Computer [29] provide one dimensional pressure data that depends on the quality of the sensor. According to the equation (1) calibration of the sensor reading x is usually performed whit regards to temperature t where both offset b and scale factor a parameters are function of temperature. These parameters can be either functions or tables or a different method of temperature corrections can be used, e.g. as described in [27].

$$y = a(t, \dots)x + b(t, \dots) \qquad (1)$$

One dimensional example can be extended for vector quantities as angular rate, acceleration and magnetic field sensors. These values are usually used to compute position of the vehicle [30]. The 3D sensor error model is usually denoted as (2):

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \boldsymbol{M} \cdot \boldsymbol{S} \cdot \begin{bmatrix} x_m & & o_x \\ y_m & - & o_x \\ z_m & & o_z \end{bmatrix} \qquad (2)$$

Where x_m, y_m and z_m are data provided by the sensor; o_x, o_y and o_z are offsets of single axes; $\boldsymbol{S}$ is a 3x3 matrix of scale factors; $\boldsymbol{M}$ is a 3x3 matrix describing misalignment of the orthogonal sensor arrangement; and x, y and z are calibrated output values. Comparison of different calibration methods is described in [31]. While it is quite simple to use described sensor calibration with angular rate or acceleration sensors the airplane heading is determined by a three dimensional magnetometer whose output depends on the position of the sensor and also on the presence of any ferrous material in the surrounding of the measurement unit. Fig. 2 depicts output of a magnetometer sensor with offsets in all three axes that are caused by hard iron distortions.

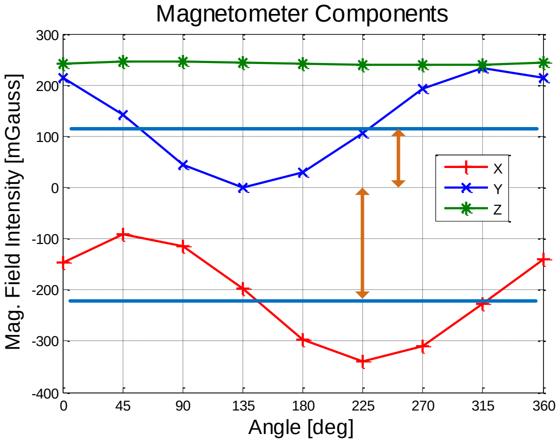

Fig. 2. Outputs of a Magnetometer Sensor before Calibration

The sensor calibration described in equation (2) will work properly just until the composition of the items disturbing the Earth magnetic field keeps stable. Any change of the field caused by surrounding material will change offsets of the measured components and resulting heading computation (3)

$$\psi = arctg(Y/X) \qquad (3)$$

will provide unexpected results. This magnetometer behavior causes problem during magnetometer usage for indoor navigation. One possible solution that removes described problems with hard iron distortions is proposed below in this article.

1.1.3 Air Data Computer

The safety of aviation depends on the precision of pressure measurements performed onboard of an airplane. An altitude measured by the atmospheric pressure is called barometric altitude where the pressure measurement conversion into altitude is calculated according to the International Standard Atmosphere (ISA) and the derived barometric formula. The important part of the barometric formula is the reference pressure level that defines origin for the calculation. The mostly used reference pressure level is a pressure at 0 m above ground level (AGL) defined according to ISA. When all the measurements on all airplanes are related to one reference level and all planes fly at different altitudes, with a safety margin, then there is no chance the airplanes could crash each other because pressure changes are smooth (continuous). This expectation is one condition for the successful operation of a concept of a new system for position angles measurement.

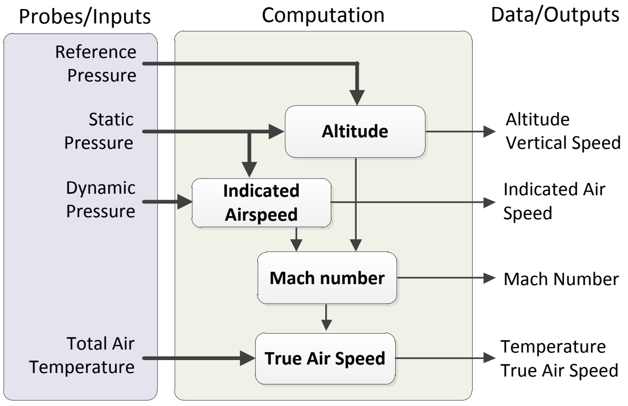

Fig. 3. Air Data Computer, Its Inputs and Outputs

The movement of the airplane in air mas generates a pressure that is related to the speed of flight. This pressure is called dynamic pressure and it is measured to get indicated air speed which is related to the wing-lift that allows the airplane to maintain altitude.

While the new system for position angles measurement uses pressure readings in principle multiple Pitot-static probes will be used. Generally the movement of the airplane and dynamic pressure will cause problems.

A combined device that measures static and dynamic pressure is called Air Data Computer. This device performs measurements, calibration of sensors, altitude calculations, calculations of different air speeds [32] and it also provides other data (see Fig. 3). Pressure sensors are highly dependent on the ambient environment [29]. Precision of the static pressure measurement is the most demanding at the 0 m AGL (6 meters or 75 Pascal) as it is depicted in meters and related pressure in Fig. 4. There are similar requirements on the differential air speed sensor which are depicted in Fig. 5. The highest requirements on the precision of the air speed measurement are around the stall speed which is usually under 100 km/h and the required precission is 8 km/h or 60 Pa.

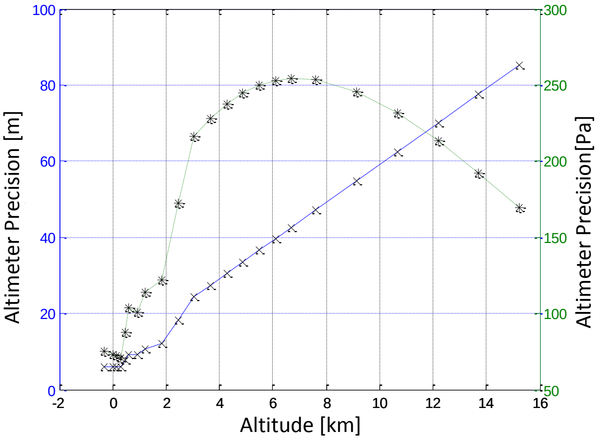

Fig. 4. Requirement for Altimeter Precision in km and Pa Related to Altitude

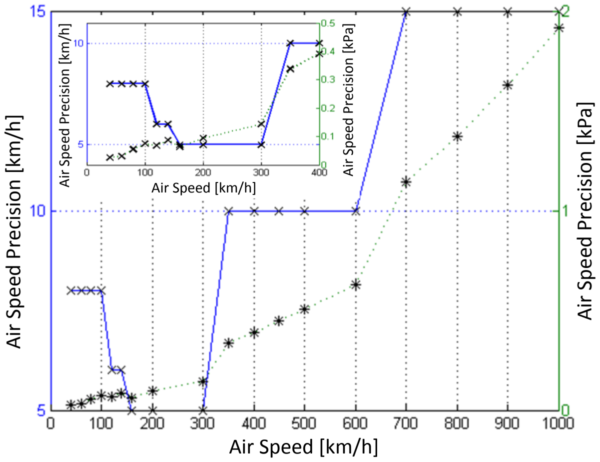

Fig. 5. Requirement for Air Speed Measurement System Precision in km/h and kPa Related to the Actual Speed

1.1.4 Inertial Measurement Unit and Global Positioning System

An Inertial Measurement Unit [13] is a device that contains a triad of accelerometers and a triad of angular speed sensors. These sensors are used to calculate orientation angles of an airplane and sometimes, also, they are used as the information source for the whole navigation solution. An IMU is a part of an Attitude Heading and Reference System (AHRS) or an Inertial Measurement System (INS). The sensors used in these systems differ in precision which is connected with their price. An INS [33], which is based on very precise and expensive sensors ~ 75 000 USD is able to maintain required navigation performance, which is a change of calculated position lower then ± 500 m, for about one hour in a mode that is based solely on the inertial sensors (pure inertial mode). Because of the price and precision, the low-cost and low precision sensors are used just for orientation angles determination. These sensors are complemented by a GPS receiver that is used as a source of navigation data. This combination is usually referred as an AHRS unit whose precision is then based mainly on the GPS and this mode is called hybrid mode. During the whole operation time, this mode keeps constant precision of 25 meters which is often supported by data fusion algorithms [34]. The INS unit referred here uses Honeywell Ring Laser Gyroscopes and

Honeywell Q-FLEX QA-950 accelerometers which provide parameters several orders better than we can get from MEMS sensors.

Qualitative comparison between a group of sensors can be performed based on Allan Variance method of moving average which plots averaging products based on averaging time. This is an official method [35] for angular rate sensors comparison. In this article we compare Allan Variance deviation for an output of Honeywell LaseRef V RLG angular rate sensor and STmicroelectronics iNemo MEMS based AHRS unit. The data were simultaneously measured from LaseRef V unit and iNemo AHRS for about one day. The output of Honeywell system is depicted in Fig. 6 from which we selected night part of the measurement with no noise caused by the people walking and closing doors in the surrounding. The Allan Variance plots comparison is depicted in figure Fig. 7. From the graphs we can read sampling frequencies of both signals which were 100 Hz for LaseRef label 327 and 50 Hz for iNemo LY330 angular rate sensor. The vertical difference clearly shows superior performance of the laser gyroscope over its MEMS alternative. We can also get impression about the best possible output provided by both sensors at the lowest point of the depicted curves. Angular rate sensor of iNemo AHRS reaches the minimum around 10^3 s which is also presented by the sensor's manufacturer. There is no minimum for the RLG gyroscope because the selected data acquisition time is too short.

The key problem with navigation solution computation and therefore conversion of the sensor inertial data to position is influenced mainly by the double integration algorithm that highlights all the sensor errors and ambient environment problems. The simplest flat Earth navigator [36] which does not take into account changes in gravitational and magnetic field, Earth coordinates and Earth rotation is depicted in Fig. 8. The accelerometer output is double integrated to provide position and velocity but before the integration the signals are usually transposed from the body frame of the strap-down measurement unit into the navigation frame where the vehicle performs its navigation. The figure clearly shows that the angular rate sensors are used to provide transformation matrix between body and navigation frame with help of single integration or fusion from different sources, e.g. accelerometers in rest, magnetometer, etc.

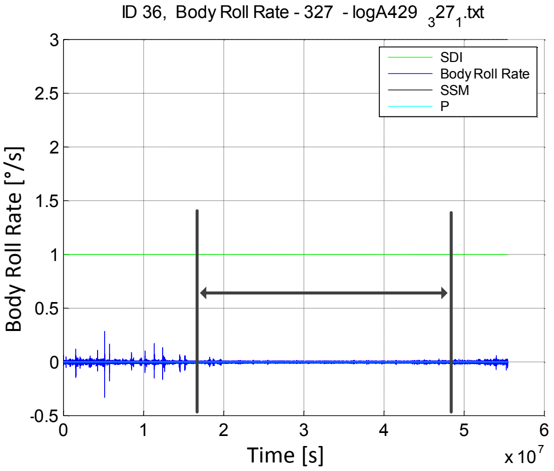

Fig. 6. Illustration of Acquired Data Set (Honeywell LaseRef V) and an Interval Used for Evaluation by Allan Variance method

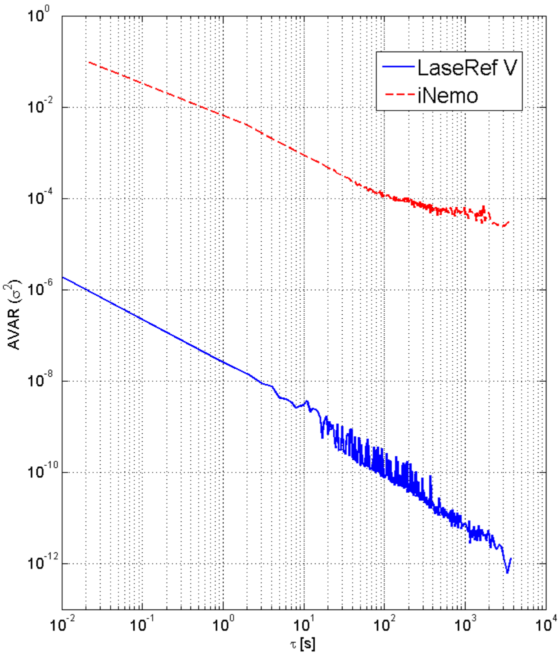

Fig. 7. Allan Variance Plot for a RLG sensor and a MEMS based device

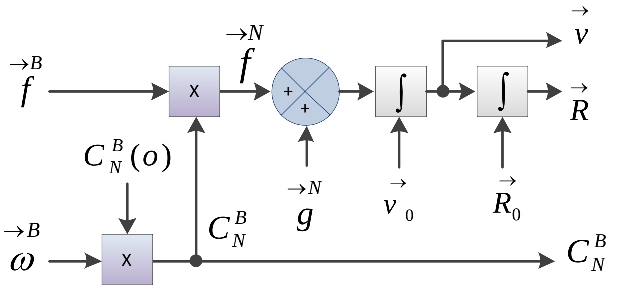

Fig. 8. Flat Earth Navigator [36]

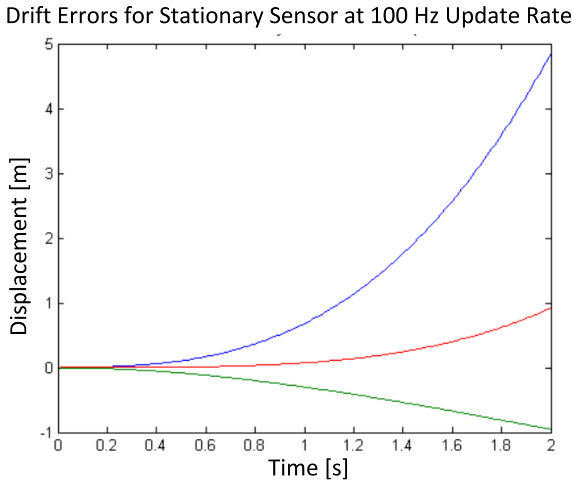

Fig. 9. Typical Output of a Flat Earth Navigator – Sensor Drift Errors [37]

To compute navigation solution with flat Earth navigator will not provide required output not even in case of better sensors (LRG). Due to the drift at the output of the sensors which is processed by the double integration algorithm the computed position of the navigation system will move for a system which is in fact stationary. The typical output [37] of a flat Earth navigator using MEMS sensors is depicted in Fig. 9 which depicts displacement after two seconds in each axe (x, y, z). The maximal displacement which is reached after two seconds is five meters in one axe. Fig. 9 shows exponential shape of the displacement drift which can be caused by the double integrated constant offset at the sensor output. It can show the calibration of the sensor was not well done or the parameters of the sensor changed based on the ambient environment and some sensor error correction mechanism has to be used.

Sensor output calibration can be performed by a set of measurements as described above but it is not usually enough because output of a sensor changes with change of the ambient environment. This problem is usually solved by fusion of multiple sensor sources as depicted in Fig. 10 where the result computed from Inertial Data is supported by Air Data Computer and GPS data [38]. The other sources of information can be compared with actual output of the inertial sensors or their computational products and the error parameters of the sensors can be estimated by a filtering.

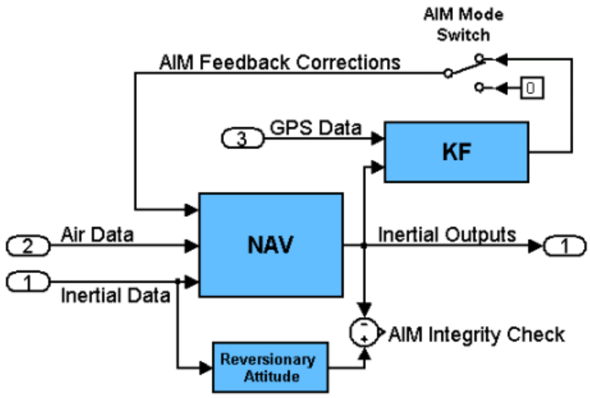

Fig. 10. LaseRefV Inertial Navigation System Dataflow, Inputs and Outputs [38]

Inertial sensors and their precision are crucial for the precision of the navigation solution. Their error models can be estimated online with help of other sources of information which usually performs more precise and in time stable measurements. The new system for position angles measurement could provide angles for body to navigational frame transformation (see Fig. 8) and also it could provide information based on which the double integration algorithm and integrated error could be reset.

1.1.5 Other Sources of Information, Magnetometer Unit and Pressure Reference System

To increase precision of the navigation solution other sources of information can be used. In the area of inertial navigation sensor an odometer, which e.g. provides information about vehicle movement based on the wheel speed sensor, is often used. For airplanes and to display safety instructions related to the actual situation engine parameters are usually measured [39] and the engine health is evaluated during the engine operation and also for emergency landing assistants [7]. This electronic assistant needs information about angle of attack and angle of sideslip which are related to the distance for which the plane can glide without properly working engine. All the data [40] are often stored in a data recorder [41] and used for more precise post flight analysis. An example of the landing assistant system is described in [42].

A magnetometer measuring Earth magnetic field is often used as another data source of the airplane heading. There is a three axes sensor which provides data about the sensor orientation with regards to the magnetic flux sensor. This is stable information that changes with Earth’s latitude and longitude but the actual vector orientation can be calculated from a model or from a table. The problem with magnetometer is caused by its calibration which is valid for one location and composition of the surrounding that contains sources of hard iron and soft iron distortions. The magnetometer calibration procedure usually provides a calibration ellipse whose deformation and position of the center allows us to get the distortion parameters (Fig. 11A). But these parameters are valid just for the single calibration and at the calibration place. While the modern MEMS sensors are small and cheap enough it allows us to design a magnetic field measurement unit that contains multiple magnetic field sensors arranged in a circle which provide possibility to measure all calibration data in one sample for the actual magnetic field distribution. This method expects that all the sensors were calibrated by a known magnetic field and their behavior is similar. In that case we can get the hard and soft iron distortions as depicted in Fig. 11A. The proposed sensor head with six sensors is depicted in Fig. 11B. Three pieces of this head rotated for 20 and 40 degrees compose a Magnetometer Automatic Calibration Sensor which is depicted in Fig. 11C. This calibration head will provide calibration data as depicted in Fig. 2 by one reading with step of 20 degrees. The precision of the sensor head depends just on the number of sensors used. The data allows us to determine X and Y offsets of the ellipse (Fig. 11A) which represent hard iron distortions and shape of the ellipse represented by q and r diameters and angle of rotation of the ellipse α that are caused by soft iron distortions. The advantage of this arrangement is independence of the magnetometer output on its actual position and magnetic field fluctuations.

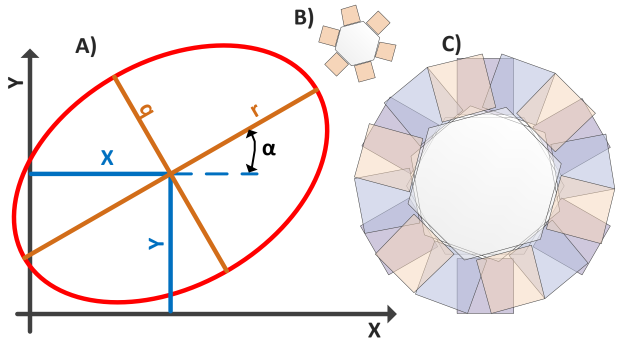

Fig. 11. A magnetometer Calibration Ellipse and Proposal of the Automatic Calibration Sensor Head

Instrument flying requires information about position angles which means pitch and roll angles to keep stable orientation of the plane which is not possible with human body sensors. Because the MEMS sensor precision is not enough and the more precise sensors are very expensive a new source of information about orientation angles is required. In aerospace the international standard atmosphere is used to maintain flight altitude and vertical distance between airplanes from 50’s. It is internationally used and recognized. Because the behavior of the atmospheric pressure is very well described we propose a position angles measurement system which is based on precise measurements of small pressure differences in the vertical direction in the atmosphere. The pressure behavior with relation to altitude is depicted in Fig. 12 where we can see a pressure change related to an altitude change. This system will be furthermore referred as Pressure Reference System.

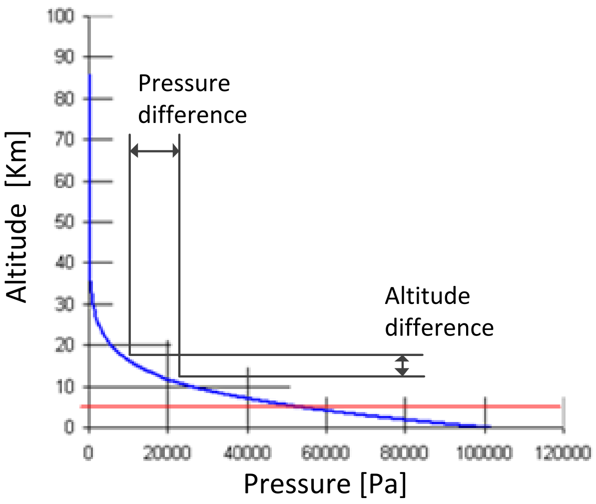

Fig. 12. Behavior of Standard Atmosphere Pressure and Principle of Pressure Reference System

1.2 Displays

The data acquired and processed by the above described systems and methods need to be visualized to the pilot. There are requirements for simple, informative way to display data based on the ergonomics of the cockpit [43][5]. The display units are generally divided on the head down displays mounted on the airplane dashboard and the head up displays mounted in the pilot's field of view.

1.2.1 Head-Down Displays

Dashboard instruments are still the most common way of displaying data. Small airplanes usually uses instruments type 1 and 2 (see introduction section of this article). Type 3 usually contains a custom made computer with all the sensors embedded into the device. Nowadays the current development effort in the area of dashboard instruments is focused on improvement of its advanced functionalities. There are different software functions performing checklists, data storage, evaluation which follows the approach generally recognized as Integrated Modular Avionics (IMA) [20][6]. The advanced display functions usually have form of electronic assistants [7] providing advices that increase safety of the flight. These systems are usually developed for one specific EFIS platform with some exceptions providing a universal programming interface [44][45].

The Pressure Reference System is being developed as a part of a set of independent distributed modules where all the main EFIS components (see Fig. 1) are developed as standalone units sharing data over WiFi network. Acer Iconia Tab is intended as a master module that controls single data providers. Fig. 13 shows the tablet running flight display instruments and also disassembled AHRS unit that contains GPS, 3x accelerometers, 3x angular rate sensors, 3x magnetometer, pressure and temperature sensors with 7-state extended Kalman filter providing output in form of quaternions, heading, pitch, and roll angles. The unit is based on ST microelectronics iNemo IMU whose parameters were described before.

Fig. 13. EFIS Running on Acer Iconia Tab Windows7 with Disassembled AHRS unit

1.2.2 Head-Up Displays

Pilots are requested to keep track with the situation outside of the airplane. While they look down on the airplane dashboard they do not pay attention on the surrounding situation which is considered as potentially dangerous. HeadUp displays solve this problem for aerospace and other vehicles. This type of display shows just a subset of all the measured data including artificial horizon which could be provided by Pressure Reference System.

Within the scope of this work a head up display was constructed and tested. The display uses 2D array of bright LED diodes which are externally controlled. The display unit is depicted in Fig. 14 which clearly shows discrete steps of the image generator. The detailed description of the display unit is available in [6].

Fig. 14. Artificial Horizon Depicted by a HeadUp display using 2D array of bright LED diodes

2 Pressure Reference System

Fig. 12 shows atmospheric pressure behavior with relation to altitude which is described in International Standard Atmosphere (ISA). The pressure difference which is recalculated to one meter of the vertical distance is 12 Pa/m at the ground level and 7 Pa/m at 5 km altitude. The graph describing atmospheric pressure change on one meter with regards to altitude is depicted in Fig. 15. This graph proves that there is a small pressure difference between two vertical sampling places that can be used for orientation angle measurement. We are trying to utilize the depicted relation for vertical distance measurements. An airplane provides possibility to mount twin sensors on places that mutually changes their position with regard to the center of the airplane as it is depicted in Fig. 16.

Fig. 16 shows an airplane flying at altitude with pressure value Pref at the point of its center of mass. While the plane flies aligned with horizon the wings keeps horizontal position and the vertical difference of the both wing tips is 0 which means the pressure difference is 0 Pa. In case the plane starts turning the wing tips change their position with regards to the reference plane and the measured pressure will be $P_{ref.} - \Delta P$ and $P_{ref.} + \Delta P$ respectivelly. The total pressure difference between these two points will be $dZ = 2\Delta P$.

Pressure differences depicted in Fig. 15 disappears in resolution and errors of absolute pressure sensors used in ADCs. Because of small pressure values a differential pressure sensor has to be used. Honeywell DC001 NDC pressure sensor is proposed to evaluate measurement principle of the Pressure Reference System. Tab. 1 shows expected voltage outputs of the selected sensor with regards to maximal and minimal pressure changes.

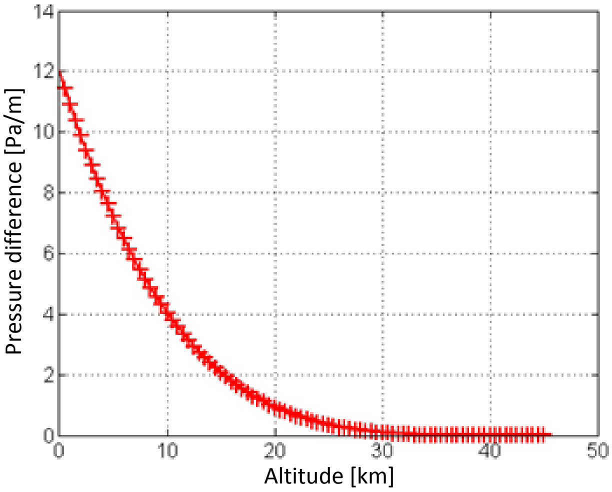

Fig. 15. One Meter Pressure Change Related to Altitude above Ground Level

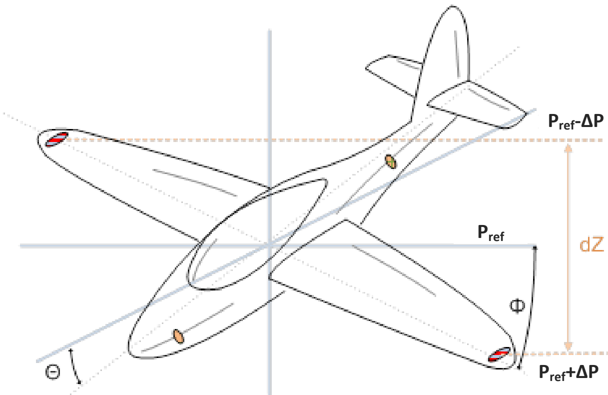

Fig. 16. Proposed Placement of Entry Points for the Pressure Reference System

Tab. 1. Differential Pressure Sensor Voltage Outputs Related to Selected Pressure Changes

Pressure [Pa]	ΔU_{out} [mV] DC001
12	96
8	64
6	48
4	32
2	16

2.1 Measurement Setup

To evaluate capability of the Pressure Reference System to measure orientation angles the measurement setup depicted in Fig. 17 was proposed and used. There were two DC001 sensors used in differential arrangement described in [42]. The sensor outputs were sampled by HP Data Acquisition Unit HP34970 together with actual power source output. DAQ unit was remotely controlled by a personal computer through Agilent 82357A GPIB to USB converter. The measurement setup also uses mechanical switch which is able to exchange measurement inputs In1 and In2 between each other. The switch is also remotely controlled by a one purpose electronic board over CAN bus. Data were acquired with help of Matlab Instrument Toolbox and a custom made toolbox used to access CAN bus.

Measurement was performed as follows: the sensor was placed at one meter above ground level; Input In1 was placed at 0 m AGL; and Input In2 at 2 m AGL. The DAQ system measured output of each sensor, their difference and power supply voltage. Mechanical switch allowed mechanically exchange pressure feeds to the sensor. A data set of fifty samples was acquired during each orientation of the inputs.

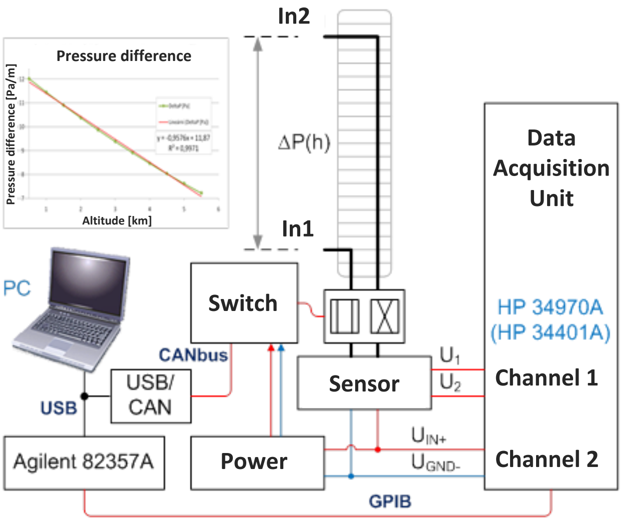

Fig. 17. Test Setup Used to Prove Capability of the Pressure Reference System

2.2 Results and Discussion

Results of the measurements acquired with help of the system depicted in Fig. 17 are depicted in Fig. 18. Every column represents average value of fifty samples for two orientations of the system inlets (in the figure the orientation is denoted as A and B). The result of the measurement can be interpreted as follows:

- In principle, the method allows vertical distance measurement.
- The amplitude for orientation A is 82 mV and for orientation B it is 88 mV which does not satisfy theoretically expected values presented in Tab. 1.
- Output signal difference is 6 mV for vertical difference of 2 m.
- The output value significantly changes with regards to the ambient pressure conditions. The maximal difference of the output signal was 20 mV and minimal was 1mV and the measured value disappears in noise.

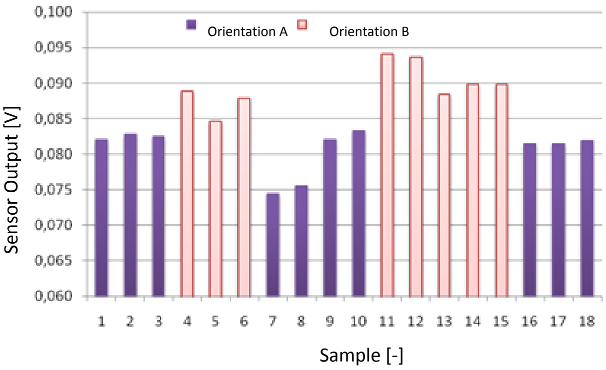

Fig. 18. Measurement Results

Unfortunately the result does not reflect expectations and a better sensor arrangement has to be prepared. Following conclusions were proposed:

- Long tubes feeding the pressure to the sensor has to be as short as possible.
- There is no time for sequential measurement. The pressure has to be measured simultaneously at different places.
- The sensitivity of the measurement module has to be increased.

3 Conclusion

This article presents a concept of a new system for position angles measurement which is based on attributes of International Standard Atmosphere and does not include double integration algorithm which is common in currently used AHRS units. The output of the Pressure Reference System should keep its precision in time regardless on short term disturbances. The article presents results of the measurements that prove capability of the proposed system for orientation angles measurement. Because the measured results do not follow theoretical expectations a closed reference volume is proposed to increase resolution of the measurement.

Next to the Pressure Reference System, a new head of a magnetometer sensor is presented that is able to measure its calibration circle in one sample and so it does not suffer by the magnetic field fluctuations.

We also summarize current situation in the area of measurement and display systems used by small airplanes. Precision of these systems is discussed, compared and disadvantages of currently used solutions are presented here. The article presents a set of modules forming distributed set of sensors of an avionics system including display units and especially a head up display unit.

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