Self Organized Maps for Intestinal Contractions Categorization with Wireless Capsule Video Endoscopy

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Abstract: Wireless Capsule Video Endoscopy constitutes a recent technology in which a capsule with micro-camera attached to it is swallowed by the patient, emitting a RF signal which is recorded as a video of its trip throughout the gut. We applied this technology to develop a first approach in intestinal contractions categorization, under the perspective of intestinal motility assessment. In order to automatically cluster the different types of contractions, we designed a computer vision system which describes video sequences in terms of classical image descriptors. We used Self Organized Maps (SOM) to build a two-dimensional representation of the different types of contractions, which were clustered by the SOM in a non-supervised way. In this work, we describe the methodology used, as well as the qualitative results of the visual assessment of this technique using a database of intestinal contractions previously labelled by the specialist in a selected pool of test studios.

Introduction

In this work, we focused our efforts on the automatic classification of the different patterns of small intestinal contractions in video endoscopy for intestinal motility assessment. The number of intestinal contractions, their typology, and their temporal distribution along the intestinal tract characterize small bowel motility patterns which are indicative of the presence of small intestine motility disorders which can be described in terms of ileus, pseudoobstruction, bacterial overgrowth, and the irritable bowel syndrome, mainly [1].

The novelty of our research in this field relies on the use of Wireless Capsule Video Endoscopy images (WCVE) [2]. In this clinical domain, the specialist has to analyse a video, and manually label each frame where a contraction event happens. Usually, each video analysis may last 1 or 2 hours, and among a typical quantity of 20.000 frames, only 700 contractions are reported. The posterior analysis of typology (i.e., the classification of all the intestinal contractions found in different categories) and their distribution along the intestinal tract represents a tedious work that deserves huge amount of inspection time. Work has been orientated to the development of a computer vision for the automatic categorization of intestinal contractions. Different classes of visual patterns of intestinal contractions are learnt by a Self Organized Map (SOM) [3], using a database where intestinal contractions have been previously labelled by the experts. Our system associates each intestinal contraction with a cluster, and provides the expert with a useful tool that lets him visualize sets of similar contraction events, calculate the total number of samples for each class and directly obtain the temporal distribution of each pattern.

Materials and Methods

WIRELESS CAPSULE VIDEO ENDOSCOPY

Wireless Capsule Video Endoscopy constitutes a recent technology in which a capsule with an attached camera is swallowed by the patient. The camera travels along the intestinal tract and emits a radio signal recorded as a video in an external device carried by the patient [2]. Once the study is finished, the final record can be easily downloaded into a PC with the appropriate software for its posterior analysis by the physicians. Recently, several works have tested the performance of capsule endoscopy in multiple clinical studies. Some of these clinical scenarios include intestinal polyposis and the diagnosis of small bowel tumors, obscure digestive tract bleeding, Crohn's disease and small bowel transplant surveillance [4, 5, 6 7, 8, 9, 10, 11]. The assessment of intestinal motility using wireless capsule video endoscopy is a novel and challenging fieldwork, to which our group has devoted its study interest [12, 13] with no previous work published in this line of research, as far as we know. In this medical image modality, the target of the labelling process is the multiple intestinal contraction sequences present in the video. In this sense, the categorization of intestinal contractions appears as a novel tool of support for the intestinal motility assessment by the expert.

CONTRACTIONS CATEGORIZATION IN CAPSULE ENDOSCOPY

The categorization of the intestinal contractions in capsule endoscopy can be performed taking into account two main perspectives: the physiological nature (phasic or sustained) and the visual appearance.

Phasic: This kind of intestinal contractions are characterized by a sudden closing of the intestinal lumen, followed by a posterior opening. This open-closed-open scheme resulted to span 4-5 seconds - corresponding to 8-10 frames, providing an acquisition rate of 2 frames per second-. The specialist usually labelled as a phasic contractions the frame where the lumen was completely closed. In this sense we defined a phasic contraction as the central frame in a sequence of 9 frames where the pattern of an open-closed-open lumen is present. If the closing of the intestinal lumen is complete, this event is categorized as an occlusive contraction, while whether the closing of the intestine is not complete, allowing a small portion of lumen at the central frame, this event is categorized as a non-occlusive contraction.

Sustained: The pattern of sustained contractions corresponds to a sequence of a closed lumen in an undefined number of frames. This pattern is highly recognizable for the presence of the characteristic wrinkles which the continuous muscular tone produces when the intestinal walls are folded in a star pattern.

Regarding the *visual appearance*, the displacement of the capsule along the intestinal tube is produced by the motility activity, which is visualized in video as intestinal contractions. This muscular activity impulses the capsule. But as long as the capsule is moving freely within the gut, this displacement may be accomplished with a certain angular deviation. In other words, should the intestinal tube be perfectly straight and the contraction event produced in a symmetric and radial way, the capsule should keep its longitudinal axis parallel to that of the intestine. Being the real scenario far from this, the longitudinal axis of the capsule experiments an angular variation while it is propelled and is no longer parallel to the intestine. The consequent result is the capsule camera no longer focusing the intestinal lumen but the intestinal walls. In addition to this, the multiple bends and folds which the intestinal tube describes, as well as the very displacement of the gut within the abdominal cavity, contribute to enhance this phenomenon.

FRAME DESCRIPTORS

With the aim of automatically detecting intestinal contractions, for each frame, 6 features were calculated based on well known intensity and texture descriptors: normalised intensity, contrast, hole detection based on a Laplacian filtering and 3 values from concurrence matrices. We build up a feature vector of 6x9 features, associating with each frame the dynamic information of the whole sequence. In this way, for each frame labelled as contraction, a sequence pattern was obtained spanning the four previous and posterior frames. This range agrees with the physiological maximal frequency of intestinal contractions as it is in concordance with the visual experience obtained by the experts during the video visualization sessions. All the chosen features are popular standard descriptors exhaustively used and referenced in the image analysis and computer vision literature [14, 15]. As far as we know, no previous works have been published to describe the kind of intestinal events we are dealing with in this sort of image acquisition technology. We are developing our project in a continuous contact with the clinical experts, and on each research step, new information is added from the expert's knowledge about different typologies of contraction events. So, our aim is to get the most general and flexible feature set, so as to be adaptable to this dynamic scenario. We reached this optimal set through an exhaustive heuristic search achieved through the repetition of several experiments, and the analysis of the relevance of each feature for classification.

SELF ORGANIZED MAPAS

Self Organizing Maps (SOMs) or Kohonen networks [3] are a specific type of neural networks which provide the possibility of reducing the dimensionality of complex multivariate data sets, allowing their visualization in a 2-dimensional representation. By producing easily comprehensible low-dimensional maps of informative features, SOMs offer a technique for visual understanding and interpretation of hidden structures and correlations in the input dataset. Several works have been published referring medical applications using SOMs in a wide range of fileldworks, including classification of craniofacial growth patterns [16], extraction of information from electromyographic signals [17], magnetic resonance image segmentation [18], cytodiagnosis of breast carcinoma [19], classification of renal diseases [20], and drug design [21], among others.

We aimed to use SOMs in order to automatically cluster the different categories of contractions present in each video. The input of the SOM consists of 54 nodes, corresponding to the 54 elements of the feature vector described in the previous section; all the contraction sequences labelled by the expert in the video are used so as to train the SOM. The output of the SOM consists of a two dimensional lattice, in which each cell represents a cluster of similar sequences. This similarity is related to the statistical correlation between the feature vectors of the different sequences. As the feature set was designed in order to describe the diverse patterns of contractions, the different cells of the SOM cluster different these visual patterns. Thus, all the contraction patterns are clustered and mapped to one of the cells of the 2D map such as the one rendered in Figure 1. For visualisation purposes, the central frame of one representative sequence is shown on each cell. An automatic tool was developed in order to let the experts select one cell and obtain all the contractions which share the common visual patterns clustered by the SOM –Figure 1a) and b)-.

Results

Our aim was to test a first approach of the use of SOM for intestinal contractions characterization. In

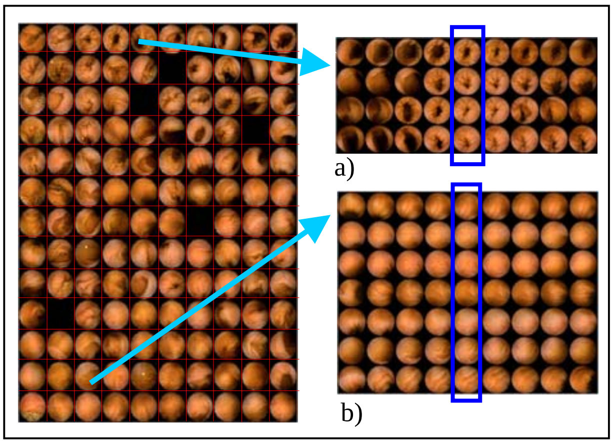

Figure 1: Selecting different cells of the SOM, different patterns of contraction are found – 4 contraction events for a) and 7 for b). The central frame of each sequence is bounded by the blue rectangle.

order to visually assess the performance of our system, the following experiments were accomplished. The experts labelled 10 different videos, corresponding to 10 corresponding to intestinal contraction events were labelled into 4 different categories: Category 1 corresponds to a perfect pattern of phasic contractions. Category 2 corresponds to a pattern in which half of the contraction sequence was lost because the camera was not focusing the intestinal lumen but the intestinal wall; Category 3 corresponds to the pattern of sustained contractions; finally, Category 4 corresponds to a pattern in which the lumen is out of the field of vision of the camera and only a portion of it is visible in some frames of the sequences. All the labelled frames in each video were used to construct the SOM. For these experiments, the developed SOM consisted of 54 input nodes and a two dimensional Kohonen layer in a fixed topollogy of 9x7 nodes arranged in a rectangular lattice. Figure 2 shows a paradigmatic example of a resulting SOM. Each cell shows the central frame of best maching sequence, i.e., a representative sample of the sequencies clustered in the cell. A set of selected cells can be visualized in Figure 3 and 4. The title of the cell references the index in the SOM: the first number indicates the row and the second indicates the column. Thus, Figure 3 shows the cluster of contractions present in cell (7,1). The number on the right represents the label assigned by the specialists. In this case, all the 12 contractions fallen in cell (7,1) have the same label (Category 1), which indicates a good performance in the clustering method. Figure 4 shows the cluster obtained for the cell (9,1). In this case, 17 contractions have been clustered. A larger variability can be observed. In this cell, not only contractions of Category 1, but also Category 2 and 4 can be found.

The same analysis can be performed for one studio containing sustained contractions, where both physiological origin and visual pattern differ from phasic. Figure 5 renders one SOM obtained from a new studio which contains a high quantity of sustained contractions. As can be seen, a gradient pattern is present, grading the SOM from the left side, with more presence of sustained contractions, to the right side. Figure 6 shows the cluster associated to the cell (4,1), with 11 contractions belonging to Category 3 and one contraction belonging to Category 2. Finally, Figure 7 pictures the cluster of cell (7,7). In this case, a cluster

Figure 2: Paradigmatic SOM for one video. A gradation in the different appearance of the cells indicates the presence of clusters of different patterns.

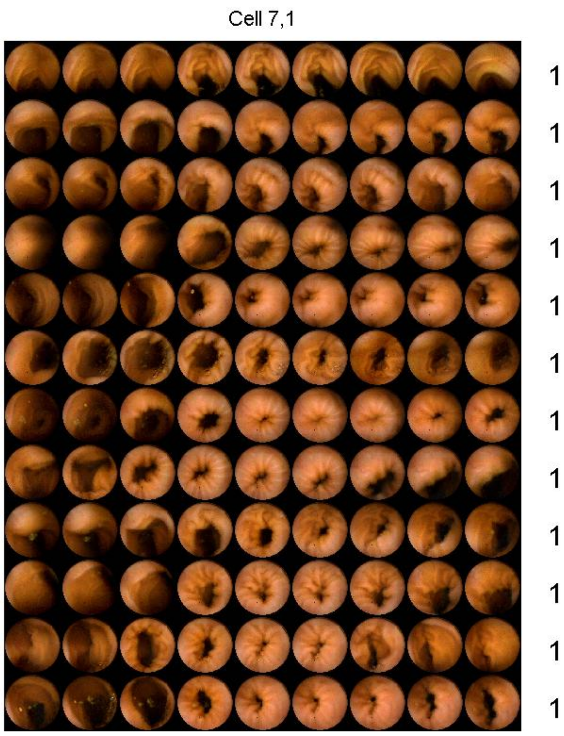

Figure 3: Intestinal contractions clustered by cell(7,1) of the SOM in Figure 2. All samples belong to Category 1.

of 5 contractions where the lumen appears out of the field of view of the camera is obtained. All these sequences happen to belong to Category 4, whose paradigm was defined in the same sense, assessing the consistency of the used method.

Conclusions

The use of SOM appears to be a useful tool in the fieldwork of categorization of intestinal contractions. Different visual patterns can automatically be detected and clustered. The posterior study of these different patterns of intestinal contractions, their frequency and their distribution, in a systematic way, can help shed light in the understanding of the physiological processes involved in intestinal motility assessment. The possibility of analysing each type of contraction in a rapid and independent way opens a promising field of study. The great reduction of inspection time is an important outcome which encourages us to study and develop this novel technique in the analysis of intestinal motility with wireless capsule video endoscopy.

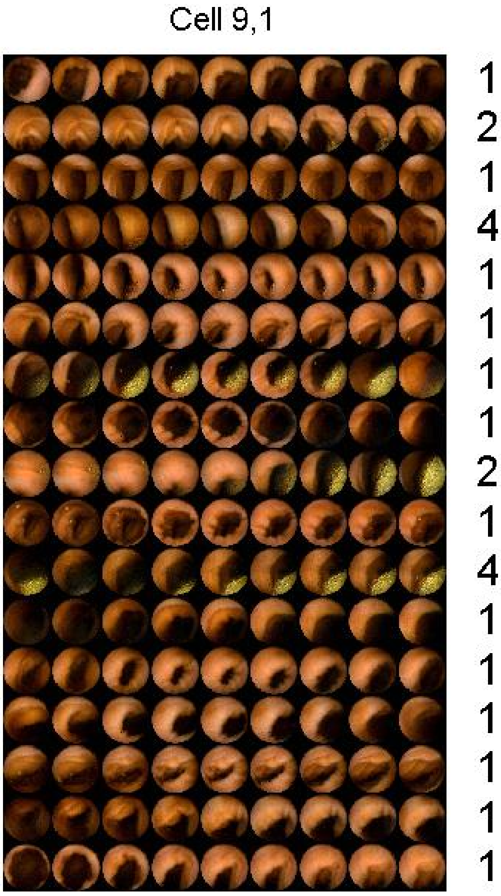

Figure 4: Cell (9,1) shows a higher variability, and different labels are present.

Figure 5: SOM for one studio with presence of a higher number of sustained contractions.

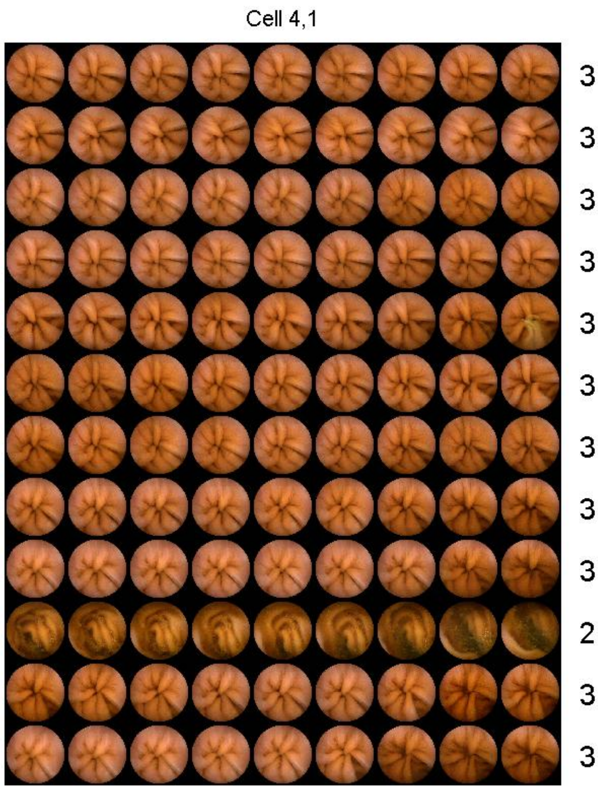

Figure 6: Cell (4,1) captures several samples of Category 3 contractions –sustained contractions-.

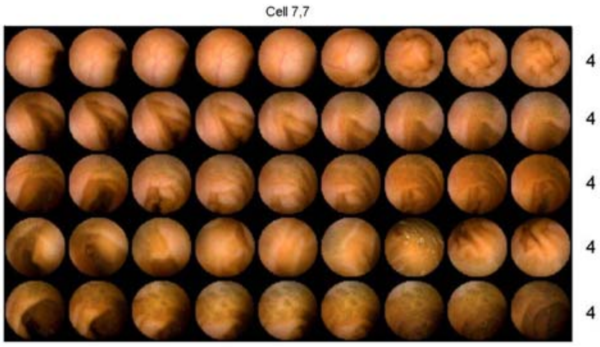

Figure 7: Cell (7,7) in the SOM of Figure 6 shows a cluster of Category 4 contractions.

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