Surgical Workflow Analysis, Design and Development of an Image-Based Navigation System for Endoscopic Interventions

Frederic Perez[1(✉)], Sergio Vera[1], Gloria Fernández-Esparrach[2],
Henry Córdova[2], Raúl San José Estépar[3], Javier Herrero Jover[1],
and Miguel Angel González Ballester[1]

[1] Alma IT Systems, Barcelona, Spain
frederic.perez@alma3d.com
[2] Endoscopy Unit, Department of Gastroenterology, Hospital Clinic,
Barcelona, Spain
[3] Harvard Medical School, Boston, MA, USA

Abstract. Endoscopic interventions in the abdominal and thoracic cavity are often hampered by the difficulty to orient in the endoscopic view. This is due to the small field of view and the inhomogeneous illumination, but also because abdominal organs are highly deformable and subject to complex movements. The use of flexible endoscopes further complicates these issues. In the context of a multidisciplinary project involving clinical and technical teams, we report the definition of clinical requirements and surgical workflow of abdominal endoscopic interventions, and present the design and implementation of a planning and navigation system. Some of the implemented features include: segmentation, tracking, landmark-based navigation, and combined surface and volume rendering. Our system is based on open source libraries, and is flexible and applicable to other types of interventions.

Keywords: Endoscopy · Navigation · Surgical planning · Tracking · Open source

1 Purpose

It is generally acknowledged that one of the foremost challenges of endoscopy is the difficulty to orient in the small and inhomogeneous field of view of the endoscope. The use of flexible endoscopes has led to unprecedented access to the abdominal cavity, enabling numerous procedures in a minimally invasive manner (such as natural orifice transluminal endoscopic surgery - NOTES). Conversely, the use of such flexible endoscopes, in the context of highly deformable organs exposed to constant motion, as is the case of the abdominal cavity, poses severe difficulties for the orientation and localization of target structures.

In this paper we present our work towards the development of a surgical navigation system for abdominal interventions performed using flexible endoscopes.

M. Erdt et al. (Eds.): CLIP 2013, LNCS 8361, pp. 91–98, 2014.
DOI: 10.1007/978-3-319-05666-1_12, © Springer International Publishing Switzerland 2014

In particular, Sect. 2 reports the analysis and modelling of clinical requirements and surgical workflows. Section 3 focuses on the design and implementation of the different elements of the system. This image-registered navigation system is based in electromagnetic tracking and built using open-source libraries, such as IGSTK and ITK, and it is modularized and fully extensible to cover multiple surgical applications. Section 4 shows results and Sect. 5 closes the paper with perspectives for future work.

This project is made possible by means of a close collaboration between clinical and technical teams, in a multi-disciplinary approach, focusing on the development of a practical system to be used in routine interventions.

2 Clinical Requirements and Surgical Workflow

The rationale for the system is to provide the endoscopist with the most adequate visual feedback of the location and the orientation of the endoscope, in order to improve instrument navigation and facilitating the recognition of anatomical structures. This has proven to have statistically significant benefits in enabling a better smoothness of motion [1–3].

A fundamental component of the system is a pre-operative CT scan of the subject, which is used to extract (segment) the relevant structures to the intervention, including bones, main vessels, skin, etc. As a result of these semi-automatic segmentation procedures a set of meshes are generated, which will be shown in the navigation views, to assist the endoscopist increasing their spatial awareness inside the subject.

Notice that although these segmentations are computed from the pre-operative CT, they still will provide valuable spatial context to the operator through a simulated virtual endoscopic view (automatically updated) and an “external” 3D view (handled by the operator). A set of 2D multi-planar reconstruction views provide further guidance by showing the current endoscope tip position.

The structures to be segmented depend on the protocol. For thoracic and abdominal interventions they may include bones, lungs, gallbladder, aortic trunk, celiac and superior mesenteric artery branches, kidneys and bladder, heart, trachea, and skin. The skin model of the subject is very important since it is used for the registration stage in the operating room.

Two procedures take place in the operating room: Calibration (including ICP-based registration—ICP standing for Iterative Closest Point), and Image-Guided Navigation (Fig. 1).

The workflow of the calibration phase consists of 3 steps. First, the operator launches the electromagnetic device, attaching two electromagnetic sensors (a free “pointer,” and another tied to the endoscope, “endoscope sensor”). After checking that the signal level from the sensors is accurate, the patient is registered with the pointer, by touching with it a set of fiducials (anatomical landmarks). Next, a continuous tracking is performed to retrieve the anterior surface of the subject, and the application saves the locations of the “point cloud.” The application computes a registration using ICP, and applies the obtained transformation to the retrieved cloud, visualizing the resulting points on top of the pre-segmented models, for the operator to decide if they match. The endoscope is activated and the operator places the

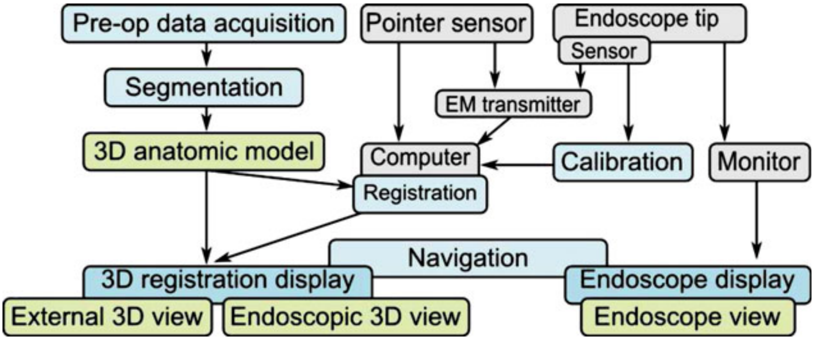


Fig. 1. Global system architecture (gray: hardware, blue: software/method, green: model/view) (Color figure online)

endoscope on top of subject's belly, and rotates the camera for the external 3D view to match the real endoscopic view/orientation with the endoscopic video to capture the relative roll of the camera. Finally, the endoscope's electromagnetic sensor fixation is calibrated with respect to the endoscope camera by touching the tip of the endoscope with the pointer.

At this moment, the endoscopic procedure and the navigation phase start (Fig. 2), the endoscopic 3D view appears, and the FOV of the endoscope is shown in the external 3D view. The application starts tracking the endoscope sensor and updates the views continuously—the operator can choose the visibility of the surface models shown in the virtual views, the MPRs in the External 3D view, and can manipulate the camera for the External 3D view at their convenience.

3 System Design and Implementation

In this section we describe technical aspects of the image-guided support system we are developing to aid during the endoscopy navigation. It is meant to be a modular system that reuses software components as much as possible. The ultimate goal is to be able to use different kinds of input systems to aid in the interventions (for therapies, or surgeries) in the operating room, as depicted in Fig. 3. The system is implemented in C++

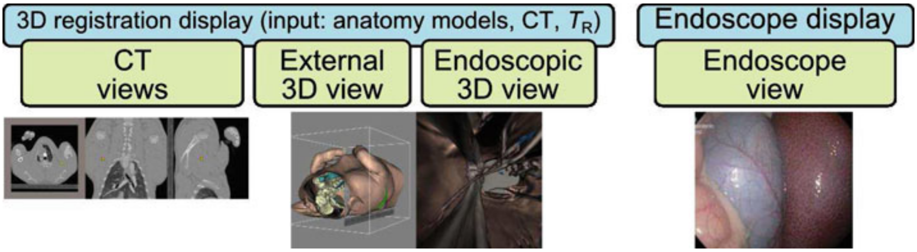


Fig. 2. The set of navigation views

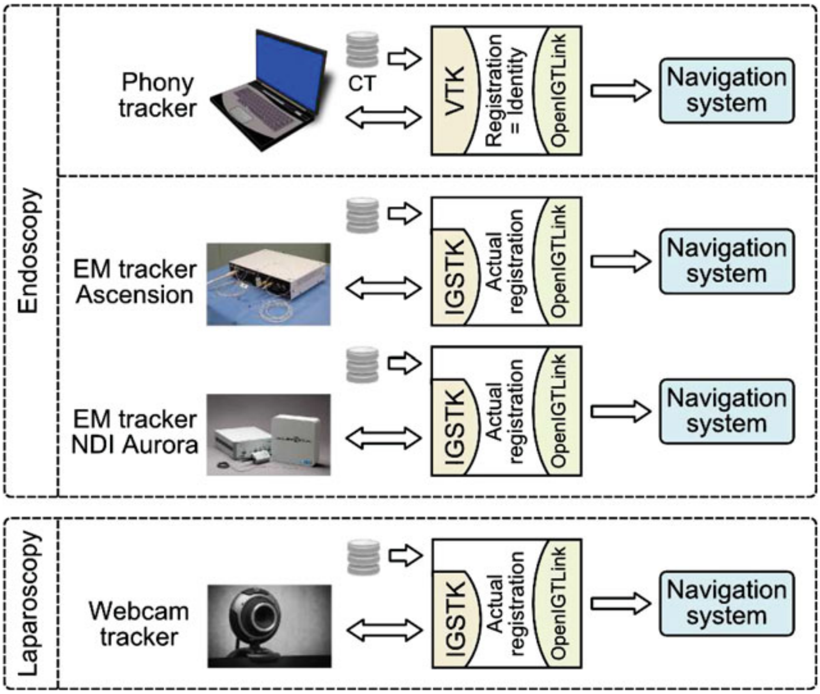
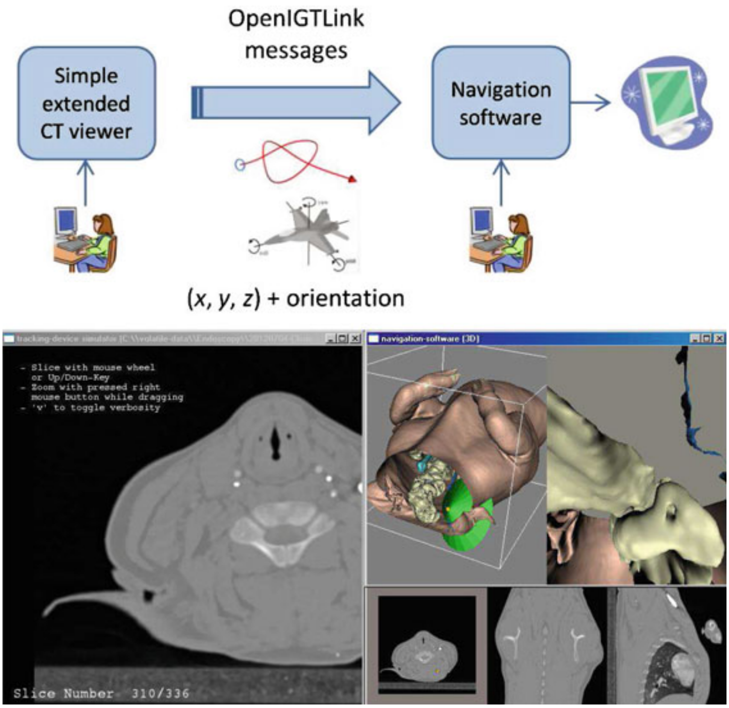


Fig. 3. General architecture of the system for a number of possible trackers and interventions

using well-known and standard open-source toolkits. The Visualization Toolkit (VTK, www.vtk.org) is used for the user interaction and visualization purposes (rendering in the 2D and 3D views, annotations, and performing volume rendering). In addition, it provides methods for manipulation of points, meshes and images, including the ICP algorithm that we have employed to align the data. Communication between devices (concretely, between the EM tracker and the navigation application) is built on top of the IGSTK toolkit (www.igstk.org), a high-level, component-based framework which provides a common functionality for image-guided surgery application. Finally, we also use OpenIGTLink (www.openigtlink.org), an open network interface for image guided therapy, to send data to the navigation part of the system.

We are currently tackling endoscopy-based procedures, such as NOTES (natural orifice transluminal endoscopy surgery)—a challenging task because of the complexities of the procedures (such as the breathing of the subject, and the flexibility of the endoscopic tube). In our preliminary implementation of the prototype we used what we call a "phony" tracker (that is, there was not an actual tracker attached to the system), consisting on a simple 2D visualization viewer that uses the keyboard to navigate through the axial slices of a pre-operative image (CT)—see Fig. 4. We used the position of the cursor within the current rendered axial slice to derive the phony location of the sensor. In addition, we provided the viewer with functionalities to change the orientation of the "endoscope" (yaw, pitch and roll) by means of key



```
- Slice with mouse wheel
  or Up/Down-Key
- Zoom with pressed right
  mouse button while dragging
- 'v' to toggle verbosity
```

```
Slice Number 310/336
```

Fig. 4. Simple setting for the "phony" tracker (top) and their corresponding views (bottom), using a swine, including the external 3D view, the endoscope view, and the MPR views

strokes. All this information was packed and sent using OpenIGTLink messages (igtl::PositionMessage, with its methods SetPosition and SetQuaternion). There was no need of computing any kind of registration since the "phony" space and the pre-operative image were the same space, since we used the same CT. The application also incorporates the functionality to capture snapshots of the current views for reporting.

Next, we successfully incorporated a real electromagnetic device (in our case, the Ascension 3D Guidance trakSTAR^{TM}, Milton, VT, USA) to substitute the phony tracker. As shown in Fig. 3, since there is no need to visualize CT slices there is no dependency on VTK; instead we used IGSTK first to establish communication with the device and then to gather the readings of their sensors. This setting also required performing an actual registration between the spaces of the operating room and the pre-operative image, to send consistent data to the navigation system. The transformation was computed by using the iterative closest point (ICP) algorithm.

Additionally, we have added GPU-based volume rendering capabilities to show non-segmented structures (see Fig. 5, where bones and vessels with contrast are drawn with volume rendering in the endoscopic view) that leads to an enhanced augmented reality environment with respect to previous systems [4]. Also, during the navigation, if the endoscopist locates a new landmark of interest (for example, a lesion), the

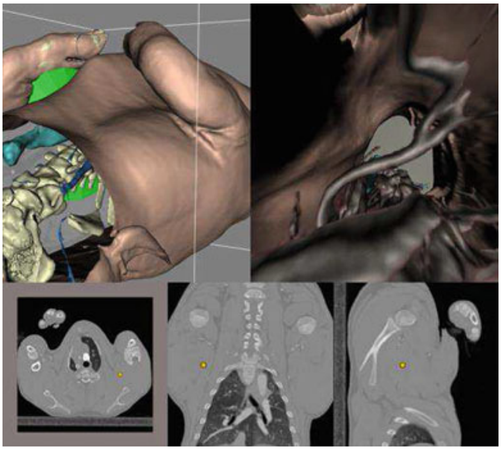


Fig. 5. Virtual navigation views using a CT scan of a swine as example—notice that volume rendering is used for the endoscopic view

software application allows tagging it for further study in the form of annotations (see Fig. 6). Finally, the system has been extended to allow storing captured poses into a file, which permits re-creating the virtual visualization for planning interventions (Fig. 7).

4 Results and Other Applications

The images above show the functionalities implemented in the current system. In addition, we have explored other uses of the navigation system, which include: cardiac

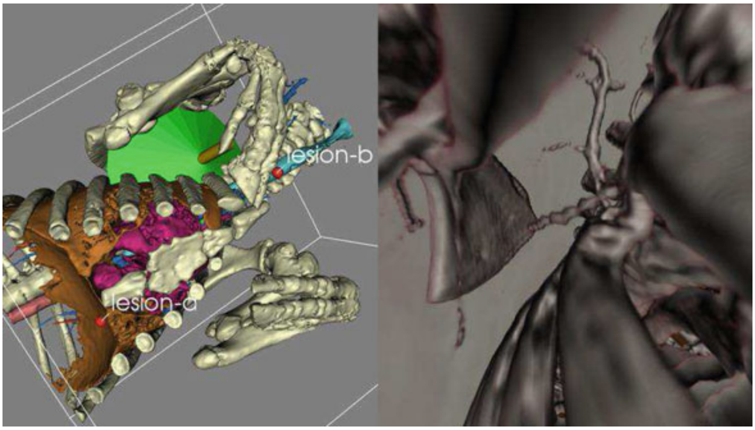


Fig. 6. 3D views with example annotations (left), and volume rendering including small vessels (right)

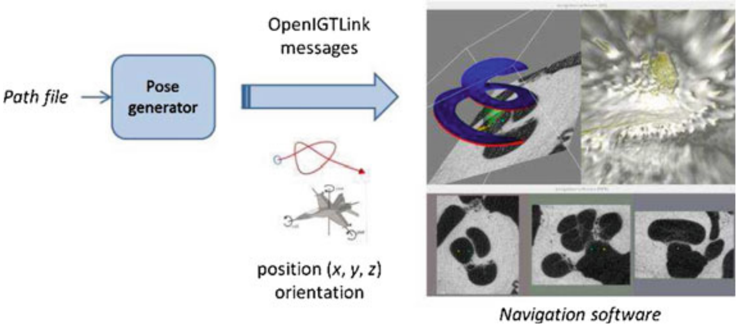


Fig. 7. Schema for the recreation of a path in the navigation system by using a planned path file

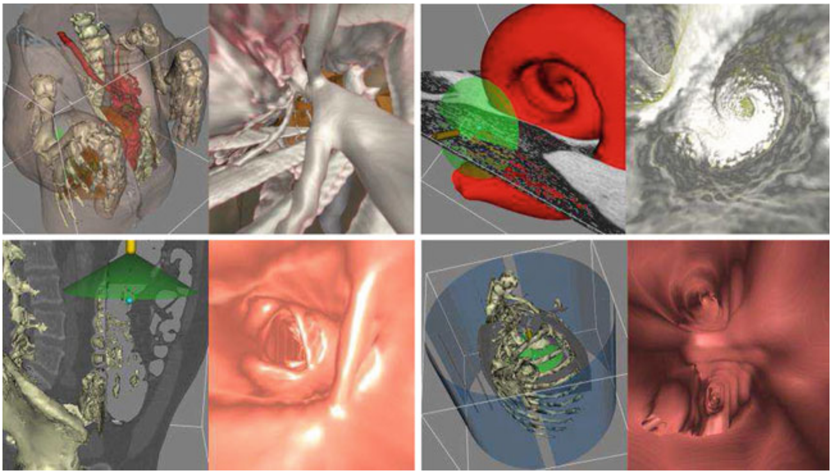


Fig. 8. Examples of usage of the navigation system: pig case, cochlear navigation, virtual colonoscopy, and virtual bronchoscopy

surgery, cochlear implantation, virtual colonoscopies and bronchoscopy, as exemplified in Fig. 8.

Our preliminary experiences show that the system is very versatile, and allows seamless integration in the surgical workflow of different surgical interventions.

5 Conclusion and Future Work

This paper has reported the design and development of a software tool for image-based navigation in endoscopic abdominal interventions. The modular system is written in C++, and is based on common and well-established open source libraries: VTK, IGSTK, OpenIGTKLink. Integration in the operating room is realised, and cases have been scheduled in order to validate the use of our system.

Work in progress includes integration with NDI Aurora electromagnetic trackers (NDI, Waterloo, Ontario, Canada), reusing most of the code and modules, as depicted in Fig. 3. Also, for laparoscopic interventions we plan to use optical trackers such as webcams (using the ArUco library—a minimal library for Augmented reality applications based on OpenCV, www.uco.es/investiga/grupos/ava/no-de/26) or the Polaris System (also by NDI) to derive the location and pose of the surgery tools within the patient—again sharing most of the code. We also plan to improve and validate the navigation system using Lego phantoms along the lines of the Image-Guided tutorial [5], and perform its actual integration in the in the operating room.

References

1. Fernández-Esparrach, G., San José Estépar, R., Guarner-Argente, C., Martínez-Pallí, G., Navarro, R., Rodríguez de Miguel, C., Córdova, H., Thompson, C.C., Lacy, A.M., Donoso, L., Ayuso-Colella, J.R., Ginès, A., Pellisé, M., Llach, J., Vosburgh, K.G.: The role of a computed tomography-based image registered navigation system for natural orifice transluminal endoscopic surgery: a comparative study in a porcine model. Endoscopy **42**(12), 1096–1103 (2010)
2. Córdova, H., San José Estépar, R., Rodríguez-D'Jesús, A., Martínez-Pallí, G., Arguis, P., Rodríguez de Miguel, C., Navarro-Ripoll, R., Perdomo, J.M., Cuatrecasas, M., Llach, J., Vosburgh, K.G., Fernández-Esparrach, G.: Comparative study of NOTES alone versus NOTES guided by a new image registration system for navigation in the mediastinum: a study in a porcine model. Gastrointest. Endosc. **77**(1), 102–107 (2013)
3. Azagury, D.E., Ryou, M., Shaikh, S.N., San José Estépar, R., Lengyel, B.I., Jagadeesan, J., Vosburgh, K.G., Thompson, C.C.: Real-time computed tomography-based augmented reality for natural orifice transluminal endoscopic surgery navigation. Br. J. Surg. **99**(9), 1246–1253 (2012)
4. San José Estépar, R., Stylopoulos, N., Ellis, R., Samset, E., Westin, C.-F., Thompson, C., Vosburgh, K.: Towards scarless surgery: an endoscopic ultrasound navigation system for transgastric access procedures. Comput. Aided Surg. **12**(6), 311–324 (2007)
5. Güler, Ö, Yaniv, Z.: Image-Guided Interventions Tutorial using the Image-Guided Surgery Toolkit. http://isiswiki.georgetown.edu/zivy/igiTutorial/igiTutorial.html