Design of Information and Communications System Based on 3D MEMS Inertial Sensors

Emil Iontchev[1], Ivaylo Simeonov[2] and Rosen Miletiev[3]

Abstract – **The current paper represents the design of the information and communication system which is based on MEMS inertial sensors, which may be useful for a control of the moving objects such as unmanned airplanes, robots, etc. It consists from 3D inertial accelerometers, 3D angular rate sensors (gyroscopes), 3D magnetometer and 3D thermometer. Also it may be extended with different type of sensors such as three-axis accelerometers, one axis gyroscope, inclinometer sensor, pressure sensors, etc. to monitor the acceleration or relative shift of the selected parts of the moving object. The system also has capability to realize a M2M functions due to the integrated GPS receiver and GSM modem. The block diagram and the communication protocol review are accomplished in the paper.**

Keywords – **IMU, MEMS, inertial sensors**

I. INTRODUCTION

Interest in the development of microelectro-mechanical systems (MEMS) has mushroomed during the past decade. In the most general sense, MEMS attempts to exploit and extend the fabrication techniques developed for the integrated circuit (IC) industry to add mechanical elements to the electrical circuits to make integrated microsystems for perception and control of the physical world. MEMS sensors allow the implementation of a lot of different functions, as free-fall detection, car navigation, map browsing, gaming, menu scrolling, motion control, vibration monitoring, antitheft and many others. The MEMS sensors are used to measure the frequency, amplitude (strength) and spectrum (signature) of vibrations, enabling the ability to perform active monitoring of moving objects such as unmanned autonomous vehicles [1-3]. MEMS sensors are also widely used in the integrated navigation systems [4-5] by using Extended Kalman filter.

The current paper represents a design of the information and communications system, based on 3D MEMS inertial sensors, which is capable of measurement and control of many individual moving parts and the entire body of the selected object (robot, vehicle, etc.). The paper discusses the used communication protocols, block diagrams of the information and communications system and sensor PCB. Also the installed MEMS inertial sensors are mentioned.

II. SYSTEM BLOCK DIAGRAM

The system block diagram is based on the following main blocks (Fig.1):

- Control and communication unit (CCU)
- Inertial measurement unit (IMU)
- Single Board Computer (SBC)
- Database server (DBS)
- Sensors

The functional connections between modules are established by digital interfaces, shown on the diagram. Their choice is based on the following criteria:

- Number of connected nodes
- Transmission speed
- Communication channel noise immunity
- End terminal device distance

The main system module is recognized as inertial measurement unit (IMU) where is installed the main 3D inertial sensor. It consists of 3D 14bit accelerometer, 3D 14bit angular rate sensor, 3D 14bit magnetometer and 3D 12bit thermometer. These sensors are integrated in the single chip solution – ADIS16405 produced by Analog Devices. The sensor data are transmitted to the PIC microcontroller via SPI interface. This bus also is connected to the main FLASH memory (MMC/SD card up to 2GB) and 14bit inclinometer with 2 axes accelerometer type ADIS16209. The inclinometer data are compared with the Extended Kalman Filter (EKF) output to calculate the filter response and accuracy.

The IMU block also contains a high sensitive GPS receiver type LEA 5S, produced by UBLOX. This receiver has 50-channel u-blox 5 engines with over 1 million effective correlators, SuperSense® Indoor GPS: -160 dBm tracking sensitivity and also supports AssistNow Online and AssistNow Offline A-GPS services and SBAS (WAAS, EGNOS, MSAS, GAGAN). The navigation data are sent via UART interface to the PIC microcontroller while the same data are transmitted via high speed USB interface to the single board computer (SBC) according to NMEA 0183 protocol. These data may also be sent to the SBC via RS232 interface with a hardware handshaking (RTS/CTS). This scheme allows sending navigation data via two independent communication channels to the SBC.

The IMU block also communicates with external sensors via high speed CAN interface, which allows connecting up to 112 nodes to the bus. These additional sensors send data about accelerations of the other object parts. The environment parameter data such as pressure and temperature are also sent to the microcontroller. The system stability and security is highly increased if the identical sensors are installed to the system due to the sensor reservation.

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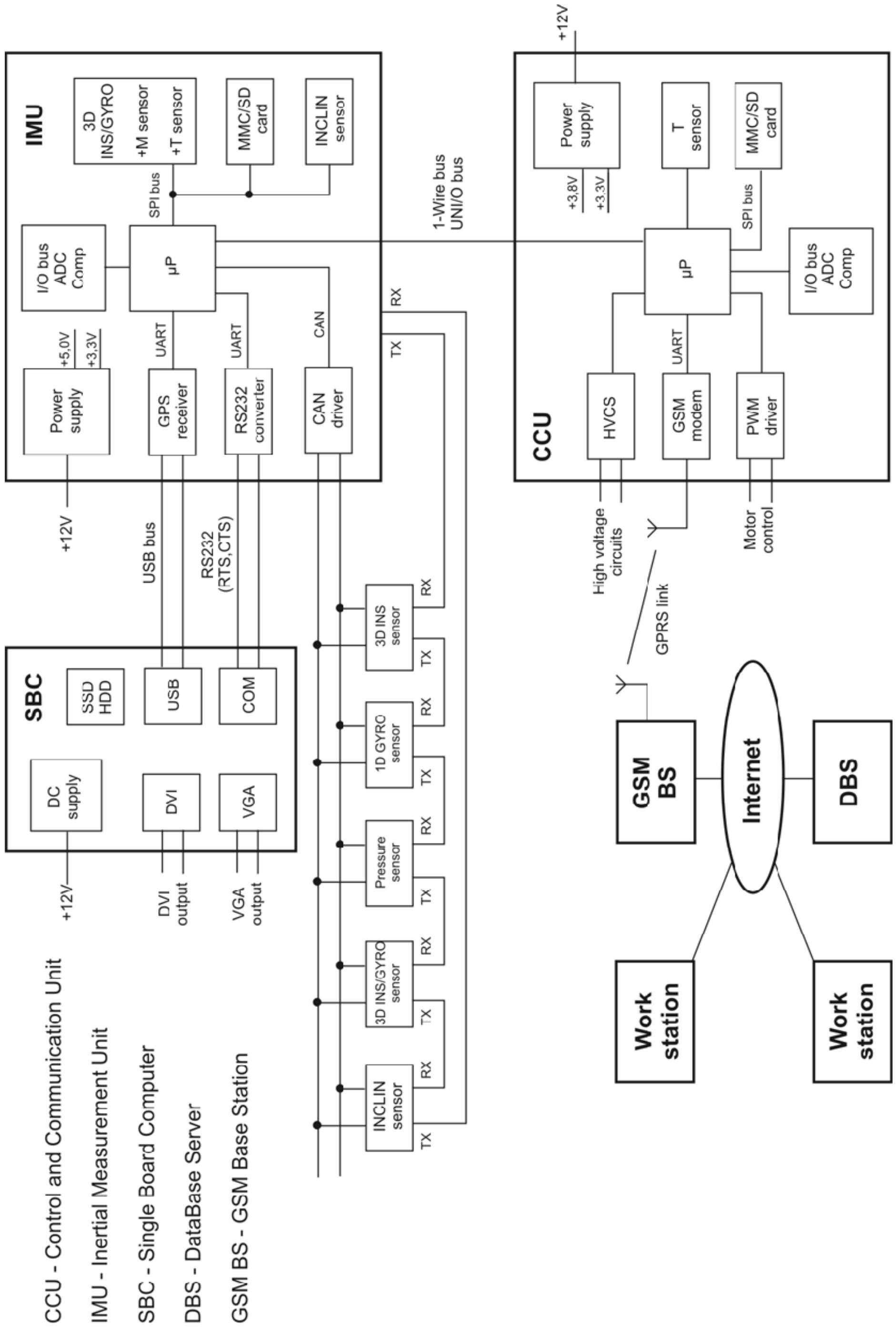

Figure 1. System block diagram

This system performance may be also achieved by using the secondary UART interface. The RX pin of this interface of one device is connected to the TX pin to another and the system commands are sent consecutively to the bus.

The IMU block may support different types of sensors, such as:

- 3-axis 12bit accelerometer (3D INS) type LIS3LV02DQ
- 1-axis 14bit angular rate sensor (1D GYRO) type ADIS16100
- Pressure sensor type SPD015A
- 3-axis 14bit accelerometer (3D INS) and 3-axes 14bit angular rate sensor (3D GYRO) with extended temperature compensation type ADIS16355 or ADIS16405
- 14bit inclinometer with 2 axis accelerometer type ADIS16209.

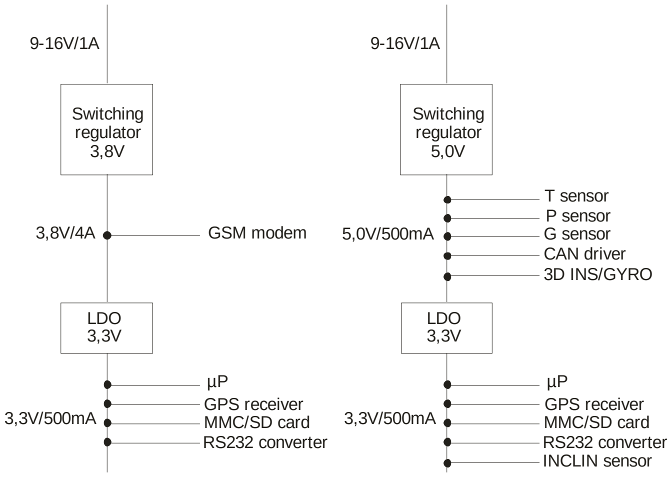

Figure 2. System supply diagram

The IMU block also supports different types of analog extensions such as 10bit ADC, 2-channel comparator with an internally generated Vref and general purpose I/O pins (GPIO).

The system supply diagram is shown at Figure 2. the external supply (9÷16V) is fed to the switching regulators, which forms 3.8V/4A to supply the GSM modem and 5.0V/500mA to supply the 3-axis inertial sensor and CAN driver. The additional LDO regulators produce a stable 3.3V power supply for onboard microcontrollers, GPS receiver, MMC/SD card and other inertial sensors.

The IMU data or states (pitch, yaw and roll information) are sent to the communication unit CCU via 1-Wire interface. According to the received information the CCU block made decisions to control the external devices such as motors via PWM driver, valves or another high voltage devices or circuits (HVCs), etc. The gathered data may also be transmitted to the database server via GPRS link over the mobile network. This function implements a M2M connected to established real-time telemetry of the remote device. The database data may be read via secure SSL channel by another remote user.

The communication and control functions of the system are performed by the CCU module.

The block diagram of the sensor unit is shown at Figure 3. It consists of a CAN transceiver MC2551 produced by Microchip Inc., microcontroller (µP), power supply and MEMS inertial sensor. The communication protocol between the sensor and microcontroller is SPI based. The sensor unit also the integrated USART module of the microcontroller to established serial connection with other sensors or to personal computer (PC) via software emulated serial protocol. It supplies by the external 5V power supply which is fed directly to the CAN transceiver and microcontroller through input LC low pass filter, which reduces the high frequency noise. The MEMS sensor is supplied by single ended 3,3V power supply which is generated by the Low Quiescent Current LDO MCP1700 in 3-Lead Plastic Small Outline Transistor SOT23 package.

III. SYSTEM APPLICATION

The proposed system may be used such as control, monitoring and communication system for a humanoid robot system (Figure 4). The shown figure represents the main moving parts of the robot while the system unit (ICS) is installed in the robot body.

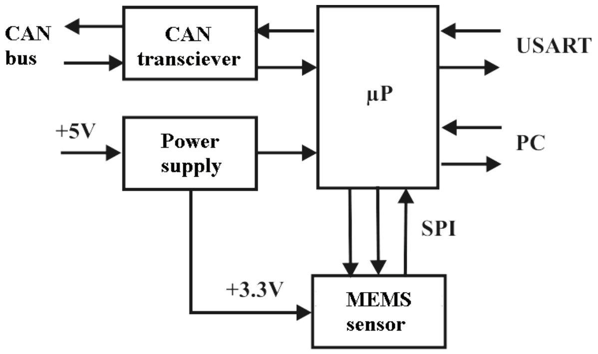

Figure 3. Sensor block diagram

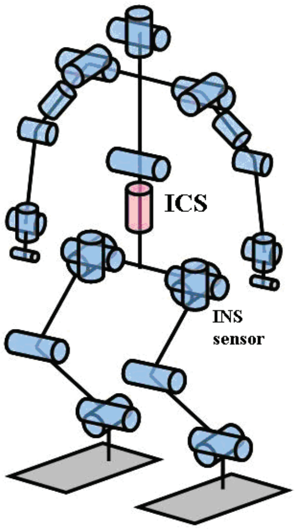

Figure 4. Robot's kinematic

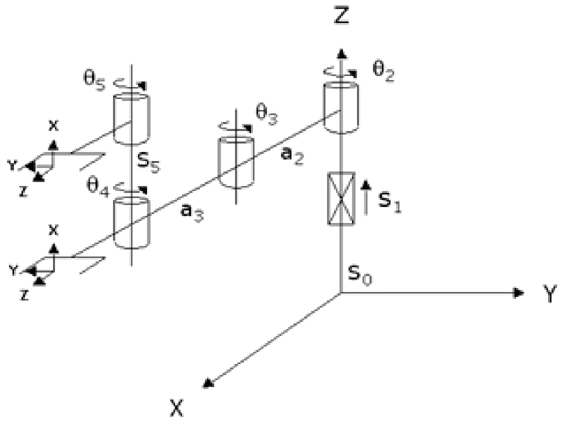

Figure 5. XYZ coordinate system orientation

If the xyz coordinate system of the sensor unit is orientated randomly according to the XYZ coordinate system of the body (Figure 5), the sensor accelerations according to the XYZ system may be calculated according to the Euler transformations [6]:

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = R_z(\chi) R_N(\theta) R_Z(\phi) \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \tag{1}$$

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -\sin\chi & \cos\chi \\ 0 & \cos\chi & \sin\chi \end{pmatrix} \begin{pmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{pmatrix} \begin{pmatrix} \cos\phi & \sin\phi & 0 \\ -\sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \quad (2),$$

where χ, ϕ and θ represents the rotation angles (Figure 6).

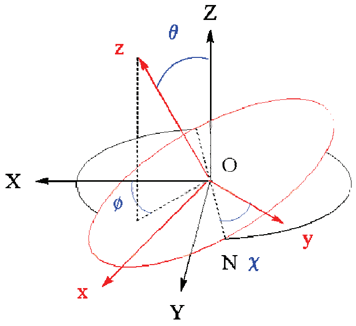

Figure 6. Rotation angles

The accelerations may be also used for calculation of the absolute speed and shifting of the selected part or relative speed and shifting between two selected nodes. These parameters are calculated by a numerical integration of the measured accelerations according to the following equations:

$$\begin{aligned} v_{i+1,x} &= v_{i,x} + \left(a_{i+1,x} - a_{i,x}\right)\Delta t \\ v_{i+1,y} &= v_{i,y} + \left(a_{i+1,y} - a_{i,y}\right)\Delta t \\ v_{i+1,z} &= v_{i,z} + \left(a_{i+1,z} - a_{i,z}\right)\Delta t \\ S_{i+1,x} &= S_{i,x} + v_{i,x}\Delta t + \frac{1}{2}\left(a_{i+1,x} - a_{i,x}\right)(\Delta t)^2 \\ S_{i+1,y} &= S_{i,y} + v_{i,y}\Delta t + \frac{1}{2}\left(a_{i+1,y} - a_{i,y}\right)(\Delta t)^2 \\ S_{i+1,z} &= S_{i,z} + v_{i,z}\Delta t + \frac{1}{2}\left(a_{i+1,z} - a_{i,z}\right)(\Delta t)^2 \end{aligned} \quad (3).$$

It is clearly visible that the integration error may be reduced while the sampling frequency is increased. The chosen 3D inertial sensor is capable to measure accelerations up to 2560 times per second.

Other application of this system might be to assess of track geometry and quality by prediction of the vehicle dynamics. Recently, interest has grown for improving the conventional track geometry inspection methods by use of a real-time simulation system, which provides performance-based assessments to identify track sections that are likely to produce dynamically high and/or unsafe vehicle response.

When the system is applied to railway track the most important signals of the vehicle response are the wheel-rail contact forces and the accelerations of the vehicle body. With two acceleration sensors witch are attached to the bearings of the axle we can measure of corrugation and other isolated faults on the rail surface. Two acceleration sensors attached to the floor of the vehicle together with sensors recording the relative distance of the axle to the vehicle floor form the basis for level and alignment signals. Lateral acceleration sensors and gyros produce the raw data for a spatial curve. The combination of INS sensors with a GPS allows for an absolute and kinematics three-dimensional description of the track inventory.

The system can measure the rail acceleration while the train passed through the place where inertial sensors are placed. The signals from them can be used in railway diagnostics to the detection of wheel flat faults.

IV. CONCLUSION

The current paper represents a design of the information and communications system, based on 3D MEMS inertial sensors, which is capable of inertial measurement of many individual moving parts and compare them to the movement of the entire body of the selected object (robot, vehicle, etc.).

This allows calculation of the velocity and shifting of the moving parts in the XYZ coordinate system and establishment of the object position and vector movement. The system is based on the latest digital MEMS accelerometers and gyroscopes and supports many eternal devices such as other digital systems or analog sensors and is capable to send all data to the remote device due to the integrated GSM modem.

The developed information and communication system is a foundation of the next generation digital three-dimensional IMU systems and Event Data Recorders (EDRs), according to IEEE1616A standard.

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