German Medical Data Sciences: A Learning Healthcare System
U. Hübner et al. (Eds.)


doi:10.3233/978-1-61499-896-9-83

# Ontology-Guided Markerless Navigation and Situational Awareness for Endoscopic Surgery

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**Abstract.** Optical navigation systems help surgeons find their way through the complex anatomy of a patient. However, such systems are accident-sensitive, time-consuming and difficult to use because of their complicated technical requirements such as the setting of optical markers and their intraoperative registration. The BIOPASS project, therefore, provides an innovative localisation system for markerless navigation in endoscopic surgery to support medical decision making. This system comprises several machine learning classifiers to recognise anatomical structures visible in the endoscopic images. To verify the data provided by these classifiers and to alert medical staff about surgical risk situations, we developed a new ontology-based software called OntoSun. Our software improves the precision and the sustainable traceability of the classifiers' results and also provides warning messages that increase situational awareness during surgical interventions.

**Keywords.** Surgical navigation, situational awareness, endoscopic surgery, biomedical ontologies, knowledge representation, formal ontology

## 1. Introduction

Although optical navigation systems help surgeons find their way through the complex anatomy of a patient and may reduce their task workload as described in [1], such systems tend to be accident-sensitive, time-consuming and difficult to use because of their complicated technical requirements. These requirements such as the setting of optical markers, preoperative imaging (CT or MRT) and intraoperative registration are described in more detail in [2-3]. The BIOPASS project [4] provides an innovative localisation system for markerless navigation in endoscopic surgery that considerably reduces the intraoperative technical requirements. In order to recognise anatomical structures visible in the endoscopic images and to predict possible subsequent landmarks, the BIOPASS system provides several machine learning classifiers as described in [5]. Nevertheless, statistically based algorithms are not able to reach the precision and sustainable traceability necessary for computer-assisted surgery [6]. To overcome this problem and to improve the surgeon's situational awareness, we developed a new ontology-based software called OntoSun as described in the next section.

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## 2. Methods

### *2.1. Design and Ontological Architecture*

The BIOPASS System serves as a clinical decision support system (CDSS) for markerless navigation during endoscopic surgery. This system has a client-server architecture with a central communication server as shown in figure 1. The BIOPASS system consists of three basic components: The endoscopic navigation system, the ontology-based software for supporting the surgical navigation and situational awareness (OntoSun), and a set of classifiers to identify anatomical structures visible in the endoscopic images. In order to ensure an effective and real-time communication between the system' components, a service oriented architecture was implemented using the MQTT-Protocol [7]. Consequently, all components run as MQTT clients and can communicate with each other in real time via a message broker. The captured information about the current surgical positions is used to enrich a situational knowledge base created by OntoSun at runtime. This knowledge base has a layered architecture that adopts different types of ontologies at different levels of abstraction. During the ontology development process, we used GFO [6] as a top level ontology and FMA [8] as a domain ontology. To harmonize GFO and FMA entities, we, additionally, developed a core ontology, called BISON [6], and utilized this ontology as a framework for the ontological analysis of functional endoscopic sinus surgery (FESS). As a result, we generated a domain specific ontology, called BISON-FESS, from an excel template using Expert2OWL [9]. This tool enables us to reduce the required development cost and provides a general solution for the implementation of other clinical use cases such as colonoscopy. The resulting ontology provides an OWL representation of domain specific entities that may appear during FESS interventions. Hence, BISON-FESS can also be interpreted as a task ontology [10] because it represents a specific navigation task that has to be accomplished using OntoSun. For this purpose, we implemented the OntoSun navigation algorithm as described in the next section.

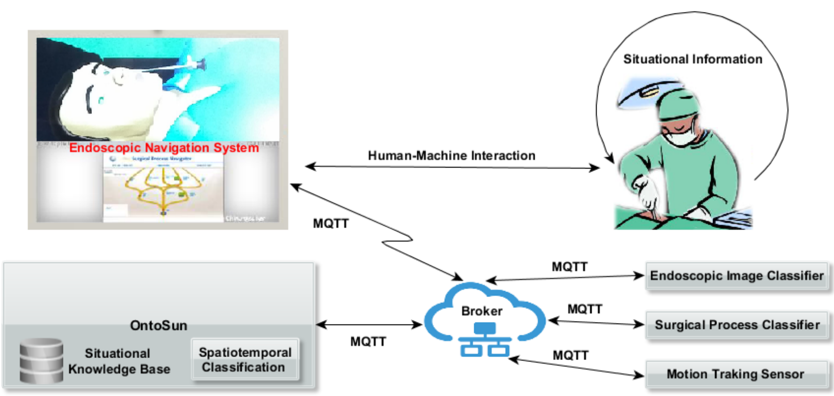


**Figure 1.** Surgical navigation using OntoSun embedded in BIOPASS CDSS.

### *2.2. Algorithm and Implementation*

The OntoSun algorithm runs across an architecture consisting of three layers. All layers are clearly distinguished by different knowledge representation formats. This distinction allows a clear separation of responsibilities between all involved developers. The external layer is a service layer that enables the communication with other system components using the MQTT protocol. During surgical procedures, this service interface captures multimodal sensor data as JSON-formatted messages [11] and uses a JSON parser to parse these data. The parsed JSON objects are then passed to the second layer called reasoning layer. The main task of this layer is to provide ontological reasoning of necessary surgical knowledge and to return the results to the service layer. For this purpose, OntoSun integrates the captured surgical information into a situational knowledge base using BISON-FESS. This information includes, inter alia, landmarks which are anatomical structures representing points of orientation. If a new landmark has been detected, the corresponding commands, implemented in the command layer, which is the third layer, are then called to generate a new representation of the current surgical situation and integrate necessary updates into the knowledge base including additional runtime knowledge as described in [12]. To allow such updates and to detect contradictory changes at runtime, we implemented the command layer by using the OWL API [13], and the Openllet DL reasoner [14]. Moreover, this layer provides a set of commands to perform atomic reasoning tasks and queries on the DL knowledge base. Hence, the command layer represents a java interface that provides basic features for bridging the core layer and the DL knowledge base.

During the development process, we adopted the model of test-driven development [15] that allowed us a continuous test, evaluation and refinement of OntoSun. Initially, we implemented a Junit test Suite and chose FESS as first exemplary clinical treatment process. We proceeded with a simple implementation of the basic OntoSun features and iteratively enhanced the developed version until all software requirements were met. We used subversion as a source code repository for version control and iteration planning. At each iteration new methods were added and corresponding tests were made. In addition, we used MQTT messages as input data to test each type of situation with exemplary situational information about FESS procedures.

## 3. Result

We developed an ontology-based software to support surgical navigation and situational awareness called OntoSun. This software component was embedded into the BIOPASS system as shown in figure 1. OntoSun runs as a web application that continuously receives MQTT messages from other components such as the mentioned classifiers and the movement sensor placed inside the endoscope. OntoSun interacts with these components by exchanging messages about situational information that occur during surgical procedures. Figure 2 depicts an exemplary FESS procedure that consists of three surgical situations. Each surgical situation is defined by its constituent parts, i.e. the anatomical structures visible in the current endoscopic image. The first endoscopic image is a snapshot of the first surgical situation and shows the middle nasal meatus (fma53139). The second endoscopic image visualises the middle nasal meatus and the middle nasal concha (fma57459), which are constituent parts of the second situation. The last endoscopic image is a snapshot of the third situation and shows the middle nasal concha. An anatomical object having the disposition to exhibit the anatomical structures shown in figure 2 is either an instance of the FMA concept fma53139 or fma57459. If OntoSun, for example, receives a message containing the IDs of both FMA concepts, the corresponding commands are then called to generate a new representation of the current surgical situation. The generated ontological representation, in this case, will describe the anatomical structures visualised in the second endoscopic image i.e. the middle nasal meatus and the middle nasal concha. These anatomical structures will be defined as presentic information i.e. they are instances of the class *Presential* in GFO. In general, OntoSun classifies the occurring anatomical structures of a situation sequentially and after each created presential, the captured information about the current surgical position is used to enrich the situational knowledge as describe in section 2.2. If this enrichment leads to a contradiction, the anatomical structure that has been added is rejected as a constituent part of the new situation. After all FMA IDs in the received MQTT message have been processed as described above, a list of the detected invalid landmarks is published as feedback message to avoid navigation errors.

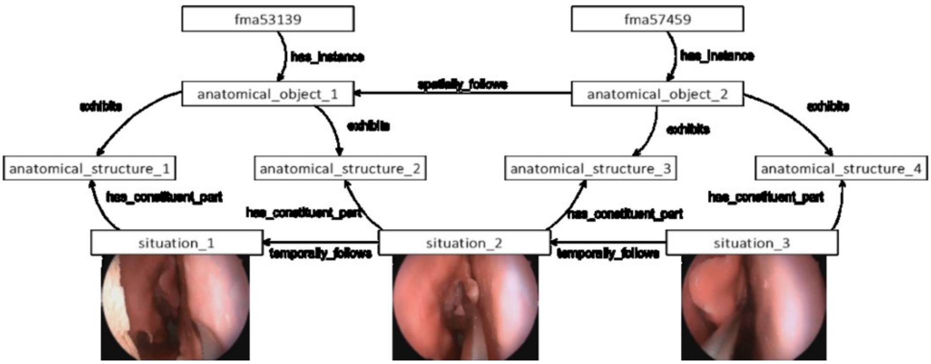


**Figure 2.** The representation of three consecutively occurring endoscopic images as surgical situations.

Furthermore, OntoSun infers possible subsequent situations and their related anatomical landmarks. If the inference engine has classified the apparent situation as surgical risk situation, OntoSun sends a warning message to the navigation system. This warning message is then displayed on the endoscopy monitor to alert medical staff and to avoid dangerous situations. As a result, OntoSun provides efficient features to increase situational awareness and to support surgical navigation. The inferred surgical knowledge can be used to improve medical decision-making in endoscopic surgery.

During the development process, we adopted an iterative development model that allowed us a continuous test, evaluation and refinement of OntoSun. The resulting software features were successfully tested and evaluated using the Junit test suite as described in section 2.2. The test results revealed the correctness of the implemented methods such as surgical risk detection and navigation support.

## 4. Discussion

To our knowledge, no papers have been published about markerless navigation and situational awareness. Therefore, we analysed existing ontologies for their potential to represent situational information as well as to support surgical navigation and concluded that none of the ontologies and tools presented in [16-19] could be applied to our project. Neither of these approaches could answer relevant competency questions such as “which anatomical landmarks may occur in the next surgical situation?”, “which surgical situation constitutes a risk situation?” and “which anatomical structures bear this risk?”. In contrast to previous studies, our approach provides not only a framework for representing the semantics of surgical information but also offers a new tool for the classification and integration of such information in a DL knowledge base during runtime. Using this knowledge base, our tool provides support for surgical navigation and situational awareness. Hence, our approach transcends these previous contributions to surgical knowledge representation. In conclusion, our tool yields promising results, which can be used to support medical decision making and reduce surgical navigation errors. Our future work will include clinical studies to provide an evidence-based evaluation of the whole system outcomes and investigate other clinical use cases such as colonoscopy.

## 5. Conflict of Interest

The authors state that they have no conflict of interests.
This work is supported by the Federal Ministry of Education and Research (German Research Foundation) under the project BIOPASS (FK: 16SV7254K).

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