Adaptive Speed and Sensitivity Configuration with Parallel Health Status Validation via a Gesture-Based Controller – Robotic Arm Interface

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ABSTRACT

Elderly people usually adverse new technologies, especially robotic system solutions, due to interrelated difficulties concerning their setup, control and operation. An intuitive gesture control algorithm for the Jaco Robotic Arm has been developed, via the Leap Motion Controller gestured based sensor. Instead of just to instruct the Jaco Robotic Arm by the Leap Motion controller, this new interface is used to measure and validate as well as the user gesture patterns in the proposed paper. Even though the implementation mainly focuses on elderly persons, e.g. Parkinson's disease is often met on individuals of this particular target group, tremor can also be detected on healthy individuals, when muscle fatigue is present. By analysing the frequency of the acquired rotational and translational user palm data retrieved by a gesture driven sensor like the Leap Motion Controller, the proposed human-machine interface is able to efficiently analyse the tremor frequency and strength, which helps the user to distinguish between a physiological and pathological tremor pattern. Because the accuracy of the measurements are suffering, while working with gestures, the calibration process of the gesture sensor has two advantages: First the arm is adjusted to a useable accuracy, and secondly the tremor and bradykinesia algorithm can work undisturbed at the same time. Due to the proposed approach, an unobtrusive user health validation has been realized, which is analysing and validating the gestures, while the user controls a robotic arm.

Keywords -
Human-Machine-Interface; Sensing; Service Robotics; Real-time Signal Processing; Ambient Assisted Living; Convolution; FIR Filter; Tremor, Bradykinesia; Leap Motion Controller;

1 Implementation of an robotic arm in a novel workplace of the future

The population of the modern civilisation is changing. In industrial nations families have in average one to two children, which is gradually leading to an aged population. This demographic change causes new challenges. Usually the newer generation takes care of the older but according to the demographic change this will cease to exist. Therefore it is important to utilize technologies that can support elderly people in an independent and self-sufficient way [1]. There are several research groups, researching in multidisciplinary teams in Ambient Assisted Living (AAL) topics. For example [2, 3] investigated, the relation between cognitive work and senilism, and it was proved that mental activity is protecting against accelerated senilism. Complementary in [4] the work performance has been studied of elderly between 70 years up to 100 years. The study showed that especially young aged (means 50 years up to 70 years) are highly able to work.

The retirement is especially for higher educated people more a punishment than a relief, as the will and ability to work is mostly given. According to the demographic change, the engagement of elderly people seems to be the appropriate solution, in order to relief the young generation as well as to prevent elderly people for accelerated senilism. Therefore in the research project USA² a decentralized workplace has been designed, in order to allow, e.g. retired engineers, to remain active by working and developing from their home environment. In order to support the users in their work, assistive robotic solutions, like the Jaco Robotic arm, have been embedded in the workspace. Such a system enables the user to reach areas within the workplace, which are normally out of reach (e.g. in the case of immobility disabilities). In order to enable elderly people, who are mostly reluctant to new technologies (especially robots), a gesture control has been implemented [1], to actuate the robotic arm in a seamless way.

Mobility issues occur mostly in high age. Often a disease like Parkinson's disease, which is more and more coming, is causing mobility issues like bradykinesia, tremor, postural instability stiffness and imbalance etc. [5]. As the number of Parkinson diseased people during the last years increased, notable research has been conducted dealing with the measurement of tremor, which presents one of the three fundamental symptoms of Parkinson [6-12]. Furthermore, in [6, 9] the identification of bradykinesia is also proposed.

In the proposed paper, the authors implement an unobtrusive tremor and bradykinesia detection, while gesture controlling a robotic.

2 Gesture controlling and analysing

The USA² project workplace, depicted in Figure 1, has been designed based on the arrangement of an aircraft cockpit. This specific configuration allows for ergonomy concerns, i.e. to be able to reach easily most of the workspace foreground area. The background area of the workspace, is utilized by mechanically actuated parts, where should remain outside the reach of the user to avoid possible injuries. The Jaco Robotic Arm represents here the interface between these two distinct zones.

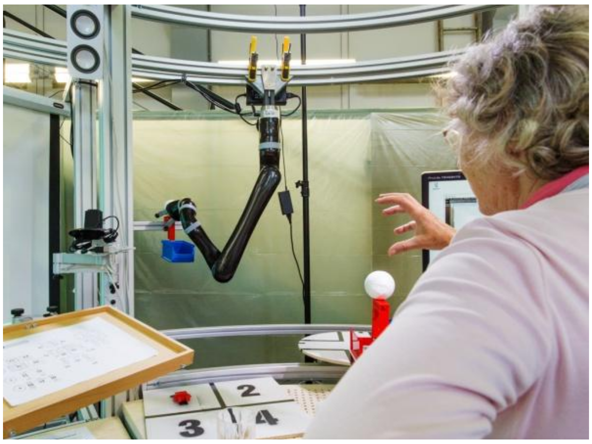

Figure 1. Proposed gesture controlled pick apn place operation using the leap motion controller and the robotic arm.

During an actual laboratory test (with more than 20 test-persons) the gesture control, and also tradition control options (like direct control over arrow buttons on a graphical user interface) have been extensively tested under various scenarios. It was noticed that following a short testing and familiarization phase, all users could control the robotic arm using the intuitive gesture driven controller. Nevertheless, without getting first familiarized with the implementation, they all experienced difficulties, especially during pick and place operations. This was also related to the missing haptic feedback due to the nature of the gesture control device. Also the extreme accuracy and high throughput rate of the Leap Motion Controller is often a challenging task [13-15], if a filtering technique is not used to normalize the user palm displacement speed with the robotic arm speed.

Therefore a pre-calibration process was necessary, as the enhanced accuracy of the Leap Motion controller translates the tremor patterns to unwanted arm oscillations on the Jaco robot arm side. During the proposed calibration phase, the user palm is held constant over the Leap Motion controller field of view. The recorded rotation and translation data are recorded and processed by a moving average filter [1]. Thereby extreme signal values are filtered out and the corresponding sensitivity threshold values for each of the measured signals are accordingly set. During this calibration process, the unobtrusive measurement of the hand tremor can also be efficiently implemented, once the user palm is held still for a short period of time over the gesture sensor.

In order to automatically adapt the movement speed of the robotic arm, the bradykinesia detection algorithm, which measures the user palm speed, can be implemented. The laboratory tests showed that with a low pre-set speed on the robotic arm, the test person could easily pick an object, however it was very difficult to bring the item to its required destination position due to the decreased speed of the arm, which required repetitive strokes of the user palm in front of the leap motion sensor field of view. On the contrary a fast transition speed results assisted on this issue, but made the pick operations more difficult. Therefore the authors investigated in the proposed paper a technique to measure the user palm movement speed, in order to identify bradykinesia and adaptively adjust the robotic arm speed correspondingly.

3 Implementation of the gesture analysis for tremor, and bradykinesia detection

The Graphical User Interface (GUI), depicted in Figure 2, supports the user to initiate the intuitive gesture control, as well as to manually adapt the sensitivity thresholds and robotic arm speed. There are also further controlling options implemented, which are already described in detailed in [1], which e.g. allow the control of the robotic arm by an on screen joystick or by pre-programmed movement trajectories. In the proposed paper it has been further developed in order to measure, detect, indicate and display the tremor and bradykinesia results.

The detected tremor is presented in the upper right plot, were hand tremor is indicated by a dominant peak at the corresponding signal frequency. Via pre-set thresholds it is possible to identify a pathological tremor, as physiological tremor presents higher frequencies (out of range of the regarded frequencies of this analysis) and have a very low amplitude. Together with the bottom right plot, depicting the hand movement speed in centimetres per seconds, it is also possible to distinguish between a real tremor and a monotone movement, since at a real tremor, e.g. caused by Parkinson's disease, the movement speed will still be low, whereas a monotone movement would normally present a higher amplitude at the lower plot. At the lower plot the mobility value is also presented, which is calculated from the route mean square values. This value is necessary to identify a bradykinesia by the average over a long time, as proposed in [9], and can also be used for the adaptive speed adaptation of the robotic arm.

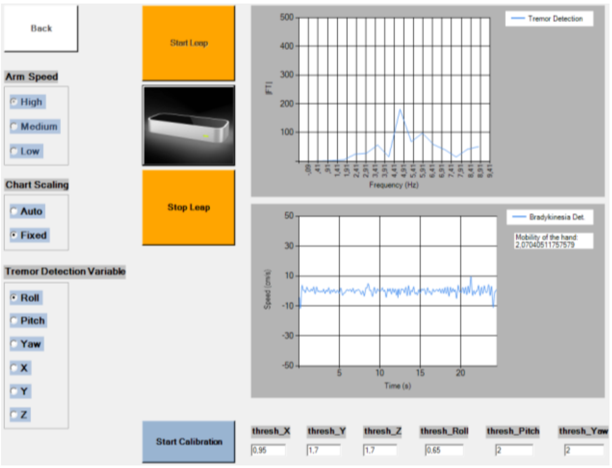

Figure 2. GUI including visual feedback of the tremor and bradykinesia detection.

The Leap Motion controller is analysing the user palm tremor, and the movement speed in the x, y, and z axes, as well as the corresponding roll, pitch, and yaw rotation angles, resulting in total 6 different signals data streams. To avoid confusion at the visual output and in order to improve the performance only one of the analysed signals is shown on GUI at each time. The user can decide on the right side (Figure 2), which signal will be displayed. The proposed algorithm for the measurement and detection of the tremor and bradykinesia is shown in Figure 3.

Figure 4 depicts the general approach to identify the tremor using the Leap Motion controller. In order to have comparable results with existing studies [6, 9, 11], the measured raw data values (position/orientation) are converted into acceleration using a double differentiation. Before using the Fourier transformation to receive the frequency spectrum of the measured acceleration, a Gaussian Window Function with $\sigma = 0.4$ is used to improve the visual result of the Fourier transform, which is displayed on the GUI. Depending on the frequency (labelled on the x-Axis of the upper plot, visible in Figure 2), at the point where the dominant peak occurs, an indication of the kind of the tremor is provided, because the amplitude and frequency range of a tremor are strongly dependent on the nature if the disease (e.g. fatigue, essential, Parkinson, etc. [16]).

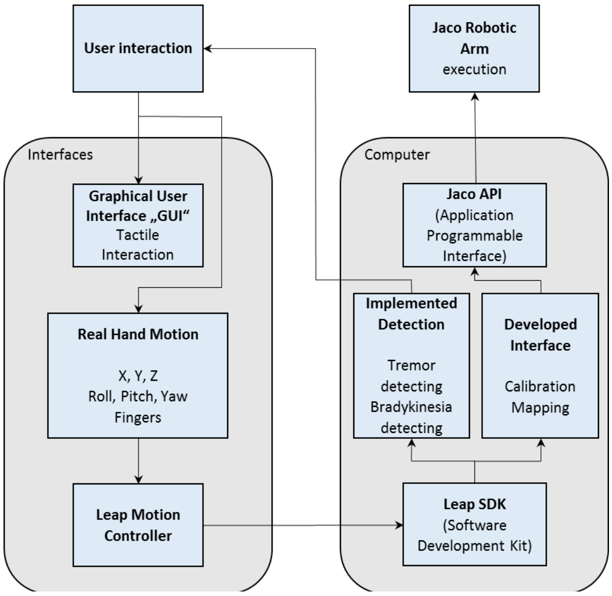

Figure 3. Proposed algorithm flow chart.

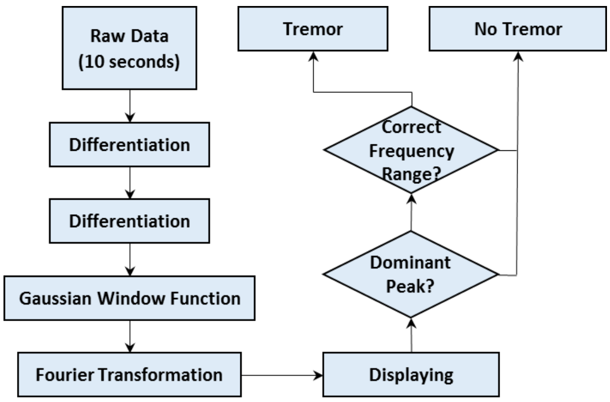

Figure 4. Proposed tremor detection algorithm.

The algorithm for the detection of bradykinesia is shown in Figure 5. Once 512 data samples regarding the bradykinesia detection have been registered, the calculation initiates. The required time window for detection becomes dependent on the computational power used, since it is reflected by the achieved sampling frequency, i.e. frame rate. The implemented algorithm has been tested on a Windows 7 (64 bit) PC with an i5 Dual Core 2900 MHz and 8 GB RAM, where the first 512 samples can be acquired in approximately 25-30 seconds, depending on the current processor load.

Because the movement speed of the user palm is of interest, the raw data get only once differentiated, which results in the palm movement speed (in centimetres per seconds). A finite impulse response (FIR) low pass filter, of n = 512 order, has been used, with an edge frequency of 3.5 Hz to filter disturbing tremor patterns. After using the root mean square of the filtered movement speed of the user palm, the value, which represents the mobility of the hand, can be extracted.

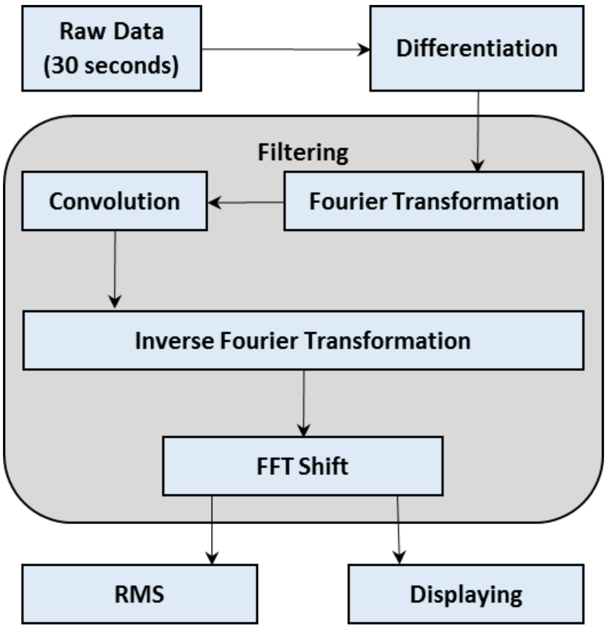

Figure 5. Proposed bradykinesia detection algorithm.

4 Mathematical implementation of the tremor and bradykinesia measurements

The algorithm shown in Figure 4 can be summarized by equation 1, as follows:

$$\bar{a} = \left|F\left(\frac{d^2x}{dt^2}\right)\right| \quad (1)$$

Here the $\bar{a}$ represents the Fourier transformed acceleration array of the recorded user palm, which has been calculated using the array x, which represents the raw data in cm of the Leap Motion controller, over time t, which is represented in seconds.

In order to implement equation (1) the differentiation $\frac{d}{dt}$ of x, has been implemented by the numerical differentiation as shown in equation 2:

$$\frac{dx}{dt} = \Delta x = x_{(i+1)} - x_i \quad (2)$$

The Leap Motion controller measures the position of the user palm relative to the sensors of the controller, and thereby the acceleration calculation can be performed using equation (3),

$$v = \frac{dx}{dt} \text{ and } a = \frac{dv}{dt} \rightarrow a = \frac{d^2x}{dt^2} \quad (3)$$

where v represents the speed of the user palm, calculated by a single differentiation, using equation (2).This allows to rewrite equation (1) as equation 4 below:

$$\begin{aligned} v_i^{n-1} &= \left[x_{(i+1)} - x_i\right]_{i=0}^{n} \\ a_{i=0}^{n-2} &= \left[v_{(i+1)} - v_i\right]_i^{n-1} \end{aligned} \quad (4)$$

or by using the Aitken's delta-squared process which allows the direct calculation of the acceleration, as seen below in equation 5:

$$a_{i=0}^{n-2} = [x_i + x_{i+2} - 2x_{i+1}]_i^n \quad (5)$$

Because the result of the Fourier transform will be used to identify the frequency of the tremor, a window function has been implemented in order to reduce the spectral leakage. After testing different window functions (Gaussian, Hamming and Kaiser Window), the Gaussian window using equation (6) was empirically selected:

$$w(i) = e^{-\frac{1}{2}\left(\frac{i-(n-1)/2}{\sigma(n-1)/2}\right)} \quad (6)$$

where a narrowness factor $\sigma = 0.4$, was used.

For the Fourier transform the Fast Fourier algorithm from Danielson and Lanczos has been used [17].

This proposed algorithm has been tested by a given sinus signal, calculated by equation (7):

$$x = \sin\left(2 \cdot \pi \cdot {}^{f}/_{f_s} \cdot t\right) \quad (7)$$

where f represents the test frequency, which has been set to 1Hz. t represents the array of the time steps, which has been set to a length of 10 seconds, which corresponds to the window length of the raw data. The variable f_s represents the sampling frequency of the signal. Figure 6 shows the proposed algorithm detection.

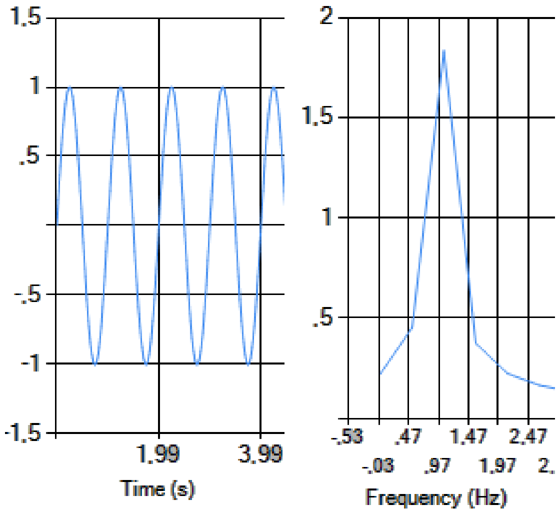

Figure 6. Recorded input signal with its resulting FFT detected peak value at 1 Hz.

In Figure 7, the FIR filter response is shown.

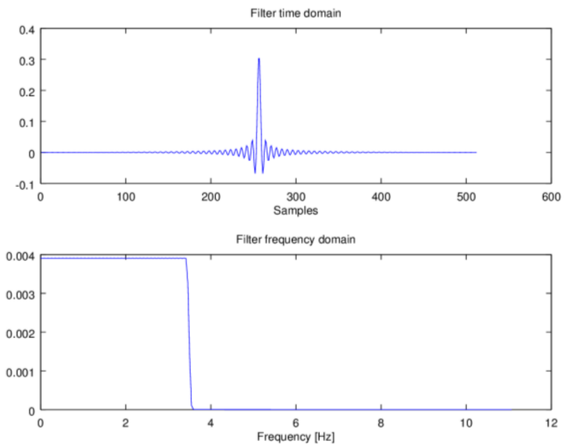

Figure 7. The FIR filter (n = 512 order and an edge frequency of 3.5 Hz).

For the convolution the Fast Fourier Transformation from Danielson and Lanczos [17] has been used and afterwards multiplied with the Fourier transform of the filter, according to equation (8).

$$\tilde{v} = \frac{dx}{dt} * h = F^{-1}\left\{F\left\{\frac{dx}{dt}\right\} \cdot F\{h\}\right\} \tag{8}$$

where h represents the FIR filter array, and $\tilde{v}$ the filtered velocity of the hand. As the values after a Fourier transformation are complex (the complex value of a number is stored in an even cell index and the real value in an uneven), the multiplication must be performed using equation (9).

$$F\left\{\frac{dx}{dt}\right\} \cdot F\{h\} = (x_1 + x_2 i) \cdot (h_1 + h_2 i) \\ = (x_1 h_1 - x_2 h_2) + (x_1 h_2 + x_2 h_1) i \tag{9}$$

In order to identify the mobility of the hand the rout mean square algorithm (equation (10)) has been used, as suggested in [9].

$$M = \sqrt{\frac{1}{n} \sum_{i=1}^{n} \tilde{v}_i^2} \tag{10}$$

Finally this value represents the mobility of the user palm in cm/s and thereby is used by the authors to adaptively configure the operating speed of the Jaco Robotic arm. To validate the functionality of the implemented algorithm, the corresponding input raw recorded data have been ported to an open source high-level interpreted language (GNU Octave), which is primarily intended for numerical computations [18]. In order to test the resulting functionality of the implemented application, a convolution using a Fourier transformation standardized function of GNU Octave, on the same raw recorded data was made. The result confirmed the accuracy of the proposed implementation as it can be seen in Figure 8.

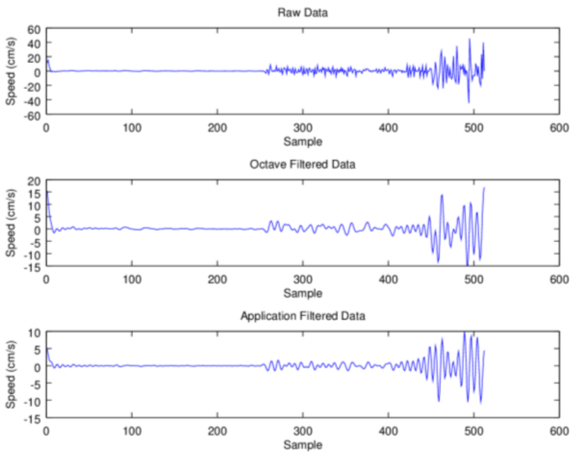

Figure 8. Results of the FIR filtering, top: raw data, middle: filtered response calculated with GNU Octave, bottom: proposed algorithm response.

The deviation in the response shown in Figure 8 is based on to the different FFT algorithm formula definition used in [17] and the one used in GNU Octave.

However, the main goal which is the filtering of the tremor related values from the user palm movement signal data is achieved in both results. Resulting mobility values are the following: $M_{\mathrm{Octave}} = 2.9081\ ^{\mathrm{cm}}/_{\mathrm{s}}$, $M_{\mathrm{Proposed}} = 2.9890\ ^{\mathrm{cm}}/_{\mathrm{s}}$.

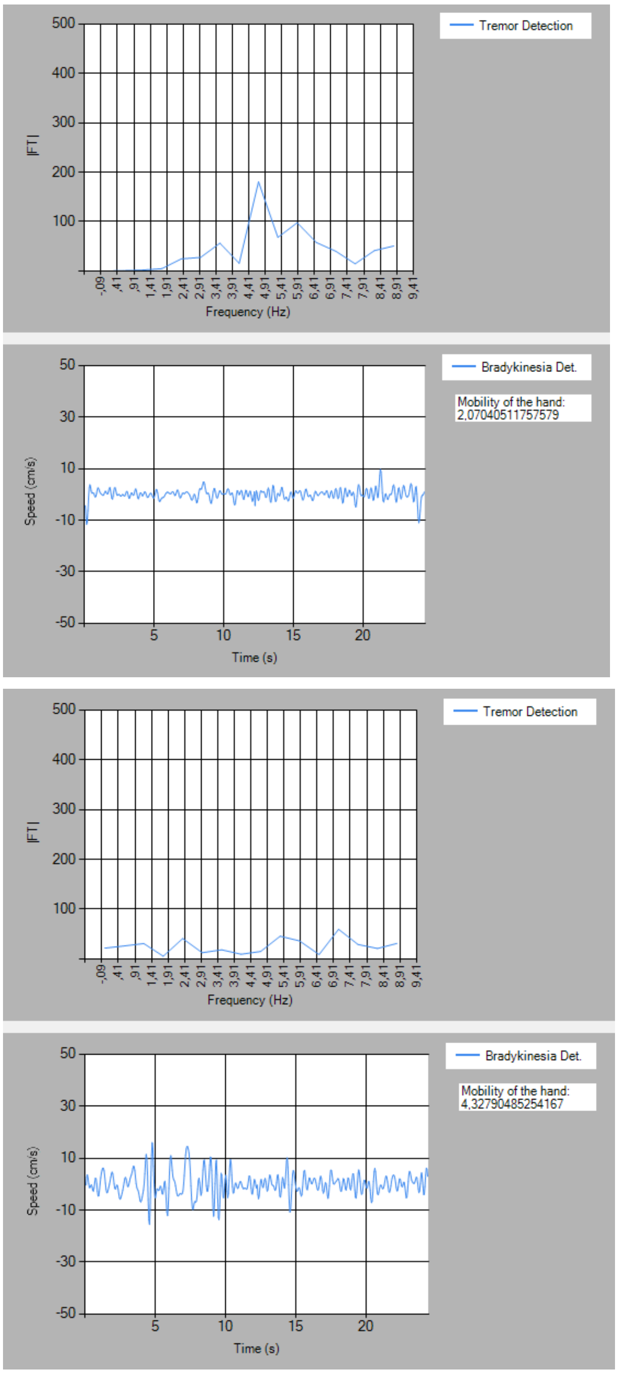

Figure 9. Measured result of moving user palm with tremor (top pair), and without tremor (bottom pair).

The visual feedback of the hand speed, Figure 9, allows the user to observe the detected tremor frequencies, which assists in the differentiation between physiological movements and pathological tremor. The lower amplitude at the bradykinesia plot (top pair), where $M_{\mathrm{Proposed}} = 2.07\ ^{\mathrm{cm}}/_{\mathrm{s}}$, and the dominant Peak is 4.5 Hz indicates that a tremor is detected. On the contrary the increasing amplitude visible at the plot (bottom pair), with $M_{\mathrm{Proposed}} = 4.32\ ^{\mathrm{cm}}/_{\mathrm{s}}$, displaying the movement speed of the hand, indicates that the user is active, whereas the missing dominant peak at the frequency analysing plot reveals, that the user is healthy. Depending on the value of M_{Proposed} and predefined thresholds, the movement speed of the Jaco Robotic arm is adaptively regulated.

5 Conclusion

A novel approach has been proposed to unobtrusively detect hand tremor and bradykinesia while gesture controlling a robotic arm. Depending on the detected tremor frequency it is possible to distinguish between Parkinson and other nerve diseases, which also cause tremor, e.g. essential tremor. The authors showed in this publication, that the Leap Motion controller is able to analyse tremor and bradykinesia, as similarly attempted in the past with gyroscope and accelerometer devices. In consideration of the Nyquist Theorem, only tremor frequencies up to 10 Hz can be investigated. The Leap Motion controller though can efficiently detect translation or rotation of the user palm for frequencies even up to 300 Hz. Therefore the performance of the aforementioned device is unmatched for the concerned implementation.

The authors used a lightweight robotic arm which was controlled by a gesture driven sensor, to exploit the potentials and possibilities of an intuitive manipulation interface. Such a human-machine interface implementation can also be applied also into construction robotics. Especially in this case, the proposed tremor and bradykinesia detection is of highly interest, once it comprises a prevention system for risk situations, such as pathologic user palm movement patterns appearing while controlling heavy payload construction robots, in order to minimize and avoid accidents.

6 Acknowledgements

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