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Intraoperative motion patterns of surgical microscopes in neurosurgery

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Introduction

Surgical microscopes in neurosurgery are used for magnified visualization of the situs during e.g. brain tumor removal or aneurysm surgery. Due to dynamic surgical events, such as tissue removal, surgeons frequently move the microscope manually to maintain a sufficient view throughout surgery.

Development of user-friendly surgical microscopes requires an in-depth understanding of the surgeon's interaction with the microscope. Previous work focused on the question "when" surgeons interacted with the microscope, by quantifying interaction frequencies based on video analysis. Our work aims at extending prior approaches to "how" surgeons interact with the surgical microscope by identifying motion behaviour patterns.

Methods

Our hypothesis is that different motion type behaviours, such as fine or coarse motions, can be distinguished from surgical data. In a first step, we conducted a qualitative analysis by observing various neurosurgical surgeries in a large neurosurgical clinic. For a quantitative analysis we use motion data from each of ten tumor and vascular cases visualized by a ZEISS KINEVO 900. We are currently evaluating different spatio-temporal data mining methods employing trajectory descriptors, such as Frenet-Serret invariants. Based on different motion types identified in the data, we are comparing characteristic motion patterns between tumor and vascular cases.

Results

First qualitative observations indicate that motions of surgical microscopes in neurosurgery can be divided in fine translational and pivoting motions, as well as coarse motions. In the tumor cases, qualitatively, small motions are more frequent, whereas in the vascular cases motions are larger in magnitude. These observations serve as a baseline for later quantitative comparison.

Conclusion

Our work supports the development of user-friendly surgical microscopes by analysing their intraoperative motion patterns during neurosurgical interventions. Future work includes validation of the quantified motion patterns derived from recorded data and quantitative comparison of motion types in tumor and vascular cases.

Efficient Body Registration Using Single-View Range Imaging and Generic Shape Templates

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Introduction

Computer-aided medical systems, are investigated to overcome human limitations concerning perception, memory or dexterity. These often require digital models describing the body position and morphology during a procedure. Operational complexity and technical limitations of established 3D imaging methods leave clinical settings in need of a method for the efficient acquisition of a three-dimensional body surface representation.

Methods

We propose an unsupervised markerless elastic body registration and completion method of single-view range images with parametric templates meshes. We acquire and triangulate a range image of the body with a stereo depth camera and perform a background-subtraction based segmentation of the body. The body is registered with a parametric template, adjusted to resemble the subject's main anthropometric features: We perform an initial positional alignment of the template with the body utilizing the acquisition angle inferred from the sagittal axis and the displacement between the centers of mass. We then apply vertex-wise affine transformations on the template, minimizing a) the distances to nearest-neighbor correspondences in the body and b) the dissimilarity of transformations of connected vertices.

Results

The registration results obtained for 4 subjects show a promising fitting accuracy with an average residual RMS Euclidean distance of 0.7289 mm for the region of the torso and 12.7326 mm for the total surface due to positional inconsistencies of the extremities. Unobserved and occluded surface areas are realistically completed by the smooth deformations of the morphologically similar template.

Conclusion

Initial experiments indicate the feasibility of our approach as an efficient body registration method. This work represents a contribution to alleviate the establishment of automated medical systems, by providing the ability to rapidly digitize the complete surface anatomy, e.g. for targeting and motion planning purposes within robotic systems. More generally, we demonstrate an alternative imaging technique, suitable for the assessment of the external morphology.

Path Planning for Robotic Camera Guidance in Laparoscopy

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Introduction

To observe the surgical site during minimally-invasive surgery of the abdomen (laparoscopy), an endoscope is introduced into the patient's abdomen and has to be guided by an assistant surgeon, who adapts the view according to the situational requirements. Endoscope guidance is strenuous and visualization errors have shown to impair surgical performance, endangering the patient's safety. Robotic assistants may be used to guide the camera tirelessly. This work investigates safe robotic path planning considering the restrictions of laparoscopy.

Methods

Sets of optimization criteria are defined to subdivide laparoscopic camera guidance into distinct path planning phases. TrajOpt, an optimization-based path planning algorithm, is employed to determine optimal, collision free paths to specified view-poses (position and orientation). View-poses are defined by the user through a graphical user interface.

Results

Laparoscopic camera guidance is implemented in the Gazebo simulator and subdivided into four phases: (1) Free space positioning, aligning the robotic manipulator with the trocar. (2) Insertion, in which the endoscope is linearly inserted through the trocar into the abdomen with a pre-selected insertion depth. (3) Pivoting, in which an algorithm determines a collision-free path according to multiple specified view poses, respecting the restricted degrees of freedom in laparoscopy as well as insertion depth. (4) Retraction, to align endoscope and trocar axes and retract the endoscope safely. All movements are optimized according to velocity, acceleration, and jerk. Paths undergo continuous collision checking after planning, however collision constraints during optimization are omitted in phase (2) due to stability of the algorithm in narrow passages.

Conclusion

An algorithm for safe robotic path planning in laparoscopy has been implemented and evaluated in a simulation environment. Future work includes validation on a real robotic manipulator as well as automatic view-pose selection, that requires minimal user interaction.

Autonomous guidewire navigation using neural networks

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Introduction

The treatment of strokes and heart diseases often requires complex navigation of a catheter from the groin to the lesion through the vascular tree. Even highly trained specialists regularly struggle with the fact that catheter movements at the proximal end of the catheter translate into unexpected movements at its distal end. Despite the amount and importance of catheter-based interventions, none or very limited assistance is used during navigation. Here, we present interim results towards an autonomous catheter guidance robot.

Methods

A control algorithm is developed to autonomously navigate a guidewire from arbitrary starting points to arbitrary targets within a vessel phantom. The algorithm consists of a neural network trained by reinforcement learning. Navigation is performed in a 2D rigid vessel phantom with an organic vessel structure, and non-intuitive and mechanically hard to reach areas. Training is performed in a simulation model and evaluation is performed on the testbench using a phantom with the same vessel geometry.

Results

The control algorithm successfully learns to navigate the guidewire from arbitrary starting points to arbitrary target points with a success rate of approximately 90%. Navigating to hard-to-reach areas is successfully shown. However, non-intuitive areas can not be reached well. When the algorithm was supplied with waypoints along the path, e.g. at every bifurcation, the success rate increased to 100%. The transfer of the algorithm to the testbench showed the same results.

Conclusion

This work demonstrates that neural networks are able to manipulate guidewires through a simplified vessel phantom. So far handling low-level control of the guidewire mechanics is possible, but the high-level control of the path planning shows room for improvement. Future work includes improving the neural network for high level control and using more complex vessel structures, e.g. 3D navigation, changing geometries, and combination of a guidewire with a catheter.

A simulation environment for visual multi-agent reinforcement learning in robot-assisted laparoscopy

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Introduction

Robotic assistance may reduce the workload of surgeons in minimally-invasive surgery of the abdomen (laparoscopy) by automating routine tasks, such as suturing. Reinforcement learning has shown promising results in learning complex policies for robotic manipulators. The individual policies in laparoscopy, however, are highly interdependent (e.g. camera guidance and cauterization) and should thus be learned in unison by employing the multi-agent reinforcement learning paradigm. Current simulators used for robotic reinforcement learning, however, are not suitable for learning surgical multi-agent policies. Here, we present a simulation environment that can be used to train, develop, and evaluate multi-agent reinforcement learning algorithms for robot-assisted laparoscopy.

Methods

Panda, an open source game engine, is extended to serve as a simulator for multi-agent reinforcement learning of laparoscopic skills. The considered sample skill is the collective control of cauterization hook and endoscope to cauterize specific points on the surface of a simulated liver, while visualizing the situs.

Results

The simulation environment is tailored to this specific use-case including features, such as rendering of RGB images, collision detection, actuating ball joints that mimic the degrees of freedom of laparoscopic tools, drawing target paths on organs, and simulating an endoscope. Compatibility with state of the art reinforcement learning algorithms is ensured by adoption of architectural design choices of the OpenAI-Gym framework. Several sample scenes of increasing complexity are implemented for detailed comparison of various algorithms regarding their capability to learn laparoscopic skills.

Conclusion

A simulation environment was developed to facilitate robotic multi-agent reinforcement learning for laparoscopic skills. Future work includes implementation of state of the art off-policy reinforcement learning algorithms and evaluation based on task completion, sample efficiency, and stability in unseen environments.