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Section: Technologies of Geodesy and Cadastre

Analysis of the use of integrated IMU module for vibration measurements

Dariusz Tomaszewski, Michał Śmieja

Uniwersity of Warmia and Mazury,Oczapowskiego 2, Olsztyn 10-719, Poland

Abstract

Lots of modern engineering structures are exposed to vibrations that can cause violation to their integrity. Reducing or eliminating the risk of oscillation protects the value of buildings and infrastructure. The devices available nowadays, however, are often too slow to detect the emergence of some dynamic factors, contributing to structural damage. This work is devoted to the analysis of the use of three – axis inertial sensor ADIS16354, made by Analog Devices, for detecting and examining vibrations to which these objects are exposed. The following study presents the initial test measurements and the results of conducted calculations.

Keywords: vibration measurements; accelerometer; tower; bridge; overpass.

1. Introduction

Along with the development of civilization and technological advancement, people began to erect larger and more complex structures (e.g. very long bridges, masts, towers etc.). These structures can be exposed to very slow displacements and deformations arising from changing solar exposure, meteorological conditions etc. but they may also be subject to vibrations resulting from wind exposure, traffic, seismic activity. If the structures are not properly examined and the results of above mentioned factors are not eliminated in time, it can cause instability or simply destruction. In recent years, many measurement strategies have been developed to monitor the behavior of engineering structures (high rate GPS, laser measurements, ground-based interferometric radar). Most of these strategies require the use of expensive equipment and that is why the survey is being hindered by the lack of proper apparatus. Due to the development of miniaturization in electronics, it is possible to perform high quality observations with the use of very small and relatively inexpensive devices (accelerometers, gyroscopes, GPS integrated modules). An appropriate combination of these sensors allows to detect the results of mentioned effects. Such integrated GPS/IMU evaluation platform was created at the Institute of Geodesy, University of Warmia and Mazury in Olsztyn.

It consists of two measuring units, GPS integrated module LEA-6T and ADIS16354 three – axis inertial sensor. The LEA-6T receiver is installed to determine the occurrence of slowly progressing deformations. The second module is a high precision MEMS IMU unit that was developed by Analog Devices. Its construction allows to measure angle rates and accelerations over three axis with a sample rate greater than 100 Hz. ADIS16354 speed enables for frequent position calculation during the vibrations not exceeding 5 Hz, as in the case of engineering objects. Due to its high performance and accuracy, it is used as a vibration measurement module within constructed GPS/IMU evaluation platform. The following paper presents the preliminary tests of ADIS16354 IMU sensor for vibration measurements at different range of frequencies, generated in the laboratory conditions.

2. Description of GPS/IMU evaluation platform.

The ADIS16354 three – axis inertial sensor is a high quality measurement module, consisting of an accelerometer and gyroscope. Its value ranks in the average price range of sensors available on the market. Selection of the measuring unit was guided by its ability to perform measurements at specific sampling rate with high resolution of readings. The construction

Corresponding author: Dariusz Tomaszewski. E-mail address: dariusz.tomaszewski@uwm.edu.pl
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and method of recording data used in the device allow to carry out readings at the frequency of up to 350 Hz. Working temperature of ADIS16354 ranges from –20 °C to 70° which enables to use it under every weather conditions. Accelerometer implemented within the device can measure accelerations with a dynamic range ±1.7 g and with initial sensitivity 0.4625 mg/LSB. At the same time, installed gyro measures angular rate with dynamics ranges from ±75 °/s to ±300°/s with smallest possible sensitivity of 0.01832 °/s/LSB. These technical conditions allow to achieve high accuracy during subsequent calculations. The ADIS15653 is presented in Figure 1.

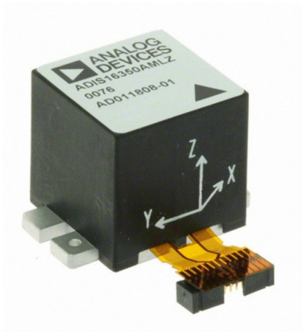

Fig. 1. ADIS16354 high precision three – axis inertial sensor

To control the readings, described measuring inertial sensor was installed as a part of GPS / IMU evaluation platform. Constructed device performs synchronized readings of GPS and IMU sensors and this solution enables to record inertial sensor readings tagged with time obtained from the GPS module. The Schema of measurement platform is presented in Figure 2.

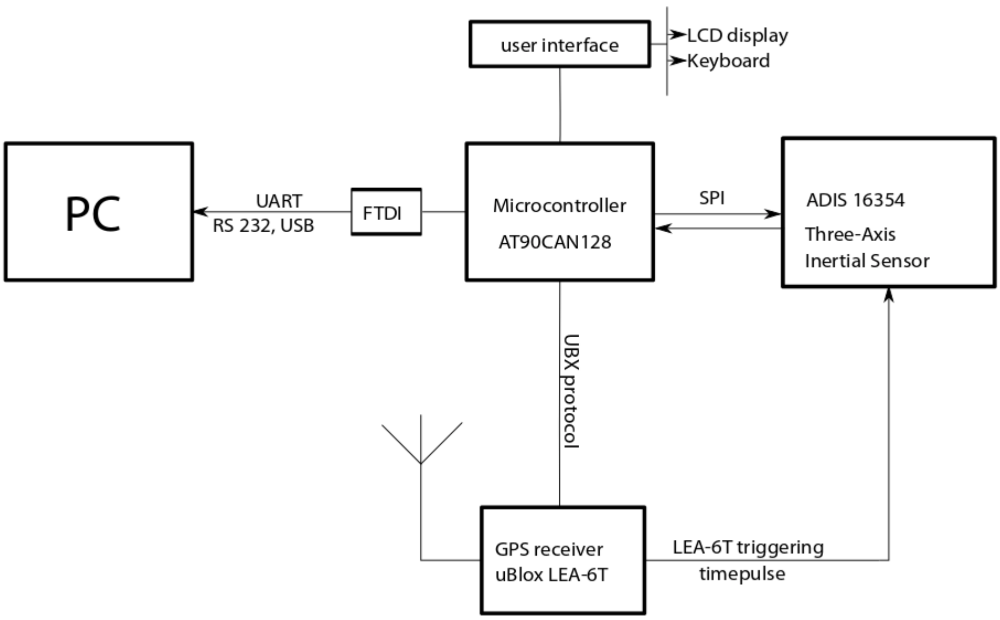

Fig. 2. Functional diagram of the GPS/IMU evaluation platform

Atmel AT90CAN128 micro controller serves as a central unit of the presented device. Its main task is collecting, acquisition and transmission of data obtained from the GPS receiver and ADIS sensors to the computer. LEA-6T is a L1 frequency, MEMS receiver. Its main advantage over other low-cost receivers is, ublox communication protocol which allows to record all raw data (pseudorange, carrier phase, doppler) that are stored during measurement.

After switching the evaluation platform on, LEA-6T receiver starts to transfer the observational data to the microcontroller. At the same time, the PPS signal is sent from LEA to trigger the inertial data acquisition process in request – answer mode. The PPS signal is used to synchronize in time the GPS module data with ADIS sensors readings. Gathered measurement data can be received and visualized in two different ways. Constructed evaluation platform has the appropriate interface for constant recording and for RS 232 communication with PC. There is a special software designed for further verification and processing of obtained data.

3. Design of the testing device.

To perform the laboratory tests of ADIS 16354 sensor usefulness for vibration measurements, a testing device was designed and then constructed. The schema of this device is presented in Figure 3.

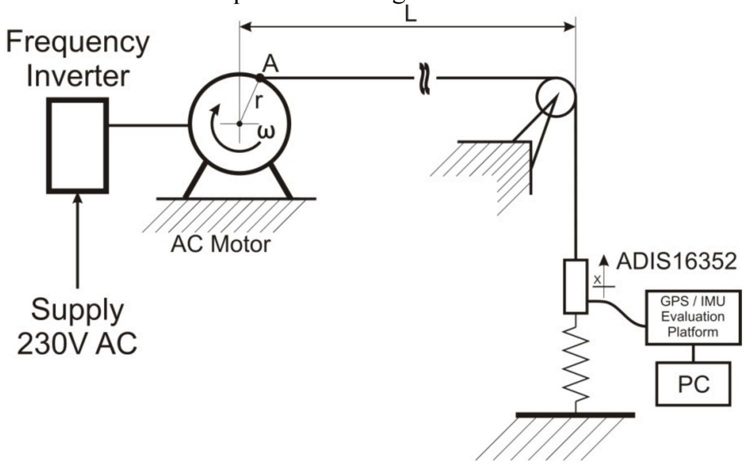

Fig. 3. The schema of testing stand

The device consisted of the frequency inverter that was used to control the revolutions of an asynchronous motor. The motor was rotating the disc at a controlled frequency. The ADIS IMU sensor was connected to the disc with the use of elastic band. The applied quotient of lengths L (elastic band length) and r (eccentricity), enables to assume that the movement of IMU can be described by sine wave equation (1).

$$x = A\sin(\omega t + \varphi) \quad (1)$$

where:
A – amplitude,
ω – angular frequency [rad/s],
φ – phase [rad],
t – time [s].

The stabilizing element in the form of a string was used to prevent the free motion of sensor in a gravitational field for accelerations exceeding g.

The asynchronous motor generates vibration with a frequency corresponding to the vibrations of engineering structures (from 0.5 Hz to 5 Hz). Frequency inverter applied in the device allows to steer the motor revolutions according to the formula [1]:

$$n = \frac{60 * f}{p}(1 - \mathrm{s}) \quad (2)$$

where:
n – number of motor revolutions per minute,
f – frequency of the electrical current,
p – number of pole pairs,
s – slip of the motor.

The experiment required the selection of values and the following numbers were assumed, r = 2.5 cm and L = 2 m. Described set of devices has been used to generate several sessions of vibration with an amplitude equal to 5 cm.

4. Obtained results

The aim of the study was to examine the possibility of vibration measurement using the ADIS16354 module. An experiment was carried out in 7 stages. At these stages the short (30–60 sec) sessions of vibrations on frequencies 0,5 Hz, 1 Hz, 2 Hz, 3 Hz, 4 Hz, 5 Hz were generated with the use of testing device [4]. Selected frequencies belong to the most common scope that is recorded during the vibration tests of engineering structures [5]. The diagram of these vibrations is presented in Figure 4.

On vertical axis of Figure 4 there are accelerations measured by ADIS16354 depicted in units of raw observation data recorded by the device. The horizontal axis depicts the time of measurement in seconds.

At the second stage of this experiment there is a rapid continuous change of measured frequency from 0,5 to 8 Hz, that lasts over 5 s. Such a leap was made to examine the device's sensitivity to unexpected changes that can occur during vibrations of engineering structures (earthquake, train passing the bridge) [3]. The changes in frequencies can be seen on the spectrum of measurement in Figure 5.

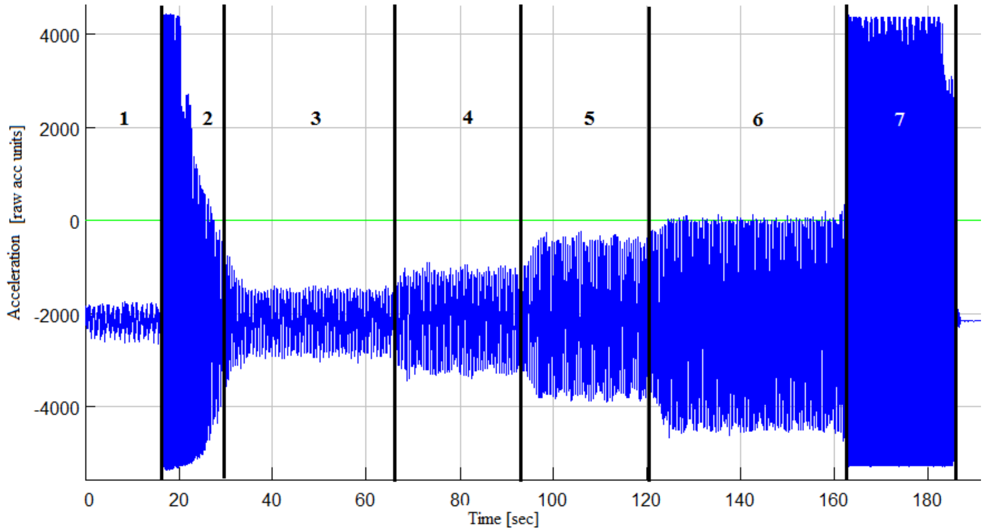

Fig. 4. Graph of measured vibrations

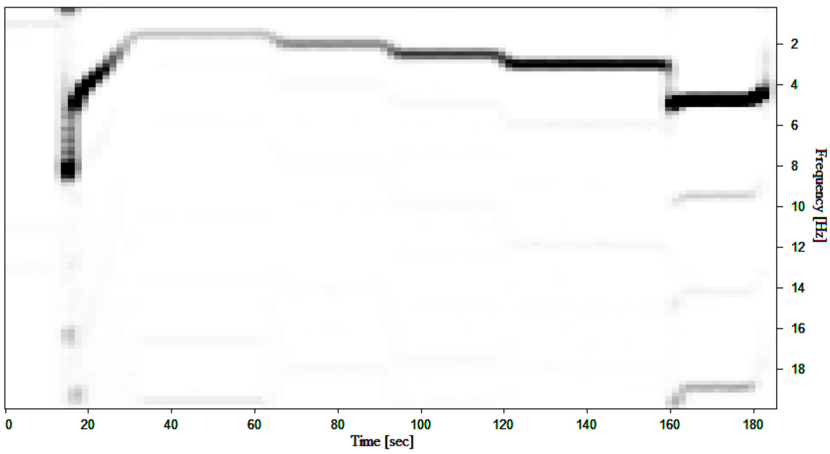

Fig. 5. Graph of the spectrum of measured vibration

On the spectrum graph one can observe how the frequency of measured vibration changes during the test. The color intensity shows that the variation in amplitude of acceleration corresponds to the values in Figure 4.

The graph presenting the frequency of device vibrations was made with a use of FFT algorithm [2]. The spectrum of the signal in presented in Figure 6.

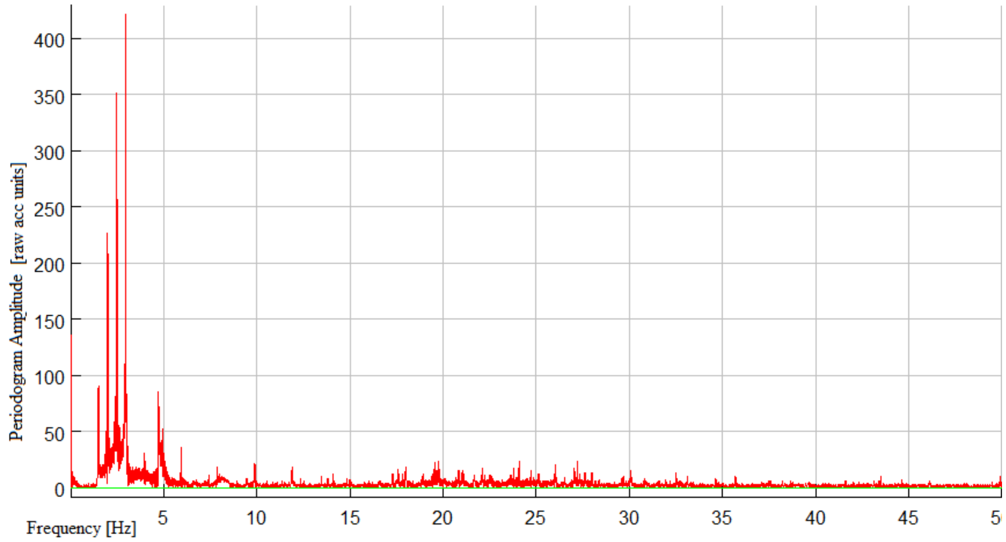

Fig. 6. Graph of the frequency of measured vibrations, performed with FFT method

According to Figure 6. it can be noticed that the readings with the highest amplitude and gain are the ones that were laboratory generated (1Hz, 2Hz, 3Hz, 4Hz, 5Hz). The graph presents the higher frequencies as well. In accordance with the ADIS 16354 datasheet the value of output noise equals 4.7 mg with density 0.24 $mg/\sqrt{Hz}$. On the basis of these figures, it can be concluded that the appearance of higher frequencies is the result of measurement noise. To obtain final results, the data was filtered with FTT-based low-pass filter with cutoff frequency of 6 Hz. Selected FTT – based filter gives very accurate results for sinusoidal wave filtering. The shape of measurement graph before and after filtering is presented in Figures 7 and 8.

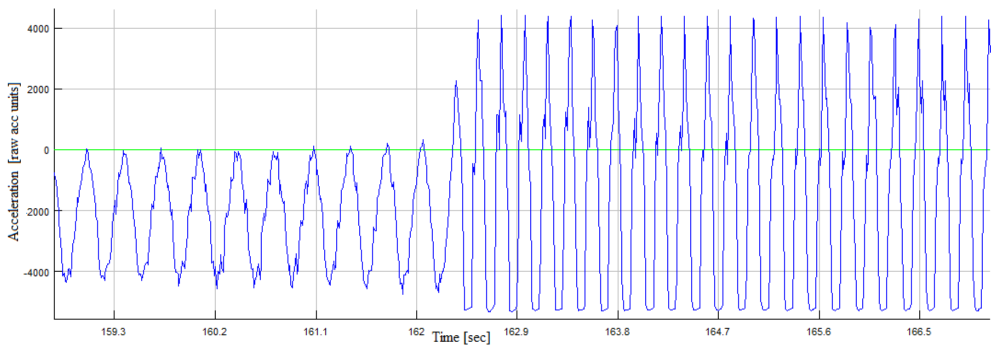

Fig. 7. Measurement data before filtering

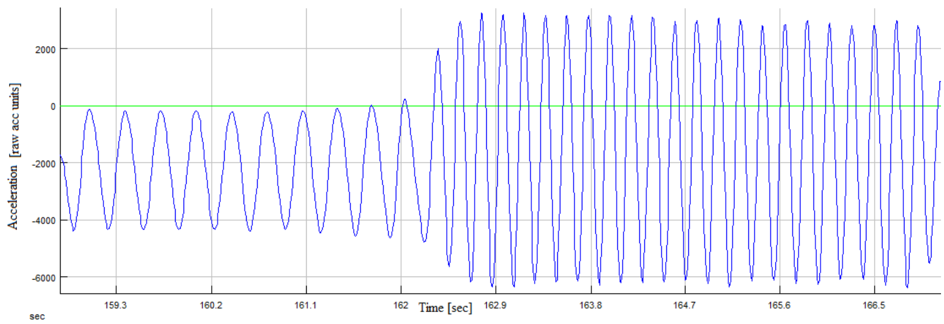

Fig. 8. Measurement data after filtering

On both graphs there is the same fragment of recorded vibration. Similar to Figure 4 the vertical axes are in the units of raw observational data from accelerometer. Horizontal axes depict the time of measurement. The filtered data in Figure 8 do not contain any operational noise, as it does before filtration in Figure 7. Three dimensional graph of measurement data including frequency, time and amplitude of measured acceleration is presented in Figure 9.

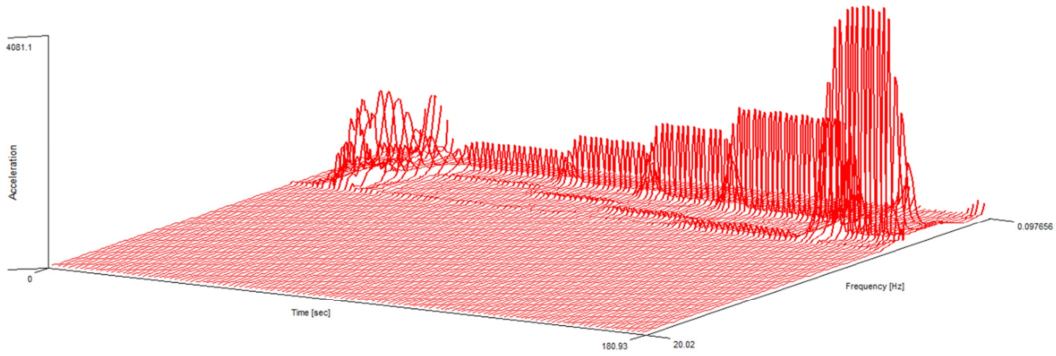

Fig. 9. Measurement data after filtering

On the basis of obtained accelerations we can compute the amplitude of measured vibration. To perform that task the value of second order-integral of acceleration over time was calculated. For all assumed frequencies the obtained value of amplitude was 50 mm. The fragment of signal data with calculated amplitude is presented in the following figure.

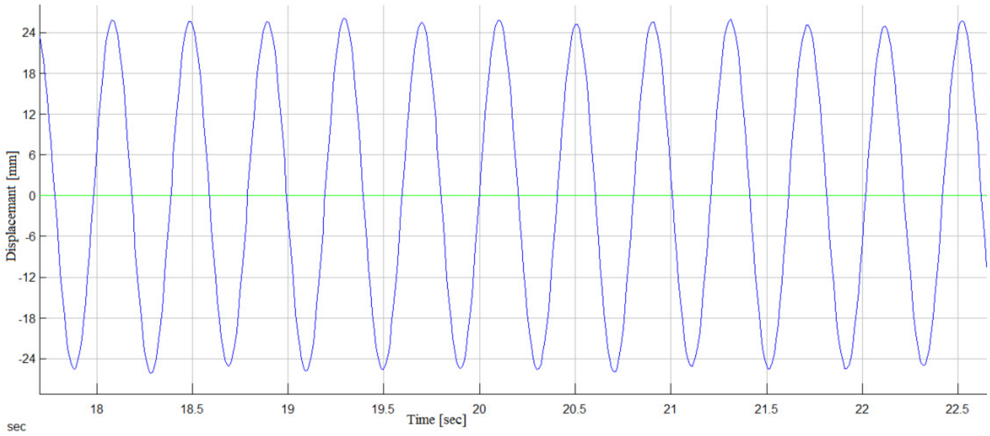

Fig. 10. Vibration with calculated displacements

The horizontal axis represents the time of measurement while the vertical axis corresponds to the values of IMU displacements in millimeters.

5. Summary

Applied accelerometer is a high precision device which is very sensitive to movement variations. Carried out tests show that it is possible to perform accurate and precise measurements of structural vibrations with ADIS16354 IMU sensor. The study indicates that the device can be used for detecting changes in behavior of an object from 1 Hz to 5 Hz without losing the character of the measured impact. At the same time, it allows to determine the amplitude of the measured vibrations with a millimeter accuracy. Performed laboratory tests indicate that the ADIS 16534 inertial sensor can be used as a vibration measurement unit for engineering structures. It is planned that in the future, measurements of bridge construction behavior will be conducted with a use of fully functional GPS/IMU evaluation platform.

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