

CHAPTER 7: VALIDATION AND VERIFICATION

7.1. INTRODUCTION

Although the results chapter suggests that the study is successful and the sEMG platform design is functional, this chapter contains the justification for the successful design of the platform. The verification process demonstrates that the developed sensor design react according to expected results. The validation process is a comparison of results to other previous conducted research results. The design is verified by ensuring that these specifications are met or exceeded.

7.2. DESIGN FOR CRITERIA

7.2.1. FUNCTIONAL CAPABILITY

The functionality of the sEMG sensor focuses on the HMI between Matlab[®]/Simulink[®]. The aim of this HMI is to serve as a research platform for further upper limb prosthetic signal processing and control algorithms. The hardware functional capabilities are the Matlab[®]/Simulink[®] interface, the dual-channel sEMG amplifier, the dual-channel analog band-pass filter and the calibration algorithm. The software capability includes the calibration and decoding algorithms.

MATLAB[®]/SIMULINK[®] INTERFACE

The HMI between a patient's muscles and Matlab[®]/Simulink[®] is functional, which verifies the sEMG platform's use in creating future research opportunities using Matlab[®]/Simulink[®]. The interface manages to send dual-channel 10-bit (two byte, in little-endian format) sEMG signals at a rate of 1 ksps, which is the desired sample frequency of sEMG signals.

SEMG AMPLIFIER

To ensure that information is not lost through the electrode interface, the frequency spectrum of the signal sensed by the sEMG platform's electrodes is compared to the results from previous studies. The expected raw sEMG signals energy density on the frequency spectrum should be comparable to previous project's raw sEMG data.

The general frequency spectrum curves from most of the projects are similar to the sEMG taken across the centre position shown in figure 82 (b). The frequency spectrum of the sEMG platform is given in figure 78 with a matching shape of the frequency spectrum graph in figure 82 (b).

Previous studies shows that a differential amplifier with a CMRR > 80 dB is required [46]. The CMRR of the INA114AP is 115 dB, and is well within the specification.

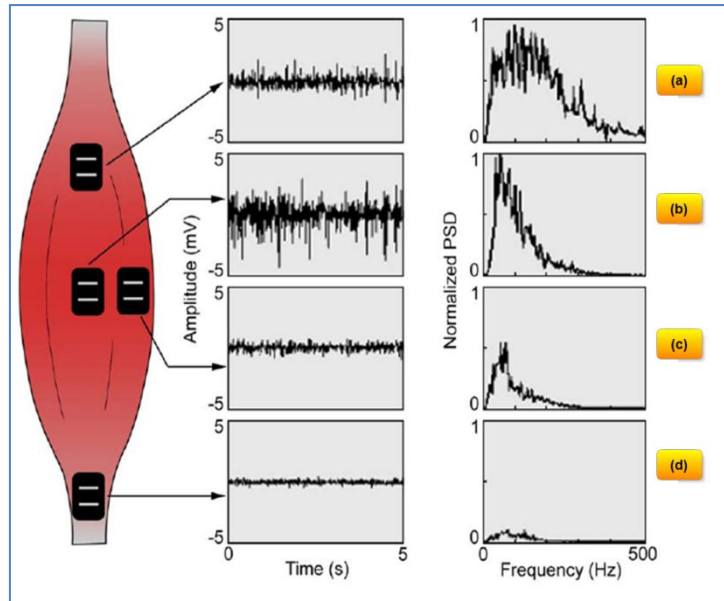


Figure 82: Typical sEMG results Frequency spectrum [43]

ANALOG BAND-PASS FILTER

The blocking capability of the lower frequencies by the band-pass filter is sufficient, but the band-pass's roll-off at the high-frequency side is slightly wider than expected, shown in figure 80. As the band-pass serves as the anti-aliasing filter, this could result in problems if the band-pass's output signal sent to the ADC contains frequencies higher than 500 Hz and aliasing occur. If the assumption is made that the sEMG signals always have the frequency characteristics as the results shown in figure 82, the band-pass filter design is sufficient for this system. Previous studies suggest a band-pass filter with -3dB cut-off frequencies at 20 - 500 Hz with a roll-off of at least 12 dB / octave [46]. This implies that at least a 4th order filter is required, which is implemented in the sEMG platform.

POWER CONSUMPTION

The standardized USB interface has a power supply capability specification of 5 V at 500 mA. The sEMG platform draws 60 mA, and with a 1.3 kg torque PDM servo attached a total of 300 mA is drawn. This power consumption is well below the specification.

CALIBRATION ALGORITHM

The calibration algorithm shows a significant improvement in the measured results in terms of signal range and the responsiveness of the system. Compared to similar systems, the calibration algorithm allows certain improvements.

The sensing capabilities of the Utah arm sEMG sensor a direct comparison of the devoped sensing platform. The Utah arm's controller uses dead-bands inside the amplifiers to eliminate noise effects. This may cause the amplifiers not to be perfectly proportional/linear. The amplifiers of the NWU development are designed to function linearly. The noise is eliminated by means of an calibration algorithm. The AutoCal® calibration algorithm used by the Utah arm focuses on tuning the amplifiers to allow the antagonistic muscles' EMG signals to have the same amplitude. The NWU development follows a different approach by identically amplifying the noise levels of the antagonistic muscles' EMG signals. The signals are subtracted resulting in the cancellation of the noise levels. This concept allows the NWU development to have a time constant of 200 ms. This

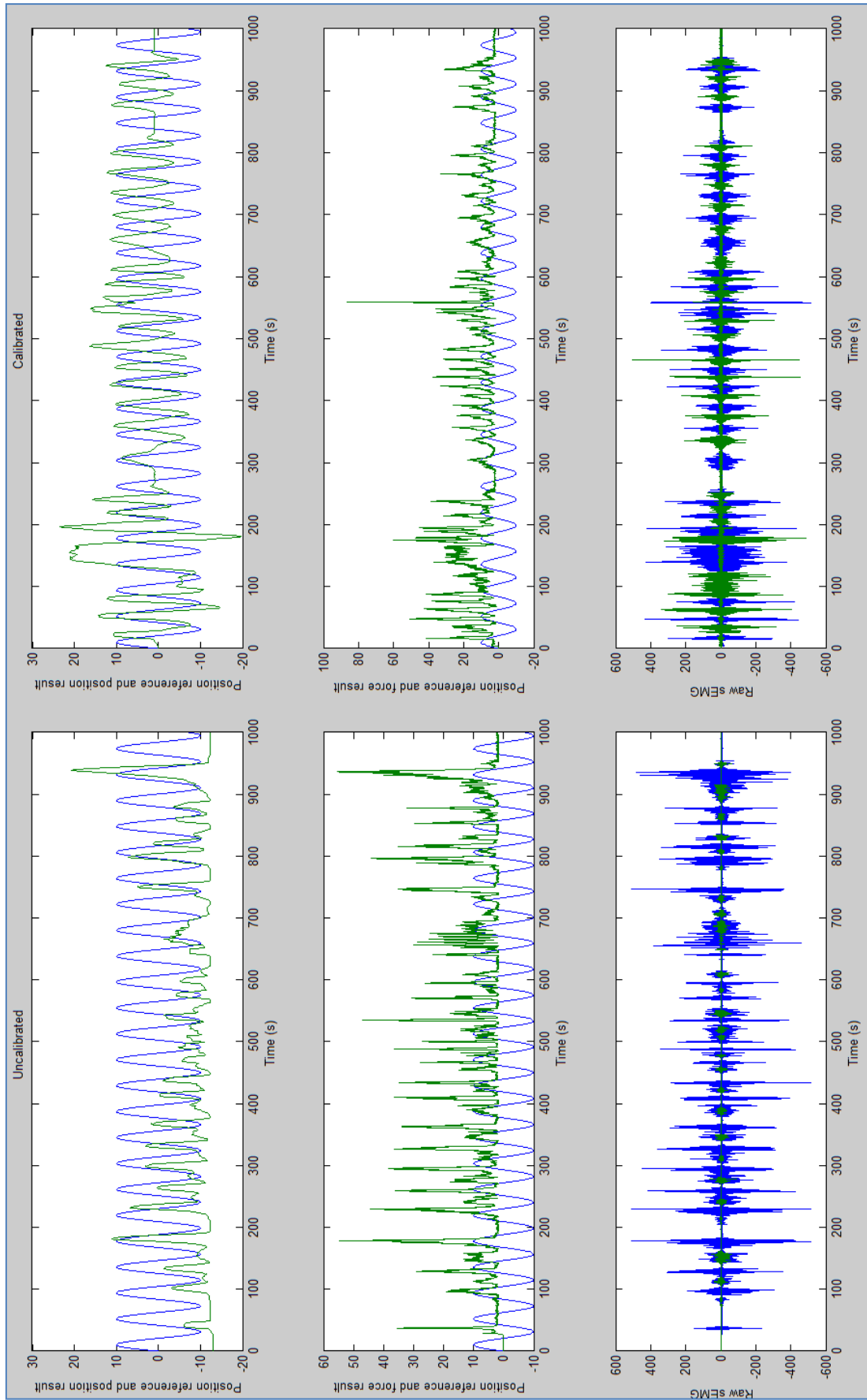


Figure 83: Calibration algorithm results

is much faster than the Utah system having a time constant of 500 ms. This allows the NWU developed system to be more responsive and proportional.

A visual verification of the calibration algorithm serves as verification of its functionality. The effect the calibration algorithm has on the performance of the decoding algorithm accuracy and range is illustrated in figure 83.

DECODING ALGORITHM

The sensor decoding algorithm is implemented by means of the Simulink[®] environment. The highest accuracy of 73.2% and average accuracy of 58.2% achieved (with visual feedback) is the combined accuracy of the proportional control model and the patient's accuracy following the animation's position. At this stage, it is not known how to separate these two variables to evaluate the accuracy of the proportional control model. An average value for the position offset of 140% is achieved without visual feedback, showing the effect visual feedback has on the patient's accuracy following the animation's position. Although the force result has not been tested for accuracy, it serves as a measure of total muscle effort of both flexor and extensor muscle groups.

7.2.2. DESIGN FOR RELIABILITY

The second differential comparison performed (digitally) in the proportional control algorithm eliminated common noise that may be entering the sEMG platform. The PCB layout ensures that the noise entering the sEMG platform will be sensed by both inputs at the same level for the digital differential comparison process to be able to eliminate the noise effectively.

The PCB layout is validated by comparing the prototype sensor performance with the PCB layout's. The two circuits are exactly the same, but the board layout is important. The importance is demonstrated by comparing the SNR. The SNR (10:1) of the prototype platform is compared to the SNR of the final PCB layout (50:1). The significant improvement in the SNR suggests a well-planned PCB layout, taken in consideration that the circuits of the prototype platform and the PCB platform are identical.

EMI improvements are noticed in the final PCB platform. Firstly, when the PDM servo is connected to the prototype platform after a serial connection is established, the serial connection resets due to the noise generated by the servo. Secondly, the servo operation causes jitter in die EMG recordings by the noise superimposed on the sEMG signals when using the prototype platform. Both of these EMI issues are absent in the final PCB platform.

7.2.3. DESIGN FOR USABILITY

The calibration algorithm increases the usability factor of the sEMG platform, as users with the minimum prior knowledge can use the platform and calibrate it with the push of a button. A USB powered design also simplifies the use of the platform, because no external battery or power adapter is required for the sEMG platform to function. For functional expansion, a second PDM servo output and a UART header is added to the final design.

7.2.4. DESIGN FOR AFFORDABILITY

There are two design considerations which have a large impact on the cost of reproducing the sEMG platform. The first consideration is the designing of a platform rather than the buy-option. The manufacturing of the PCB costs is proportional to the number of copper layers inside the PCB. The final PCB layout is done on a single two copper-layered PCB.

The second consideration is, to use inexpensive stainless-steel electrodes, rather than the popular, but expensive Ag/AgCl electrodes to sense the sEMG signals on the patient's skin. Calculations show, the inexpensive electrodes have no significant decline in performance. Previous studies show that

electrodes with an impedance of around 2 M Ω exist and could be used if the input impedance of the differential amplifier is greater than 1.3 G Ω [39]. The proposed differential amplifier has an input impedance of 100 G Ω , and satisfies this condition.

7.2.5. DESIGN FOR TESTABILITY

Clearly marked test-points on the PCB facilitate the testing of individual modules, and the bypassing of any module on the sEMG platform.

7.5. CONCLUSION

Future studies using this sensing platform are provided with a functional sEMG sensor being verified and validated. The cost of the design is low, but the performance compares to expected performance. The performance measures include SNR and frequency response. This implies that the issues identified in this study have been correctly addressed and verified. The next chapter is a discussion of the recommendations for future projects.