Robust Visual Augmented Reality in Robot-Assisted Surgery

Maria Paola Forte

Advisor
Prof. Elena De Momi

Co-Advisor
Prof. Katherine J. Kuchenbecker

Tutor
Thibaud Chupin

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1. Research context

2. Main contributions
   - Problem statement and goal
   - Approach
   - Validation and results

3. How the developed technology can contribute
Augmented Reality Surgical System

Interactive experience of a real-world environment whose elements are "augmented" by computer-generated perceptual information.

1. Research Context

2A. Communication Interface

2B. Vision-based AR

2C. Latency

3. Conclusions and Future work

[jolesz]
AR in laparoscopic robot-assisted surgery

Overlay of preoperative data in the surgical field (e.g., ultrasound, CT, anatomical 3D reconstructions) [Bernhardt et al.]

Virtual markers; e.g., precise evaluation in tumour resection

[Tang et al.]
Can augmented reality improve safety and task efficiency in robot-assisted laparoscopic surgery?

Development of a robust augmented reality system that works on a clinical da Vinci® Surgical System
Problems and main contributions

A. Previous solutions not applicable to different robotics surgical systems
   Device independent

B. Previous solutions did not automatically overlay the virtual content
   Stereo-reconstruction to position the content automatically in 3D space

C. Previous solutions did not have real-time capabilities
   Optimizing latency and delaying only the virtual content
Problem
The different generations of the da Vinci® have different resolutions and clinical systems do not have access to the API

Goal
To automatically detect and adapt to the resolution and to enable the communication without using the da Vinci Research Kit or the API
Architectures

1. Research Context
2A. Communication Interface
2B. Vision-based AR
2C. Latency
3. Conclusions and Future work

Legend: optical paths
digital data

da Vinci® vision pipeline
Stereo viewer
Video processors
CCUs
Camera head
Stereo endoscope

Surgeon console
Patient cart
[Intuitive Surgical]

[Gere et al.]
Video capture and playback card

Selection of a video capture and playback card

Keying is the overlaying of computer-generated content over the source video

Development of the drivers

Legend: 
- optical paths
- digital data

[Gere et al.]
Validation and results

**Automatic detection of video resolution**

Compare images in the real and modified setup
Correct size and video frame; negligible visual defects, noise and colour distortions

Tried on the first and third generation of da Vinci® (with different resolution) and with two DeckLink Duo 2 and a DeckLink Quad 2

**Success**
Vision-based augmented reality system

Problem
Automatic overlay of virtual content in a clinical da Vinci® System is not compatible with the existing active technique AR tools

Goal
To develop a vision-based augmented reality system that works on a clinical da Vinci® System
Stereo vision is the visual perception of objects, with either one (2.5D) or two eyes (3D)

The main cue to the impression of depth is the binocular disparity, obtained when we observe 3D structures with two eyes
Goal: overlay the virtual pin on the real tool tip

Stereo matching: technique used for finding corresponding pixels in stereo-pair images

Rectify and undistort

Toe-in method

Real tool  Virtual content

C_L  C_R

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[Intuitive Surgical]  [Gere et al.]
Algorithms used

Stereo computer vision

Stereo endoscopic images

1. Image rectification
2. Stereo matching
3. Filtering
4. Refinement

- **a. Bilinear**
- **b. Semi-global matching (SGM) and tuning of the parameters**
- **c. Fast Global Smoother (FGS)**
- **d. Left-right consistency check**
Comparison between surfaces and depths measured with a digital calliper (ground truth) and the developed software.
Validation and results: overlaying

Left camera

Check if the virtual content is overlaid in the same position in the left and right images.

Misalignments perceived when the virtual object is covered by a real object

Right camera

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Latency

Problem
Computationally intensive methods fail to achieve real-time (< 284 ms) capabilities

Goal
To optimize the solution to seamlessly integrate the virtual content into the surgeon console
Optimization

Hardware optimization:
• Selection of a video capture and playback card with high performance and that allows keying
• Use of splitters not to interrupt the video stream

Software optimization:
• C++
• ROS (Robot Operating System) architecture
• Algorithms for the stereo-reconstruction
Processing approach

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Validation and results

Comparison between the timestamp of the frame acquired by the input driver and the timestamp of the virtual content sent to the output driver

Lower than 150 ms (including 62 ms of inherent latency of the da Vinci® vision pipeline) affecting only the virtual content
The surgeon has no means to mark vital organs (e.g., the urethra). To estimate the distance of the tools from the vital organs previously marked, virtual markers could be applied and fixed so that the surgeon does not have to repeatedly identify the same organs.

In training, to visualize virtual fixtures indicating areas that have to be avoided and to identify tools in their proximity.
Future work

1. To focus on the interaction technology: e.g., using the neural network for pose estimation combined with voice inputs

2. To move the virtual content in accordance to the movement of the camera and of the underlying tissue

3. To have surgeons evaluating the developed software
Thank you for your attention