Study of Asynchronous Mode of Quad Sensor Structure

Rumen Stoyanov Yordanov, Rossen Georgiev Miletiev, Emil Ivanov Iontchev and Ivaylo Petrov Simeonov

Abstract – **The current paper discusses the asynchronous mode of the quad sensor structure to increase the Nyquist limit. This may be achieved using uniform or nonuniform sampling schemes by control of the FSYNC inputs of the MEMS sensors. The studied mode is tested and the results show the possibility to increase the sensor performance using the quad sensor structure.**

Keywords – **quad sensor structure, MEMS**

I. Introduction

One of the main tendencies in the development of MEMS sensors is directed to the improvement of their parameters especially to reduce the noise and errors, because the measurement accuracy is directly connected with the noise characteristics, sampling frequency, etc.

The MEMS sensors are widely used in different applications like free-fall detection, precise tracking [1], kinetic measurements [2], tilt measurements [3], vehicle vibration monitoring [4], antitheft and many others. These applications require low cost MEMS sensors but their noise parameters are very inferior respect to the aviation or military sensors [5]. In our previous paper [6] we described the quad sensor structure and the simulation results of the noise reduction in respect to the single sensor parameters.

The current paper discusses the working modes of the quad sensor structure, especially the uniform sampling asynchronous mode towards enhancement of the frequency limit of the sensor structure. It is shown that the quad sensor structure may increase the Nyuquist limit up to 4 times according to the single sensor one.

II. Quad Sensor Structure Modes

The quad sensor structure is based on MPU-6000 MEMS sensors which combines a 3-axis gyroscope, 3-axis accelerometer, and a Digital Motion Processor™ (DMP). It consists of four identical MEMS inertial sensors Q1÷Q4, multiple output clock generator and microcontroller with integrated USART interfaces to send the data to PC (Figure 1). The choice of the MPU-6000 MEMS sensors is based on the FSYNC (Frame synchronization) input. The external sync signal connected to the FSYNC pin may support image, video and GPS synchronization [7]. All ICs are clocked by the multiple output clock generator which may distribute five ultra low jitter clocks from a crystal input. Four of these 5 clocks are used in the quad sensor structure and the fifth one is connected to the microcontroller clock input.

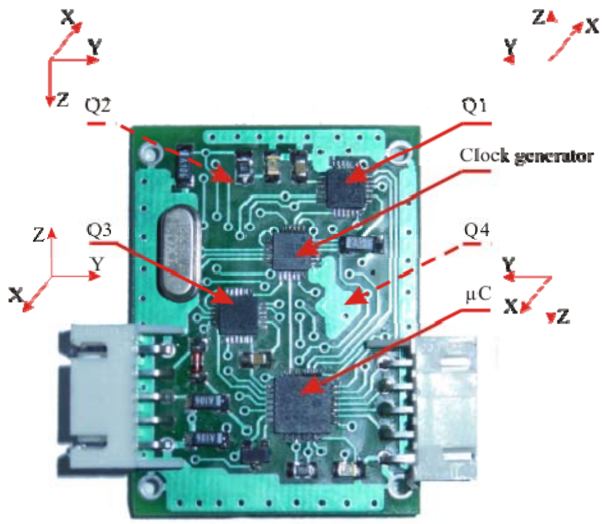


Figure 1. System top view

The working modes of the quad sensor structure may be summarized as follows:

I. Synchronous mode

The synchronous mode is distinguished with simultaneous sampling of the signal for all four sensors (Figure 1a). This mode is realized by a simultaneous activation of the FSYNC inputs of the MEMS sensors. This action is possible because all FSYNC inputs are connected to the same port (PORTA) of the microcontroller [6] and only one instruction is required to set all PORTA outputs simultaneously. This mode may be used for the different signal processing purposes such as:

1. Synchronous one sensor mode

Synchronous one sensor mode is used for the noise reduction of the MEMS sensors [6], which distinguish with a high noise level. This noise consists of low and high frequency components, which influence the measurement values. The high frequency noise is recognized as a Gaussian white noise, while the low frequency one has a high correlation value.

2. Synchronous multisensor mode

Rumen Yordanov is with the Faculty of Electronic Engineering and Technologies at Technical University of Sofia, 8 Kl. Ohridski Blvd, Sofia 1000, Bulgaria, E-mail: yordanov@tu-sofia.bg

Rosen Miletiev is with the Faculty of Telecommunications at Technical University of Sofia, 8 Kl. Ohridski Blvd, Sofia 1000, Bulgaria. E-mail: miletiev@tu-sofia.bg

Emil Iontchev is with the Higher School of Transport “T. Kableshkov” 158 Geo Milev Street, Sofia 1574, Bulgaria, E-mail: e_iontchev@yahoo.com

Ivaylo Simeonov is with the Faculty of Computer Systems and Control at Technical University of Sofia, 8 Kl. Ohridski Blvd, Sofia 1000, Bulgaria, E-mail: ivosim@abv.bg

The synchronous multisensor mode is used in the diagnostics of the vibration processes because the signal processing of the inertial data from the four sensors may calculate the amplitude and the phase of the vibration and the vibration source also may be localized according to the inertial acceleration parameters. This mode is based on the signal processing of the MEMS sensor array.

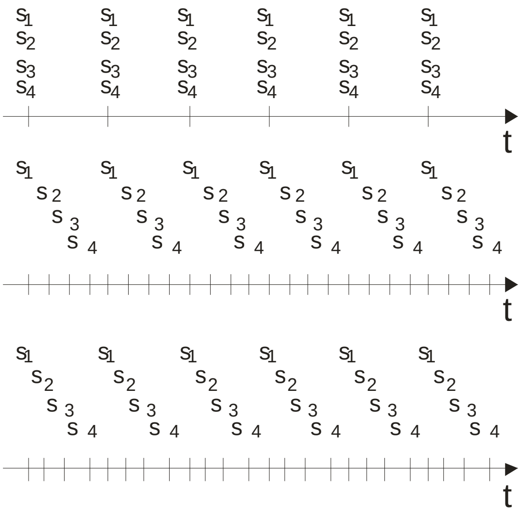
II. Asynchronous mode

1. Uniform sampling asynchronous mode

The uniform sampling asynchronous mode is realized when the FSYNC inputs of the MEMS sensors are set consecutively at the given period of time (Figure 1b). If the sampling frequency of the single sensor is equal to F_d then the sampling frequency of the sensor array structure is equal to $4F_d$. This circumstance allows increasing the Nyquist limit four times in relation to the single sensor.

2. Nonuniform sampling asynchronous mode

The nonuniform sampling asynchronous mode is realized when the FSYNC inputs of the MEMS sensors are set using nonuniform sampling scheme (Figure 1c). The nonuniform sampling may be used to increase the Nyquist limit and detect very high frequency components in the signal spectrum.



a) Synchronous mode
b) Uniform sampling asynchronous mode
c) Nonuniform asynchronous mode

Fig. 1. Working modes description

III. QUAD SENSOR SIGNAL PROCESSING

The asynchronous mode of the quad sensor structure is tested by simulation of the “jump” of the tram wheel through the cotter on the tram rail. The geometric parameters and the cotter position are shown at Figure 2. This situation is chosen to produce high frequency oscillations which are measured by the quad sensor structure [8]. The sampling frequency of the single sensor is equal to 25Hz and the FSYNC sensor inputs are set using uniform sampling asynchronous mode (Figure 1b) which increases the sampling frequency of the structure to 100Hz.

The experimental data are obtained and processed in the MATLAB environment.

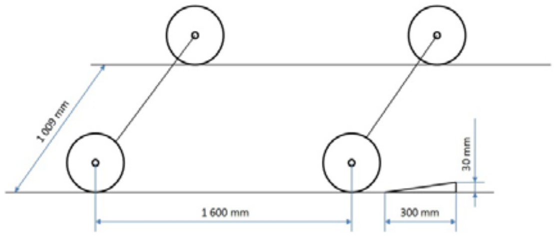


Fig. 2. Experimental diagram

The data from the four sensors are combined and the signal waveform and result spectrum densityare given at Figure 3 and Figure 4 respectively.

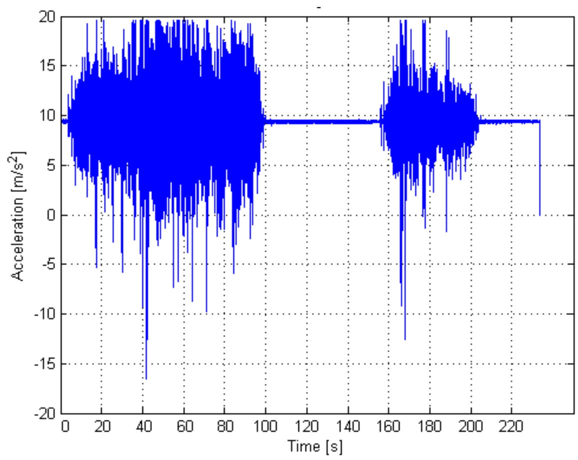


Fig. 3. Time domain signal representation

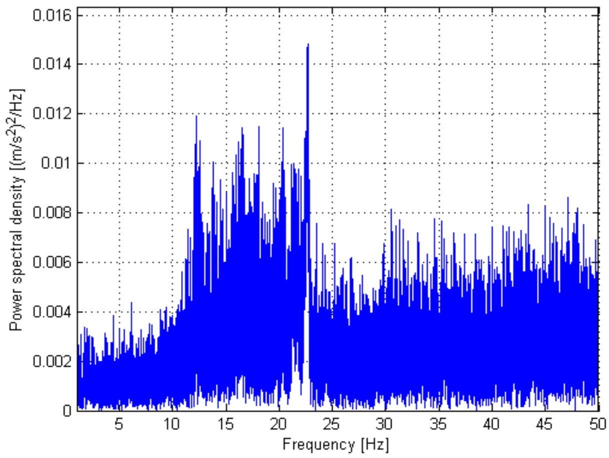


Fig. 4. Frequency domain signal representation

It is clearly visible that the main frequency components are situated between 12 and 22Hz and they are correctly established when the result sampling frequency of the structure is equal to 100Hz. When the sensor data are processed individually and the sampling frequency of the single sensor is equal to 25Hz then the main frequency components exceed the Nyquist limit and the signal spectrum results are incorrect (Figure 5).

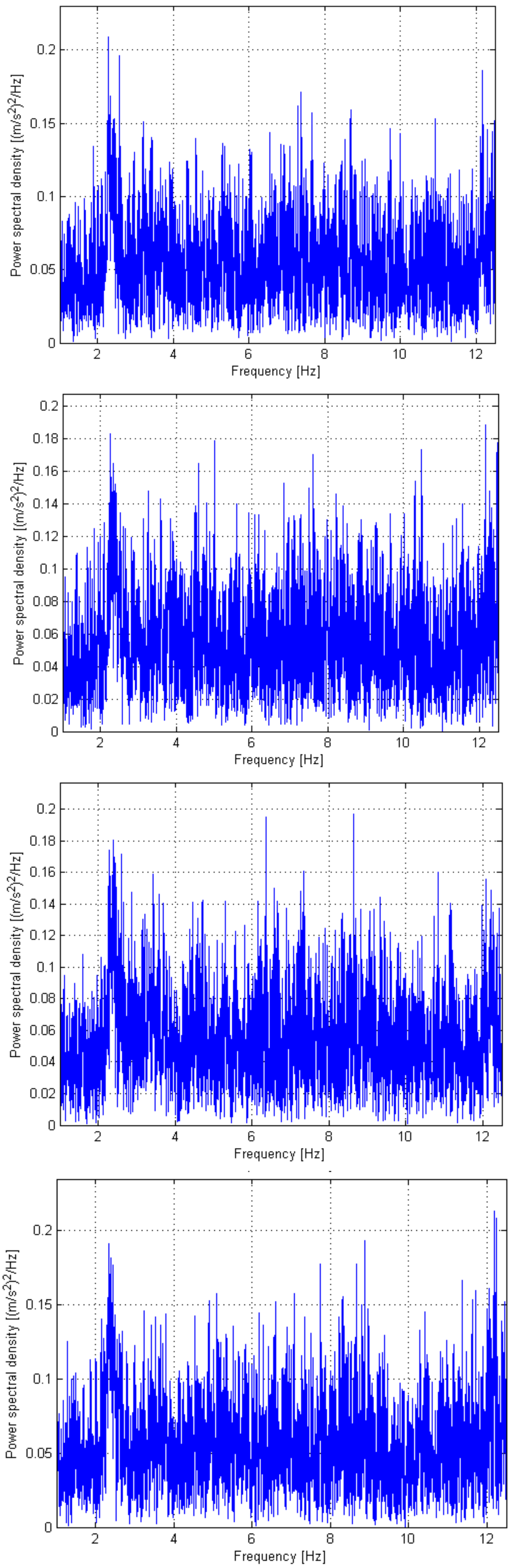


Fig. 5. Power spectrum density of the single sensor Q1-Q4 respectively

IV. CONCLUSION

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 and many other applications.

The paper discusses the quad sensor structure which is capable to improve the noise characteristics and parameters of MEMS inertial sensors. This structure may be also used to increase the sampling frequency four times according to the sampling frequency of the single inertial sensor if the FSYNC pulses are distributed evenly at the time. Therefore the quad sensor structure is very flexible towards signal processing of the inertial data from the integrated sensors and the working modes may be switched over according to the application requirements.

ACKNOWLEDGMENT

This paper was prepared and supported by R&D at Technical University of Sofia under contract number No.141PR0008-03.

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