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MANOMETRY-BASED COUGH IDENTIFICATION ALGORITHM

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***Abstract**: Gastroesophageal reflux disease (GERD) is a common cause of chronic cough. For the diagnosis and treatment of GERD, it is desirable to quantify the temporal correlation between cough and reflux events. Cough episodes can be identified on esophageal manometric recordings as short-duration, rapid pressure rises. The present study aims at facilitating the detection of coughs by proposing an algorithm for the classification of cough events using manometric recordings. The algorithm detects cough episodes based on digital filtering, slope and amplitude analysis, and duration of the event. The algorithm has been tested on in vivo data acquired using a single-channel intra-esophageal manometric probe that comprises a miniature white-light interferometric fiber optic pressure sensor. Experimental results demonstrate the feasibility of using the proposed algorithm for identifying cough episodes based on real-time recordings using a single channel pressure catheter. The presented work can be integrated with commercial reflux pH/impedance probes to facilitate simultaneous 24-hour ambulatory monitoring of cough and reflux events, with the ultimate goal of quantifying the temporal correlation between the two types of events.*

***Keywords**: Biomedical signal processing, cough detection, gastroesophageal reflux disease.*

***ACM Classification Keywords**: I.5.4 Pattern Recognition: Applications – Signal processing; J.3 Life and Medical Sciences*

1. Introduction

The latest comprehensive statistics provided by the National Institutes of Health suggests that gastroesophageal reflux (GER) and related symptoms affect approximately 20% of the US population, resulting in over 700,000 annual hospitalizations [1]. GER, which occurs in healthy individuals without causing discomfort, is characterized by the movement of gastric content into the esophagus. Reflux episodes are considered a disorder, known as gastroesophageal reflux disease (GERD), when the episodes become frequent, prolonged, and/or are ineffectively cleared back into the stomach. An individual suffering from GERD shows problematic symptoms, such as heartburn, discomfort, and chest pain, which result due to prolonged exposure of the distal esophageal mucosa to the refluxate. Excessive exposure can lead to further consequences, such as esophagitis and esophageal ulceration.

GERD is commonly cited as a significant cause of chronic cough [2-5]. In multiple studies, GERD has been documented to be a cause of chronic persistent cough in 38 to 82% of patients [2]. Irwin et al. report that GER can cause cough either by aspiration of gastric content, or by stimulation of the distal esophagus due to repetitive or prolonged GER events [3]. It has also been documented that cough may precipitate GER by stimulating transient lower esophageal sphincter (LES) relaxation [2]. To determine if a patient suffering from chronic cough should be treated for GERD, it is important to quantify whether there is a causal relationship between cough and reflux. In addition to facilitating the diagnosis, more accurate identification of the temporal correlation between cough and reflux can lead to a more appropriate treatment [6].

Numerous studies have focused on determining this temporal correlation [5-8]. However, they rely on manual identification of cough, either through the interpretation of user diaries and user-triggered events [5, 7, 8], or through the manual analysis of manometric recordings, identifying cough as simultaneous, short duration, rapid pressure rises (time to peak less than 1 second) across multiple manometric recording sites [6]. This results in a time-consuming process, prone to user error.

In this paper, we present an algorithm for accurately identifying coughs based on a single-channel manometric recording using a custom pressure probe optimized for cough detection [9]. The algorithm can be implemented in real-time, allowing a simultaneous indication of cough events with the recording of reflux episodes. The two-stage algorithm, which consists of a filtering stage followed by a decision stage, has some common elements with the real-time QRS detection algorithm proposed by Pan and Tompkins [10, 11]. In particular, the cough detection algorithm has a similar filtering stage to its QRS counterpart, with both algorithms sharing the goal of reducing high-frequency noise components and removing low-frequency baseline drifts and pressure changes, thus amplifying the pressure response of interest. The filtering stage of the proposed algorithm differs mainly in the bandpass frequency, which is specific to coughs, and in the utilization of integration in a time window corresponding to the typical duration of a cough. The decision stage of the cough detection algorithm has also been adapted specifically to isolate the pressure response characteristics of a cough.

2. Methodology

2.1 Algorithm Description

2.1.1 Overview

Initially, the presented cough detection algorithm employs a combination of bandpass filtering, differentiation, and moving window integration to magnify the short, rapid pressure rises characteristic of cough events and to reduce the baseline drift and the low-frequency pressure variations characteristic of esophageal peristalsis. The second stage of the algorithm consists of decision logic which performs the recognition process, determining the occurrence of a cough based on a combination of dual-threshold and width detection. To demonstrate feasibility of the algorithm on acquired manometry tracings, development was initially performed in Matlab (The MathWorks, Natick, MA).

In the following sections, each stage of the algorithm is described in more detail.

2.1.2 Filtering Stage

The analysis of manometry tracings acquired using a single-channel fiber optic pressure catheter showed that the frequency components of the pressure rise associated with a cough typically range from 2.5 Hz to 5 Hz. An initial bandpass filter stage is used to attenuate signal components and noise artifact outside this frequency range. The bandpass filter is achieved using cascaded low-pass and high-pass filters. Both filters are zero-phase, least-squares approximations, 17th order FIR filters. The low-pass filter, which has a 3-dB frequency of 5 Hz, reduces high-frequency noise. The high-pass filter, which has a 3-dB frequency of 2.5 Hz, reduces lower-frequency peristaltic contractions and baseline drifts. Following the bandpass filtering stage, the signal is differentiated. The differentiation stage focuses on identifying cough by its characteristically steep slope. The resulting signal is then rectified, making all data points positive facilitating the decision process. Finally, the signal is integrated to provide an average of the output, thus incorporating the width of the cough episode into the output signal.

2.1.3 Decision Stage

The output of the filtering stage results in the amplification of cough events and the reduction of high-frequency noise and low-frequency pressure rises due to peristalsis. Because the filtering stage dramatically improves the cough signal-to-noise ratio, the decision stage of the cough detection process is simplified. Cough detection on the filtered data relies on first determining the maximum peak within a given sampling interval. This can be determined recursively in real-time. The threshold is then adjusted automatically based on the current maximum peak. The threshold has been empirically set to 0.33 of the maximum peak of the current interval. By periodically adjusting the threshold based on the maximum peak of the current sampling interval, the algorithm adapts to changing characteristics in the signal. After determining the threshold, the algorithm searches for a dual crossing of the threshold, with the first crossing registering a positive slope, the second crossing registering a negative slope, and the time interval between the crossings being within the cough duration parameter. The cough duration has been set to 400 ms, based on measuring cough durations on manometry tracings.

2.2 Evaluating the Algorithm

Evaluation of the discussed algorithm was performed using esophageal manometry recordings acquired with a single-channel pressure catheter optimized for cough detection. The catheter [9], comprises a miniature white-light interferometric fiber optic pressure sensor encapsulated in such a manner as to optimize sensitivity to pressure at the catheter tip, such as that experienced during a cough event, while reducing sensitivity to circumferential force, such as that experienced during esophageal peristalsis. The esophageal probe interfaces to an optical signal conditioner which converts the optical signal to an analog output. The analog output is sampled at 50 Hz using a PCMCIA data acquisition board (National Instruments, Austin, TX) and a custom-designed real-time software application on a laptop computer. A block diagram of the system is shown in Figure 1.

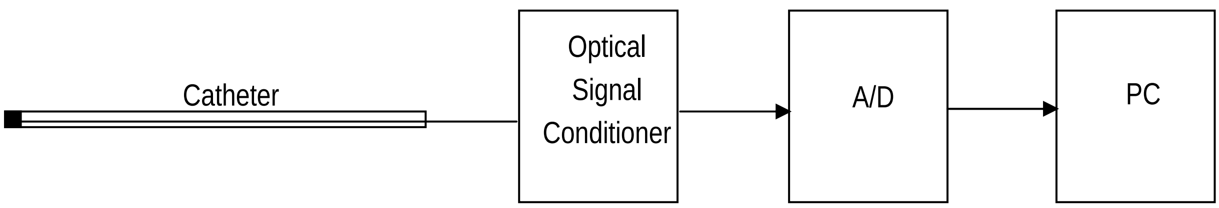

Figure 1 - Block diagram of experimental setup.

In vivo esophageal recordings were acquired from a healthy volunteer. Three separate trials were performed to ensure repeatability. In each trial, the volunteer performed a series of respiratory and gastrointestinal events, such as swallowing, belching, heavy breathing, coughing, throat clearing, and laughing. The volunteer also initiated movement (i.e. head rotation, bending, and standing) to attempt to introduce unwanted artifacts. All events were marked on the recording at the exact time of their occurrence.

3. Results

Preliminary testing of the algorithm on in vivo data samples demonstrated a consistent detection of cough events. Figure 2 shows the original signal and the output of each filtering step for one in vivo sampling interval recorded from the healthy volunteer.

In Figure 2a, the raw signal is shown, with gastrointestinal and respiratory events that occurred during the sampling interval indicated. The output of the low pass filter can be observed in Figure 2b, which reduces the high-frequency noise ripples. Figure 2c, which shows the output of the high pass filter, demonstrates the amplification of the cough events, while attenuating the slower pressure variations resulting from talking and swallowing. The differentiation process amplifies slope information, shown in Figure 2d, which is then rectified resulting in a signal comprising positive data points, shown in Figure 2e. The final output of the moving window integrator is shown in Figure 2f, where it can be observed that the cough signals have been amplified, while other pressure variations have been reduced.

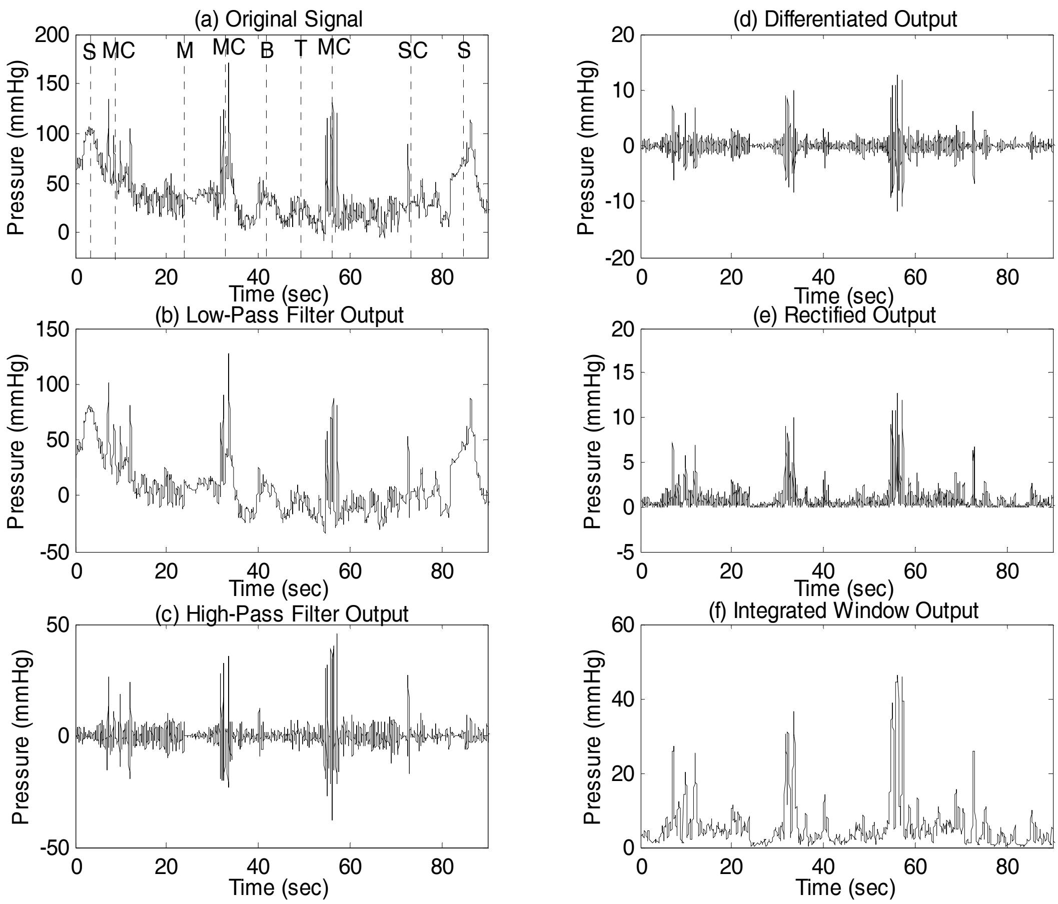

Figure 2 - Sample data of (a) original signal, (b) low-pass filter output, (c) high-pass filter output, (d) differentiated output, (e) rectified output, and (f) integrated window output.
S indicates a peristaltic contraction resulting from a swallow,
MC indicates the occurrence of multiple coughs, or a cough burst,
M indicates patient movement,
B indicates a belch,
T indicates patient talking,
SC indicates the occurrence of a single cough.

The final result of the cough detection algorithm is depicted in Figure 3, where the cough identification results (Figure 3c) are compared with the raw signal (Figure 3a) and the output of the filtering stage (Figure 3b), which supplies the input signal to the decision process. Despite the presence of noise artifacts and two high pressure variations resulting from peristalsis, the algorithm has successfully identified all cough events in the given sample by targeting a dual crossing of the established threshold within the set duration. This can be observed in Figure 3c.

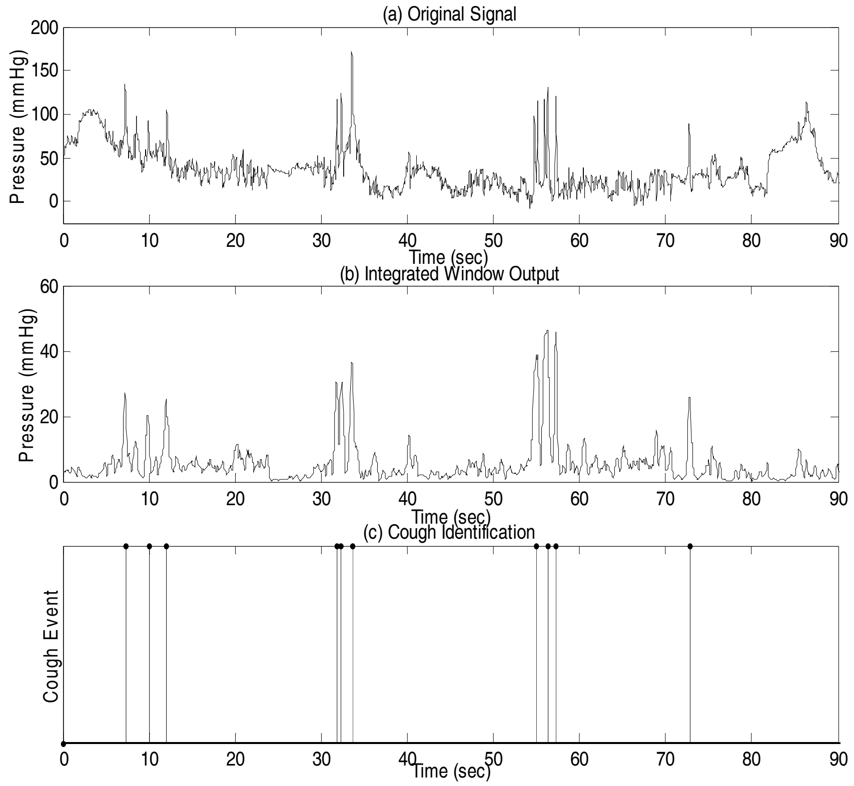

Figure 3 - Sample data showing cough identification,
including (a) original signal, (b) integrated window output, and (c) final algorithm results.

4. Discussion

In recent years, numerous studies have attempted to define the temporal correlation between cough events and reflux events in a pursuit to fully understand the relationship between chronic cough and GERD [5-8]. In these investigations, a tool to facilitate the identification of cough episodes without manual analysis of sound recordings, diary annotations, or manometry tracings is still lacking. In the present study, we developed an algorithm for conveniently identifying coughs based on a single manometric channel recording.

Using an algorithm consisting of a filter stage to amplify frequency components associated with the characteristics of cough while attenuating other pressure artifacts, followed by decision logic to identify the cough events from the filtered signal, cough episodes have been correctly identified in samples acquired via manometry. The successful demonstration of the feasibility of the algorithm paves the way for more robust testing using a larger database of manometric readings. Using the algorithm structure presented, specific parameters, including the filter cut-off frequencies, the duration of cough events, and the adaptive threshold setting, may be adjusted to more accurately satisfy the characteristics of cough based on a larger sampling pool of test recordings. Also, a further qualifier can be added to the real-time implementation, in which the definition of a cough can be modified to include bursts of two, three, or more cough events.

5. Conclusion

An innovative algorithm for identifying cough events based on manometric recordings was developed. Initial testing of the algorithm was performed on in vivo data samples acquired using a single-channel pressure catheter. Preliminary studies indicate that the algorithm is suitable for cough detection. By integrating the technique with a single-channel pressure and pH/impedance catheter for 24-hour ambulatory monitoring of cough and reflux, a suitable diagnostic tool for GERD could be achieved.

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