Fuzzy-EMG-Based Assistive Interface for Children with Spinal-Muscular-Atrophy

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***Abstract*— Spinal Muscular Atrophy (SMA) is a progressive neuromuscular disorder. Usually, this condition is considered genetically induced with no known cure to date. Children are born with the condition and develop muscular weakness progressively as they grow. The weakness ultimately encompasses the whole muscular function rendering the limbs dysfunctional or paralyzed. Many children with SMA, if they do not have the weakness from the beginning, will start having the disease manifesting itself on the legs first and then the arms and, in due time, they will become quadriplegic and even more disabilities can follow including speech impairment. Assistive Technology support for people with such disabilities often requires identification of the best residual muscular function so that this can be utilized as a means of voluntary control. Electromyography (EMG) is a popular clinical procedure to monitor muscular function in a large number of healthcare and other clinical measurements. It translates muscular activity into proportional voltage signals which can then be used for analysis and other applications. Most of the existing assistive applications are based on amplitude thresholding of the EMG signals, which can drift over time due to fatigue on part of the patient and partly due to changes at the electrode interface over the period of use. This requires that a care-giver must re-calibrate the signal threshold making the process both impractical and prone to errors. In this paper, a new approach has been presented that alleviates the need for re-calibration of thresholds for such applications development. Fuzzy classifier has been used on pattern-related features from the signal samples and based on that appropriate computer signals can be generated to be adapted in an Assistive application such as playing a computer game, using serial keyboard interface, controlling the wheelchair/other-hardware, or even being able to generate text.**

I. Introduction

According to National Institute of Health, USA, Spinal Muscular Atrophy (SMA) is a type of genetic/hereditary condition that manifests in weakness and, ultimately, complete loss of the voluntary control in the limbs (arms and legs). While the condition is congenital, it may only become noticeable in infants and children at a later age. The disorder is a direct consequence of a mutated gene known as the Survival Motor Neuron gene (SMN1), which is primarily responsible for the production and cloning of a protein essential to motor neurons. The absence or lack of this protein causes lower motor neurons in the spinal cord to degenerate and consequently die. The whole process is quite painless irrespective of the age of the onset and the severity of symptoms. The disease is categorized in 3 types; Type I (also known as Werdnig-Hoffman disease, or infantile-onset SMA) is evident at birth or within the first few months. It is quite evident from the beginning of the onset with symptoms such as floppy limbs and trunk, feeble movements of the arms and legs, swallowing and feeding difficulties, and impaired breathing. The intermediate form, Type II, usually starts around 6 to 18 months of age. Symptoms include more impaired lower limb function, followed by upper limb function. Type III (also called Kugelberg-Welander disease) manifests between 2 and 17 years of age and include difficulty running, climbing steps, or rising from a chair. The lower extremities are most often affected. Figure 1 is a pictorial representation of how the protein generation is connected to the muscular functions [1].

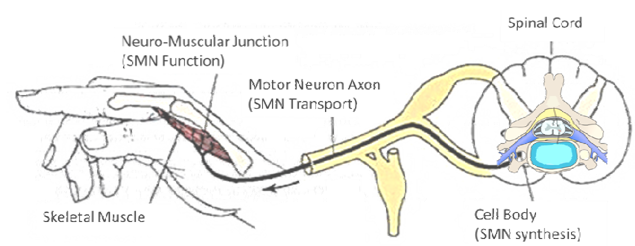

Figure 1. Diagram of connectivity between SMN and the limb muscles.

The prognosis is poor for babies with SMA Type I with a high fatality rate. However, for children with SMA Type II and III, the prognosis for life expectancy or for quality of life roughly correlates with how old they are when they first begin to experience symptoms. While life expectancy is reduced, one of the main concerns is that the individual becomes more and more dependent on others as the disease progresses into advanced stages. This causes paraplegic as well as quadriplegic scenarios and may further include respiratory infections and/or speech and auditory impairments. However, it has been claimed that with appropriate care, persons with this condition may have a normal lifespan [2]. This, however, is completely undermined by the level of dependence on others such patients have due to mobility and/or dexterous disabilities. At present, there is no cure for this disease. Medical treatment and physical therapy can help in managing symptoms and related complications.

II. Assistive Technology

Assistive technology, in general, refers to "any item, piece of equipment, or product system, whether acquired commercially, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities" When this term is applied to SMA patients, it usually corresponds to the development of

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software and/or hardware solutions that could enable the person with disability to become more independent in terms of performing several day-to-day activities. Different types of input methods are utilized for such patients corresponding to the available movements and application type. However, when the disease is already at an advanced level, very few muscles are capable of producing any functional movements. Hence, EMG sensors are sometimes used to capture muscular intention in order to translate them as inputs from the user for specific applications.

Electromyography (EMG) is a commonly used technique for evaluating and recording the electrical activity produced by skeletal muscles [3]. It detects the electrical potential generated by muscle cells when electrically or neurologically activated. The resulting voltage signals are used in many clinical and biomedical applications. A more recent area of applications is use of these signals as a controlling impetus for prosthetic devices etc...

Assistive Technology researchers have worked in primarily two directions; developing EMG based hardware controlling system in order to use it with wheelchair control, exoskeleton control, etc… [4-9], and the second direction is the use of these signals to interact with specialized learning computer games and similar applications. The work presented in this paper belongs to this second category.

In this category, the main interest is to map the EMG signals to a computer based application that resembles a game or other interactive activity. Many researchers have argued the validity as well as the usefulness of this approach when dealing with day to day applications that can be beneficial to SMA patients [11-13]. The targeted applications include computer usage, communication applications, and other related functions associated with motor disabilities [14-16].

The main processing step needed to deduce specific pattern from the EMG signal is primarily the main interest of all the R&D personnel in this area. The processing of EMG signals has been in the research community for quite some time now and a large number of specific algorithms have been developed as well [17]. One approach in pattern classification of these signals is based upon feature extraction. Many researchers have suggested different application-specific features [18-19]. Almost all known techniques in classical and soft computing world have been applied on EMG signals for classification objective [17, 20]. However, most of these systems were confined up to the research domain and, due to many algorithmic complications; the results were not commercialized as a product for common usage. In fact, the latency between the motor actions and the computer based application response could become artificially large if the underlying technique is algorithmically complex. Hence, one simple solution was found commercially that detected muscle activity using the EMG probes and made the decisions using a threshold-based signal response [21]. However, due to fatigue in the muscle, these responses also change and needed fine tuning/re-calibration from time to time.

In the presented work here, the shortcomings of the simple thresholding algorithms as well as complex algorithms have been addressed by utilizing on-the-fly heuristical calculation and their Fuzzy classification technique. The complete algorithm is outlined in the next section.

III. Proposed System

In this paper, the work presents a scenario of detecting muscular movements from facial muscles, especially the eyebrow movement muscles. The system has been designed for children with advanced SMA to the extent that they can only use muscles in the face and fore-head regions. The muscular movements are often controlled and voluntary in nature and hence provide excellent input impetus from the patient. Figure 2 shows the overall block diagram of the proposed system.

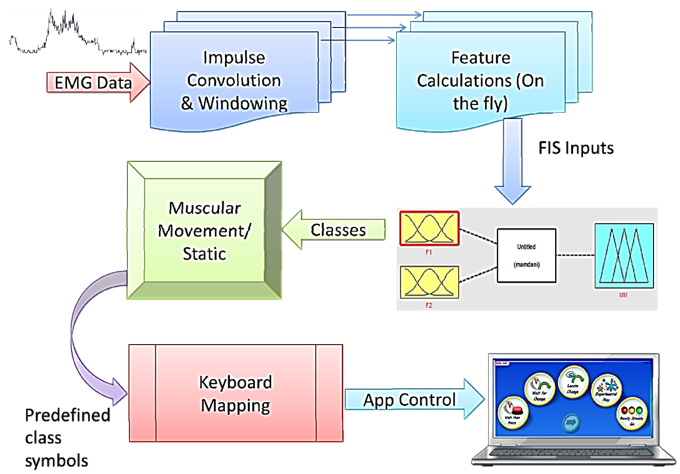

Figure 2. Overall block diagram of the proposed system.

While there are plans to extend this proof of concept design into a completely ubiquitous module, at present the usual adhesive EMG probes are being used as the main input channel. The standard 3-probe system has been utilized and can be seen in Figure 3 as a typical application of detecting eyebrow movements.

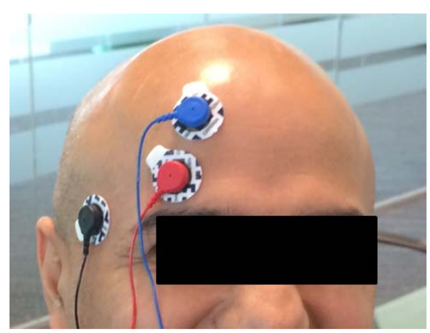

Figure 3. Typical arrangement of the EMG probes for detecting eyebrow movements.

The signal from the EMG probes is passed through two types of calculation systems. A subset of incoming samples is collected as a packet. Typically, this packet has 10 samples corresponding to a 10Hz sampling frequency. In order to match various parts of the packet with a rising signal due to the EMG action, each packet is correlated with an impulse function of type [0 0 0 0.5 1 0.5 0 0 0] corresponding to a gradual peak function. The correlated signal is a pattern matching technique to bring up similar structures more than other artifacts, such as rest condition and noise. If the eyebrow has been moved then it should appear as a rising pulse function and after correlation with a similar function would enhance the magnitude irrespective of the actual magnitude itself. This is the main idea in the proposed work which makes the technique more robust to noise and fatigued-muscle responses. In order to quantify further, two statistical features were calculated for each packet of samples. First one is the energy of the packet, and second one is the energy of the correlated signal. The energy is calculated as:

$$\epsilon_i = \sum_{k=1}^{n} x_k^2 \qquad (1)$$

Where ϵ_i is the Energy of the i^{th} packet containing n samples represented by x_k. As stated earlier, n = 10 in this case. The correlation function (σ_i) between the signal samples x_i and the gradually rising impulse function y_i is given by:

$$\sigma_i = \sum_{k=1}^{n} x_i \;\; y_{i+k} \qquad (2)$$

These features provide the basis for Fuzzy classification system that detects the movement based on the rules that connect the patterns present in the signal to the actions required by the application.

A. Hardware Details

At present, the proposed system is based on EMG signal acquisition into the computer using standard EMG probes and signal amplifiers [22]. The amplified signal is then read by a standard low-cost Data Acquisition module (NI USB-DAQ 6008) [23] into the main application environment of LabVIEW which implemented the above algorithm as well as the Fuzzy Classifier (discussed next) in such a way that when the detection is positively classified, it is mapped to one of the keyboard keys as an emulated keyboard. This would enable the use of such mapping control commercially available computer game functions. The main idea was to map these specific keys to the Windows system DLL, user32.dll. Figure 4 shows the hardware used in this work.

IV. Fuzzy Classifier

The Fuzzy Classifier was built in this work in order to detect reliably if the muscular click was in fact made or not. The general architecture of this classifier is shown in Figure 5 with the two input and one output membership functions shown in Figure 6. The rule-base is composed of the following rules:

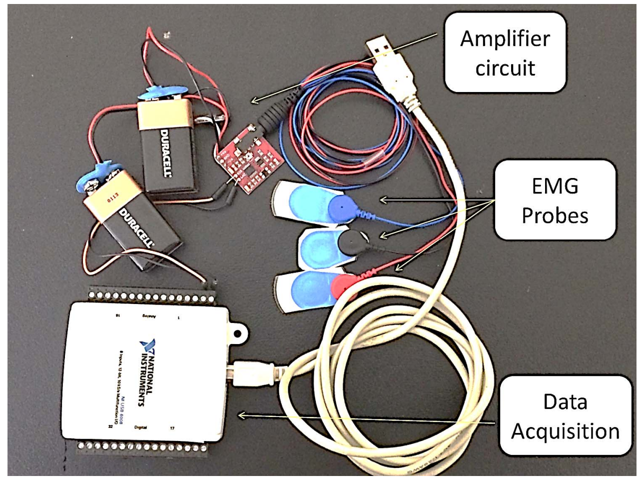

Figure 4. The experimental hardware used in this work. The DAQ module was connected to the PC using USB port.

1. If (F1 is High) and (F2 is High) then (MM is Highly-Likely)
2. If (F1 is Medium) and (F2 is High) then (MM is Highly-Likely)
3. If (F1 is Medium) and (F2 is Medium) then (MM is Likely)
4. If (F1 is Low) and (F2 is Low) then (MM is Unlikely)

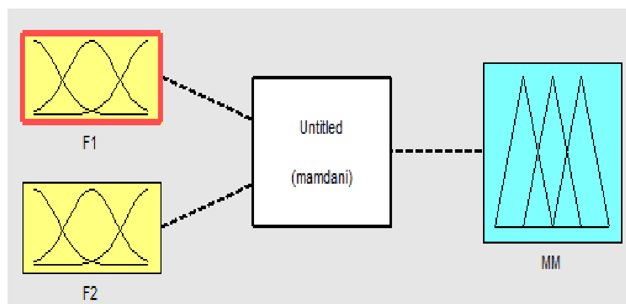

Figure 5. The propose Fuzzy Classifier with two input features (F1 and F2) with one output (MM=Muscle Movement).

The rules essentially discredit any input energy flicks smaller than 10% of the total amplitude range and would also discredit if there is a marked difference between the two input values F1 and F2 which essentially corresponds to the noise or unwanted artifacts in the signal. Figure 7 shows the overall decision surface.

Figure 8 shows the effect of these features and on classification compared to the raw data (dotted line in the Figure). The Amplitudes were quite high for all legitimate eyebrow movements of various magnitudes and hence created positive classification all the time which in turn was mapped to the SPACE BAR key which was later used with the actual testing.

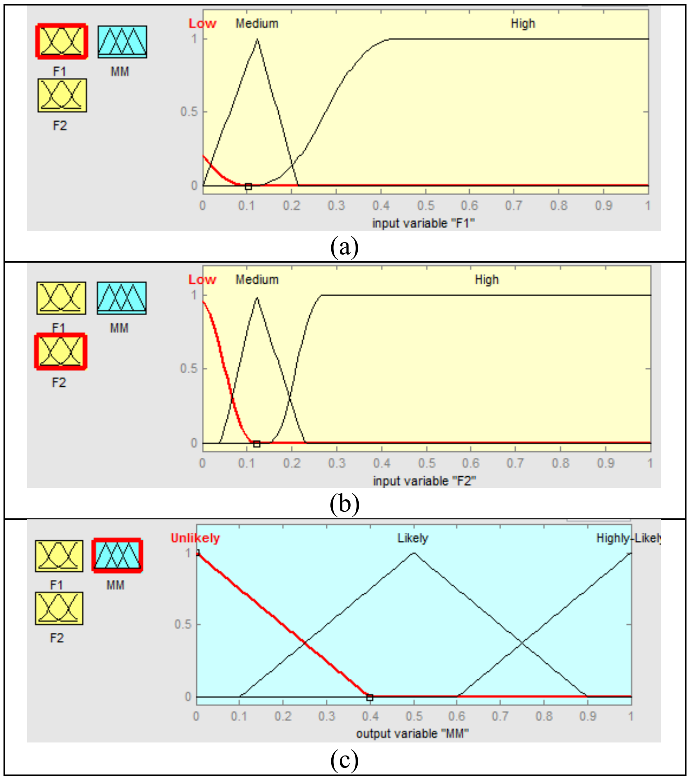

Figure 6. Membership Functions, (a) Input F1, (b) Input F2, and (c) Output MM.

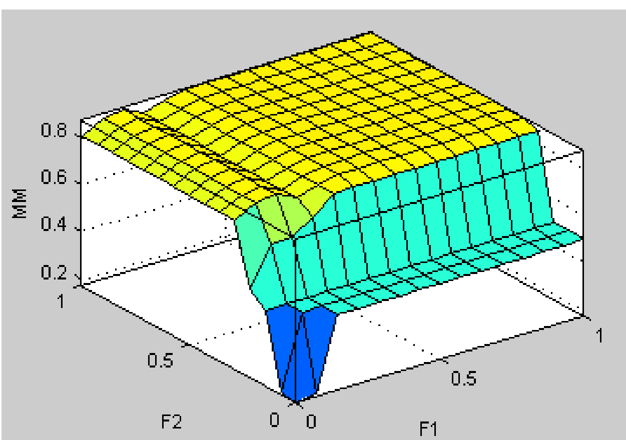

Figure 7. Overall Decision surface for the classifier.

V. Testing

In this work, a severely disabled patient's case is presented. The patient is a 21 year old resident patient in the intensive care unit of a local hospital. He has needed full time care and support from a very early age and has lived in the hospital during this time. Over this period, the patient had very limited access to any form of education. However, having had exposure to a multicultural staff, he has picked up an understanding of English, Urdu/Hindi, Malayalam and Philipino in addition to his mother tongue Arabic.

The degenerative SMA condition for this patient is an example of an extreme case characterized by complete paralysis in the limbs and physical disability. Usually confined to bed and needing a respirator, he was observed to have no controlled movement in any of his limbs, nor the ability to be able to move his head independently. He is unable to speak but demonstrates an understanding of language and is able to communicate to a certain degree by responding to conversation with facial gestures such as smiling, raising his eye brows or frowning to indicate yes and no, for example. This consistent and reliable control over certain facial gestures prompted the idea of using the EMG based system for developing a method for controlling Assistive Technology. Therefore, a commercially available EMG controlled switch for computer control was tested [Ablenet.com]. The device (the Impulse Switch), in conjunction with a Windows software interface can be set up to trigger a switch output once muscle activity goes beyond a certain threshold. This threshold needs to be modified (by nursing staff or care-givers) over the course of the day as the muscle fatigues and with changes at the electrode interface. Hence the proposed technique was used in order to replace the existing threshold based system. The target games used were the same games (from Inclusive Technologies [24]) that the patient was familiar with while using the previous system. An example of such games is shown in Figure 9. The game is related to waiting for certain amount of time and pressing Spacebar on the keyboard so that an action can take place. A wrongly timed key press would result in an error message.

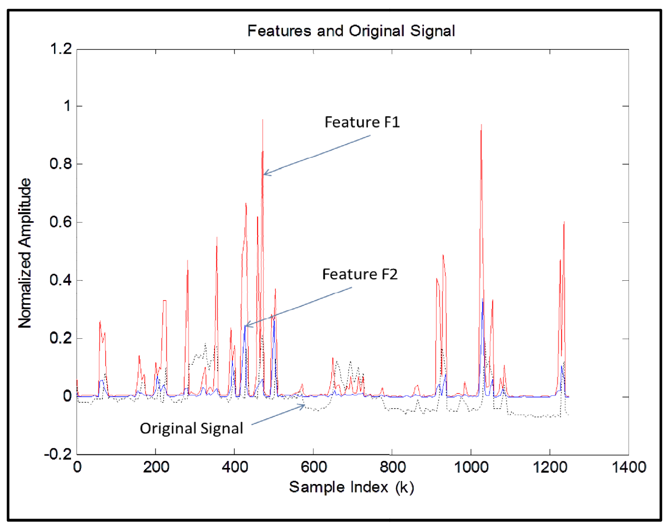

Figure 8. The amplification of the true eyebrow movements by the features vs. the original signal.

VI. Conclusion

In this paper, a framework has been presented for using the EMG sensor probes to read the facial muscular responses, especially the muscles controlling eyebrow movement as the input to recognition system to detect the binary input from patients with Spinal Muscular Atrophy. The purpose of this system is to enable these children to be able to use computers with such a control system and hence be able to play games and participate in other learning activities. The same concept can extended further to control other assistive hardware in order to improve their quality of life. The presented framework is being tested at the local hospital with SMA patients and encouraging results are being obtained which will be used in further improving and fine-tuning the technique.

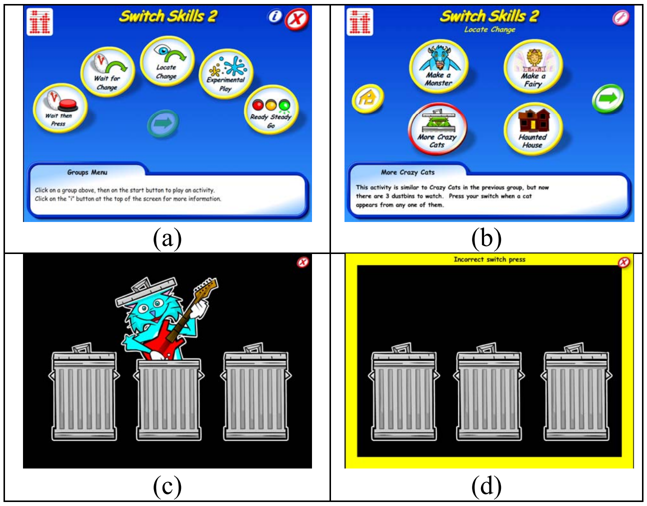

Figure 9. A typical game application used with the proposed system. (a) Initial screen of the application, (b) selected game menu, (c) correct key-press result, and (d) wrong key-press result if the key is pressed too early.

The presented work has shown that the features used here are very robust towards the reduced response effect due to muscular fatigue and hence enables the user to keep on using the interface for a longer period of time without the need of manual calibration by a care-giving staff member.

With keyboard mapping, any available computer application can be used. However, due to the binary nature of the muscular input, the concept cannot be extended to many keys, hence restricting to a smaller subset of games and computer activities. This may be customized based on the capability of the individual user and a state-machine approach can be used to increase the number of keys that can be mapped.

The work is being further extended into mapping several modes into various actions for a PC application as well as for remote robotic control.

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