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Cinemanography: fusing manometric and cinematographic data to facilitate diagnostics of dysphagia

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Abstract: Dysphagia, the difficulty in swallowing, is one of the most common and, at the same time, most heterogeneous symptom of the upper digestive tract. Due to its lifetime prevalence of about 5%, every 19th person is affected on average, especially with increasing age. Dysphagia occurs in both benign and malignant diseases of the esophagus and the oropharyngeal tract as well as in neuromuscular diseases. Even dysphagia caused by benign diseases can lead to significantly reduced quality of life.

The diagnostics of the actual underlying disease in patients with dysphagia is commonly conducted using a combination of endoscopy, esophageal manometry, functional assessments and radiologic means, e.g. X-ray-fluoroscopy. As these examinations are typically performed in sequential order, it remains to the physicians to combine the relevant information from each modality to form a conclusion. We argue that this is neither an intuitive, nor a standardized form of presenting the findings to the physician. To address this, we propose a novel approach for fusing time-synchronized manometric and X-ray data into a single view to provide a more comprehensive visualization method as a novel means for diagnosing dysphagia.

Keywords: cinematography; data fusion; dysphagia; esophageal manometry; fluoroscopy; X-ray.

Introduction

Dysphagia — the inability or difficulty to swallow — affects about every 19th person during their lifetime. Developing dysphagia is especially likely for elderly people, since it occurs in up to 33% of the population above the age of 65 years [1, 2]. The symptoms range from swallowing problems in specific — e.g. very dry or fibrous — food to being unable to even swallow saliva. This has a decisive influence on the quality of life of the patients, especially if they are no longer able to eat in public or to eat sufficiently at all (leading to malnutrition).

After malignancy has been ruled out using endoscopy and tomography, the standard for diagnosing benign, oropharyngeal and esophageal dysphagia is a combination of esophageal manometry, functional assessments (e.g. FEES, fiberoptic endoscopic evaluation of swallowing) and X-ray-fluoroscopy [3, 4]. While manometry is the gold standard in the investigation of muscular (dys) function in detail, X-ray imaging provides detailed information on anatomy and localization of structural alterations for dysphagia. Usually, manometry and X-ray recordings are performed consecutively and thus cover separate timespans. Consequently, different acts of swallowing and motility events are recorded, that cannot be compared head-to-head. While motility disorders of the tubular and distal esophagus can be comprehensively clarified, oropharyngeal dysphagia still poses major problems due to swallowing in a highly dynamic system and the interaction of a large number of muscle groups and cranial nerves. Furthermore, pressure and X-ray recordings are commonly displayed side-by-side during diagnostics, which is neither an intuitive nor an ergonomic form of presenting these "two sides of the same coin" to clinicians (Figure 1).

To address this, we propose a novel approach for fusing time-synchronized manometric pressure data and

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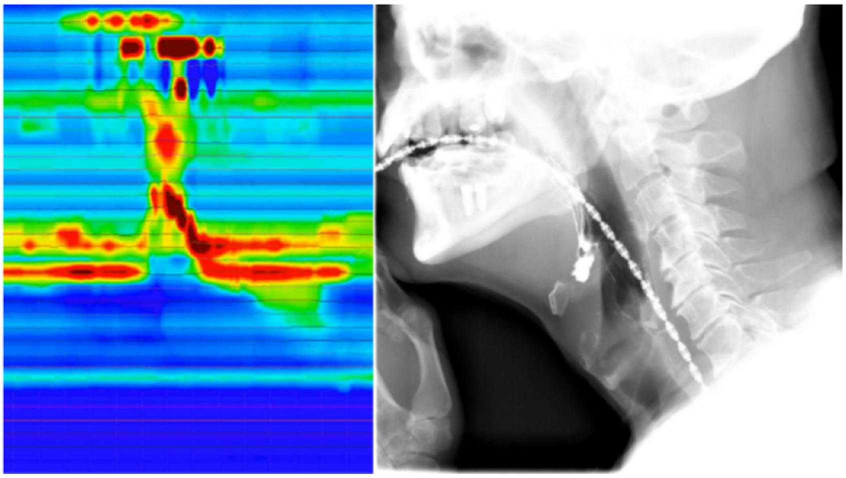

Figure 1: Status quo: time-synchronized oral, manometric data (left side) and cinematographic imaging (right side) of a patient with oropharyngeal dysphagia. The two modalities are presented side by side.

X-ray imaging into a single view to provide a more comprehensive visualization method when diagnosing oropharyngeal and esophageal dysphagia.

Related work

A related approach in the lower digestive tract has been proposed by Davidson et al. [5] for pan-colonic manometry, where fixed anatomical reference points are identified on a 3D finite element surface of the colon. The manometric data from anatomical sites is then translated to corresponding points on the geometric mesh. The work aims at providing a more comprehensive and intuitive visualization method when diagnosing abnormal colonic function, such as constipation. However, the 3D model of the colon used for this approach is not patient individual and cannot visualize movement of the colon.

For these reasons, we strongly believe that a visualization based on patient-individual X-ray-cinematography is better suited for diagnosing dysphagia in a highly dynamic area such as the oral and pharyngeal cavity and the esophagus.

Methods

We used state-of-the-art high resolution manometry probes with a 10 French diameter and 36 coated circular pressure sensors distributed along the probe in 1 cm equal distances [6]. For the manometric data recording and visualization, the software platform ViMeDat™ (Standard Instruments, Karlsruhe, Germany) with the mobile data logger MALT™ (Standard Instruments, Karlsruhe, Germany) has been used. The cinematography data provided by an extended digital imaging X-ray machine (Philips Medical Systems, Hamburg, Germany) has been recorded simultaneously at the Department of Diagnostic and Interventional Radiology at Klinikum rechts der Isar (University Hospital, Technical University Munich, Germany), such that both data sets are time-synchronized and both reflect exactly the same oro-pharyngeal-esophageal events (Figure 1). With the manometric probe inserted transorally into the esophagus, study participants were asked to swallow multiple times 10 mL of fluid contrast agent in an upright position, while an X-ray cinematography was conducted during each act of swallowing.

In a next step, the positions of the pressure sensors in the manometric probe have to be detected for each frame of the X-ray cinematography. For this, we used a template-matching algorithm (OpenCV) with a set of randomly extracted templates from separate cinematography data sets [7, 8]. Regarding this template-matching process we experienced difficulties when working with underexposed X-ray data, since fine details are lost and the sensors tend to blend into the backdrop, particularly around the mandibular corpus and angelus. A more balanced exposure might be beneficial for the detection process but comes only with an increase in radiation dose, which is not in line with radiation protection regulations in humans.

Subsequently, we fitted a cubic b-spline through the detected sensor positions in each frame to estimate the path of the entire manometric probe (Figure 2) and track its movement across the X-ray frames [9–12]. This also allows for estimating sensor positions that have not been successfully detected by the template matching. Thereby, under-exposed parts of the X-ray frames with poorly visible sensors can be bridged very effectively. With these refinements in place, the automated probe recognition provided quite stable results, even in poorly exposed areas.

In a next step, the manometric pressure data is visualized as overlay on top of the X-ray frames. The time-variant manometric pressure information was extracted from the xml-based ViMeDat™ project file structure. According to the common visualization of high-resolution manometries in spatio-temporal color plots, the manometric pressure information of each pressure transducer was embedded in the cinematography data. Pressure values along the manometry catheter are detected at 1 cm equal distances and in high-resolution manometry these values are commonly interpolated in-between these pressure transducers for a smoother visualization. While this way of visualizing is well-established in the field, we aim at evaluating different visualization concepts together with healthcare professionals to identify the optimum in the context of our cinemanography approach. Due to its clear and precise nature, we chose a simple visualization using dots above each sensor position as a starting point (Figure 3).

For executing the process described above and visualizing the results, we developed a graphical user interface (GUI) application based on Python and PyQT (Figure 2) [13].

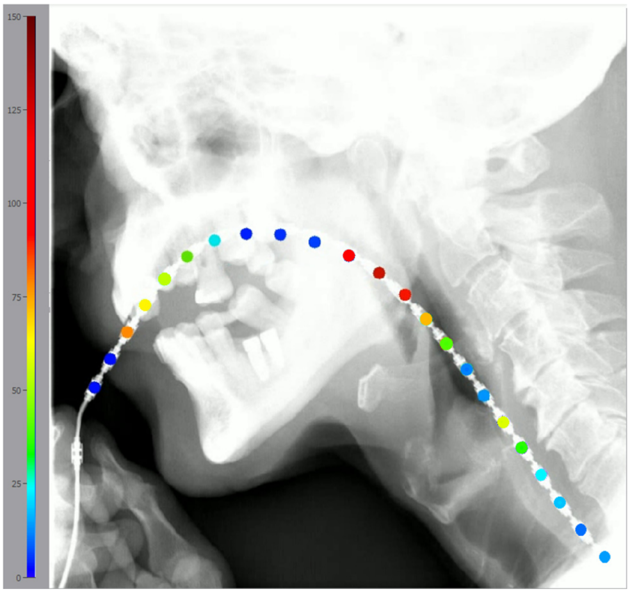

Figure 2: Output of the visualization engine. The basic visualization approach shown in the figure is one of several modes available to the user. Pressure color-coded in mmHg.

Results

We tested our sensor detection algorithm on a small patient data set with positive outcome. Both experienced examiners and junior doctors appreciated our program as intuitive and as enrichment for the diagnosis of benign forms of oropharyngeal or esophageal dysphagia.

As mentioned before, the template matching approach alone yields rather poor results in underexposed areas of the X-ray frames. However, when combined with the cubic spline-fitting, sensor positions can be estimated quite reliably. Though further tests need to be carried out on a broader data set to be able to provide statistically significant accuracies and evaluate the robustness of the approach.

Our new cinemanography tool for fusing manometric and cinematographic data can be used to create patient-individual, but standardized examinations or to create specific project files associated with different clinical cases that patients' examinations can be integrated in. After time-synchronized manometric and X-ray (video) data has been loaded into a project, the sensor detection algorithm can be started. Once the analysis has terminated, the detected sensor positions are shown in the X-ray cinematography and the pressure values are overlaid. For the actual diagnostics, the clinicians can play back these augmented videos and watch the pressure variation over time at the measuring locations along the oro-pharyngeal cavity and the esophagus.

When showing fused cinemanography to medical experts, overall positive feedback was reported. As manometries are typically performed by gastroenterologists in functional laboratories, and X-ray-fluoroscopies are performed in the radiologists' department, this new diagnostic means brings together specialists not only locally, but also in the diagnosis of oropharyngeal dysphagia.

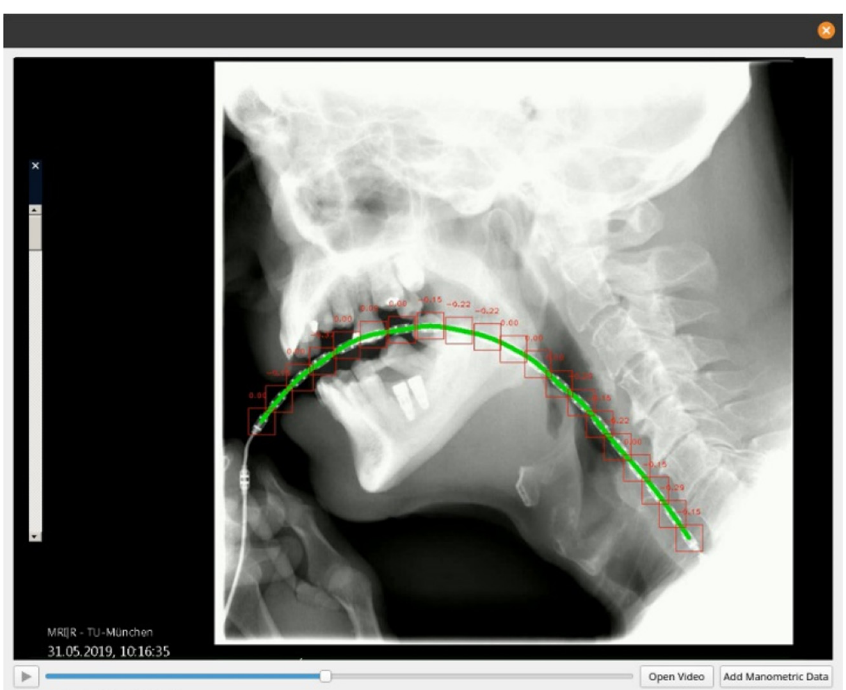

Figure 3: Graphical user interface with fitted cubic b-spline (green) through the detected sensors (red) along the manometric probe.

Conclusion

Despite todays' technical possibilities, the fusion of multiple diagnostic means of different origins is still often done by hand, meaning a medical expert reviews findings one by one or in a non-intuitive and insufficient way side by side. When investigating particularly oropharyngeal dysphagia manometric and cinematographic data is most commonly used. The goal of our work was to develop a tool for fusing manometric and X-ray-cinematographic information into augmented, patient-individual examinations. The great feedback by medical experts shows the huge potential of such fused imaging applications, which directly support medical doctors in daily clinical routine.

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