Synchronization of Measurement Data with the Reference System

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Abstract. Today, most devices are equipped with sensors that enable the collection of process data that influences the control parameters. Sensors are to replace human senses and provide information from the environment to the control algorithm. In many cases, the sensors used are subject to reference measurements from an external diagnostic system, which is to eliminate possible errors in the installation of sensors or the operation of the control algorithm. For this purpose, external systems are most often used that do not duplicate any errors from the sensors used. Most often these are vision systems that are based on the measurement of markers mounted on the tested object. The most important effect of the reference system is the verification of sensor data or the correction of the control algorithm that processes sensor data. Often, when comparing two measurement systems, there is a problem with unequal sampling rates. The main problem is comparing the two graphs as the number of data / arguments is different. In order to compare two graphs, many methods are used to reduce or extend the number of arguments. The use of data expansion or reduction methods may result in an additional error. In this article, methods of reducing measurement data from IMU sensors and encoders connected to servo motors will be presented. There is a significant difference in sampling time for the two measurement systems shown. At the beginning, the methods and applications of algorithms in the literature will be discussed. Then, the measurement data will be compared with the data processed by the algorithms. The final point of work will be the combination of the data processed by the algorithm with the measurements. Two measurements were also compared in order to estimate the measurement error and a comparative algorithm was proposed.

1. Introduction
The synchronization process of two graphs containing measurement data consists of two main stages: synchronization of the sampling frequency and elimination of the time shift between the graphs. The first step is to synchronize the two graphs by knowing the sampling frequency of the two devices - the measuring and reference system. The article presenting the synchronization of two signals generated by an unknown dynamical system is [1]. The synchronization takes place through a hybrid chaotic system, which was considered in [1] with the use of two synchronizations: identical synchronization (IS) and generalized synchronization (GS). The developed model of the hybrid synchronization system was created by integrating the IS and GS systems. The study of the synchronization of coupled oscillatory systems and the relationship between phases and frequencies of signals is discussed in [2]. The article [2] presents methods of
phase and frequency estimation on the basis of time series as well as methods of detection and quantification of the tested synchronization. The research in [2] was carried out on the basis of data from the verification of body posture in healthy patients and patients with neurological diseases. The application of the Kuramoto synchronization algorithm was applied in [3] to the analysis of coupled nonlinear dynamical systems. An overview of the application of synchronization methods in the field of biological signals is presented in [4], in particular, the issue of quantification is discussed. Combining nonlinear and chaotic systems based on common signals on the basis of the sign of sub-Lyapunov exponents was presented as a synchronization method in [5]. The study of signals measured from neural systems using the synchronization likelihood (SL) is presented in [6].

The presented methods of synchronization related to specific algorithms, while in this paper the first stage of synchronization is down-sampling. The article [7] presents methods of recognizing human physical activity based on Down Sampling One Dimensional Local Binary Pattern (DS-1D-LBP). Subsequent use of down-sampling in the OptD method allowed to reduce the points obtained by LIDAR [8]. The next article that used the down-sampling method to detect planes from a 3D point cloud was [9]. The article uses the octree-based down-sampling method to reduce the number of points. Down-sampling is also used in Deep Convolutional Neural Networks (DCNN) to reduce the number of network parameters [10]. The article [10] proposes an algorithm for the elimination of errors arising during down-sampling by a random shift of the sampling layer taking place during model training. The down-sampling method is also used to eliminate redundant points in the 3D point cloud when measurements are made in different coordinate systems [11]. Article [11] has developed two approaches to the redundant number of points: the first method is planar-based adaptive down-sampling to remove redundant points from areas with high point density while preserving points occurring in areas with lower density, the second method is to remove peak points in the Gaussian sphere [11]. The down-sampling algorithm is also used to remove measurement noise [12]. The measurement noise is identified by down-sampling, then up-sampling and comparing the results with a noisy signal [12]. The last stage of data synchronization after the down-sampling method is applied is the removal of samples resulting from the difference in the time of switching on of two measuring devices. This article uses the cross-correlation method. The article [13] presents a method for normalization of cross-correlation from non-normalized form. In article [14] the temporal autocorrelator was used as a generalized class cross-correlation.

This article will discuss the method of synchronizing two data charts from two measurement systems - the verified and reference system. At the beginning, the model on which the measurements were made, i.e. the industrial robot, will be presented. The model was equipped with IMU sensors (measurement system for verification) and a reference system in the form of encoders installed in the motors. When trying to compare two signals, there is the problem of different sampling rates and differences in the start time of data recording. Synchronization of the measurement data will be performed by applying down-sampling first and then cross-correlation to eliminate differences in the recording start time. The presented algorithm can be used to synchronize and analyze data collected from sensors and data generated from the level of the simulation program [15-17].

2. Real model and measurement system

In the research on the synchronization of two measurement signals, the Fanuc ARC Mate 100iB robot was used - figure 1, where the place of installation of IMU sensors and the location of motors with encoders were marked.
Figure 1 shows the real model of an industrial robot with the marked encoder and IMU sensor from which the measurement data are collected. The encoder is the reference system for measuring with the IMU sensor. Measurement data is collected from the encoder and processed using the control system and LabView software to the value of the rotation angle of a given robot segment. Data from the IMU sensor are collected in the form of angular velocities and linear accelerations and processed according to the dependencies described in [18] to the form of the torsion angle of a given term. Data from IMU sensors are collected with a sampling frequency of 50Hz, while the encoder sampling frequency is 4kHz. Based on the presented data, it can be concluded that there is a significant difference between the sampling frequencies, in addition, the two measurement systems are not synchronized in time, therefore, apart from changing the sampling frequency in the data of one of the measurement systems, the difference resulting from the measurement activation time should also be removed.
Figure 2. Diagram of the measurement data processing and synchronization system.

Based on figure 2, the synchronization process and the resulting comparison of two data sets consists of:

- sampling frequency synchronization,
- cross-correlation – elimination of the shift in time (removal of the difference in the time of measurement activation and deactivation) on the basis of the dependence and the algorithm [19],
- comparison of two measurements.

Using the algorithm presented in figure 2, the Octave program described in the following chapters of this work was developed.

3. Data synchronization
The data intended for the synchronization process are presented in figures 3 and 4.

Figure 3. The values of the angle of rotation of the Fanuc industrial robot element read from the encoder.
Figure 4. The values of the angle of rotation of the Fanuc industrial robot element read from the IMU.

Figures 3 and 4 show the measurements of the torsion angles of the same member of the industrial robot, but read from two measuring systems. Based on the analysis of the graphs, it can be concluded that there is a significant difference in the sampling frequency, which also results from the system documentation.

Figure 5. Compilation of two measurement signals after down-sampling.
Figure 5 shows a summary of the measurement data from the IMU sensor and the motor encoder. The encoder data has been processed by the down-sampling algorithm. It can be concluded from the graph that the measurement with the IMU sensor was activated after the data acquisition system from the motor encoder. Thus, both plots need to be cross-correlation in order to ultimately synchronize both signals.

![Cross-Correlation](image)

**Figure 6.** Implementation of the cross-correlation algorithm on the basis of two signals (IMU and encoder) - the inscription on the graph indicates the number of samples that should be subtracted from a given graph in order to synchronize.

The implemented cross-correlation algorithm, on the basis of the entered two measuring signals (IMU and the encoder) (figure 6), determined the number of samples that corresponds to the time difference between the activation of the measurement by the IMU sensor and the reference measurement carried out by the encoder. The cross-correlation algorithm performed showed an offset of the size of 195 samples of recorded data by the encoder before the IMU sensor measurement system was activated. Therefore, 195 samples should be subtracted from the signal recorded from the IMU sensor to ensure potential synchronization of the two signals. The next step is to combine the two signals and compare them in order to estimate the measurement error with any dedicated algorithm.
Figure 7. Compilation of two measurement signals after the synchronization process has been completed.

Figure 7 shows two signals: IMU and the signal from the encoder. The blue color is the IMU signal, while the brown color is the encoder graph. The measurements were subject to down-sampling and cross-correlation processes. As a result of the cross-correlation algorithm, 195 samples were removed from the IMU signal. Figure 7 shows that the two signals overlap, therefore the correct synchronization of the measurement data took place. It can also be concluded from figure 7 that the algorithm for removing excess samples, which result from unequal shutdown time of the measurement systems, has not been prepared, while the potential algorithm would only include the procedure of removing samples from the signal with a larger number of samples based on the difference in the length of both signals. In the case under consideration, the removal of the samples is unnecessary due to the perfect overlapping of the signals. If there are clear distances between the graphs, an algorithm should be used to calculate the average distance between the graphs, i.e. the average measurement error. An example of such an algorithm is DTW.

4. Conclusions
In this work the algorithm of measurement data synchronization was implemented. The torsion angles of the industrial robot were tested on the basis of data from IMU sensors and encoders. The IMU sensors were the verified measurement, while the encoder was the reference measurement. The problem discussed in the article was the unequal sampling frequency of both measurement systems, which made it impossible to compare the graphs and determine the measurement error. The method proposed in the article for the synchronization of measurements was the method of using
the down-sampling and cross-correlation algorithm to determine the difference of samples resulting from unequal on and off times of the measurement system. Based on the data from both systems, the data synchronization process was carried out, which was very accurate and therefore it was not required to use the algorithm to compare the results in order to determine the measurement error. Subsequent research will consider signals that will not be so well correlated (the article presents sensors that measured the same physical quantities). In case of synchronization errors, an additional PCA algorithm will be applied.

5. References

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