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ASSESSMENT OF THE APPROXIMATION ACCURACY OF THE POINT TRAJECTORY WITH USE OF INERTIAL SENSORS

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Abstract: *In this work, the possibilities of point trajectory evaluation with use of commercial inertial sensors pack, IMU (Inertial Measurement Unit), are presented. The first step was to assess the acceleration frequencies for indicative fast movement of the 2R arm. During this move, the sensors pack was attached to the end of the arm, the nature of the arm movement similar to a fast swing of a human arm. Based on the received data, the sampling frequency has been determined. Afterwards, the real measurement has been taken using a linear guide. When the measurements were being taken, the IMU was not able to rotate in the gravitation field. The recorded measurements have been processed with use of the time window double integration algorithm. Subsequently, the calculated data from experiment has been compared with the real displacement of the IMU.*

Keywords: **IMU, trajectory tracking, AHRS**

1. Introduction

The evolution of mechatronic systems requiring 3D space navigation has led to a need for approximation of the controlled systems way. It is necessary to detect unintended shifts of the controlling object. The accuracy of shift approximation is often less important than its detection. For example, if the mobile robot (Balchanowski, 2016) is sliding off a slope as a result of traction loss, or if the mobile robotic arm (Szrek, Balchanowski, 2017) base is unexpectedly moving during its work. Next possible use of the mentioned system is in wheel-legged-robot (Gronowicz et al, 2014), in order to reduce the fuselage shakes.

Detecting unintended shifts of the controlling object is possible with use of devices. These include: RADAR (Sztarski, 1981), LIDAR (SICK), stereoscopic vision cameras sets, such as Kinect (McWerthor, 2017) or Optitrack (OptiTrack). Triangulation or trilateration systems use radio frequency waves (calypteaviation.com) or optical flow sensors (people.ece.cornell.edu). One characteristic that connects all these systems together is the necessity of finding the reference point in the global coordinate system. If precision information about tracking point movement is not necessary, the shift approximation on the basis of measured acceleration should be sufficient.

To determine the movement on the basis of a triaxial accelerometer, the information about sensors' orientation is necessary. The sensors' orientation is calculated using a 9 DOF IMU. The orientation of the IMU is described by the quaternion or Euler angles. Aftera precise orientation determining it is possible to subtract the gravity vector from measured acceleration. The accuracy of this operation is very important, the residual gravity in accelerometer indication leads to incorrect shift calculation. If the accuracy of gravity vector determining is sufficient, it is possible to calculate the object shift with the use of a double time window integration algorithm. High accuracy determining of gravity vector is possible during zeroing of the sensors kit. At the same time, the gyroscope drift and magnetic flux vector are calculated. The location where the zeroing procedure took place is the reference point of translation measurement. However, the use of double time window integration algorithm has led to the loss of this point during time of the systems' work.

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2. Development

The basic question during signal processing is to determine the sampling frequency that is consistent with Kotielnikow-Shannon theorem (Kaczorek et al, 2009). During the experiment MiniIMU 9v5 (Leyko, 2010) Sensors kit was used, which have a 500 [Hz] maximum sampling frequency. In order to determine whether the MiniIMU sensors kit's speed is sufficient for measuring the accelerations of investigated movement, the mathematical model of 2DOF robotic was used. It is illustrated in Fig.1. The hypothetic situation was described by Lagrange's equation (Ursel, 2016). In the mathematical model, torsion springs Cs1 and Cs2 were used as drives. The variable tension of Cs1 and Cs2 was used to move the 2DOF arm during the simulation. The simultaneous equation was solved by means of the explicit method (Munoz et al, 2017). The motion of hypothetic arm was created to be similar to a fast swing of a human arm. The trajectory of the arm points are shown on the Fig. 2. The time of drives' position changing is 0,5 [s]. Oscillations that are visible in the Fig. 2 are a result of fast drives stopping and torsion springs Cs1, Cs2. Information about acceleration of point C was used to perform the Fourier transform (Fig. 3). On the basis of Fig. 3, it can be concluded that the main frequencies of point C acceleration are not more than 50 Hz. The low frequency character of measured acceleration (Fig. 4) confirms that simulation results are credible. It is very important, especially in the event that the measured data are garbled by high frequency noise, e.g. noise from poorly lubricated parts or gears. In this case, it is possible to reduce the influence of noise by using the low pass filter.

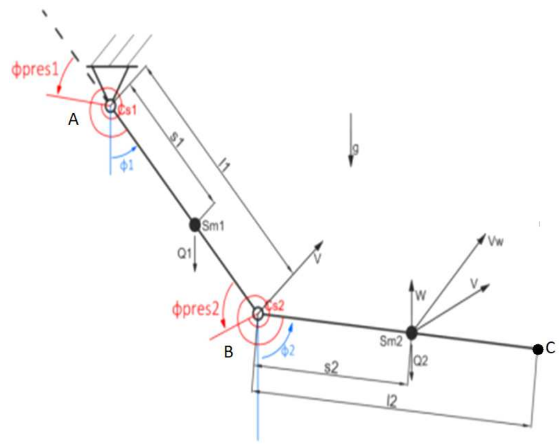

Fig. 1: Mathematical model of 2DOF arm.

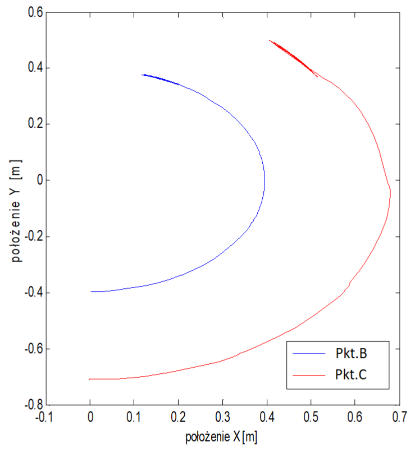

Fig.2: The point B and C path of 2DOF arm

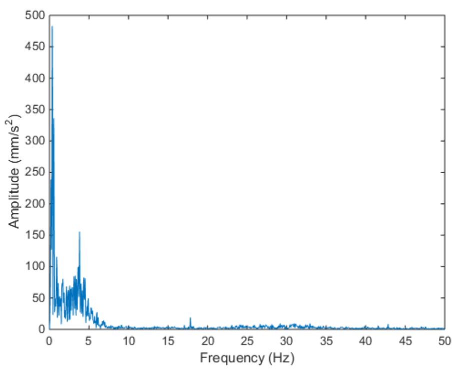

Fig.3: Amplitude frequency spectrum of measured Y axis acceleration

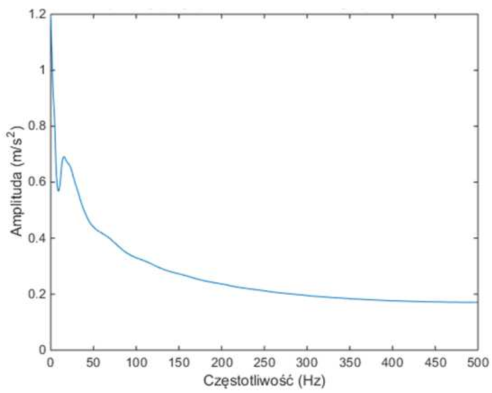

Fig.4: Amplitude frequency spectrum of point C

3. Development – IMU Measurements

In order to determine the degree of similarity between approximated shifts and given shifts, the followed experiment was conducted. The tested sensors kit was sliding on a linear guide, along the Y axis direction of the tested accelerometer. The Y axis was perpendicular to gravity vector, allowing for minimal gravity influence on Y axis's acceleration read-outs. The measurement kit is shown (Fig.8), it consists of a linear actuator with a MiniIMU9v5 sensor kit, a servo and a displacement measuring incremental encoder. The IMU orientation remained unchanged and, as a result, the influence of poor gravity vector subtracting was negligible. During the experiment,the IMU sensors kit was driven two times in both directions from the start point. The amplitude of IMU shifts was 120 [cm]. Obtained data are shown in Figures: (Fig.4 - Fig.7).

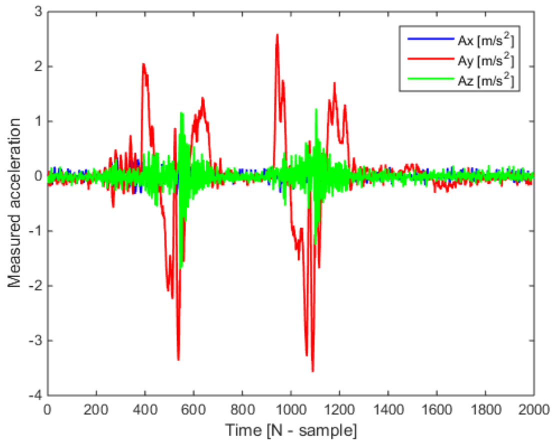

Fig. 5: Measured accelerometer data

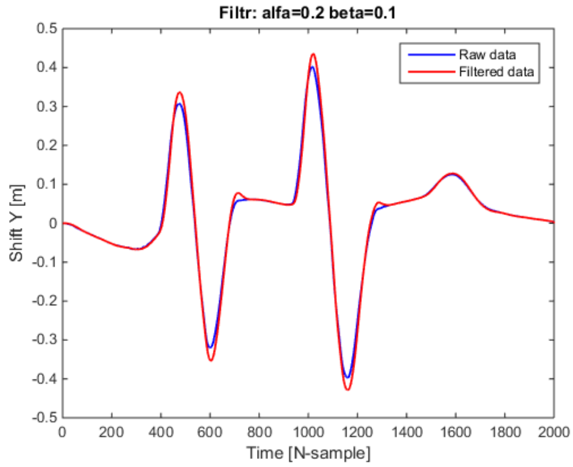

Fig.6: Calculated Y axis shift

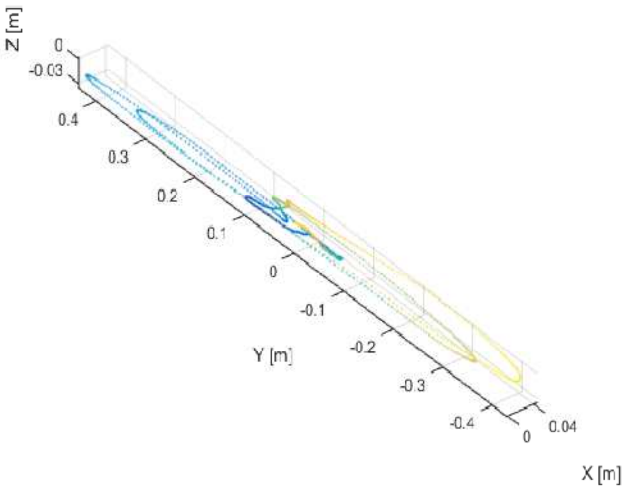

Fig.7: 3D space graph of full three axis calculated shifts

Fig.8: Measurement kit.

The data provided by the accelerometer was filtered using the Alfa-Beta algorithm. It has helped to eliminate high frequency noise resulting from the structure of the accelerometer. After obtaining well filtered data, the shifts were calculated using the time widow double integration algorithm. The length of time window has determined how many samples are remembered by integration algorithm. This method allows one to reduce the influence of the asymmetry of processing acceleration. If the fields under positive and negative side of measured acceleration graph are different, it results in poor acceleration symmetry during measurement. Ideal symmetry of measured acceleration indicates that tracking object was stopped after movement. The size of time window has been determined experimentally from 500 samples. After obtaining the shifts graphs, the comparison between calculated and ideal delivered shifts has been made (Fig.8). A 3D space shifts graph, is shown in Figure (Fig.7), was made using all three axis readings. In order to determine the degree of sampling period correctness, fast Fourier transform was performed (Fig.4).

4. Conclusions

Asymmetry of acceleration distribution is likely due to gravity vector influence. The ideal precision subtracting of gravity vector is possible only when the sensor kit is fully motionless. If the sensor kit is moving, the approximated subtracting of gravity vector is possible only with using full AHRS (Altitude Heading Reference System) readouts. The real minimal error of AHRS system that was tested was approximately +/- 5˚. As a result, the accurate shifting acceleration readouts is severely hindered.

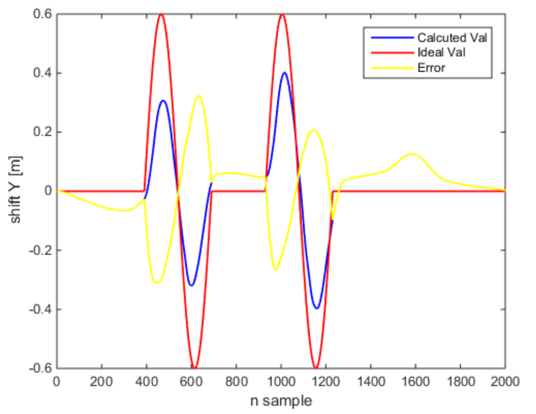

Fig.9: Comparison of shift results with ideal delivered shift

Obtained shifts results are much different than the expected translation effect, and, with the use of the describing method, they could not be used directly to judge the controlling systems. The obtained graph provides information only about the character of occurred object translation. In Figure (Fig.9), the yellow line indicates the error of shift calculation and ideal shift of accelerometer. Its maximal value was 53% of slider range.

The frequency analysis of investigated acceleration shows that high frequency noise influence is not a significant factor that impedes the shift calculation based on acceleration. The content of high frequency components of amplitude frequency spectrum is much lower than low frequencies waves. In order to obtain an accurate trajectory calculation of investigated IMU sensor kit, it is essential to precisely calculate the gravity vectors and subtract them from full acceleration readout.

References

Bałchanowski, J. (2016) Modelling and simulation studies on the mobile robot with self-levelling chassis. *Journal of Theoretical and Applied Mechanics*, 54(1), pp.149-161.

Calypte Aviation. (2014) *Radionawigacja, cz.1 radiowe pomoce nawigacyjne*. [online] Available at: http://calypteaviation.com/2014/10/radionawigacja-cz-1-radiowe-pomoce-nawigacyjne/

Gronowicz, A., Sperzyński, P., Szrek, J. and Jakubiak, J. (2014) Wheel-legged robot - construction and obstacle detection sensors. In: *New advances in mechanisms, transmissions and applications*, proc. of the second conference MeTrApp 2013. Mechanisms and Machine Science, ISSN 2211-0984, 17, pp.191-198.

Kaczorek et al. (2009) *Podstawy Teorii Sterowania*. WNT.

Leyko, J. (2010) *Mechanika Ogólna - Dynamika Tom 2*. PWN

McWerthor, M. (2010) *What Is Inside a Kinect* [online] kotaku.com. Available at: https://kotaku.com/5682075/whatsinside-a-kinect

Munoz, J., Premerlani, W., Julio, J. and Weibel, D. (2017) *Oprogramowanie*. Available at: https://github.com/pololu/minimu-9-ahrsarduino

OptiTrack (2018) *V120:Duo*. [online] Available at: optitrack.com, http://optitrack.com/products/v120-duo/

SICK (2018) *MRS1000*. [online] Available at: https://www.sick.com/pl/pl/rozwiazania-pomiarowe-i-detekcyjne/czujniki-3d-

Szrek, J. and Bałchanowski, J. (2017) Modelling and simulation researches of dynamics of translational parallel mechanism. In: *Engineering Mechanics 2017*, Brno Technical University, Brno, pp. 974-977.

Sztarski, M. (1981) Radary. MON

Ursel, T. (2016) *Stabilizacja Efektora Manipulatora Mobilnego z Użyciem Czujnik.w Inercyjnych*. Master's Thesis. Wrocław University of Science and Technology, Wrocław.