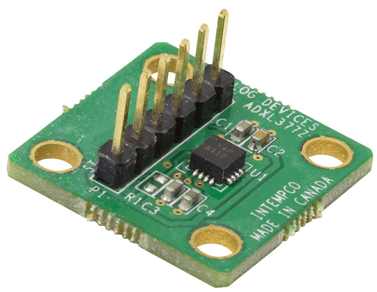
Course of Measurements for Automation and Industrial Production

ADXL377 inclinometer system User's Guide



Course professor:
Sergio RAPUANO

Authors: Angelo CARAVELLA, Gerardo MANGANIELLO

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Aim of the project

The objective of this project is to develop a comprehensive system for the ADXL377 accelerometer, configured as an inclinometer to measure pitch (forward/backward tilt) and roll (side-to-side tilt) angles. The system includes the design and construction of a signal conditioning circuit to adapt the accelerometer for inclination measurements. After constructing the circuit, an adjustment process is performed using an ellipsoidal fitting procedure, followed by a precise calibration to ensure optimal performance of the entire system. The user can utilize the system to measure pitch and roll angles in real-time, with the ability to adjust the system for improved measurement accuracy. The visualization of the yaw angle is not supported.

Chapter 1

System requirements

To successfully run the system, the following hardware and software components are required.

1.1 Hardware requirements

- **ADXL377 Accelerometer**: the triaxial accelerometer used for measuring tilt;
- **Pre-assembled signal conditioning circuit**: the accelrometer is mounted on a board with a pre-assembled signal conditioning circuit, which adapts the accelerometer's outputs to provide usable signals for the data acquisition system;
- **National Instrument USB-6008 DAQ device**: this device interfaces the accelerometer with the computer running LabVIEW. It features analog input channels required for acquiring the accelerometer's output signals.
- **Power supply**: it provides the necessary voltage for the signal conditioning circuit and accelerometer. Make sure that it matches the following requirements:
  1. **+10V and -10V** for powering the operational amplifiers in the conditioning requirements;
  2. **3V** for powering the accelerometer;
  3. **Current limitation**: set the maximum current to 0,005A (5 mA) to protect the circuit and ensure proper functioning. This prevents overcurrent and potential damage to components;
- **PC or Laptop**: a computer with sufficient processing power to run LabVIEW nad perform real-time data acquisition;

- **Cables and connectors**: used to connect accelerometer and DAQ board to the PC.

1.2 Software requirements

- **LabVIEW**: the graphical programming environment used to operate the inclinometer system. Ensure that version 2024 is installed for the system functionalities.
- **NI-DAQmx Drivers**: appropriate drivers must be installed to interface the USB-6008 DAQ device with LabVIEW.

Chapter 2

Installation and setup

2.1 Wiring Connections

It is important to note that each wire is clearly labeled, making it easier for users to correctly connect the system components. To properly connect the accelerometer and its signal condioning circuit to the power supply and USB-6008 DAQ device, follow these instructions:

1. **Power Supply**:
   - **+10V (Red wire)**: connect this wire to the 10V of the power supply. It provides positive voltage to the operational amplifiers in the conditioning circuit.
   - **-10V (Blue wire)**: connect this wire to the -10V of the power supply. It provides negative voltage to the operational amplifiers.
   - **GND (Brown wire)**: connect this wire to the common ground of power supply.
   - **3V (White wire)**: connect this wire to the 3V of the power supply. It provides positive voltage to the accelerometer.

2. **Signal outputs**:
   - **X Output**: connect this wire (**red wire**) to the analog input channel **AI0** on the USB-6008.
   - **Y Output**: connect this wire (**yellow wire**) to the analog input channel **AI1** on the USB-6008.
   - **Z Output**: connect this wire (**white wire**) to the analog input channel **AI2** on the USB-6008.
   - **Ground**: connect this wire (**green wire**) to the GND channel on the USB-6008.

3. **DAQ Device - NI USB-6008**:
   - Once all the wiring is complete, connect the USB-6008 DAQ device to the PC: ensure the PC has an available USB port.
4. **Software detection**:
   - After the DAQ board is connected to the PC, the system should automatically detect the device. Verify the connection using the NI Measurement & Automation Explorer (**NI MAX**).

2.2 Precautionary Measures

Users should be aware of the following:

- **Electromagnetic interference**: an environment with strong magnetic fields or other sources of electromagnetic interference can affect the precision of the measures, introducing noise or distorting the output signals.
- **Correct positioning of the accelerometer**: make sure that the accelerometer is well-mounted on the board and oriented properly for tilt measurements. For consistent and precise measurements, avoid any physical movement or vibrations that might disturb the entire sytem.
- **Hysteresis**: during the calibration process, hysteresis was observed in the system. This means that there is a small difference in the measured angles when increasing the tilt versus when decreasing it. The user should be aware that this hysteresis effect could result in minor discrepancies in measurements, particularly during repetitive tilting motions.

Chapter 3

User interface Guide

3.1 Overview of the User Interface

The graphical user interface (GUI) of the application is designed to provide a clear and intuitive way to interact with the inclinometer data. It consists of several key components that display real-time data, settings, and controls.

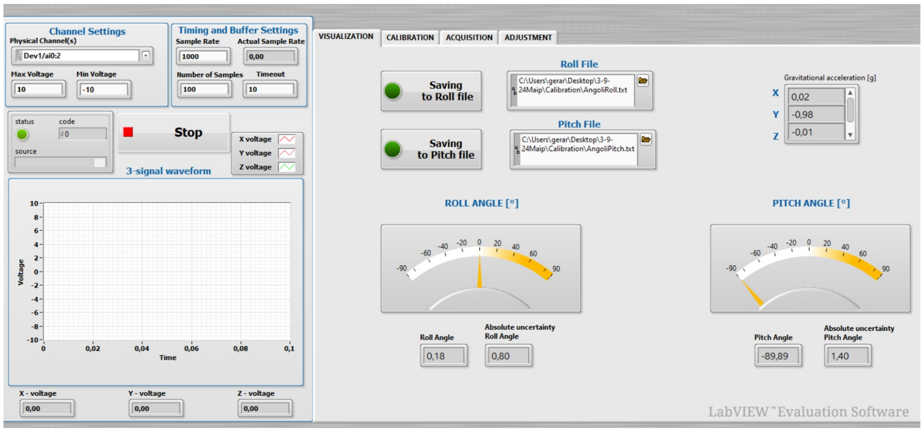

Figure 3.1: OverView

3.2 Measurement settings

On the left side of the interface, the user can set the parameters for data acquisition and view the timing and buffer settings.

3.2.1 Channel settings

- **Physical Channels**: allows the user to select the physical channels on the DAQ device that will acquire the data. The X, Y, and Z outputs from the accelerometer should be assigned to specific analog input channels.
- **Minimum and Maximum Voltage**: specifies the maximum and minimum voltages value the user expect to measure.

3.2.2 Timing and buffer settings

- **Sample rate**: specifies the rate at which data is sampled from each channel;
- **Actual sample rate**: the actual sampling rate used by DAQ;
- **Number of samples per channel**: defines how many samples are collected from each channel before the data are processed and displayed.
- **Timeout**: specifies the amount of time that the system will wait for the required number of samples to be acquired.

3.2.3 Signal display

A real-time graph displays the voltage signals from the accelerometer for each axis (X, Y, and Z). This graph shows how the voltages measured by the DAQ device vary over time, giving the user immediate visual feedback on the accelerometer's output.

3.2.4 Stop button

A button labeled "**Stop**" allows the user to halt the program at any time.

3.2.5 Error display

Any errors detected by the system are displayed through a dialog box, showing the error code and a brief description.

Figure 3.2: Measurement Settings

3.3 Visualization Tab

The **Visualization tab** provides real-time data display and the option to save key measurements. The user can observe the processed data from the accelerometer in motion, focusing on tilt angles, acceleration values, and associated uncertainties.

- **Real-time display of Pitch and Roll angles**
  - The user can monitor the values of the pitch (**rotation around the side-to-side axis**) and roll (**rotation around the front-to-back axis**) angles in real time. These angles are calculated based on the values of gravitational acceleration along the 3 axes and measure angles between **-90° and +90°**, providing a visual representation of the device's tilt as it moves.
  - Alongside the real-time values of pitch and roll angles, the system also displays the uncertainty associated with each angle measurement.
- **Gravitational acceleration value of each axis**

  - The tab also shows the current values of gravitational acceleration on the X, Y, and Z axes. These values reflect how the sensor is oriented in relation to Earth's gravity.
  - The values of acceleration are obtained through a fitting algorithm. Specifically, the output voltages from the accelerometer are adjusted using an ellipsoidal fitting procedure. This adjustment converts the raw voltage data into gravitational acceleration values **[g]**, allowing for accurate real-time readings during motion.

- **Data saving functionalities**
  - The user has the ability to save the real-time pitch and roll angles by pressing the **save buttons**. Automatically, the system writes the data to two separated files.

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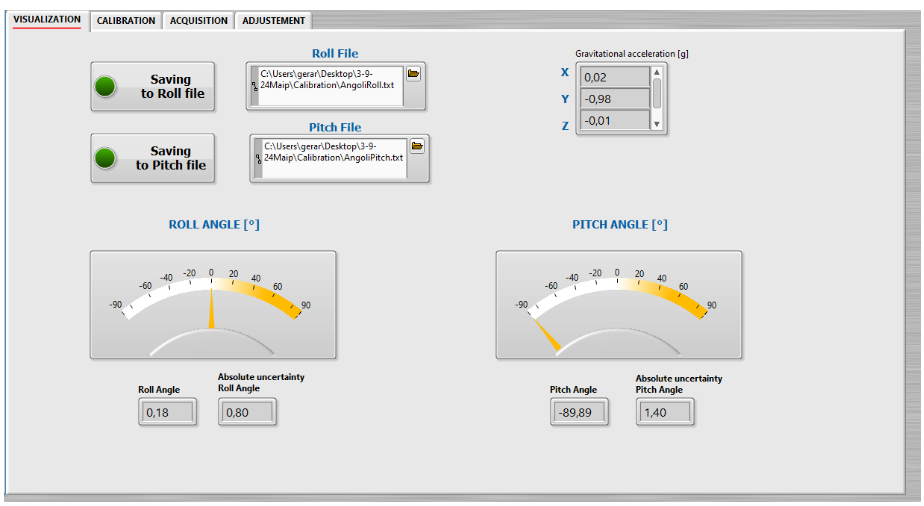

Figure 3.3: Visualization Tab

3.4 Calibration Tab

The **Calibration tab** allows the user to visualize the calibration curves for the pitch and roll angles, obtained through a calibration procedure.

- **Calibration Curves for Pitch and Roll**
  - The user can view the calibration curves for both the pitch and roll angles. Each curve compares the experimentally measured angle (Y-axis) with the actual angle (X-axis) of the reference system

- **Best-Fit Line Equation**
  - Next to the calibration graph, the equation of the best-fit line is displayed in the form:

$$Measuredangle = Slope * TrueAngle + Intercept$$

- **Slope and Intercept**
  - The slope and intercept of the best-fit line are shown for each calibration curve.
- **Uncertainty in calibration**
  - For each calibration curve, the system also displays the absolute uncertainty

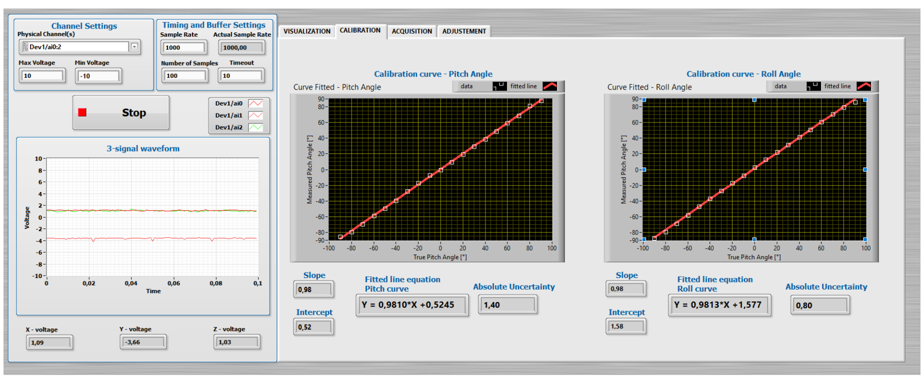

Figure 3.4: Calibration Tab

3.5 Acquisition Tab

The **Acquisition Tab** allows the user to save the raw voltage data from the accelerometer's output to a file for further analysis. Additionally, while the data are being saved, they are plotted on a 3D graph to visually represent the distribution of the points in space.

- **Saving Raw voltage data**
  - The user can save the raw voltage data from the accelerometer's X, Y, and Z channels by starting the data acquisition process. This data are essential for post-processing and potential recalibration of the system.
  - The saved data includes **X voltage, Y voltage and Z voltage**, corresponding respectively to the X-axis, Y-axis and Z-axis acceleration.

- **3D plot of data point**
  - As the user saves the data, the system simultaneously plots the voltage values in real time on a 3D graph. This graphical representation shows how the sensor data distribute in space, offering a clear visualization of the accelerometer's behavior over time.
  - The 3D plot provides an intuitive way to understand the orientation of the sensor and how the accelerometer's raw data varies with movement.
- **Data for Recalibration**
  - The saved raw voltage data can also be used for recalibration purposes. If the user identifies a need for recalibration (e.g., due to changes in environmental conditions or sensor drift), the raw data can be processed and analyzed to adjust the system's performance accordingly.

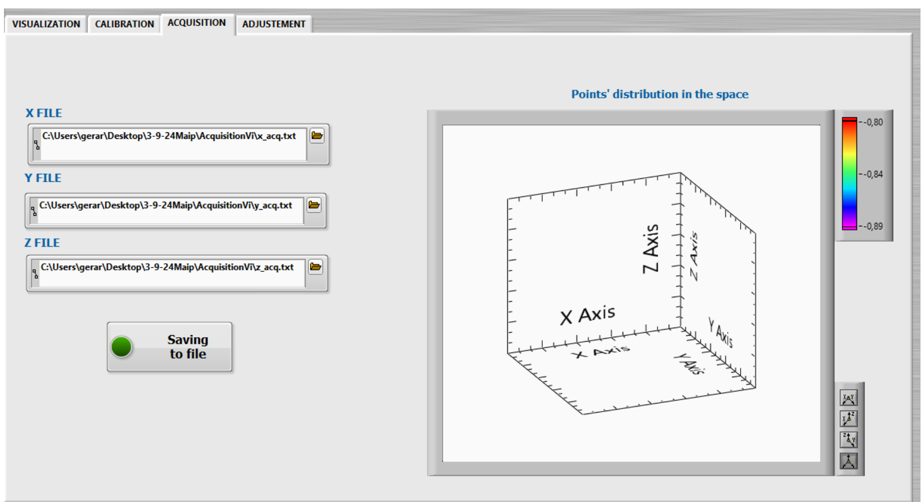

Figure 3.5: Acquisition Tab

3.6 Adjustment Tab

The **Adjustment Tab** allows the user to perform adjustment, using the raw voltage data previously saved from the Acquisition Tab. This process involves ellipsoidal fitting of the data to ensure accurate sensor adjustment.

- **Importing Data for Calibration**
  - The user can load the raw voltage data files acquired from the Acquisition Tab to perform the adjustment procedure.

  - It is crucial that the data points, when plotted in 3D space, **form an ellipsoid**. This is indicative of accurate and complete data necessary for the calibration process.

- **3D Visualization**
  - After loading the data, the system will plot the adjusted points in a 3D graph. If the data forms a valid ellipsoid, the adjustment procedure will transform this into a **unit sphere** (i.e., a sphere with a radius of 1), which signifies a successful calibration.
  - If the data does not approximate an ellipsoid, the resulting calibration will be unreliable, and the user should recheck the data acquisition process before proceeding.

- **Ellipsoidal Fitting Parameters**
  - The tab also displays the M matrix and the b vector used in the ellipsoidal fitting algorithm. These mathematical components are part of the algorithm that adjusts the **raw voltage data into gravitational acceleration values** (in units of g).
  - While the matrix and vector are important in the background for the fitting process, it is not necessary for the user to fully understand their role unless they are familiar with the technical details of ellipsoidal fitting algorithms.

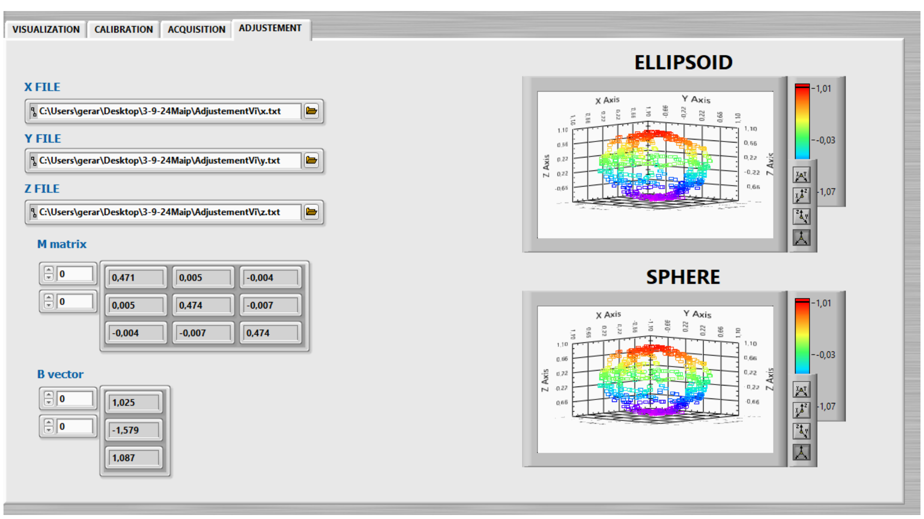

Figure 3.6: Adjustment Tab

Chapter 4

Usage tips and best practices

4.1 Power supply stability

- Before starting the entire system, verify that the power supplies are delivering the correct voltages: +10V and -10V for the operational amplifiers, and 3V for the accelerometer.
- Make sure the current limits on the power supply are set to 5 mA to protect the components from damage.
- Sudden fluctuations in the power supply can affect the signal conditioning circuit, leading to incorrect measurements.

4.2 Avoiding Electromagnetic Interference

- Keep the accelerometer and its conditioning circuit away from sources of electromagnetic noise, such as motors, power lines, or other electronic devices.

4.3 Proper Sensor Placement

- When mounting the accelerometer on the board, ensure that it is positioned flat and properly aligned to measure tilt accurately along the X and Y axes.
- Excessive vibrations or instability during measurement can introduce noise into the system and lead to inaccurate tilt angle readings.

4.4 Validating Data Acquisition

- Always verify the data acquisition process by observing the 3D plot in the Acquisition Tab. The points should form a coherent pattern (ellipsoid) before proceeding with the adjustment steps.

4.5 Adjustment considerations

- For successful adjustment in the Adjustment Tab, the voltage data must form an ellipsoid. If this is not the case, recalibrate using a new data set that better reflects the accelerometer's full range of motion.
- After performing the ellipsoidal fitting, the data should be transformed into a unit sphere. If the adjustment fails to produce a sphere, repeat the acquisition process with greater precision.

4.6 Hysteresis considerations

- During calibration procedure, hysteresis was observed. To achieve more accurate results, conduct multiple readings and consider the average value.

Chapter 5

Troubleshooting

This section can help the user resolve potential issues. Here are a few examples:

5.1 No data acquisition

If the system does not acquire data, check that the USB-6008 DAQ is properly connected to the PC and recognized in the NI Measurement & Automation Explorer (NI MAX).

5.2 Inaccurate Tilt Angle Readings

If the pitch and roll angles seem incorrect, ensure that the accelerometer has been properly adjusted, using data that forms an ellipsoid.

5.3 Data File Not Saving

Ensure that the file path is correctly specified and that the PC has permission to write to the selected directory.

5.4 Unstable Voltage Readings

Ensure that the system is isolated from noise sources and verify that the power supply provides stable +10V, -10V, and 3V voltages with the current limited to 5 mA.

Appendix A

Specifications of the National Instruments USB-6008 DAQ Device

For detailed specifications and features of the National Instruments USB-6008 DAQ device, please refer to the official datasheet available online at the following link: USB-6008 DAQ Device [1]

[1]https://users.physics.unc.edu/ sean/Phys351/techresource/docs/USB6009%20User%20Manual.pdf

Appendix B

Ellipsoidal Fitting Algorithm

For an in-depth understanding of the ellipsoidal fitting procedure used in adjustment, refer to the following paper:

- **Title**: "A Method for Real-Time Compensation of Magnetometers Embedded on Smartphones"
- **Authors**: Pasquale Daponte, Luca De Vito, Francesco Picariello, Sergio Rapuano, Carmine Sementa
- **Published in**: Institute of Electrical and Electronics Engineers (2016)

List of Figures