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Multiprotocol Sensor Network Based on Inertial MEMS Sensors Part I. Network Topologies and Analysis

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Abstract - **The current paper represents a multiprotocol sensor network based on inertial MEMS sensors which is capable of measuring the accelerations of the given point of the network. The proposed network consists of two branches – CAN and USART(I^2C/LIN) bus which are independent. The master sensor may read the slave sensor data from one of the selected protocols depends from the network length, network nodes, noisy environment, etc. The possible topologies, communication principle and network analysis is performed.**

Keywords – **MEMS sensors, CAN, USART**

I. INTRODUCTION

MEMS sensors allow the implementation of a lot of different functions, as free-fall detection [1], car navigation, map browsing, gaming, menu scrolling, motion control [2], vibration monitoring [3], antitheft and many others [4]–[6]. Micro electro mechanical systems (MEMS) technology has developed considerably in recent years and many sensors utilizing this technology are available in the market. MEMS technology enables miniaturization, mass production, and cost reduction of many sensors.

MEMS-based sensors are a crucial component in automotive electronics, medical equipment, smart portable electronics such as cell phones, PDAs, and hard disk drives, computer peripherals, and wireless devices. These sensors began in the automotive industry especially for crash detection in airbag systems. Throughout the 1990s to today, the airbag sensor market has proved to be a huge success using MEMS technology. MEMS-based sensors are now becoming pervasive in everything from inkjet cartridges to cell phones. Every major market has now embraced the technology.

The MEMS accelerometers and gyroscopes are both sensors which can perfectly address active safety systems in the automotive domain. Control of car roll-over, vehicle stability for skidding and antilock braking, parking brake energy, activation of wheel pressure monitoring, suspension adaptation to car and road condition, and other ones are all features are extending more and more any active safety system will be embedded soon in our cars.

Moreover MEMS sensors allows instantaneous detection of any information used by those functions, with an high level of precision and accuracy, with a very low impact in term of space, together with high level of integration with other systems.

The physical mechanisms underlying MEMS accelerometers include capacitive, piezoresistive, electromagnetic, piezoelectric, ferroelectric, optical, and tunneling [7]. The most successful types are based on capacitive transduction; the reasons are the simplicity of the sensor element itself, no requirement for exotic materials, low power consumption, and good stability over temperature [8]. Although many capacitive transducers have a nonlinear capacitance vs. displacement characteristic, feedback is commonly used to convert the signal to a linear output. The output can be analog, digital, ratiometric to the supply voltage, or any of various types of pulse modulation. Sensors with digital output are convenient when the data must be transmitted without further noise degradation [9].

Sometimes MEMS sensors are used to measure a relative speed or shifting simultaneously between two or more parts. In this case the sensors have to be started simultaneously and synchronized to form a sensor network.

Applications of inertial sensors have now extended into the field of networked sensing systems. The current paper represents the network topologies of such type of sensor networks based on MEMS sensors which are used to measure linear accelerations between *n* points.

II. SENSOR NETWORK DESIGN

The sensor network design is based on the RS232 and CAN communication standards and protocols. The both standards have the specific advantages. CAN was originally developed for use in vehicles, but is also extremely successful in the field of industrial automation due to very good network stability, flexibility in terms of intercommunication of the devices (producer/consumer principle) and the low costs. Further advantages of CAN are the possible line length of up to several kilometers, the good electromagnetic compatibility (EMC) and the availability of CAN interfaces on most industrial microcontrollers. In addition, there is a wide range of development and test tools as well as communication software. On the other hand, CAN is a bus with line topology and limited stub line length, the use of topology components is particularly advantageous in sensor communication systems.

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RS232 standard is used for only point to point communication between two devices. No network topology can be build due to the permanent activity of the transmitter.

The multiprotocol sensor network may have two different topologies depends on the connection of the USART (Universal asynchronous receiver/transmitter) bus. The first topology is shown at Figure 1. The CAN connected sensor network consists of one master (microcontroller) and *n* slave sensors, which allow to measure accelerations at the selected object point.

The sensor network is divided to two branches – one for UART bus (ring topology) and the other for the CAN bus (linear topology). The UART bus connects the TXD pin of the (*k*-1)-th sensor to the RXD pin of the K-th sensor. Therefore the commands are sent consecutively from one sensor to the next one. When the command reaches the selected sensor, it processes the command and send the response to the (*k*+1)-th sensor. So the USART devices are connected consecutively to form the network. At this topology the transmitters and the receivers are constantly active and the information is transferred from one sensor to another.

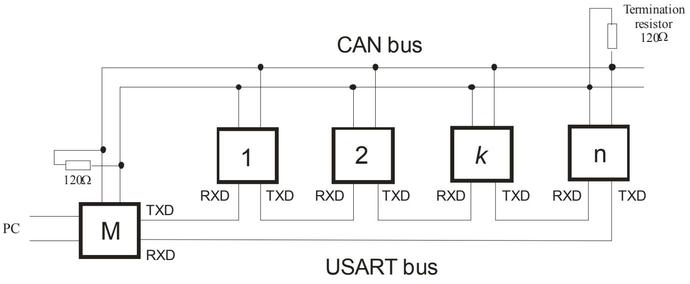

Figure 1. Network topology #1

This topology is suitable for longer sensor networks because the maximum bus length is limited to $n/2.L_{1,max}$, where $L_{1,max}$ is equal to 3m (TTL level). In the same the data communication speed is lower because sensors are connected consecutively.

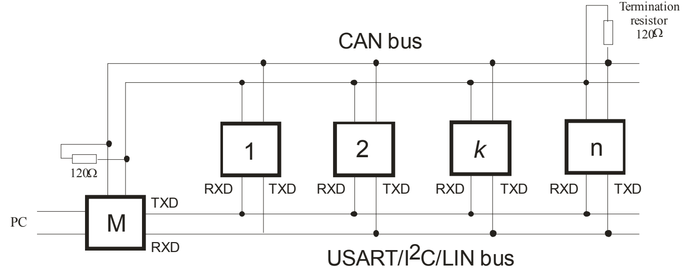

Figure 2. Network topology #2

The other sensor network topology is shown at Figure 2. The CAN bus topology remains the same while the USART bus is formed analogous to the CAN bus topology. To prevent the simultaneous work of the USART transmitters (drivers) only one transmitter at a time have to be active and transmits the data to the master sensor. In the same time the sensor receivers remain active, but their number is limited because the bus load is increased according to the equation:

$$R_L = \frac{R_{in}}{n}, \qquad (1)$$

where $R_{in} = \frac{V_{DD}}{I_{IL}}$ - input impedance of the microcontroller I/O pin;

$I_{IL} \le 1\mu A$ - input leakage current [11] and

n - number of network nodes.

This topology is suitable for a star networks because the node lines between master and slave sensors are limited to $L_{1,max}$ (3m) but the data communication speed is faster because the slave sensors communicate directly with the master sensor.

The typical high level input voltage is set to $0.7V_{DD}$ (V_{DD} – supply voltage) [11]. In this case the bus high logic level have to be higher than this limit $V_{IH} \ge 0,7V_{DD}$. The high logic level of the bus may be calculated according to equation:

$$\frac{V_{IH}}{V_{DD}} = \frac{R_{in}/n}{R_{out} + R_{in}/n} \ge 0,7, \qquad (2)$$

where $R_{out} \le 75\Omega$ - driver I/O impedance [10].

This equation defines the maximum bus nodes to guarantee the high logic level:

$$n \le \frac{3}{7}.\frac{R_{in}}{R_{out}}. \qquad (3)$$

III. SENSOR NETWORK ANALYSIS

The UART baudrate may be calculated according to the algorithm described below. If we assume that the inquiry is 1 byte long, the response is (m + 1) bytes long and it is sent by the i-th sensor, then the command will reach the selected sensor for ($i\Delta t$) seconds where Δt=10/B (B = Baudrate) is one byte propagation time.

The sensor network time diagram is shown at Figure 3.

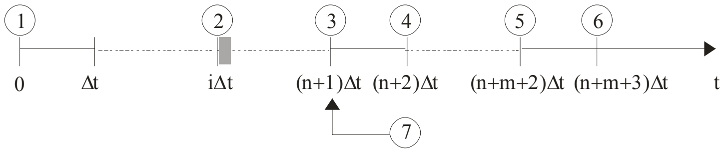

Figure 3. Sensor network time diagram

The system communication principle is based on the following steps (Figure 3):

1. initial time – master sensor sends one byte inquiry whish is equal to requested sensor number;
2. the request is received by the *i*-th sensor, which sends SYNCH byte to the master sensor. At this time the slave sensor starts the acceleration measurements, marked as a gray section;
3. SYNCH byte is received by the master sensor and it is forwarded to PC;
4. SYNCH byte is received by PC
5. (*m*+1)-th byte is received by the master sensor
6. (*m*+1)-th byte is received by PC
7. master sensor sends a request to (*i*+1)-th sensor

The number of the slave sensors and the number of the data bytes are limited from the time, defined by two acceleration samples $\Delta T=1/F_{\text{acq}}$ (F_{acq} – data acquisition frequency):

$$(n+1)(m+1)\Delta t \le \Delta T \tag{4}$$

Therefore, the number of slave sensors is limited according to the equation:

$$n \le \frac{B\Delta T}{10(m+1)} - 1 \cdot \tag{5}$$

On the other hand when the request to (i+1)-th sensor reaches the i-th sensor, it has to accomplish its transmission. The i-th sensor receives the request to the (i+1)-th sensor at a time (n+1+i)Δt, when it accomplished its transmission at a time (m+1+i)Δt. To ensure the above mentioned feature, the next inequality had to be fulfilled:

$(m+1+i)\Delta t \le (n+1+i)\Delta t$

Therefore $n \ge m$. (6)

By combining the inequalities (5) and (6), the following limitation is defined:

$$m+1 \le \sqrt{\frac{B\Delta T}{10}} \cdot \tag{7}$$

The number of data bytes m have to be greater then 6 (2 bytes per each axis).
Therefore the baudrate has to fulfill the inequality:

$$7 \le m+1 \le \sqrt{\frac{B\Delta T}{10}} \qquad \Rightarrow B\Delta T \ge 490 \tag{8}$$

The network communication principle may also be based on the self organized structure. In this case the master sensor does not send requests to the selected slave sensor. The i-th slave sensor monitors the data transmission and when it detects that the (i-1)-th sensor transmits it acceleration data, then it starts to send its acceleration data as (i-1)-th sensor finished its transmission. This requires each slave sensor to send its number which increases the data bytes to (m+2) ones. In this case the equation (4) is modified as follows:

$$n \le \frac{B\Delta T}{10(m+2)} - 1 \cdot \tag{9}$$

IV. SINGLE SENSOR DESIGN

The principle schematic of the single sensor unit is shown at Figure 4. It consists of inertial sensor (for example 3-axis accelerometer LIS3LV02DQ produced by ST [12]), PIC microcontroller with build-in CAN module PIC18F2420, CAN transceiver MCP2551 by Microchip Inc. and a power supply unit.

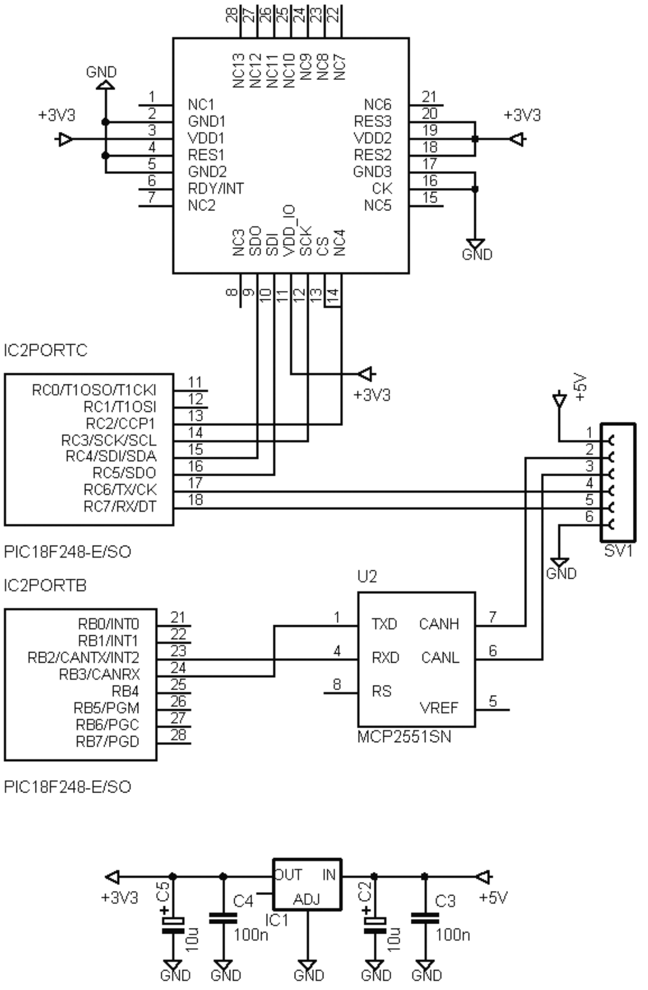

Figure 4. Single sensor schematic

The complete measurement chain is composed by a low-noise capacitive amplifier which converts into an analog voltage the capacitive unbalancing of the MEMS sensor and by three ΣΔ analog-to-digital converters, one for each axis, that translate the produced signal into a digital bitstream. The ΣΔ converters are coupled with dedicated reconstruction filters which remove the high frequency components of the quantization noise and provide low rate and high resolution digital words. The charge amplifier and the ΣΔ converters are operated respectively at 61.5 kHz and 20.5kHz. The data rate at the output of the reconstruction depends on the user selected Decimation Factor (DF) and spans from 40 Hz to 2560 Hz [12].

The communication protocol between the sensor and microcontroller is SPI based. The sensor unit has also the integrated USART module of the microcontroller to establish 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 (L=2,7μH, C=1μF ceramic and C=10μF tantalum electrolytic capacitors). This filter reduced 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, which is capable to deliver 250mA output current. The LDO output is stable when using only 1 µF output ceramic capacitance [13].

The proposed power supply is very flexible because the sensor network may be supplied by USB ports of the personal computer. The supply current is less then 10mA which is far from the USB supply limitations (100mA). So the USB bus may power the sensor network chain because it usually contains less than 8 nodes. In the other cases the sensor network has to be supplied by another external power source.

The dimensions of the single sensor element are clearly visible at Figure 5.

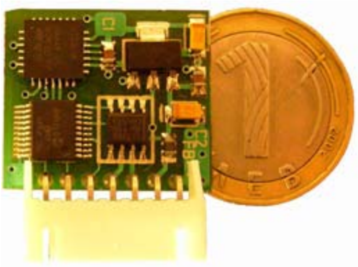

Figure 5. Single sensor element

V. CONCLUSION

The current paper represents a multiprotocol sensor network based on inertial MEMS sensors which may be used for a simultaneous measurement of the linear accelerations of the given set of points. This allows calculation of the relative speed and shifting of the moving parts. The MEMS sensors have digital output (SPI™) and build-in ΣΔ analog-to-digital converters are capable to convert the accelerations to a digital beam with up to 2560 Hz.

The network topology may be configured to the one of the proposed topologies depends of the network structure, communication baudrate, network length, etc.

Our future work is directed to the development of the algorithms based on the system communication principle described above.

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