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Abstract-Title:
TOWARDS AUTOMATIC RECOVERY OF SURGICAL WORKFLOW

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Abstract-Text:
Introduction
For the design of context-aware service systems in operating theaters of the future, workflow recovery has a crucial function. Abstract knowledge about which actions are performed can be used for many applications [2-4] such as optimizing the workflow, recovering average workflows or for guiding and evaluating training surgeons [4,5]. Especially for automatic report generation and finally for monitoring in a context sensitive operating room, an automatic approach is necessary that can handle incoming signals without human interpretation. This paper describes a novel way for automatic recovery of the surgical workflow. Without using an implicit or explicit model of the surgery, the system performs this task by synchronizing sequences of multidimensional state vectors. Each sequence represents the recorded signals during each recorded surgery. The algorithms have been tested on 17 signals of ten different surgeries of the same type. The resulting temporal registration is correctly performed up to seconds, which is our sampling rate. The temporal registration can be visualized in our software by displaying videos of the recorded surgeries in a varying speed. The videos of different surgeries with different durations are visualized precisely synchronized to the same workflow phases. The videos can be replayed in a way that one surgery remains at its original speed and the other one is replayed synchronized to the other. The surgeries can also be visualized at the speed of an average surgery that has been generated by the system. Methods
The laparoscopic instruments used by the surgeon in a minimally-invasive surgeries strongly correlate with the underlying workflow. We account for the ongoing actions during the procedure with a binary model for the instrument usage: A series of multi-dimensional state vectors over time takes into respect that several instruments can be used simultaneously. Currently, we observe the usage of 17 different laparoscopic instruments. Our novel way of workflow recovery is based on the following four steps: 1. Synchronization of events. Using the DTW algorithm similar to Wang and gasser [1], we synchronize different surgeries with variable duration in a non-linear manner. Due to the synchronization of signals, the underlying events and workflow steps are synchronized automatically as well. 2. Creation of an average surgery. An average surgery is created. It reveals events that are common to all procedures. 3. Identification of workflow phases. Common events within the average surgery trigger the start and end points of workflow phases. 4. Obtaining workflow phases for the original surgeries. Using the time mapping from each surgery onto the average, workflow phases for each original surgery can be identified at the end of the procedure. Results
All of the surgeries have been synchronized with our software. For validation, 13 trigger

events have been assigned manually. A maximum tolerance of five seconds deviation between these timestamps was tolerated. Deviations higher than five seconds were classified as wrong phase detections. In six procedures with 13 trigger events each, the proposed system was able to identify 92% of the events correctly. Moreover, 83% of the correctly classified phases were detected with a precision of one second or less. These results demonstrate that our approach is reliable and promising. The video presentation shows the user interface and some exemplary results. Discussion We have shown that our approach of workflow recovery is able to identify common phases in different surgeries of the same type even under the conditions of a real surgery. For this task, an average surgery is computed from a set of signals from exemplary surgeries, which already provides the desired key information for many workflow specific applications. Our system can identify the change of workflow phases with a reliability of 92% and a tolerance of 5 seconds. Each of the signals including the video stream from the laparoscope and the video streams of our three external cameras can be shown simultaneously for two or more surgeries. The fine-grained synchronization of the algorithm allows for stretching the playback speed in a way that the surgeries are visualized according to the workflow phases. Therefore, each single frame of all 24 videos is appropriately labeled with synchronized workflow information for further studies. The playback is useful for thorough and unprecedented analysis of surgical workflow, educational and training purposes and evaluation of surgical skills. References

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