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Multi-modal Intelligent Seizure Acquisition (MISA) system - A new approach towards seizure detection based on full body motion measures

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Abstract— **Many epilepsy patients cannot call for help during a seizure, because they are unconscious or because of the affection of their motor system or speech function. This can lead to injuries, medical complications and at worst death. An alarm system setting off at seizure onset could help to avoid hazards. Today no reliable alarm systems are available. A Multi-modal Intelligent Seizure Acquisition (MISA) system based on full body motion data seems as a good approach towards detection of epileptic seizures. The system is the first to provide a full body description for epilepsy applications. Three test subjects were used for this pilot project. Each subject simulated 15 seizures and in addition performed some predefined normal activities, during a 4-hour monitoring with electromyography (EMG), accelerometer, magnetometer and gyroscope (AMG), electrocardiography (ECG), electroencephalography (EEG) and audio and video recording. The results showed that a non-subject specific MISA system developed on data from the modalities: accelerometer (ACM), gyroscope and EMG is able to detect 98% of the simulated seizures and at the same time mistakes only 4 of the normal movements for seizures. If the system is individualized (subject specific) it is able to detect all simulated seizures with a maximum of 1 false positive. Based on the results from the simulated seizures and normal movements the MISA system seems to be a promising approach to seizure detection.**

I. INTRODUCTION

Epilepsy is a neurological disorder: the propensity of the brain to generate epileptic seizures. Approximately one third of the patients continue to have seizures in spite of adequate medication. Many of these start suddenly and unpredictably, make the patient lose consciousness and may carry risks of severe trauma and even death. If the patient is alone the seizures may pass unnoticed, especially during sleep. This makes it desirable to detect them, if it is not possible to prevent them. When the seizures are detected an alarm can warn staff at the hospital or relatives at home of the seizures. Today such alarm systems exist, but they are not reliable. A study on the sensitivity of epilepsy bed alarms and pulse oxymeters [9] showed that in the case of tonic-clonic seizures the sensitivity was 30-35% and for other seizures it was even less. A new device for warning about seizures is therefore needed. Several groups have worked on detecting seizures based on ACM data [1], [6], [7]. Nijsen et al. [1] have shown that in a test on 18 patients it was possible to detect the seizures of 10 patients based on visual inspection of ACM data. From these results an alarm system based on ACM data seems as a good approach. Other modalities which might improve the functioning of ACM data for detection of epileptic seizures are EMG, gyroscopes and magnetometers. The current paper therefore proposes a new approach to seizure detection denoted Multi-modal Intelligent Seizure Acquisition (MISA) system containing all of the four above mentioned modalities. This system is the first to provide a full body description for epilepsy applications. For this graphical description of the subject the magnetometers help the positioning in space. Nijsen et al. [2] state that to capture the majority of the seizures (especially the myoclonic seizures) focus should be on the lower arm which is the body part mostly involved in myoclonic seizures. Based on this result the current paper initially is centered on the movements of the lower arm. We analyzed signals from the movement sensor on the lower arm and the EMG from the biceps. As a first step in developing the MISA system the current paper will examine whether the different modalities of the system provide complementary information with respect to the detection of seizures.

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II. METHODOLOGY

A. Subjects and Data Collection

The data was collected in the Epilepsy Monitoring Unit (EMU) at the Danish Epilepsy Center in Dianalund. The subjects were monitored for about 4 hours and EEG, AMG, EMG, ECG, audio and video recordings were stored. The AMG sensor system used is Xsens MVN, which is developed by Xsens Technologies [10]. Xsens MVN contains 16 sensors placed in a suit worn by the test subject. Each sensor contains both a 3D accelerometer, 3D magnetometer and 3D gyroscope. Data from the AMGs are sent via a bluetooth connection to a server where it is stored. The subject wore 28 surface EMG electrodes resulting in 14 bipolar EMG channels placed on 14 muscles. The active EMG electrode is placed on the belly of the muscle, while the reference electrode is placed on nearby bone or tendon. The EMG signals are collected at a sampling frequency of 1 kHz (bandpass filter: 1 Hz - 500 Hz). The digital signals were synchronized with the signals from the other modalities recorded during monitoring. In the future all modalities will be wireless, whereby the MISA system will be completely

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wireless, making it easier for the patients to get around and be more free of equipment.

For this pilot project three test subjects were enrolled, two males and one female, though gender has no theoretical influence. Due to ethical considerations we only included adults, whereas children will also be included in the more detailed follow-up investigation. The recordings contain normal activity such as eating, biking, use of computer and cellular phone and gambling with dices. Furthermore the subjects were instructed by physicians to simulate 15 seizure events of three seizure types (five events of each). The seizures simulated are tonic-clonic, versive-asymmetric tonic and myoclonic. The times when seizures occurred have been clinically annotated.

B. The seizures

1) Tonic-Clonic: This type of seizure is generated with the test subject lying on a bed. The tonic phase is made as an isometric contraction in all muscles at once (limbs extended). This is followed by the clonic phase which consists of rhythmically repetitive jerks made by alternation of contracting and relaxing the muscles.

2) Versive - asymmetric tonic seizure: The versive seizures are characterized by a forced turn of the head to an almost uncomfortable angle, where the subject looks to a side and upwards. This is followed by an isometric muscle contraction in an asymmetric posturing with an arm raised above the head.

3) Myoclonic: A myoclonia is a very short lasting jerk (less than a second), where just a single muscle contracts. To simulate this, one biceps has been contracted for as short a time as possible.

C. Multi-modal Motion Data Presentation

In MATLAB a program is designed to visualize the simulated seizures and the normal physiological movements. The program is able to display acceleration and angular velocity in three dimensions, in addition to the electrical signals from the muscle (EMG).

From a visual inspection of the data, it can be seen that for all modalities each seizure type is stereotypical. Two figures each showing the acceleration and angular velocity in the lower arm together with the EMG signal from the biceps are presented.

In Fig. 1 a simulated tonic-clonic seizure is presented. For this simulated seizure the tonic phase lasts about 8 seconds followed by the clonic phase lasting about 14 seconds, where the rhythmic repetitive jerks are easily seen. The tonic phase starts with a high acceleration and angular velocity of the lower arm, but through the tonic phase these values are close to zero, because the arm is not moving, the muscles are isometrically contracted, as indicated by the EMG signal. Later in the clonic phase the acceleration and angular velocity are again large, seen as rhythmic jerks caused by alternating activation-deactivation of the muscles. The absolute maximum amplitudes of the acceleration and angular velocity are about 100 m/s^2 and 10 rad, respectively. The absolute maximum amplitude of the EMG signal is about 3 mV.

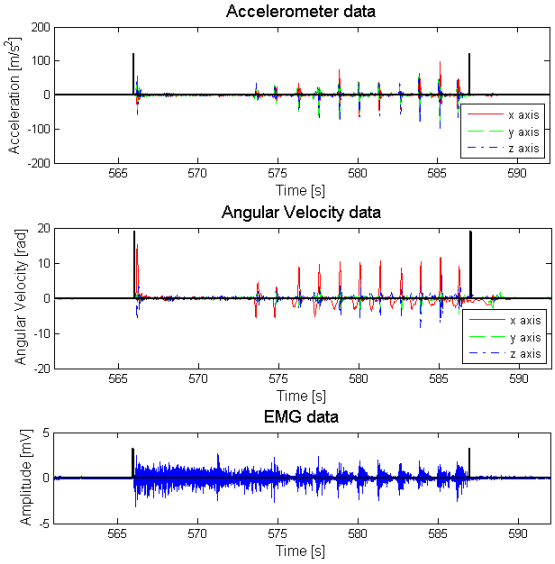

Fig. 1. A tonic-clonic simulated seizure framed by the black vertical lines placed by physicians. On top of the figure the acceleration is shown, in the middle is the angular velocity and at the bottom the muscle activity. The acceleration and angular velocity are from the AMG sensor at the lower arm, whereas the EMG data is from the biceps.

In Fig. 2 the data from a versive - asymmetric tonic seizure is shown. As it can be seen in the first part where the head is turning the lower arm is not involved, but when the raised arm becomes part of the seizure (asymmetric tonic seizure) the amplitude of the acceleration and angular velocity increases to about 30 m/s^2 and 12 rad, respectively. At the same time the EMG signal has an absolute maximum amplitude of about 2.5 mV.

The data from the myoclonic seizure is not shown, but the duration is found to be about half a second. Real myoclonia are even shorter in duration. The acceleration, angular velocity and EMG signal have absolute maximum amplitudes of 35 m/s^2, 7 rad and 3.5 mV, respectively.

D. Processing Motion Data

Based on the seizures having stereotypical patterns, theoretically it should be possible to distinguish the seizures from the normal activities by a biomedical signal processing algorithm. A simple approach towards such an algorithm could be the Root-Mean-Square (RMS) value, $\mathrm{RMS}(\mathbf{x}) = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\mathbf{x}(n)^2}$, which is often used in connection with physiological data [4]. This is calculated for a window of half a second of the data and the windows are overlapping by 50%. The size of the window is chosen based on the fact that the myoclonic seizures are shorter than half a second, so to enhance the amplitude of these seizures a short window is needed. On the other hand the window should not be too short, which would induce a poor frequency resolution. Normally a window of 1 second is used when working with physiological data [3].

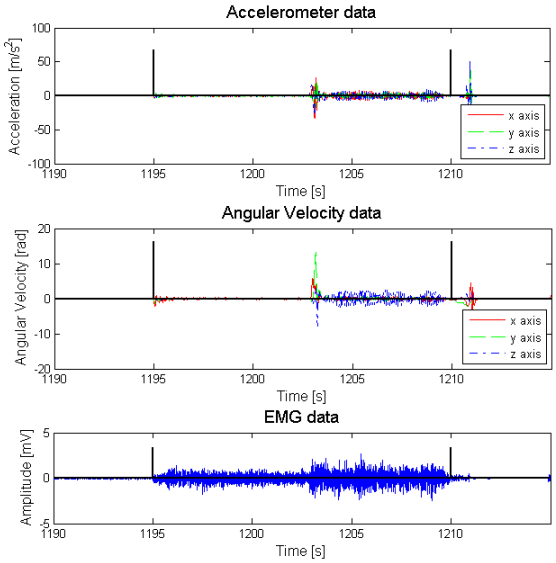

Fig. 2. A versive - asymmetric tonic simulated seizure framed by the black vertical lines placed by physicians. On top of the figure the acceleration is shown, in the middle is the angular velocity and at the bottom the muscle activity. The acceleration and angular velocity are from the AMG sensor at the lower arm, whereas the EMG data is from the biceps.

The RMS value of a window is calculated for all three modalities: acceleration, angular velocity and muscle activity. For the acceleration and the angular velocity it is proposed that the mean of the RMS values are calculated across the three dimensions, $\text{RMS}_{\text{total}} = (\text{RMS}_x + \text{RMS}_y + \text{RMS}_z)/3$. This is seen similar in other research projects [8]. This is done for all the time epochs analyzed (i.e. the periods containing the seizures and the periods containing different normal activities performed by the subjects). The periods of the normal activities are identified visually by inspection of the videos. From the RMS values the largest value is found for each modality for each period analyzed. These results can be plotted in a feature scatter plot showing the possibility of distinguishing seizures from normal activity.

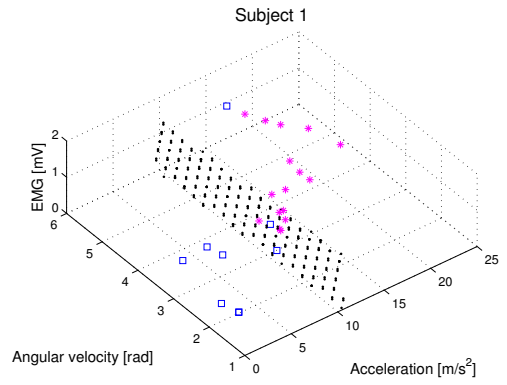

Fig. 3. The absolute maximal RMS values for simulated seizures and normal activities for the first subject. The * denote the seizures, whereas the squares denote the normal activities. The · marks the Bayes classifier discriminating between seizures and normal activity.

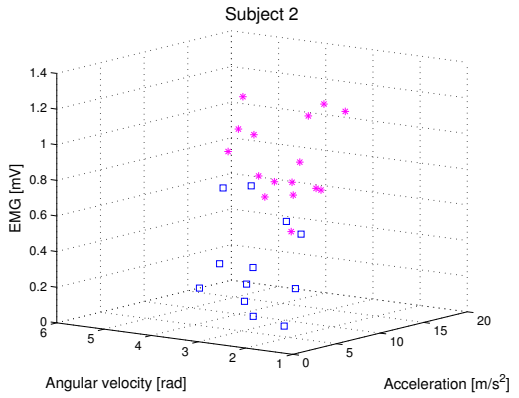

Fig. 4. The absolute maximal RMS values for simulated seizures and normal activities for the second subject. The * denote the seizures, whereas the squares denote the normal activities.

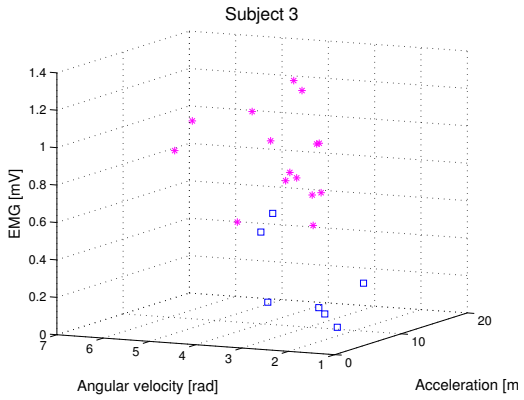

Fig. 5. The absolute maximal RMS values for simulated seizures and normal activities for the third subject. The * denote the seizures, whereas the squares denote the normal activities.

III. Results and Discussion

From the feature scatter plots for the two subjects shown in Fig. 3, 4 and 5, it can be seen that the different modalities provide complementary information, meaning that the group of seizure-events cannot be differentiated from the group of normal activities based on just one modality. It is seen that the seizures are actually grouped in the 3D plot whereas most of the normal activities are grouped at another place in the feature space. Only few of the normal activities are placed closer to the group of seizure data than the one with normal activity data. Those that are placed closer to the group of seizure data are still not surrounded by seizure data, but are only placed in the outer sphere of the seizure-group. This means that by using all modalities it becomes possible to distinguish between seizures and normal activities. The distribution functions of the data are assumed to be gausian, which makes the Bayes classifier optimal. In Fig. 3 a Bayes classifier decision boundary is added, based on the decision function [5]:

TABLE I

DETECTION OF SEIZURES BASED ON DATA FROM THE LOWER ARM SENSOR AND THE BICEPS. (AV: ANGULAR VELOCITY)

Modalities			**1. subject**		**2. subject**		**3. subject**		**All**	
ACM	AV	EMG	Sen [%]	FP	Sen [%]	FP	Sen [%]	FP	Sen [%]	FP
x			100	2	53	1	67	3	87	8
	x		53	1	73	6	67	0	52	6
		x	100	1	100	2	100	3	96	4
x	x		100	3	93	2	100	2	89	8
x		x	100	1	100	2	100	0	96	3
	x	x	100	0	100	2	100	0	98	4
x	x	x	**100**	**0**	**100**	**1**	**100**	**0**	**98**	**4**

TABLE II

DETECTION OF SEIZURES BASED ON DATA FROM THE THIGH SENSOR AND THE QUADRICEPS. (AV: ANGULAR VELOCITY)

Modalities			**1. subject**		**2. subject**		**3. subject**		**All**	
ACM	AV	EMG	Sen [%]	FP	Sen [%]	FP	Sen [%]	FP	Sen [%]	FP
x			67	6	100	9	33	0	33	7
	x		67	3	67	0	67	3	78	12
		x	100	6	67	2	100	3	100	15
x	x		80	2	100	0	93	2	91	6
x		x	100	4	100	3	100	2	98	11
	x	x	100	4	100	4	100	2	89	7
x	x	x	**100**	**4**	**100**	**0**	**100**	**2**	**98**	**8**

$$d_i(\mathbf{x}) = \ln P(C_i) \quad - \quad \frac{1}{2}\ln|\mathbf{C}_i| \quad - \quad \frac{1}{2}\left[(\mathbf{x}-\mathbf{m}_i)^T \mathbf{C}_i^{-1}(\mathbf{x}-\mathbf{m}_i)\right] \quad (1)$$

where $i = 1, 2$ and $\mathbf{m}_i$ and $\mathbf{C}_i$ are the mean and covariance matrix for class *i*, respectively. These measures are given by:

$$\mathbf{m}_i = E_i[\mathbf{x}] \quad (2)$$

$$\mathbf{C}_i = E_i\left[(\mathbf{x}-\mathbf{m}_i)(\mathbf{x}-\mathbf{m}_i)^T\right]. \quad (3)$$

Since no a priori probability is known and data are to be split in two classes, $P(C_i)$ is set to 1/2. The use of a classifier indicate the possibility of classifying multi-modal motion signals as seizure or non-seizure. In Table I the sensitivity (sen) (percentage of the seizures that are detected) and false positives (FP) (the number of normal activities that are detected as seizures during the 4-hour recording session) are given for each subject, for the three modalities separately and for a combinations of them. It is clearly seen that the best results, i.e. the highest sensitivity and the lowest number of false positives, are achieved when all three modalities are used. The table both shows the result of a subject specific MISA system for each of the subjects and of the non-subject specific MISA system. The non-subject specific system is able to detect 98% of the simulated seizures and at the same time it captures only 4 false positives. On the other hand the subject specific systems are able to register all simulated seizures and only captures 0-1 false positive. The movements that are detected as seizures for the non-subject specific system constitute one period of gambling with dices from the first and the second subject, respectively, and furthermore one period of biking from the second and the third subject, respectively. The periods of gambling with dices might be registered as a seizure due to the relatively high muscle force and the rhythmic/alternating feature of the movements while shaking the dice cup. This could be mistaken for a clonic movement. There are no physiological explanation to why the biking periods are detected as seizures based on the data from the arm, since it is mostly the legs that are used on an exercise bike.

Furthermore the same study is made for the sensor at the thigh and the EMG electrode at the quadriceps. The results seen in Table II show that it is not just a MISA system based on data from the arm that makes it possible to distinguish between simulated seizures and normal activities. Even a MISA system based on the leg is able to partly detect the simulated seizures without detecting too many false positives. This is explained by the fact that the legs are also involved in some of the seizures as it is difficult to keep them entirely still when contracting other muscles during the seizures where the legs are not involved.

IV. CONCLUSION

A fairly simple first version of the MISA system in a non-subject specific version is shown to be able to achieve a sensitivity of 98% and at the same time only capture 4 false positives. This means that it is actually able to distinguish between the simulated seizures and the normal activity from the test subjects in this study. Looking at the subject specific MISA system even better results are seen with a sensitivity of 100% and only 0-1 false positive. Based on these results and the knowledge of real seizures having an even larger force than one can produce voluntarily, it seems possible

to distinguish between real seizures and normal activity based on biomedical signal processing algorithms dedicated for a MISA system. Furthermore it has been shown that the use of all the modalities of the MISA system provide complementary information which ensures a higher classification accuracy. Real seizures might not be as similar as the simulated ones. This means that in a future perspective more advanced features should be extracted and possibly a non-linear classification algorithm should be used to distinguish between seizures and normal activities. A second generation fully automatic MISA system is under development based on data from epileptic patients.

REFERENCES

[1] T.M.E. Nijsen, J.B.A.M. Arends, P.A.M. Griep and P.J.M. Cluitmans, "The potential value of three-dimensional accelerometry for detection of motor seizures in severe epilepsy", *Epilepsy & Behavior*, 2005, vol. 7, pp. 74-84.

[2] T.M.E. Nijsen, R.M. Aarts, J.B.A. Arends, and P.J.M. Cluitmans, "Model for arm movements during myoclonic seizures", *Engineering in Medicine and Biology Society, 29th Annual International Conference of the IEEE*, 2007, pp. 1582-1585.

[3] D.A. Gabriel and G. Kamen, "Experimental and modeling investigation of spectral compression of biceps brachii sEMG activity with increasing force level", *Journal of Electromyography and Kinesiology*, 2008.

[4] H. Linderhed, "Methods for Analysis and Evaluation of Surface EMG", *Linkpings universitet*, 1 edition, 1996.

[5] R.M. Rangayyan, "Biomedical Signal Analysis - a case-study approach", *Wiley-interscience*, 2002, pp. 460-461.

[6] G. Becq, S. Bonnet, L. Minotti, M. Antonakios, R. Guillamaud, and P. Kahane, "Collection and exploratory analysis of attitude sensor data in an epilepsy monitoring unit", *Proceedings of the 29th annual international conference of IEEE EMBS*, France, 2007, pp. 2775-2778.

[7] K. Cuppens, S. Omloop, P. Colleman, B. Ceulemans, and B. Vanrumste. "Detection of nocturnal epileptic seizures of pediatric patients using accelerometers. *Belgian Day on Biomedical Engineering*, 2007.

[8] T.R. Burchfield and S. Venkatesan, "Accelerometer-based human abnormal movement detection in wireless sensor networks", *Proceedings of the 1st ACM SIGMOBILE international workshop on Systems and networking support for healthcare and assisted living environments*, ACM New York, NY, USA, 2007, pp. 67-69.

[9] R.M. Mathiasen and C.P. Hansen, "Sensitivity of Epilepsy Bed Alarms and Pulse Oxymeters in the Danish Epilepsy Centre, Dianalund", *Epilepsia*, 2005, vol. 46 (Suppl. 6), pp. 50.

[10] Xsens Technologies B.V., Website: http://www.xsens.com/en/home.php/ (2008), January 16, 2009