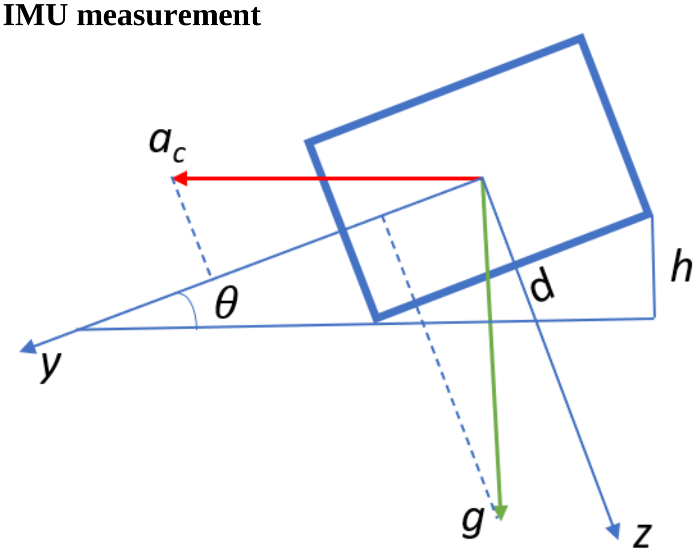
Assignment 1 - Railroad predictive maintenance

Introduction

One of the biggest challenges facing modern day railroads is monitoring the condition of the track itself. It is of interest to monitor the *geometry* of the railroad track, especially the tilt or *cant*. Railroad tracks are exposed to the forces of nature, in particular movement of the ground. The forces affected on the track by passing trains are significant. Over time, these forces can alter the geometry of the railroad tracks, which in turn can lead to derailment of trains. Hence, we want to build a system that can monitor the track geometry based on sensor readings in order to detect such changes.

Measuring track geometry directly is straightforward; in particular, the cant of the track can be measured with a manual spirit level. To avoid manual measurements, a better solution would be to measure the forces that act on the train while driving on the track. One way to measure these forces is so use Inertial Measurement Units (IMU) attached to the train.

IMU measurement



There are two forces of interest in this application: gravity and centripetal acceleration. The latter is given by $a_c = \frac{v^2}{r}$, e.g. driven by the trains velocity and the curvature of the track. The effect of gravity is determined by the angle of the train track. By measuring the acceleration of the train perpendicular to the track, we can estimate these two forces (or accelerations, since we can neglect the train mass).

Model

The forces/accelerations, e.g., gravity and centripetal acceleration, are connected to the measured acceleration as:

$$a = \frac{v^2}{r}\cos\theta - g\sin\theta$$

By knowing the curvature *r* and the traveling velocity *v* of the train, we can compute the *nominal* acceleration we would expect to measure. This can be compared to the *actual* measured acceleration (see Problem 3).

Frequency information

In this task, we will study the frequency information contained in the acceleration data. For this purpose we will use the Fast Fourier Transform (FFT) algorithm.

Model validation using FFT

A common use of the FFT algorithm is to validate models. First, we create a set of simulated data, i.e. use the model to be validated to simulate an expected response from the system. Next, we subtract the simulated from the measured data and study the resulting *residuals,* e.g. the difference between measured and simulated, that which is *not* explained by the model. If the model is an adequate description of the data generating system the residuals should be purely random white noise. Hence, comparing modeled and simulated data by subtraction, and using FFT on the difference, we would expect to see a flat frequency spectrum, i.e., where the energy and therefore information content is evenly distributed across the frequencies.

Data

Attached to this task is an example of a dataset collected from an IMU installed on a freight train (inside the locomotive) that travels up and down Breviksbanen. The data has been provided by CEMIT Digital (a company in Porsgrunn which specializes in railroad predictive maintenance and monitoring). These data will be the foundation of the rest of this task.

The .csv file also contains two columns of data, the measured sideways acceleration for a segment of Breviksbanen and the corresponding simulated sideways acceleration from the simplified model.

The sample rate is 500Hz (needed to run FFT):

Task description

Your task is to solve the following three problems by writing a Python program. Other programming languages may be used instead, but some details for the Python program is specified here: Use the packages in ***Numpy*** to load data and ***scipy.signal*** to execute the FFT algorithm. Use the ***Matplotlib*** for plotting the results. Write a short report on your results. Explain your actions and reasoning, and document and discuss the results. That means you should include necessary figures, plots and codes, but equally important, they should be supported by your explanations, reasoning and discussions. You need to include any references you have been using, and include figure numbers and figure texts. There is no template for this assignment.

We encourage group work, but the submission is individual, so no copy and paste are allowed. In fact, your submissions will be compared to other submissions and other documents found on the internet. A similarity score for each submission will be automatically calculated. Submissions with high similarity score will be evaluated for plagiarism, which can lead to strict consequences for your studies. So, please no copy and paste! However, we understand and accept that the codes will have a high degree of similarity.

Problem 1 - Load data

Load the attached data from .csv file into a ***numpy*** array. Plot both measured and simulated acceleration data on top of each other. Also plot the difference a_sim - a_meas. Discuss in your report any similarity between the two data columns.

Problem 2 - FFT

Run FFT on the acceleration data. What does the resulting frequency spectra tell you? Can you, based on the source of the data (moving train), give a physical explanation of the results?

Problem 3 - Compare model with measurement

Subtract simulated data from measured data. Run FFT again on the difference between measured and simulated data. Compare the resulting spectra to that in task 1. Is there any difference? If so, explain the difference in information content.