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Swallow Detection Algorithm Based on Bioimpedance and EMG Measurements

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Abstract: Image-based swallowing assessment tools like videofluoroscopy and endoscopy allow experts manual investigation of a few individual swallows. However, these tools are expensive and can only be used by clinicians. Systems which utilize easily attachable, inexpensive and non-invasive sensors at the throat could be a real progress for diagnosis and therapy.
This contribution investigates the use of a combined electromyography (EMG) and bioimpedance (BI) measurement at the throat to automatically detect swallowing events. The absolute value of the measured BI completely describes the swallowing process, i.e. the closure of the larynx. There is a typical reproducible drop in BI during a swallow. The muscle activity needed for the laryngeal movement during a swallow is measured using EMG. The presented algorithm involves a valley detection in order to perform a segmentation of the BI signal. Additionally, only BI valleys that coincide with EMG activity are selected for feature extraction. In the second part of the algorithm, extracted features of the BI and integrated EMG are fed into a support vector machine (SVM) which is able to separate BI valleys related to swallowing events from valleys which are not caused by swallowing.
The detection algorithm has been tested on data from nine healthy subjects. The data set contained 1370 swallows of different bolus sizes and consistency and was effected by other movements and speech. The combined BI/EMG segmentation detected 99.3% of all swallowing events. The subsequently applied classifier showed a sensitivity of 96.1% and a specificity of 97.1% for the test data.

Keywords: Classification, Signal processing, Medical systems, Detection algorithms, Signal-processing algorithms, Time-series analysis.

1. INTRODUCTION

Swallowing is a complex vital process that takes place either consciously or subconsciously depending on the current phase of the swallowing. Controlled by cortical processes, which are coordinated in the brain stem (i.e. pattern generators), multiple muscles have to be activated in a timely manner for a swallow. Swallowing disorders (dysphagia) can lead to serious complications, including malnutrition and pneumonia, which can be lethal. The complete closure of the larynx and its timing take a central role in safe swallowing. The larynx is the bifurcation between the trachea and the oesophagus. In case of closure failure, saliva, liquid or food penetrates the airway (aspiration), which may have the consequences described above. The causes of swallowing disorders are mostly severe brain injuries and strokes. Every second stroke patient suffers from dysphagia, which is chronic in one quarter of the patients (Bath et al., 2002).

Because of the complex anatomy, the overlapping muscular processes, and the complex control, the diagnosis of swallowing disorders is extremely complex. Standard examination methods in swallowing disorders are videofluoroscopy and fiberoptic endoscopy. Both are technically complex procedures which can in most cases only be performed by clinicians.

In contrast, a system which utilizes easily attachable, inexpensive and non-invasive sensors and that contains an automatic algorithm for detection of swallows can be used for instantaneous biofeedback of the swallowing process or for continuous long-term measurements. Such a real-time measurement method should furthermore give reproducible and reliable results.

First approaches in this direction have been based on dual-axis swallowing accelerometry signals (Sejdi et al., 2009; Damouras et al., 2010), dual-axis swallowing accelerometry signals in combination with nasal respiration and submental mechanomyography signals (Lee et al., 2009), as well as swallowing sounds (Lazareck and Moussavi, 2002; Sazonov et al., 2010). Swallowing accelerometry and swallowing sounds measure the vibration and the noise which is caused by swallowing. However, vocalization which is

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caused by speech or a cough can severely disturb the measurement signal and swallow detection. These negative effects can only be partially reduced by algorithms (Sejdi et al., 2010). Therefore, it is necessary to study the performance of other real-time capable measurement methods which allow a robust detection of swallows even in presence of speech, neck or head movements.

Electromyography (EMG) can be used to measure the electrical activity of muscles and muscle groups. The EMG signal provides information about the onset and the level of muscle activation. However, EMG alone is not sufficient to evaluate swallowing (Hillel et al., 1997). Amft and Troster (2006) combined EMG measurement with swallowing sound recordings in order to detect swallowing. The results show that there is still room for improvement.

A Japanese group studied a four-electrode transcutaneous bioimpedance (BI) measurement at the throat for the assessment of swallowing (Kusuhara et al., 2004; Yamamoto et al., 1998). In a study by Yamamoto et al. (2000), the reproducibility of the curve for small changes in the electrode positions was determined. The resulting trace was interpreted as a reflection of the entire swallowing process (oral, pharyngeal, esophageal phase) caused by movement of the larynx, pharynx, throat, and oesophagus.

To our best knowledge, nobody tried to apply automatic swallowing detection based on BI. This contribution investigates the use of a combined EMG and BI measurement at the throat to automatically detect the laryngeal movement during swallowing. The presented algorithm consists of a valley detection which selects parts of the BI signal that might be related to swallows. Only valleys that coincide with EMG activity are then selected for feature extraction. In the second part of the algorithm, the extracted features are fed into a support vector machine (SVM) in order to separate swallows from non-swallows. The developed algorithm was tested on data from healthy people.

2. METHODS

2.1 Signal acquisition

The measuring system PhysioSense which allows two independent BI measurements and provides up to four channels of EMG measurement has been used. This device was developed at the Technische Universität Berlin, Control Systems Group (Nahrstaedt et al., 2010). The device has two galvanically isolated current sources. One current source generates a sinusoidal current with a frequency of 50 kHz, while the second current source is set to a frequency of 100 kHz. Thus, two independent BI measurements can be performed simultaneously. Both current sources can be used either for the four-electrode or the two-electrode measurement method (Martinsen and Grimnes, 2008). In the first case, seperate electrodes are used for applying the current and measuring the voltage. In the latter case, the voltage is directly measured over the current source output. The device measures the absolute value of the BI without phase information. The sampling frequency is 4 kHz. The measurements are sent in real-time via USB to a PC. The device fulfills the following standards: IEC 60601-1:1998+A1:1991+A2:1995, IEC 60601-2-40 and IEC 60601-1-2:2007.

For the measurement of the trans-pharyngeal BI at the throat, the four-electrode method at a frequency of 50 kHz was used. Additionally, EMG was measured across both voltage measuring electrodes. The electrodes of the current source were placed on both sides of the onset of the sternocleidomastoid. The voltage measurement electrodes were placed laterally between the hyoid bone and the thyroid cartilage (Fig. 1). For this, Blue Sensor N ECG electrodes (Ambu Ltd., United Kingdom) were used.

A typical time course of the integrated EMG (after the processing described in Section 2.2 and 2.3) and BI during a swallow is shown in Fig. 5. The laryngeal closure reaches its maximum when the BI is at its local minimum.

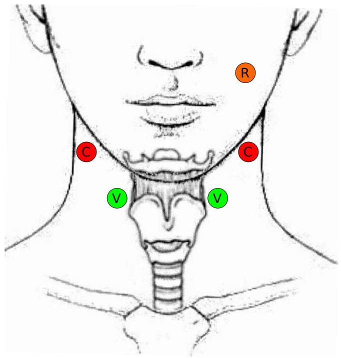

Fig. 1. Electrode positions (C - current electrodes, V - voltage measurement electrodes, R - reference electrode)

Nine adults participated in this pilot study. The exclusion criteria were: younger than 18, older than 50, pregnancy, a history of dysphagia, implanted cardiac pacemaker or defibrillator, metallic implants or central venous catheters. The participating subjects were two women (mean age 28.5) and seven men (mean age 27.4). This study was approved by the ethic board of Berlin at the Charité Berlin (EA1/160/09 and EA1/161/09). In order to examine the accuracy of the automatic detection, sensitivity and specificity were determined.

During the examination, each subject was sitting at a table, where they were connected to the measurement device through electrodes. Each subject was instructed to mark every swallow using a manual switch. Except for the consistencies of the boluses that the subject had to swallow, there were no guidelines. All subjects were allowed to talk, move their heads and place the food/liquid to their mouths on their own. Each subject was examined on two different days. In each of both sessions, the subjects first swallowed their own saliva for a period of 10 minutes. Then they drank 200 ml of water and finally ate 100 g of yogurt. In total, 1370 swallows were recorded.

2.2 Preprocessing

First jumps and spikes in the EMG signal are detected and removed. For this, the difference in EMG amplitude of subsequent samples is stored in a sequence. A spike/jump in the original signal is detected if the corresponding value in the difference sequence is at least eight times greater than the standard deviation of the difference sequence. Under the assumption that the sequence has a normal distribution, the probability is almost zero that a difference