Employing Process Models for Surgical Training

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***Abstract*—The exponential rise in minimally invasive procedures throughout the last three decades shifted the focus from individual manual skills to complex engineering solutions. To streamline the delivery of these novel techniques, Surgical Process Models (SPMs) have been under development. SPMs provide the basis for machine learning algorithms to frame the surgical procedure and anchor themselves into the workflow. Process recording is an essential tool to create an accurate representation of the SPM. Process recording, continued with human expert evaluation have been used to assess operator skills and compare interventional approaches. In this paper, we present a web-based surgical process recording tool which is evaluated in a surgical training scenario. Our aim is to involve the trainees in process recording, therefore actively exploring the generic process model of laparoscopic cholecystectomy. Along with training we also use the process records to identify the most accurately represented time points of process transitions, therefore providing target events for future monitoring systems.**

***Index Terms*—Ontology; Surgical Workflow; Surgical Process Modeling; Surgical Data Science**

I. Introduction

Surgery requires the physician to execute delicate tasks while having a perfect understanding of the techniques the pathology requires. Training traditionally includes a hands on approach, where the resident learns while assisting with cases. With Minimally Invasive Surgical (MIS) techniques (such as laparoscopy) gaining widespread use, both the required manual skills and the cognitive load on the surgeon have significantly increased. As opposed to open surgery, MIS procedures are performed through small incisions, while the operation field is only visible indirectly through cameras or other imaging devices. Many of the MIS tools also restrict the degrees surgeon is able to move. These technological challenges had required the development of special procedural approaches. Many systems have been developed to expedite the training of manual skills outside the Operating Room (OR). Some of these systems are simple box trainers, while others include robotic manipulators, or use virtual reality to achieve this goal [1]. While manual skills are undoubtedly essential for surgery, it is also important to address the new surgical approaches developed for MIS interventions. Traditionally, these procedural flows can be learnt from textbooks, by watching videos, or on the fly by participating in surgeries. In this article we explore how video based learning can be augmented using knowledge models. More precisely the presented software allows the trainee to record workflows of individual surgeries using a general process model of the procedure.

A. *Surgical Process Models*

The need for the methodological study of surgical procedures emerged with the introduction of laparoscopy during the early 90's [2]. The reason behind this is that MIS procedures required a significant investment (in equipment and operator trainig) from the hospital which needed to be objectively justified. The first studies focused on describing the surgical procedure as a sequence of tasks and mainly focused on the completion time of each procedure element. In 2001, Mackenzie et al. presented a decomposition of surgical tasks, where not only the linear flow was studied, but also a hierarchical decomposition of the surgery [3]. Their work established six granularity levels for process description: the procedure, the step, the substep, the task, the subtask, and the motion. For example Laparoscopic Cholecystectomy (Procedure) is composed of several steps such as "Creating the Peritoneum" which is composed of substeps like "inserting the Veress needle". While it is questionable if granularity levels can be clearly isolated, the described levels proved to be useful for surgical process research. While in this paper we focus on employing process models in surgery training, a comprehensive review of surgical process modeling can be found in [4].

II. Materials & Methods

A. *Ontologies*

Ontologies are a way of storing information in a machine readable format. We can look at ontologies as vocabularies enriched with semantic information in the form of axioms [5]. With other words, ontologies not only store a vocabulary, but also store how the terms of that vocabulary relate to each-other. Ontologies already have an established place in the medical domain, but they are mostly used as a terminology standard (Foundational Model of Anatomy [6], SNOMED-CT [7] etc.). In our context, we use ontologies to query information about the surgical workflow. The use of ontologies in workflow modelling originated from industrial manufacturing, where the Process Specification Language (ISO 18629 standard) gained widespread use [8]. Within the medical field, no general process description methodology have been adopted, instead, surgical process research focused on domain specific

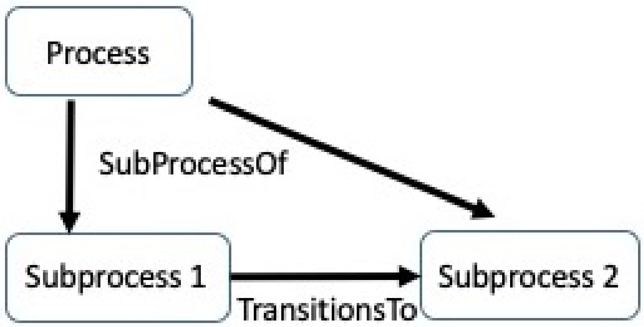


Fig. 1: Base model of the workflow ontology. The inverse properties are not represented.

ontologies such as: laparoscopic surgery (LapOntoSPM [9]) or orthopedic surgeries (OROSU [10]). The OntoSPM international group aims to bridge these ontologies by linking them with general concepts to the upper ontology: Basic Formal Ontology (BFO) [11].

B. Surgical Process Recording

Surgical Process Models can represent individual surgeries (iSPM), or a generic approach to an intervention (gSPM). The research by Neumuth et al. showed that iSPMs can be used to compare procedures, or to estimate the gSPM [12]. During our research we showed laparoscopic cholecystectomy videos to trainees, and asked them to isolate the procedure steps based on a prepared gSPM. Our hypothesis was that active process recording is a superior training method compared to passively watching the procedure. After watching the video, we asked the trainees to fill out a questionnaire about the procedure. We created the gSPM using a simplified workflow ontology which only represented how the procedure elements relate to each-other. The horizontal axis used the term ”transitionTo” and ”transitionFrom” to represent a process following another, while the term ”subProcessOf” and ”superProcessOf” was used to represent the hierarchical decomposition. This structure is visualized in Fig. 1.

C. Software Architecture

Currently, two proprietary products are available to record surgical workflows, The SWAN Suite (Innovation Center Computer-Assisted Surgery, Universitaat Leipzig) [13], and the b<>com software [14] (University of Rennes and the Institute of Research and Technology). In our previous work, we also presented the OntoFlow software, a java-based solution providing direct integration of ontology development and process recording [15]. While all three software have a good range of functionality, we decided to opt for a web based solution to reach out to more students by providing an easily accessible platform. The user interface (client side) is written in javascript, and can be run from any modern browsers. For the server side, we developed two php-based solutions. The first method stored the ontology in a Apache Jena Fuseki database, and queried it trough a SPARQL endpoint. Then the queried data was sent to the client via jQuery. The advantage of this method is that SPARQL provides a great flexibility, and the query result provides information that is not asserted in the original ontology. The drawback is that the system runs resource extensive operations, which can significantly impact the performance of the software. We found that in case of a PC (Dell Latitude D830, CPU: Intel Centrurio Duo 2.2GHZ, 2GB RAM) which is dedicated to running Jena Fuseki, the system experiences a 2-3 seconds of delay when acquiring the new procedure elements. We also tested the system with a buffer incorporated, yet found that the delay is still not tolerable when the procedure is recorded to a fine granularity. These results suggested an alternative solution, when the ontology is directly loaded into the server side, and php is used to pre-process it while the page loads. In our case this means to isolate all the process elements, and to create a transition and subprocess matrix. These resources are then passed on to the client javascript, and no further communication occurs between the server and client side. This solution proved to be significantly faster, and non obtrusive to the user experience. The developed application is able to display the video of the surgery alongside the multiple granularity generic process model. The application window is shown in Fig. 2.

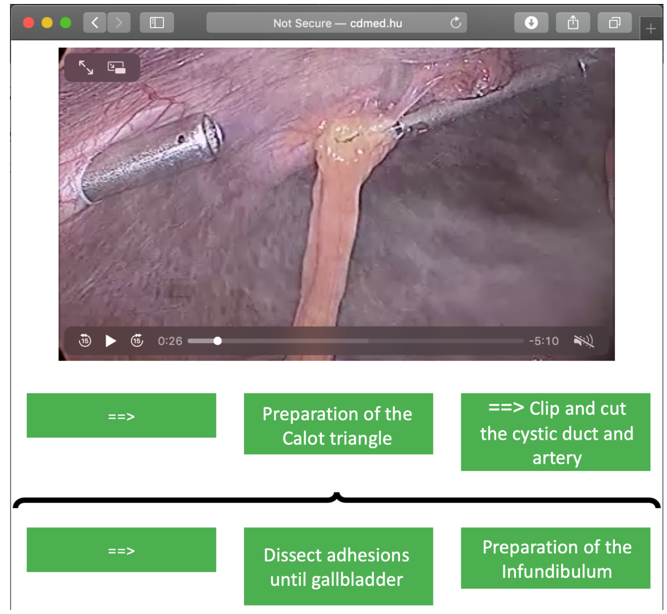
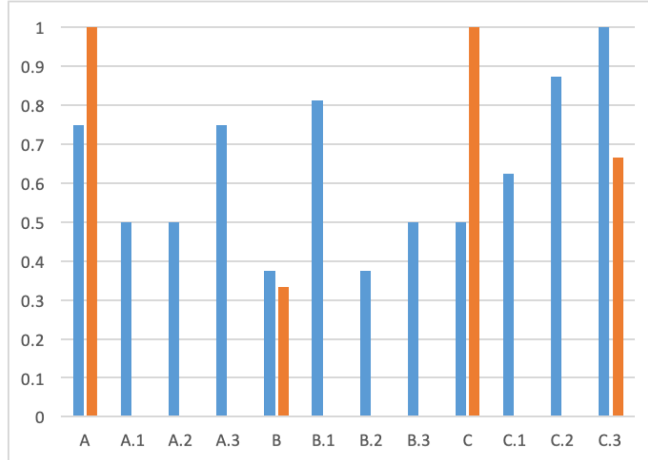


Fig. 2: The application's main window presenting the laparoscopic cholecystectomy procedure. The arrows on the left allow the user to rewind the video to the start of the process element, while the buttons on the right roll the process to the next steps. The horizontal bracket represents the process hierarchy.

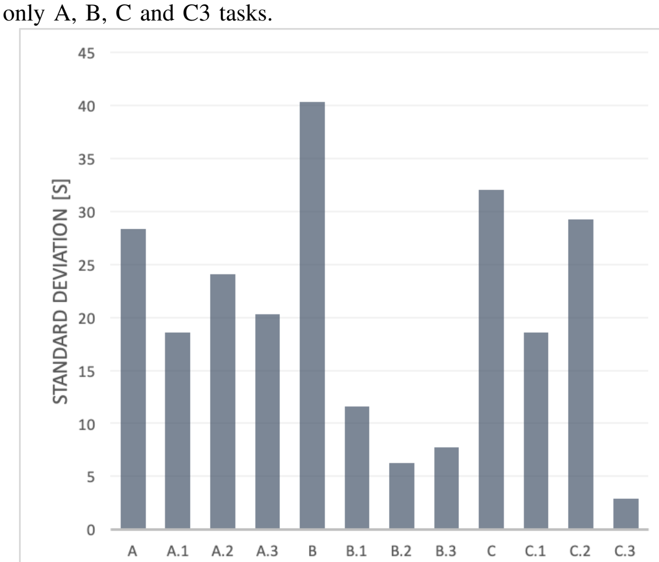
III. Results

The participants (10 students) were presented a video of a Laparoscopic cholecystectomy. First, they watched a pre-annotated video, after which they were asked to annotate the same video using the process recording tool. As a control group, 6 participants did not use the recording software, but only watched the video twice. While the whole procedure is over 20 minutes long, the video was edited down to 5 min 38 seconds. Based on surgery literature, we identified 3 tasks and 7 subtasks, covering the part of the procedure which was recorded via the endoscopic camera. We measured retention of task names by asking both groups to write down the tasks and subtasks they recollect from the observed procedure. This is shown in Fig. 3a. It can be easily seen that while the process recording group recollected some of the subtasks among the main tasks, the control group has only memorized the main task features.

Within the process recording group we collected information about the recorded tasks timestamps. We found that the transitions were identified with a standard deviation between 3 and 40 sec. We calculated the standard deviation for each recorded transition point which is shown in Fig. 3b. As a reference point, we can look at the end of the procedure where the video switched to a banner. At this point, the the human observer's reaction time differences showed 2.88 sec variation. Within the surgical process, the most accurate transition point occurred between cutting the cystic duct and cutting the cystic artery (6.2 sec), signaling a well identifiable time-point in the surgical process. The reasons behind this may include the two easily identifiable cutting method with the diathermy tool. When sensors are deployed to observe the manipulation of these diathermy tools, the registered activity can be used to automatically anchor the process model to a well defined time point. Finding these anchor points can lead to automated process recording, enabling context aware surgical assistance. As an example the recognition of the process transition "clipping the cystic artery" to "cutting the cystic artery" can be a trigger for a robotic device to prepare the hook device for the preparation of the gallbladder. The understanding and accurate monitoring of the surgical workflow enables the high level control of such sub-processes automatons eventually leading to full surgical automation.



(a) Compared retention (fraction of people recollecting the procedure element) of the task elements. Left Columns: the group using the process recording software. Right Columns: the control group watching the annotated video twice. Note that the control group is non zero at only A, B, C and C3 tasks.



(b) Standard deviation of finding the transition (end) points of processes.

Fig. 3: Process elements: (A) preparation of the Calot triangle (B) cystic duct and artery clip and cut (C) preparation of the gallbladder Sub-processes: (A.1) dissection of adhesions (A.2) preparation of the infundibuli (A.2) mobilizing the cystic duct and artery (B.1) cystic duct and artery clip (B.2) cystic duct cut (B.3) cystic artery cut (C.1) preparation of the gallbladder sides (C.2) preparation of the gallbladder off the liver bed (C.3) removing the gallbladder

IV. Conclusion & Discussion

Some MIS procedures already gained widespread use, and new techniques are often introduced. The spread of these is limited by the availability of equipment and by the imperfect information flow. SPMs are capable of capturing the surgical process in a reproducible way, and therefore could be used to expedite the information exchange between medical centers. In this preliminary research, we presented a training tool that utilizes SPMs and process recording to enhance surgical training. The results presented in this paper suggest that process recording can be employed to involve trainees in the exploration of the process model. The recorded process model provides information on the trainees understanding of the procedure, and how well a procedure is defined. While the former one can be used for training evaluation, the later can help in understanding the necessary requirements of monitoring systems. MIS is a technology and resource intensive field of surgery, where the rapid development of new surgical approaches requires methodological evaluation. SPMs provide an objective representation of the surgical process, and therefore can be used to compare individual procedures, as well as different surgical approaches. The comparison of individual SPMs can be used for surgical skill assessment, which is an essential part of surgical training and quality assurance [16]. On the other hand, general SPMs are valuable for defining the safety margins of procedures, and therefore by identifying low risk subtasks, can be a cornerstone of future automation efforts [17]. Medical Robotics is an emerging field, where safety standards are just under development [16], [18]. With the help these international benchmarks, both the safety of the robot operation and the safety of the medical device shall be assured. General SPMs provide a basis to connect the robotic/device safety domain with human patient care standards. This is an increasingly important area in surgical robotics, as the lack of standardization delays technology transfer [19].

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References

[1] L. Jaksa, T. Haidegger, P. Galambos, and R. Kiss, "Tools for laparoscopic skill development – available trainers and simulators," *Orvosi Hetilap*, vol. 158, no. 40, pp. 1570–1576, Oct. 2017.

[2] C. A. Taylor, M. T. Draney, J. P. Ku, D. Parker, B. N. Steele, K. Wang, and C. K. Zarins, "Predictive medicine: Computational techniques in therapeutic decision-making," *Computer Aided Surgery: Official Journal of the International Society for Computer Aided Surgery*, vol. 4, no. 5, pp. 231–247, 1999.

[3] C. MacKenzie, Ibbotson AJ, Cao CGL, and Lomax A, "Hierarchical decomposition of laparoscopic surgery: A human factors approach to investigating the operating room environment." *Minim Invasive Ther Allied Technol*, vol. 10, no. 3, pp. 121–128, 2001.

[4] F. Lalys and P. Jannin, "Surgical process modelling: A review," *International Jour- nal of Computer Assisted Radiology and Surgery*, vol. 9, no. 3, pp. 495–511, 2014.

[5] S. Grimm, A. Abecker, J. Völker, and R. Studer, "Ontologies and the Semantic Web," in *Handbook of Semantic Web Technologies*, J. Domingue, D. Fensel, and J. A. Hendler, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 507–579.

[6] C. Rosse and J. L. V. Mejino, "A reference ontology for biomedical informatics: The Foundational Model of Anatomy," *Journal of Biomedical Informatics*, vol. 36, no. 6, pp. 478–500, Dec. 2003.

[7] D. Lee, N. de Keizer, F. Lau, and R. Cornet, "Literature review of SNOMED CT use," *Journal of the American Medical Informatics Association*, vol. 21, no. e1, pp. e11–e19, Feb. 2014.

[8] C. Bock and M. Gruninger, "PSL: A semantic domain for flow models," *Software & Systems Modeling*, vol. 4, no. 2, pp. 209–231, May 2005.

[9] D. Katic, C. Julliard, A.-L. Wekerle, H. Kenngott, B. P. Müller-Stich, R. Dillmann, S. Speidel, P. Jannin, and B. Gibaud, "LapOntoSPM: An ontology for laparoscopic surgeries and its application to surgical phase recognition," *Int J Comput Assist Radiol Surg*, vol. 10, no. 9, pp. 1427–1434, Jun. 2015.

[10] P. J. S. Gonçalves and P. M. B. Torres, "Knowledge representation applied to robotic orthopedic surgery," *Robotics and Computer-Integrated Manufacturing*, vol. 33, pp. 90–99, Jun. 2015.

[11] B. Gibaud, G. Forestier, C. Feldmann, G. Ferrigno, P. Gonçalves, T. Haidegger, C. Julliard, D. Katić, H. Kenngott, L. Maier-Hein, K. März, E. de Momi, D. Á. Nagy, H. Nakawala, J. Neumann, T. Neumuth, J. R. Balderrama, S. Speidel, M. Wagner, and P. Jannin, "Toward a standard ontology of surgical process models," *International Journal of Computer Assisted Radiology and Surgery*, pp. 1–12, Jul. 2018.

[12] T. Neumuth, P. Jannin, J. Schlomberg, J. Meixensberger, P. Wiedemann, and O. Burgert, "Analysis of surgical intervention populations using generic surgical process models," *International Journal of Computer Assisted Radiology and Surgery*, vol. 6, no. 1, pp. 59–71, Jan. 2011.

[13] T. Neumuth, N. Durstewitz, M. Fischer, G. Strauss, A. Dietz, J. Meixensberger, P. Jannin, K. Cleary, H. Lemke, and O. Burgert, "Structured recording of intraoperative surgical workflows," in *31th. SPIE - The International Society for Optical Engineering*, vol. 7. Horii SC, Ratib OM (eds): SPIE Bellingham, 2006.

[14] b<>com, "Surgical Workflow toolbox-annotate," https://b-com.com/sites/default/files/Surgery%20Workflow%20toolbox-annotate.pdf, Jan. 2017.

[15] D. Á. Nagy, I. J. Rudas, and T. Haidegger, "OntoFlow, a Software Tool for Surgical Workflow Recording," in *IEEE 16th World Symposium on Applied Machine Intelligence and Informatics*, Kosice and Herl'any, Slovakia, Feb. 2018, pp. 119–124.

[16] R. Nagyné Elek and T. Haidegger, "Robot-Assisted Minimally Invasive Surgical Skill Assessment—Manual and Automated Platforms," *ACTA POLYTECHNICA HUNGARICA*, vol. 16, pp. 141–169, 2019.

[17] T. D. Nagy and T. Haidegger, "A DVRK-based Framework for Surgical Subtask Automation," *ACTA POLYTECHNICA HUNGARICA*, vol. 16, pp. 61–78, 2019.

[18] K. Chinzei, "Safety of Surgical Robots and IEC 80601-2-77: The First International Standard for Surgical Robots," *ACTA POLYTECHNICA HUNGARICA*, vol. 16, pp. 171–184, 2019.

[19] T. Haidegger, "Autonomy for surgical robots: Concepts and paradigms," *IEEE Transactions on Medical Robotics and Bionics*, vol. 1, no. 2, pp. 65–76, 2019.