



Development of an intelligent surgical training system for Thoracentesis



Hirenkumar Nakawala*, Giancarlo Ferrigno, Elena De Momi

Department of Electronics, Information and Bioengineering (DEIB), Politecnico di Milano, Piazza Leonardo da Vinci, Milan, 20133, Italy

ARTICLE INFO

Article history:

Received 21 March 2017

Received in revised form 19 June 2017

Accepted 31 October 2017

Keywords:

Surgical training

Thoracentesis

Ontology

Production rules

Tracking

Object recognition

Phase recognition

ABSTRACT

Surgical training improves patient care, helps to reduce surgical risks, increases surgeon's confidence, and thus enhances overall patient safety. Current surgical training systems are more focused on developing technical skills, e.g. dexterity, of the surgeons while lacking the aspects of context-awareness and intra-operative real-time guidance. Context-aware intelligent training systems interpret the current surgical situation and help surgeons to train on surgical tasks. As a prototypical scenario, we chose Thoracentesis procedure in this work. We designed the context-aware software framework using the surgical process model encompassing ontology and production rules, based on the procedure descriptions obtained through textbooks and interviews, and ontology-based and marker-based object recognition, where the system tracked and recognised surgical instruments and materials in surgeon's hands and recognised surgical instruments on the surgical stand. The ontology was validated using annotated surgical videos, where the system identified "Anaesthesia" and "Aspiration" phase with 100% relative frequency and "Penetration" phase with 65% relative frequency. The system tracked surgical swab and 50 mL syringe with approximately 88.23% and 100% accuracy in surgeon's hands and recognised surgical instruments with approximately 90% accuracy on the surgical stand. Surgical workflow training with the proposed system showed equivalent results as the traditional mentor-based training regime, thus this work is a step forward a new tool for context awareness and decision-making during surgical training.

© 2017 Elsevier B.V. All rights reserved.

1. Introduction

Surgery is a highly complex process that requires excellent technical skills [1] e.g. dexterity, procedural knowledge, non-technical skills, e.g. cognitive skills (context awareness, decision-making, and planning) [2,3], and clinical skills [4] e.g. assessment, diagnosis to achieve better patient outcomes and to improve the quality of performance in the operating theatre. Recently, following the emergence of new technologies, e.g. robot-assisted surgeries, the focus on surgical care is moving also towards the quality rather than only on the quantity of the procedure performed. The quality was also further enhanced with the recent advancements in surgical training regimes e.g. by employing surgical simulators [5,6] in advanced surgeries, e.g. thoracic surgeries. In a particular study, researchers [7] have shown that technical errors account for only 4.3% of errors during surgery, while most errors are non-technical errors and pertain the clinical decision-making process.

Although context awareness is an important cognitive skill of the surgery and part of the decision making, most of the current surgical training environments are focused on improving only surgeons' technical skills. The surgeon's capacity to make the intra-operative situational judgements are influenced by surgeon's technical capabilities, patient's conditions, and the competence of the assisting trainee [8]. As traditional training methods are designed under the mentorship of different expert surgeons, the competence of expert surgeons is prime and training could be highly variable. Mental models of the surgeon's experiences stored in the memories of interventions and clinical situations influence the judgements related to context awareness [8]. Novice surgeons who learn to perform high-risk interventions extensively use rule-based decision-making. With long-term experience and training, these rules can be retrieved from the memory with little or no efforts [8]. Also, the growing presence of intra-operative sensors, e.g. endoscopic cameras, and representational information, e.g. on monitors, during the procedures make the surgical training more difficult without the explicit understanding of the procedure along with the contextual awareness. In envisaged operation theatres [9], the efficacy of the operation will be achieved by addressing the workflow issues, where study participants also highlighted context

* Corresponding author.

E-mail addresses: hirenkumar.nakawala@polimi.it (H. Nakawala), giancarlo.ferrigno@polimi.it (G. Ferrigno), elena.demomi@polimi.it (E. De Momi).

awareness as an important functional requirement. The research also suggested that there is a lack of information on resources necessary to support surgical tasks and to efficiently plan the surgical process, which increases the surgical workflow variability and could be structured by grounding surgical process information in the ontology.

As a prototypical scenario, we chose Thoracentesis procedure. Pleural effusion is a life-threatening condition, often associated with other diseases, in which there is a collection of pathogenic or non-pathogenic fluids between the lung tissue and pleural space. Common symptoms of pleural effusion are pleuritic chest pain, coughing, and dyspnoea [10]. An invasive procedure, Thoracentesis, is performed for the removal of fluid from the pleural cavity. A needle is inserted into the chest cavity and the fluid withdrawn using a syringe [10]. Procedure-related complications occur with at most 33% of people and are a major problem, and can range from pain, dry cough, no fluid return, or subcutaneous collection. Many life-threatening complications also arise due to surgical mishandling such as pneumothorax, pulmonary oedema, unintentional puncture of spleen or liver and sheared off catheter in the pleural space and in some exceptional conditions such as winging of the scapula [11]. Indeed, although Thoracentesis is a very simple procedure, procedure-related complications are higher than expected. A recent survey highlights gaps of knowledge and skills in conducting diagnostic and therapeutic Thoracentesis and shows significant training gaps as well [12]. Due to lack of experience (65% cases) and lack of expert supervision and guidance (49% cases), junior doctors were referring their patients to radiology departments for ultrasound guided Thoracentesis in majority of cases (75–100%) [13]. The survey highlights junior doctors' deficiency in knowledge and procedural skills in performing Thoracentesis. Simulation-based training [14] and phantom model-based training [15] on Thoracentesis has enhanced skills of the surgeons; however, the training systems were focused on manual dexterity and lacked the aspects of context-awareness, intra-operative real-time guidance. Thus, there is indeed a need to create an intelligent training system.

We implemented an intelligent training system using knowledge-based system engineering. In this context, an ontology can be applied as a knowledge representation approach for process model that represents key concepts with their properties, relationships, and constraints for Thoracentesis. An ontology provides a rich set of relationships between domain concepts, generally a set of 'part-of' or 'is-a' relations, and allows semantic rules to administer those relationships. In general, ontology holds all pertinent knowledge about the surgical procedure and can be represented in a computer interpretable format to reason over that knowledge to infer information on surgical tasks. Our approach for object recognition consists of the amalgamation of knowledge representation and sensor data to recognise surgical instruments in surgeon's hands for detecting surgical steps and on the scrub nurse surgical stand for further guidance on the required instrument in the next step of the surgical process. Knowledge representation and rule-based machine learning are involved in the object categorization process. Knowledge-based systems [16–18] have been used for object recognition by building a well-defined set of vocabularies for the domain of interest. Unfortunately, most of the algorithmic concepts in 3D computer vision are data-driven and recognition is mostly accomplished by describing the object's geometrical (roughness, curvature, for example) or physical features (colour, texture, for example). Data-driven technologies heavily rely on algorithmic parameters and the object features itself. Moreover, these methods are highly static and few times do not achieve desired results in dynamic settings.

We previously developed [19] an ontology-based context-aware system framework for surgical assistance by combining

image processing and semantic technologies to recognise surgical instruments on the surgical stand during Thoracentesis steps. The framework consisted of a Graphical User Interface (GUI), where user queries the surgical step, and then the retrieved step is sent to the ontology component through Robot Operating System (ROS) [20] topics and messages. The ontology component finds an instrument instance corresponding to the surgical step in progress by reasoning on the logical propositions specified in the ontological assertion box [21]. After recognising the instrument instance, a template-matching algorithm was used to recognise the instruments on the surgical stand. The system identified the contexts, e.g. surgical instrument, by a manual query on the surgical task, e.g. the requirement of a 50-ml syringe to withdraw the fluid from the chest cavity.

In this article, we discuss the rule-based intelligent surgical training system, which uses ontology as a knowledge base, production rules as a workflow model, and computer vision techniques for object detection. The rule-based inference mechanism removed the need of complex queries, manual input from the users, and structured the surgical workflow for automatic workflow execution. We also included the inference mechanism within the ontology to recognise surgical instruments and materials. Surgical workflow was constructed as mutual influences between the surgical tasks. The system does compliance checking between the prescribed workflow and the observed actions. Therefore, the developed system needs the results, e.g. information, on the earlier step and next instrument, from the previous surgical task as an input to execute the workflow sequences. The developed system also offers a low-level understanding, e.g. information on surgical actions, for each surgical step. The developed system provides automatic interpretation of surgical workflow and help trainee surgeons to learn Thoracentesis workflow efficiently, and eventually it may improve the patient care.

2. Materials and methods

2.1. Context-aware software framework for intelligent training system

The framework for intelligent training system comprises three components to automatically derive information on the surgical workflow for surgical training and contextual awareness:

1. *Knowledge module*, where we implemented procedural knowledge on Thoracentesis in the form of an ontology and surgical workflow management through inference rules;
2. *Computer vision module*, where we implemented a) segmentation and tracking algorithms in the "Segmentation node" and "Tracking node" respectively to detect surgical instruments/materials using point cloud data acquired from two imaging sensors; and b) "Markers node" – binary square fiducial markers for surgical instruments/materials recognition.

2.2. Knowledge module

2.2.1. Ontology for Thoracentesis

Ontology for Thoracentesis was built using a top-down approach, where most general concepts of the domain, such as phases (e.g. "Penetration") were first analysed and thereafter specialized concepts, such as actions (e.g. "WithdrawLargeSyringe"), were implemented. The needed information about Thoracentesis was obtained from a journal article [22], several online web resources, which were selected through HONcode search engine [23] for health information authenticity, and asking the opinion of a physician. The latter information was then analysed using the

Download English Version:

<https://daneshyari.com/en/article/6853352>

Download Persian Version:

<https://daneshyari.com/article/6853352>

[Daneshyari.com](https://daneshyari.com)