MUSTOF - taking endoscopy to a higher dimension

A novel 3-D hybrid endoscope for NOTES

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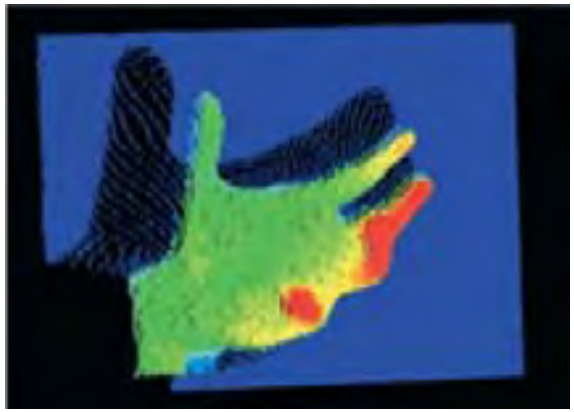
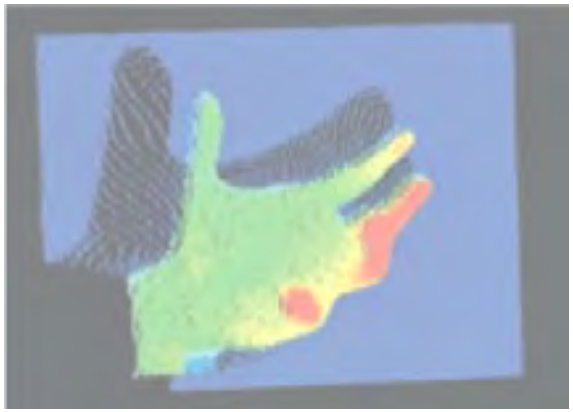
Content



Overview



Background of the project group

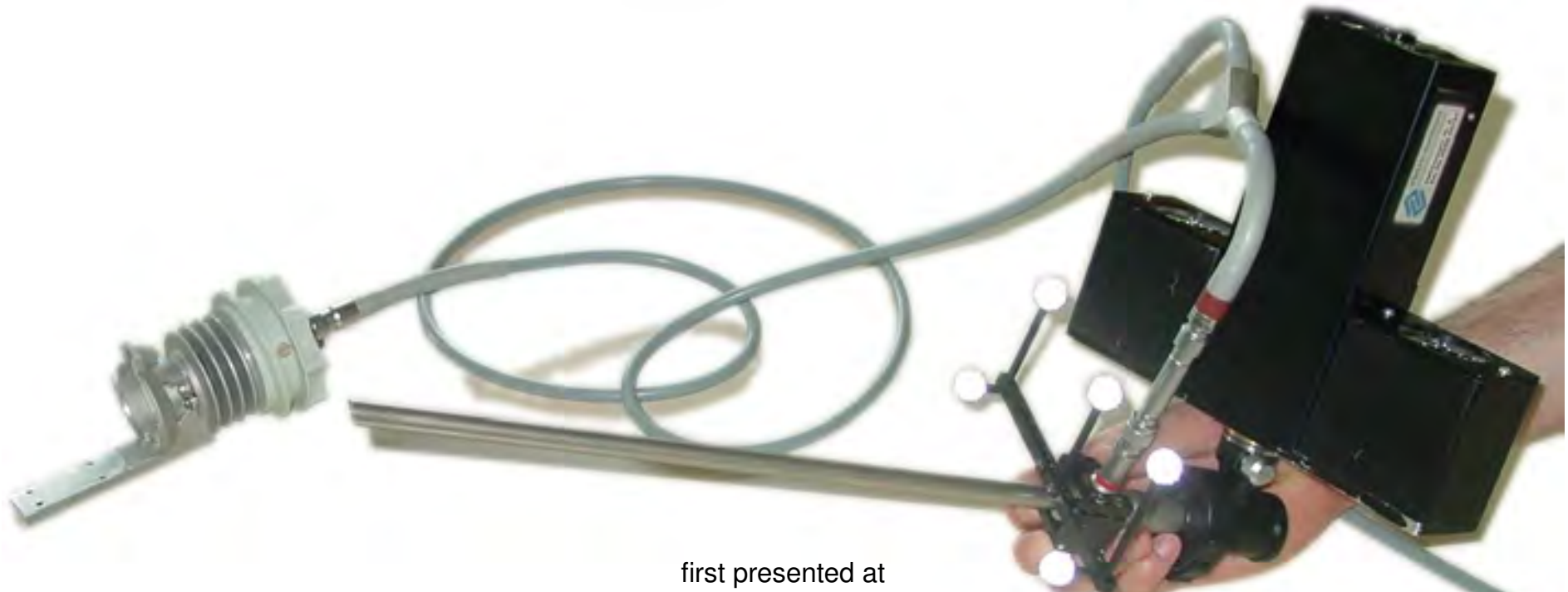
Our team: Multiple interests, one vision...

- Organisational and personal infrastructure of the group:
  - computer scientists
  - electrical engineers
  - physicists
  - physicians
- Industrial partners:
  - endoscopy
  - camera
  - software

Figure: In the operation room

First prototype of a 3-D endoscope

based on time-of-flight technology



first presented at

'Towards NOTES^{3D}'

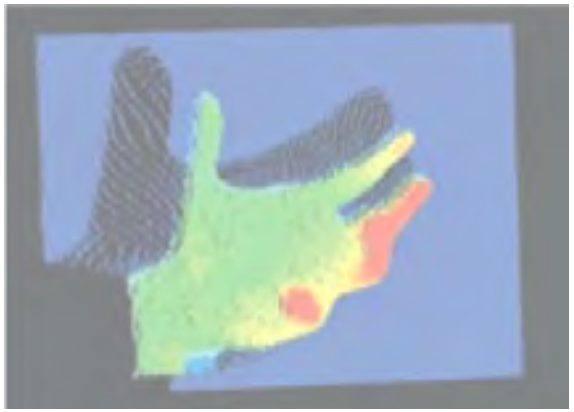
Paketantrag

Participating institutes:

- LME, Erlangen (Prof. J. Hornegger)
- MITI group, Munich (Prof. H. Feussner)
- CAMP, Munich (Prof. N. Navab)
- MED1, Erlangen (Prof. E.G. Hahn)

Submitted during 3rd Russian-Bavarian Conference on Biomedical Engineering

Overview



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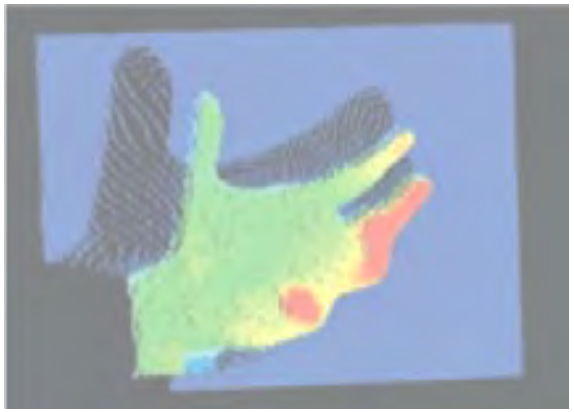


Time Line

From open surgery to NOTES

Surgery can be done as:

- open surgery
  $\rightarrow$ for hundreds of years
- minimally invasive / laparoscopic surgery
  $\rightarrow$ since the beginning of the 90s
- and through natural orifices
  $\rightarrow$ "no longer if but when" (W. O. Richards, D. W. Rattner 2005)

$\Rightarrow$ July 22/23, 2005 white paper and foundation of Consortium for Assesment and Research (NOSCAR) on NOTES: Natural Orifice Translumenal Endoscopic Surgery

NOTES Publications

Fast growing community

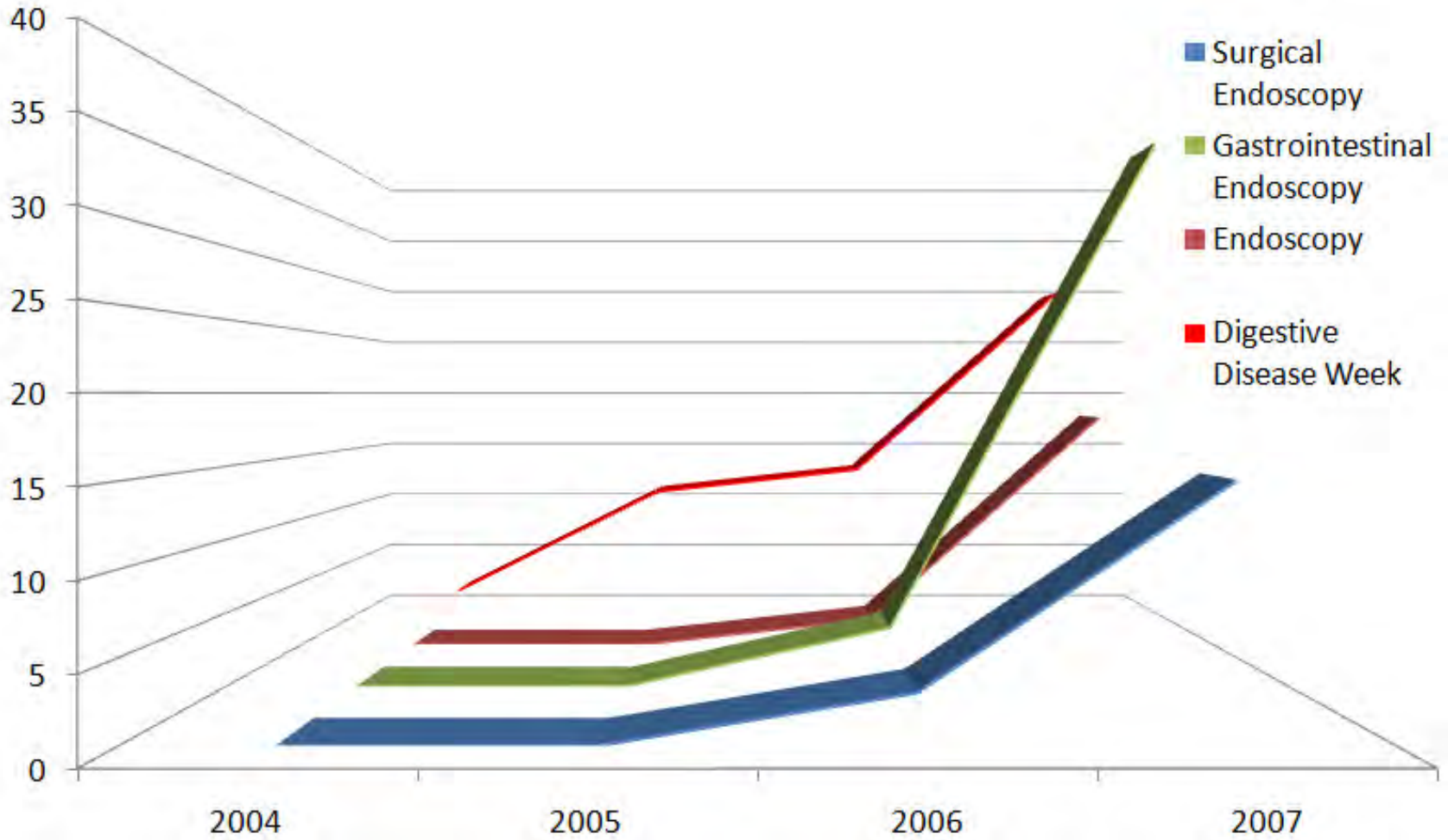


Figure: NOTES Publications in SE (SAGES), GIE (ASGE), Endoscopy (ESGE), DDW

Participating groups with NOTES

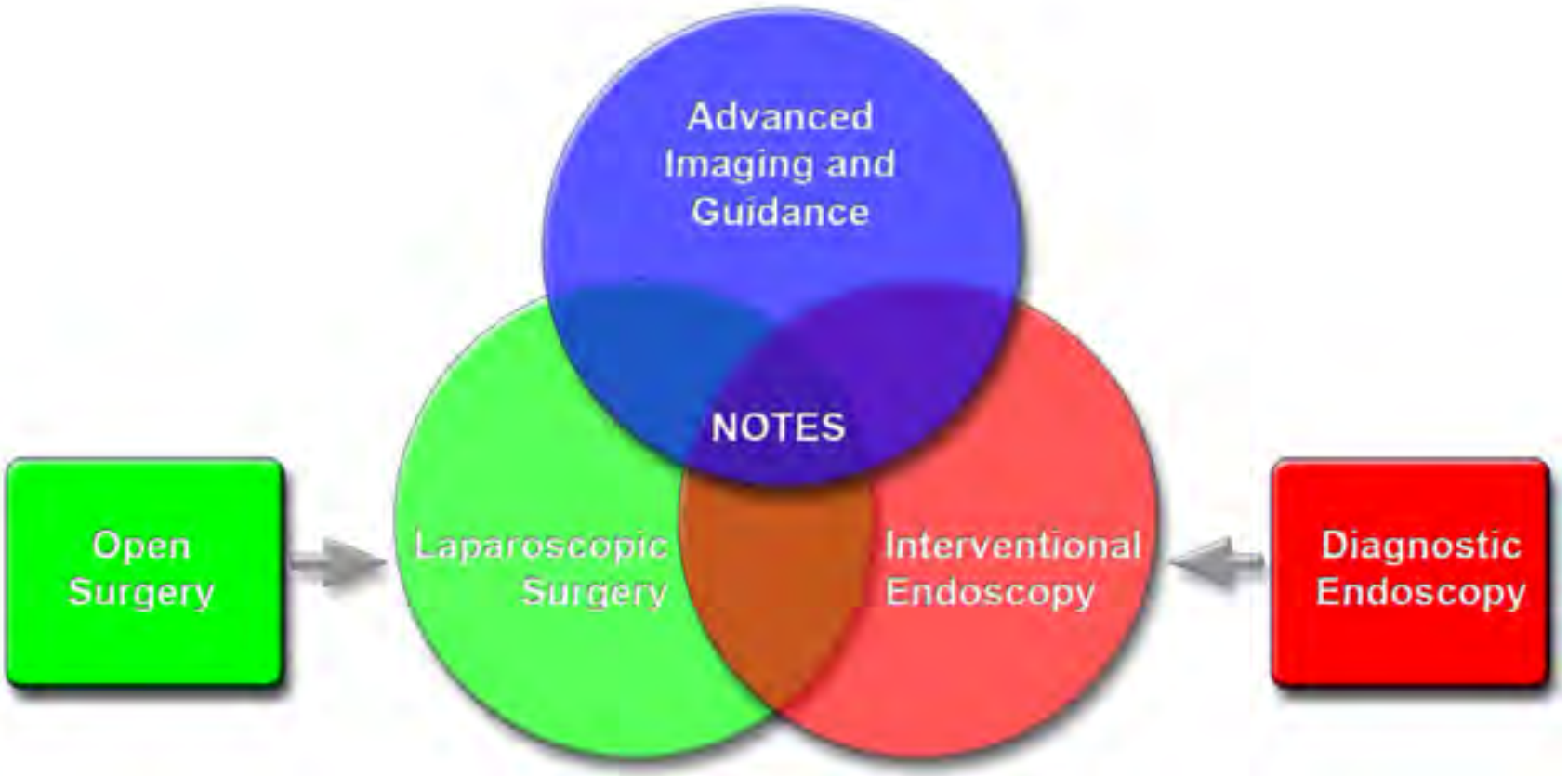


Figure: Interdisciplinarity of NOTES

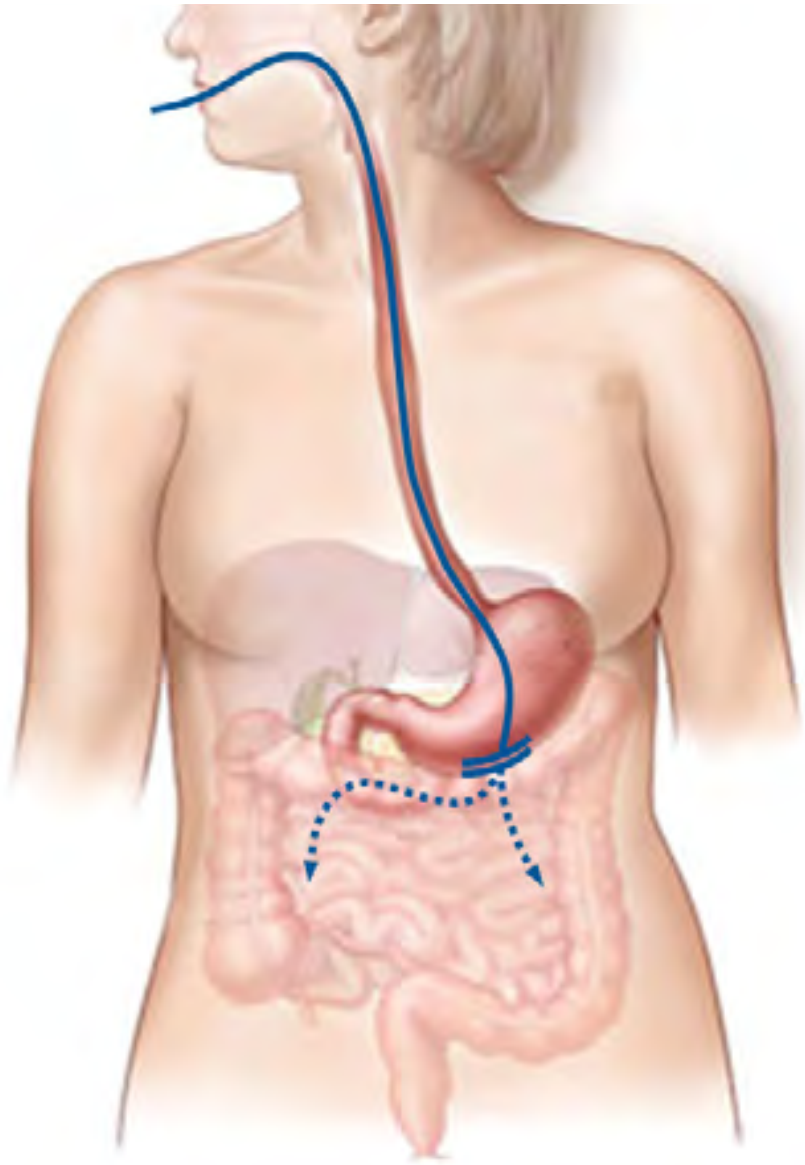
Benefits

of Natural Orifice Translumenal Endosopic Surgery (NOTES)

Expected benefits of NOTES:

- Less pain
- Faster recovery
- Better cosmetic results avoiding skin incisions
- Lower risk for herniation
- No risk for eventration
- Lower risk for wound infection
- Lower risk for adhesions

Peroral transgastric route



Flexible endoscope through wall of stomach

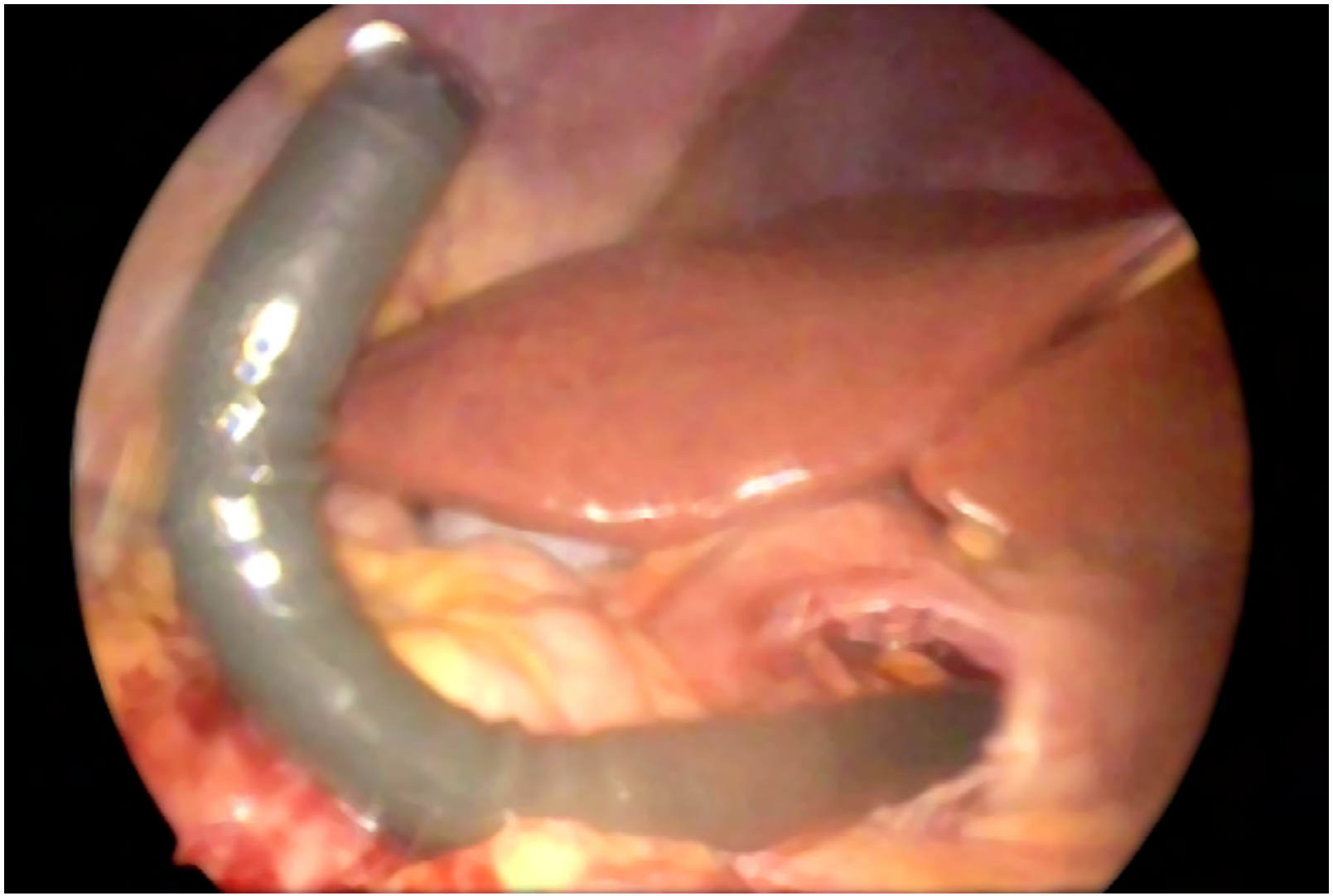
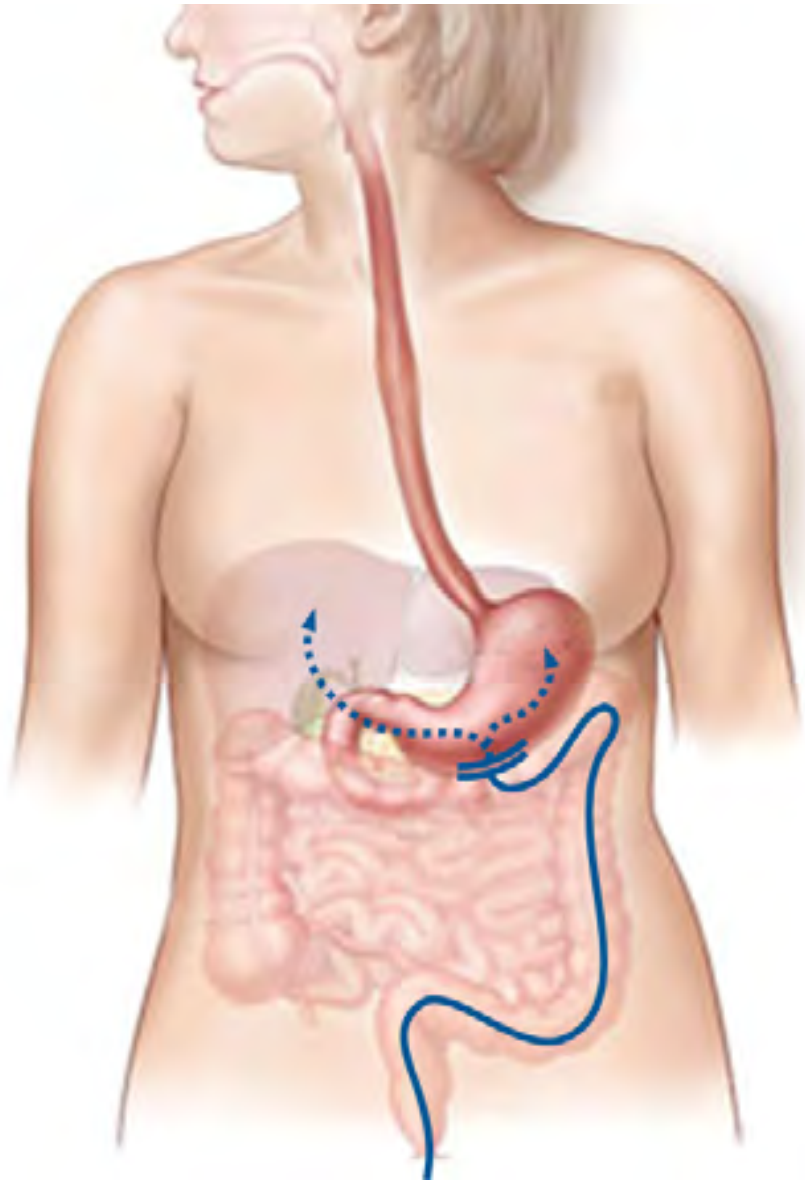
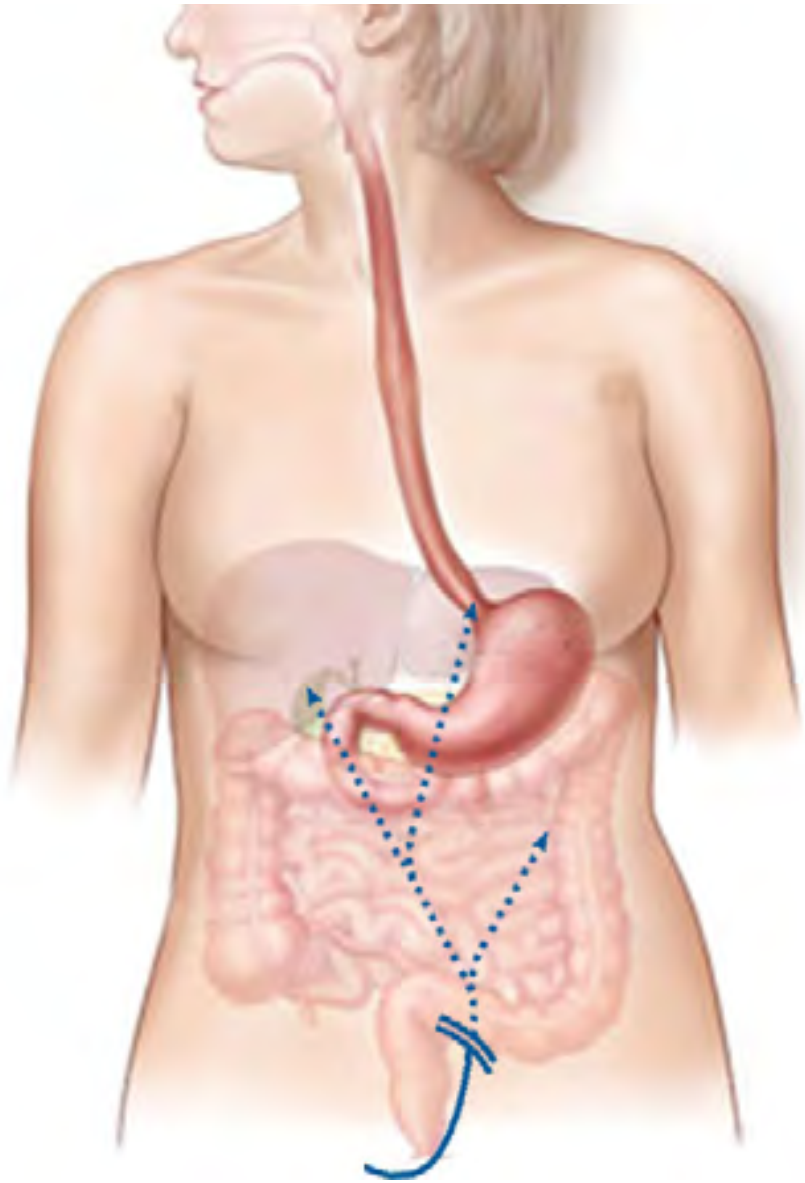


Figure: Resection of gastric stromal tumor (J.L. Ponsky 2006)

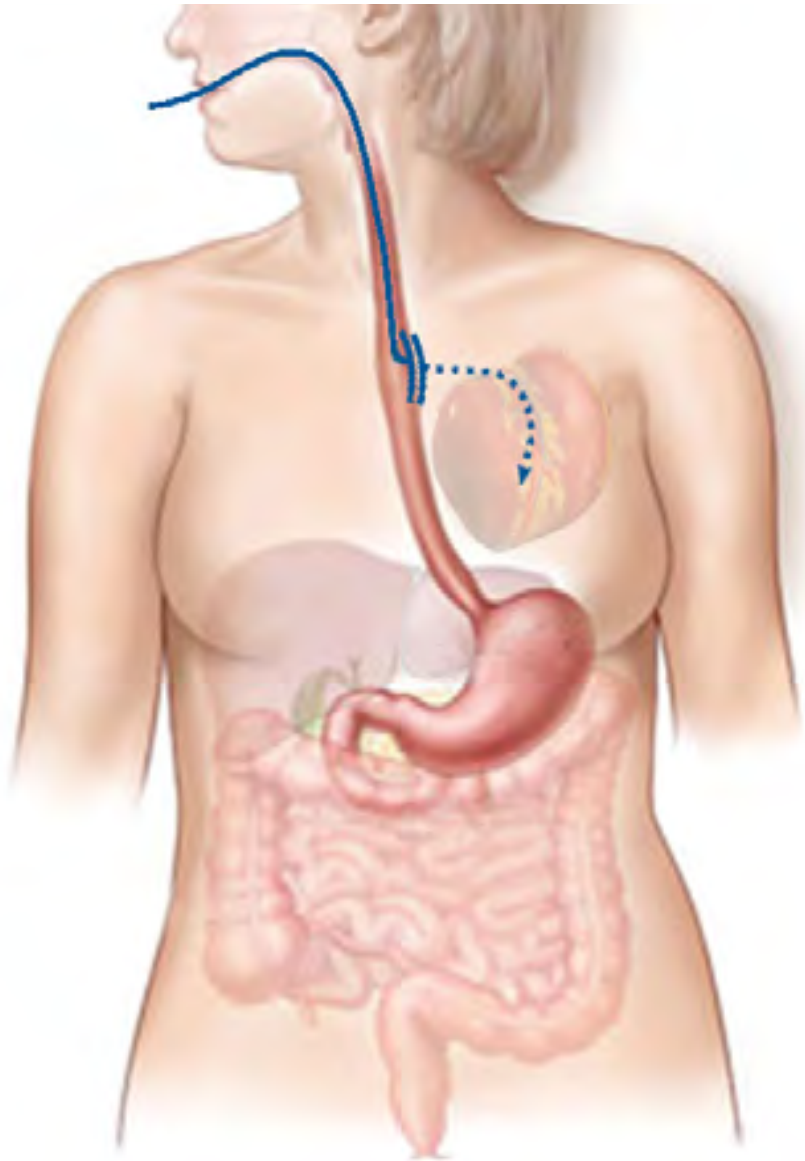
Peranal transcolonic route



Transvaginal route



Peroral transesophageal route



Possible therapies

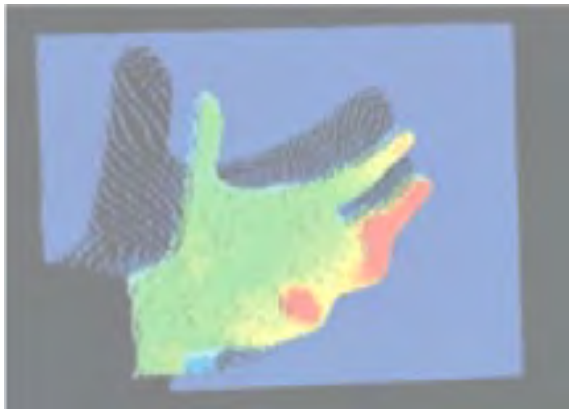
using NOTES technique

Some actual discussed and tried therapies with NOTES:

- appendectomy
- cholecystectomy
- splenectomy
- gastrojejunostomy
- lymphadenectomy
- nephrectomy
- liver biopsy
- hernia repair

Figure: Splenectomy (Kantsevoy 2006)

Overview



Potential barriers to clinical practice

according to the NOTES white paper

- Access to peritoneal cavity
- Gastric or intestinal closure
- Prevention of infection
- Development of suturing and anastomotic (nonsuturing) devices
- Maintaining spatial orientation
- Development of a multitasking platform
- Management of intraperitoneal complications and hemorrhage
- Physiologic untoward events
- Training other providers

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- Access to peritoneal cavity $\Rightarrow$ item we could support
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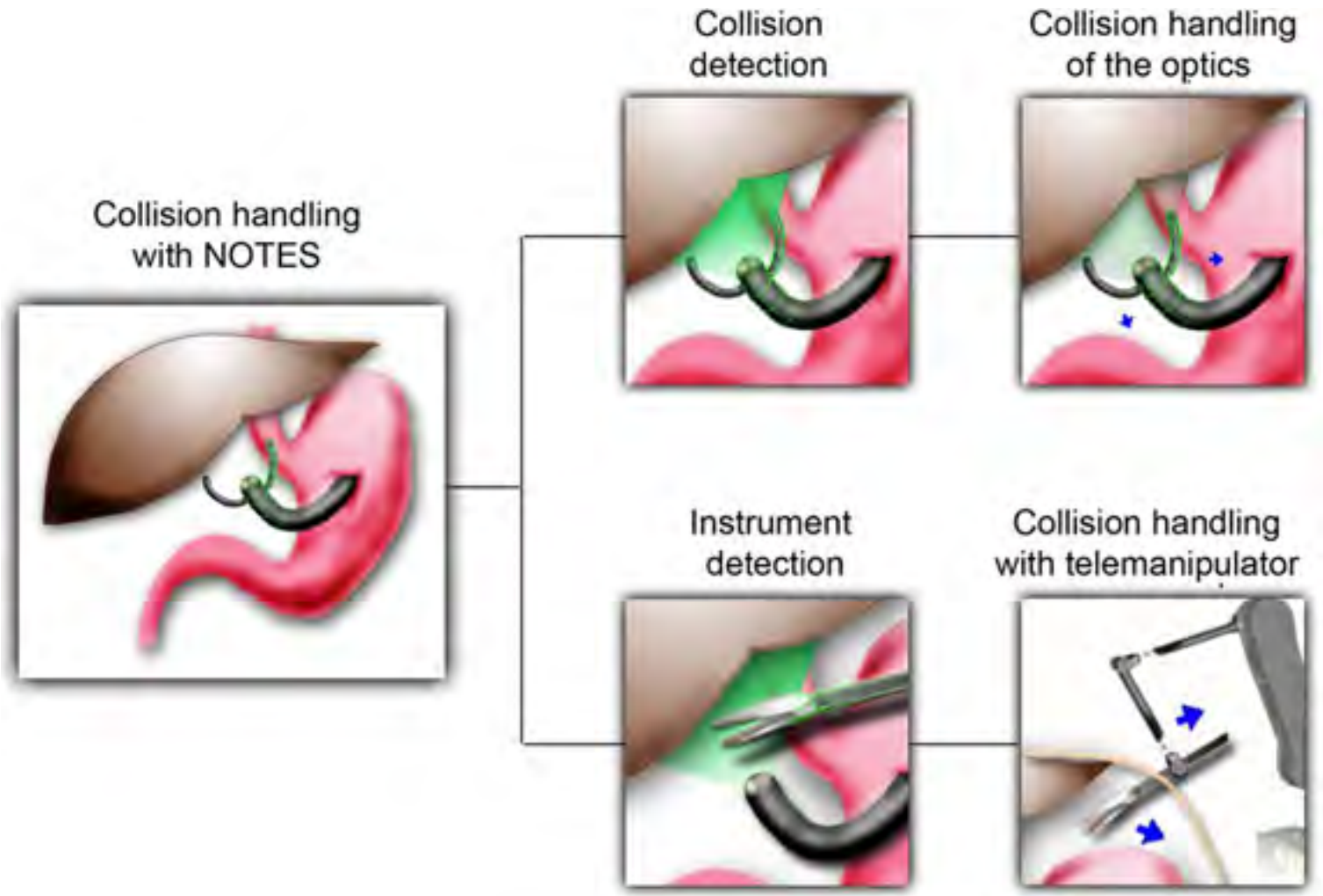
Access to peritoneal cavity: NOTES^{3D}

Multi-Sensor-Time-Of-Flight (MUSTOF) technology enhances NOTES for 3-D:

- NOTES^{3D} could be used to register online optic 3-D data with preoperative MR or CT volumes
- So combination of actual view of operation area with Augmented Reality (AR) is possible
- The optimal access point to peritoneal cavity can be found by visualisation of organs behind gastric or colonic wall

Collision prevention

Paketantrag 'Towards NOTES^{3D}'



Dynamic reconstruction

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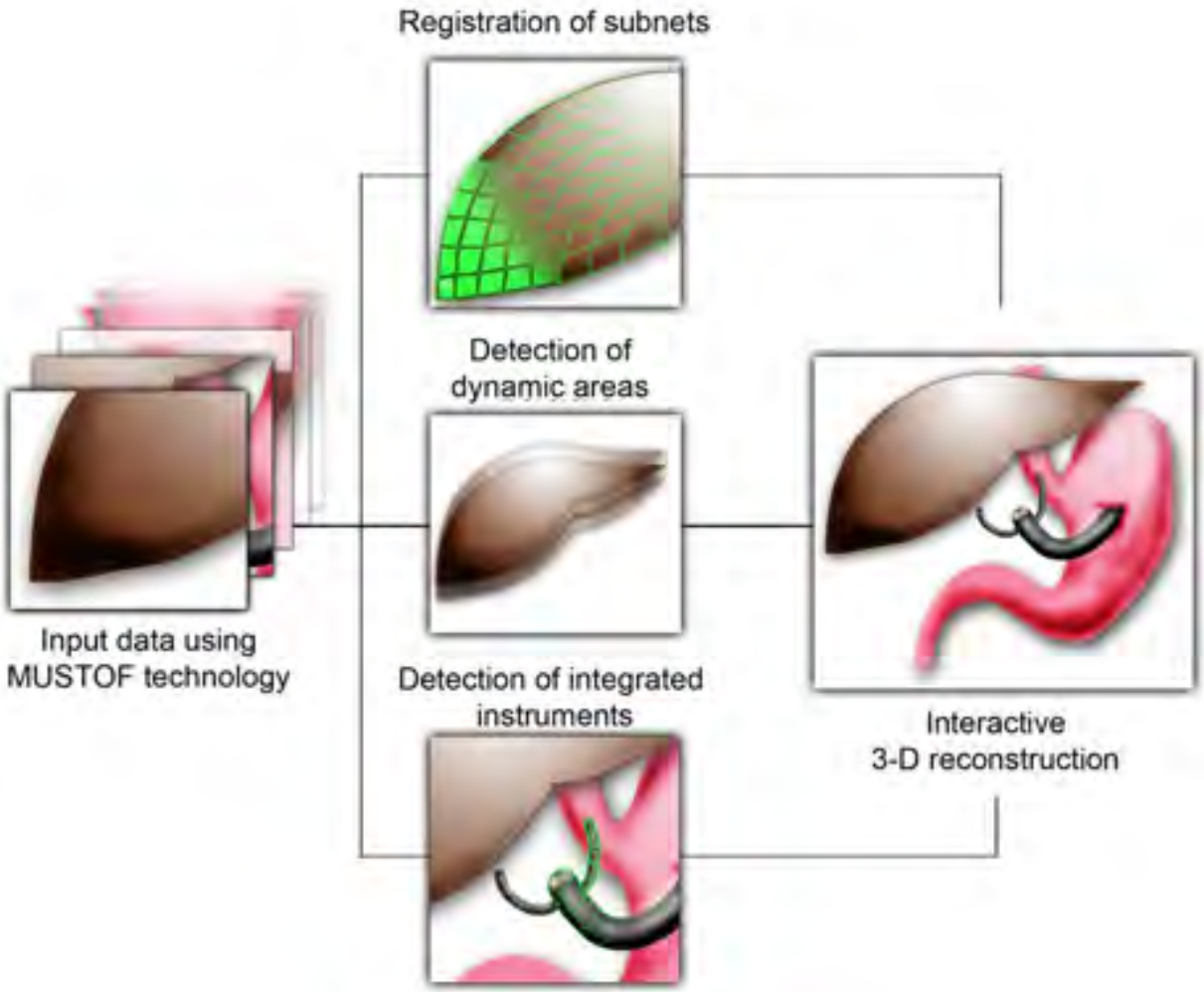

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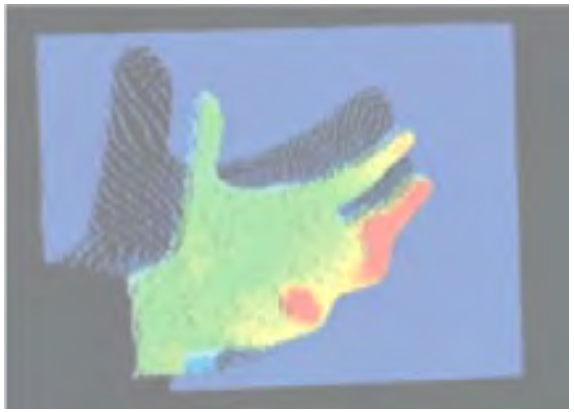

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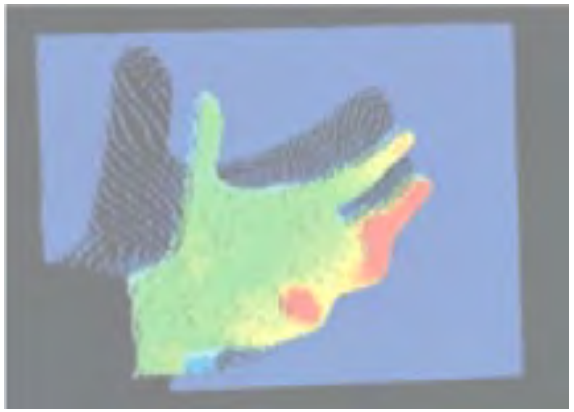


State of the Art

Time-of-Flight (TOF) technology

- Lateral resolution: 120×160 pixel
- Depth resolution: 3 mm
- Wavelength: 870 nm
- Pixel dimension: $40\mu m \times 40\mu m$
- Modulation frequency: 20 Mhz ($\Rightarrow \lambda = 15m$)
- Framerate: >12 fps

Figure: TOF-camera and example images

State of the Art

Time-of-Flight (TOF) technology

- Lateral resolution: 176×144 pixel
- Depth resolution: 2,5 mm
- Wavelength: 870 nm
- Pixel dimension: $40\mu m \times 40\mu m$
- Modulation frequency: 20 Mhz ($\Rightarrow \lambda = 15m$)
- Framerate: >25 fps

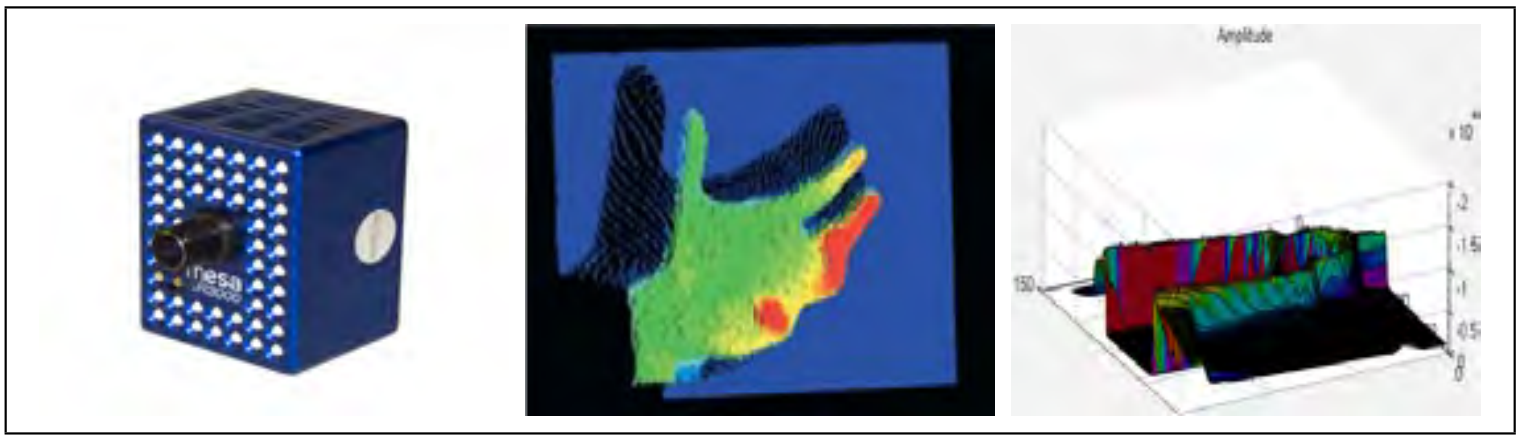
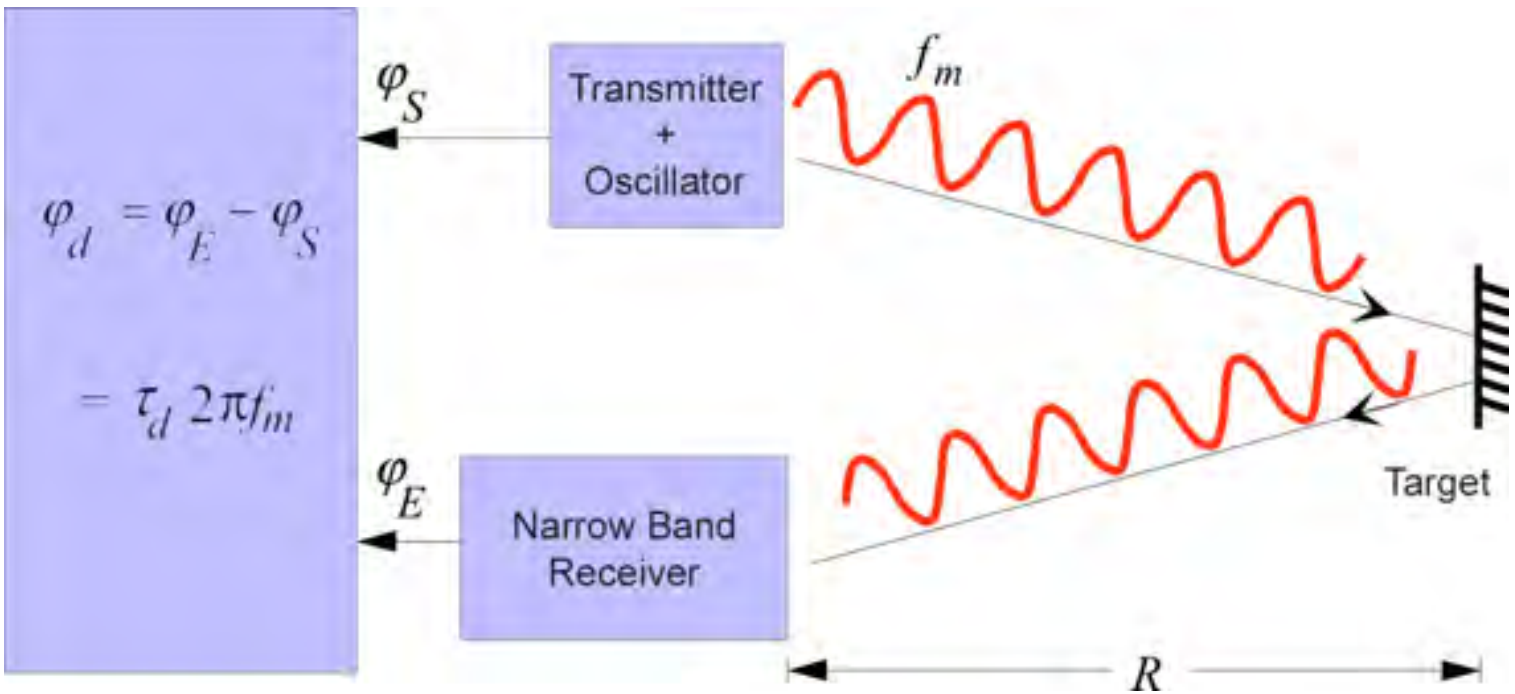


Figure: TOF-camera and example images

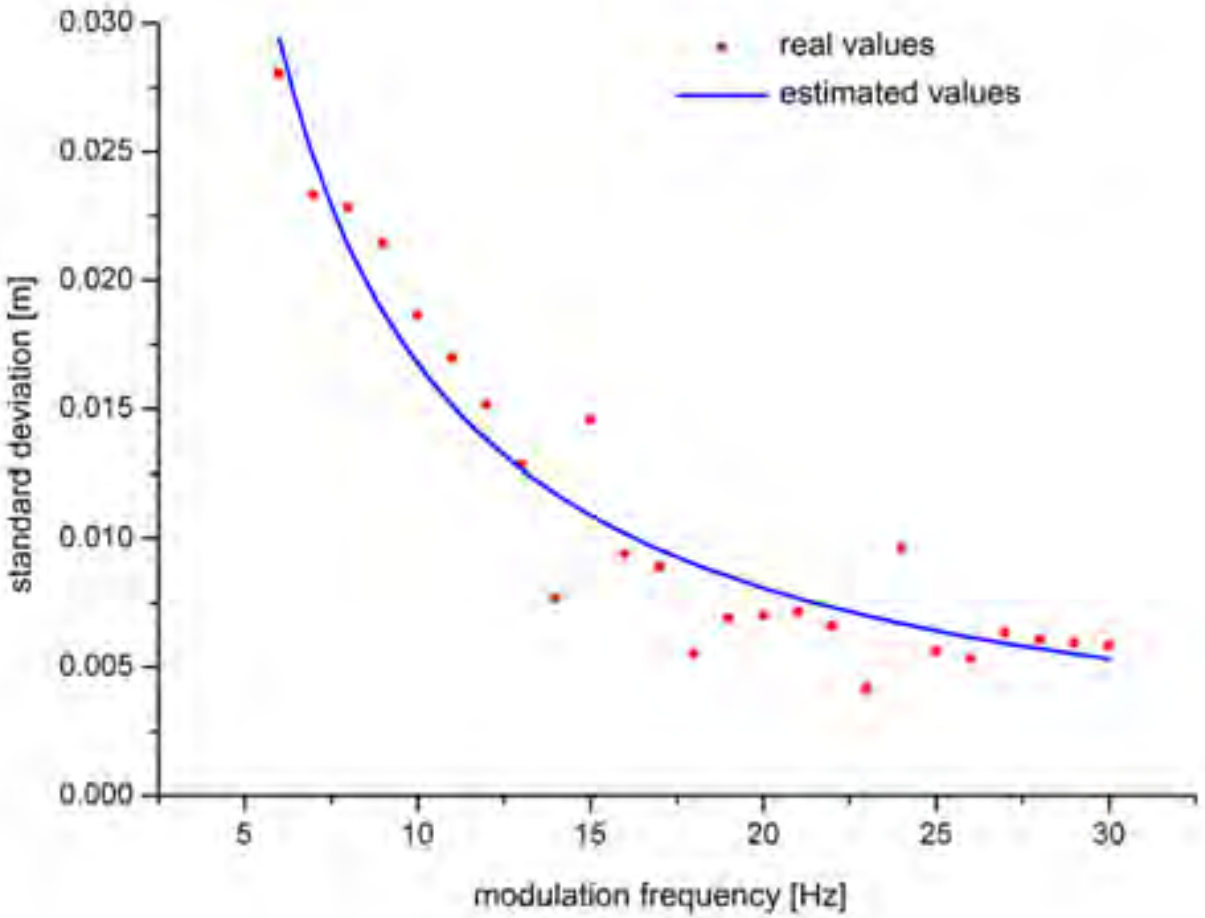
Time-of-flight principle

Continuous wave modulation



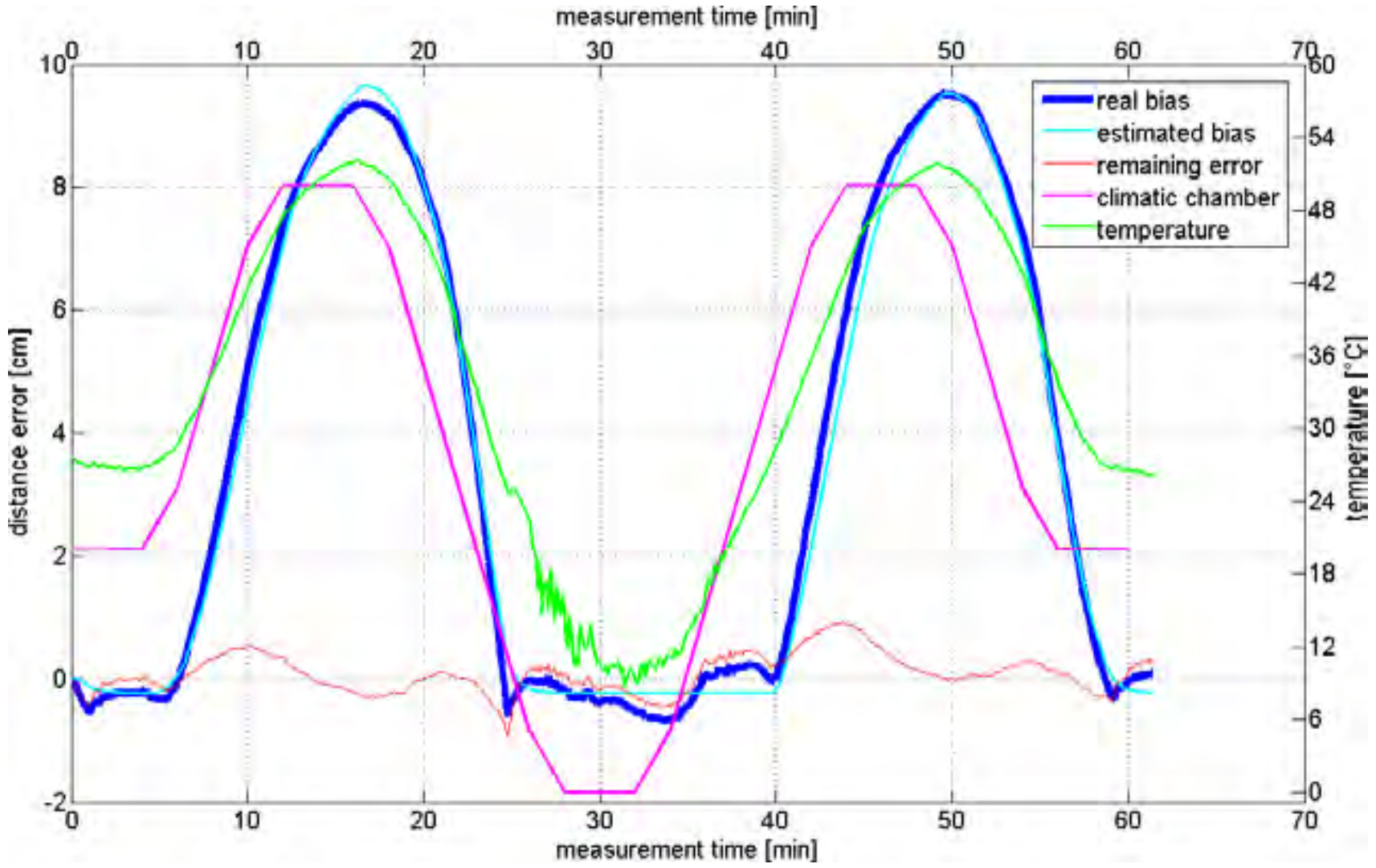
Modulation frequency

Frequency depending standard deviation



Compensation of temperature variation:

Temperature depending error = bias (mesa)



Variation of integration time:

Standard deviation and amplitude vs. integration time (pmd)

Comparison pmd/mesa:

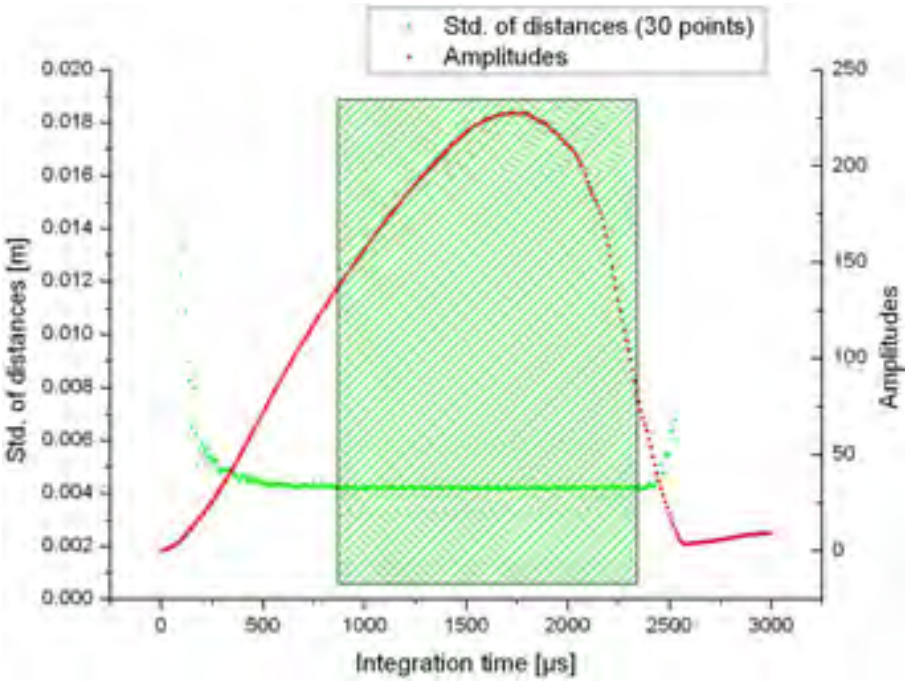


Figure: integration time vs. amplitude and standard deviation (pmd)

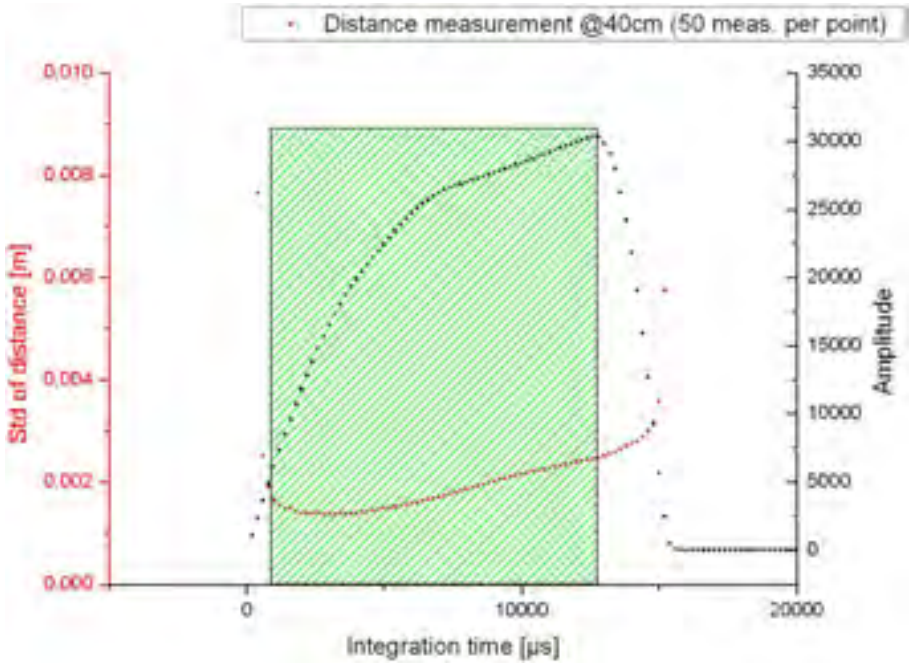


Figure: integration time vs. amplitude and standard deviation (mesa)

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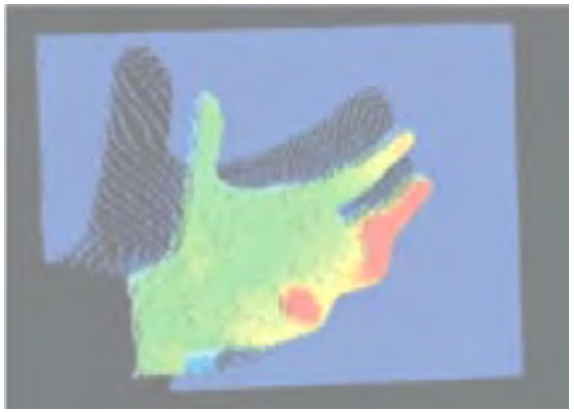


Idea of MUSTOF

Parallel acquisition with TOF camera and CCD camera

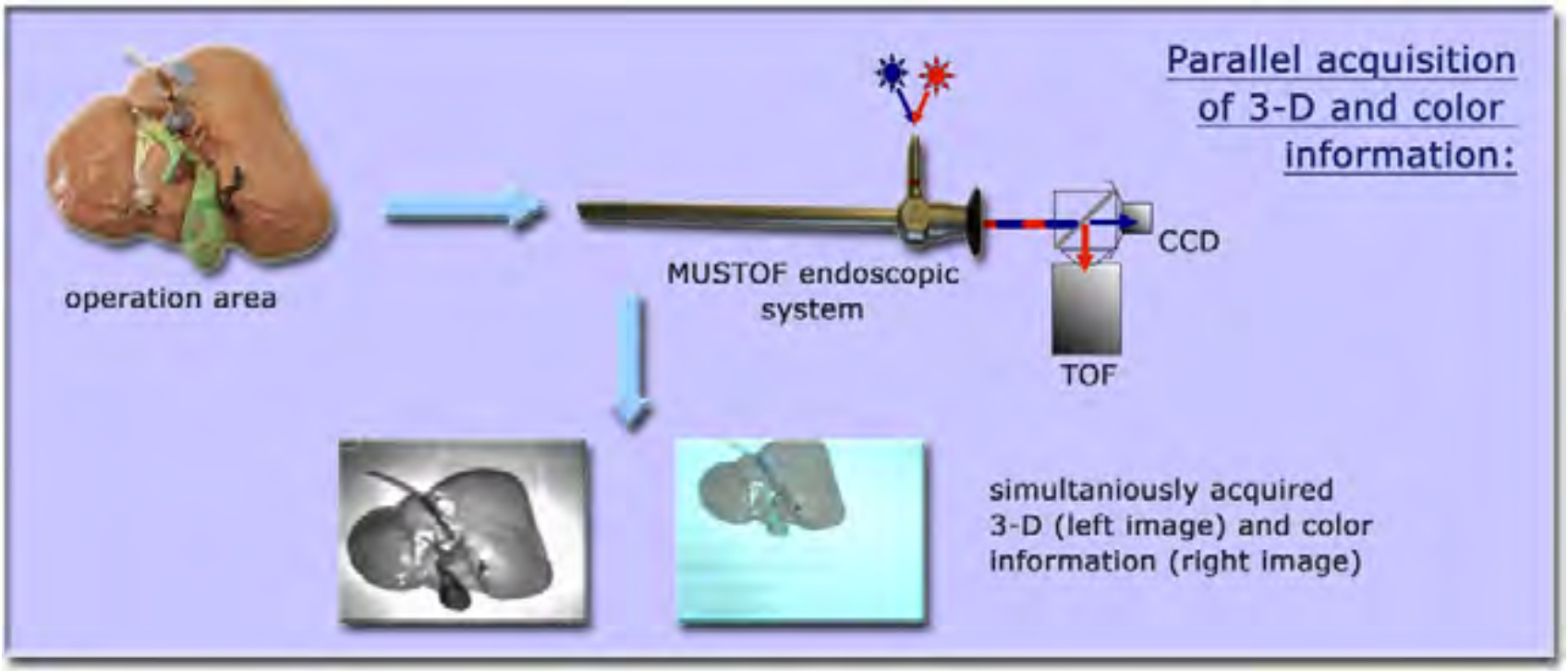


Figure: Paketantrag 'Towards NOTES^{3D},

Required Methods

Calibration and Registration of TOF camera and CCD camera

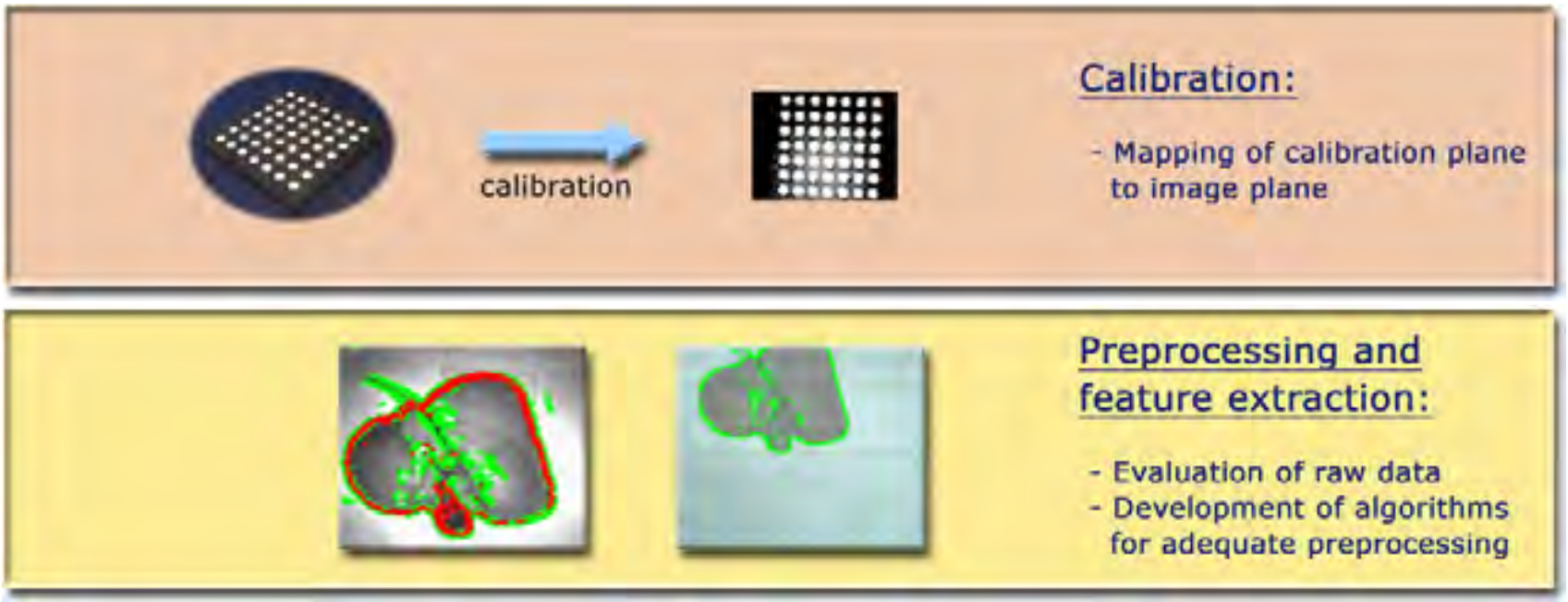
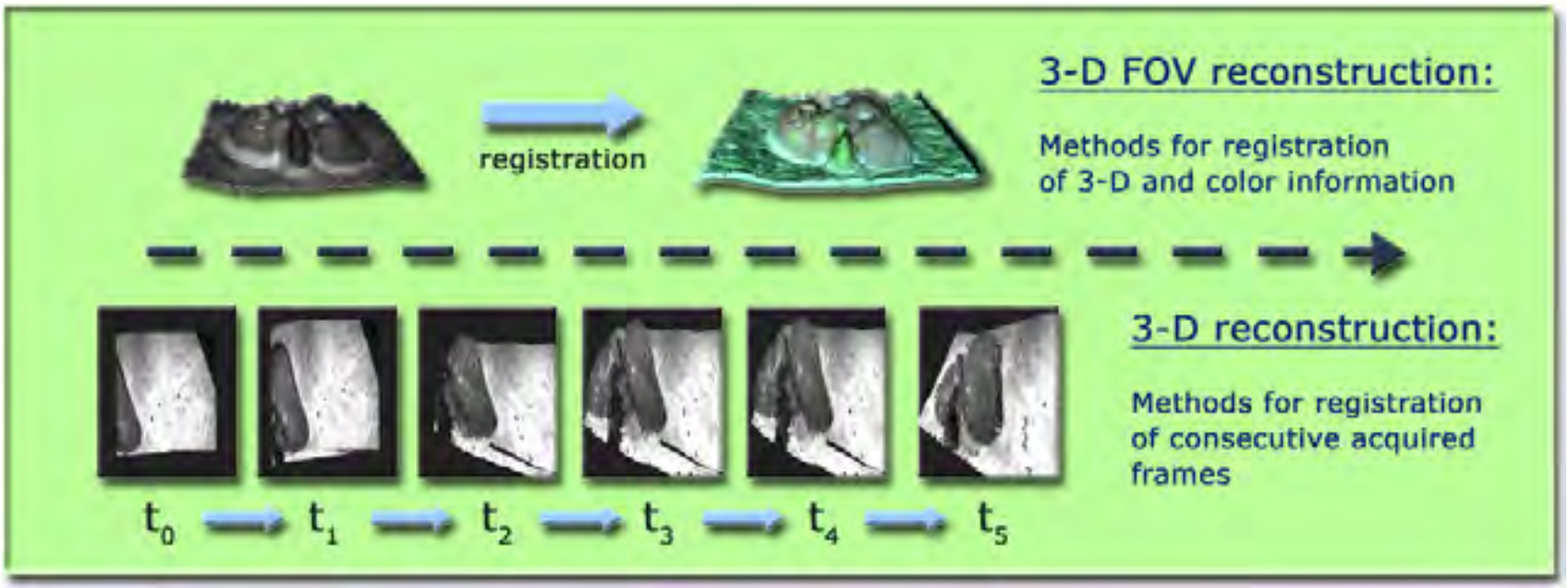


Figure: Paketantrag 'Towards NOTES^{3D},

Required Methods

Reconstruction of static or almost static 3-D scenes



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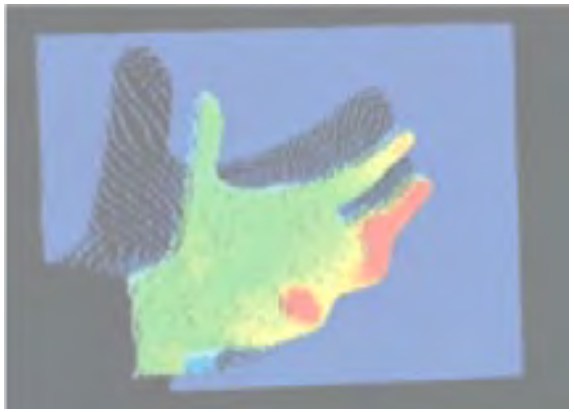


Averaging of consecutive TOF frames

Results

- Test scenario: clinical object *liver model* close up

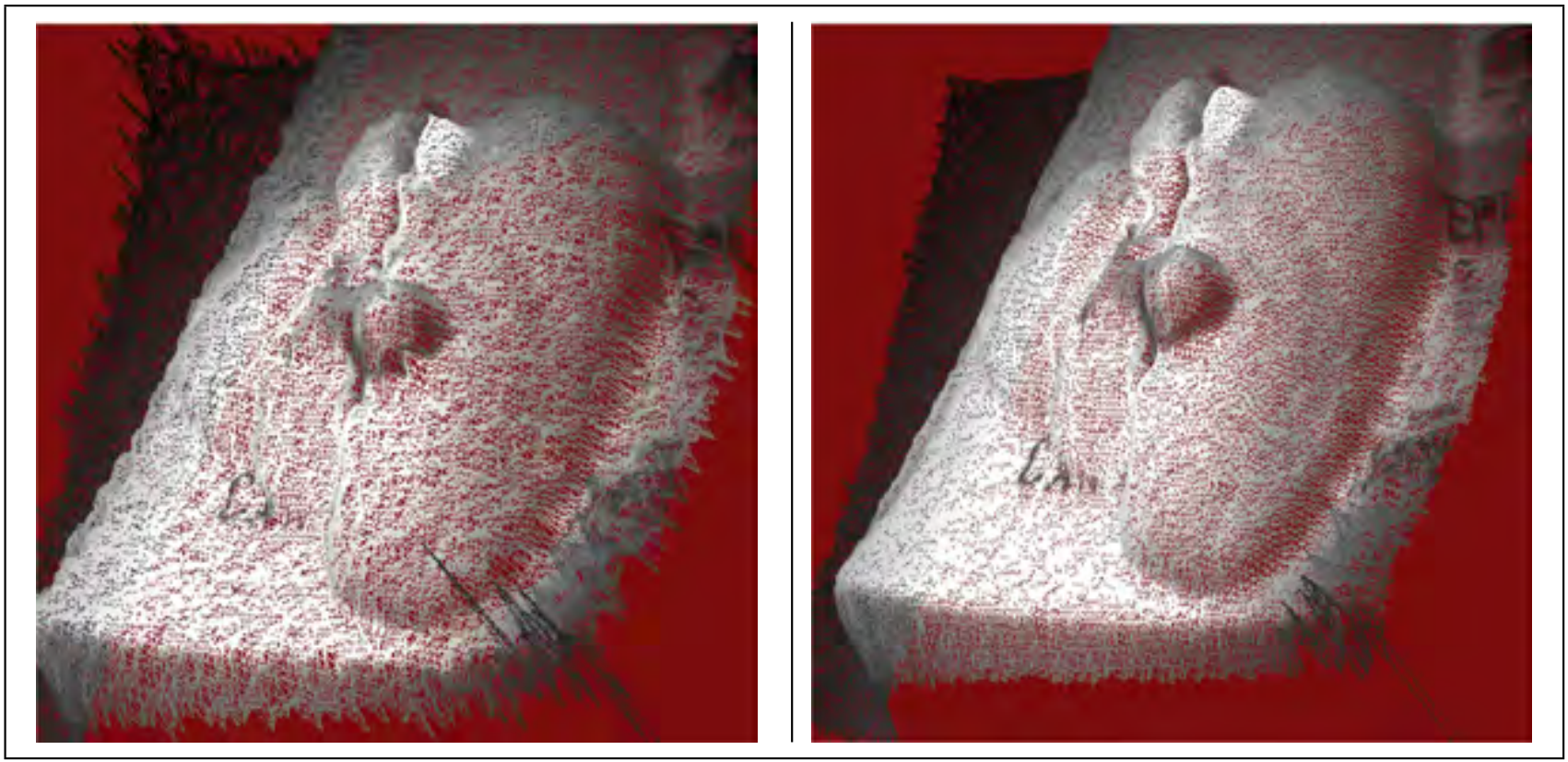


Figure: 3D surface reconstruction. Test scenario: Liver model. Left: original data. Right: result of averaging 10 consecutive frames.

Outlier detection and removal by histogram analysis

Results

- Test scenario: clinical object *liver model* close up

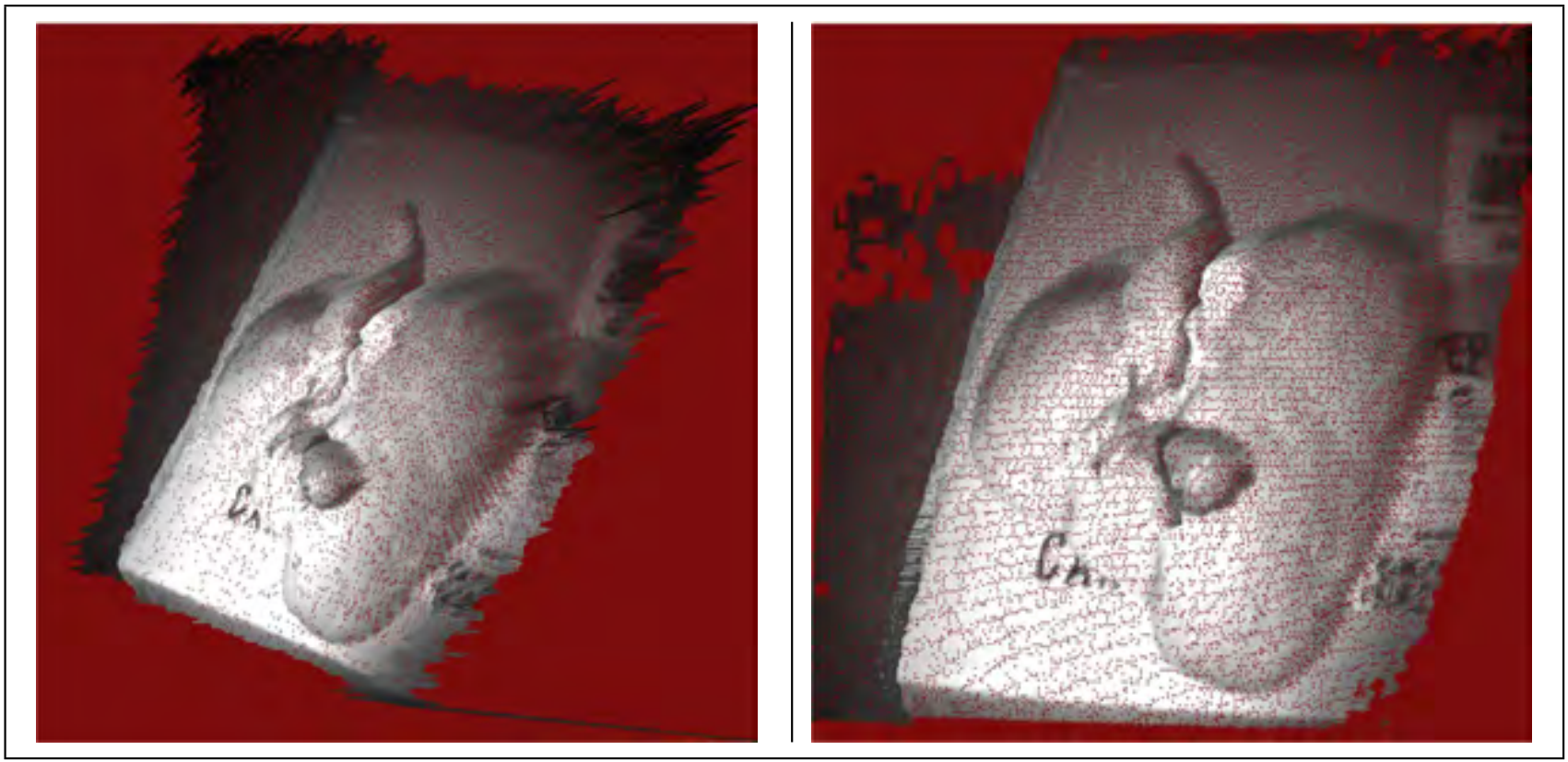


Figure: 3D surface reconstruction. Test scenario: Liver model. Left: original data. Right: result of outlier removal.

Feature detection

Results

- Test scenario: *liver model* close up

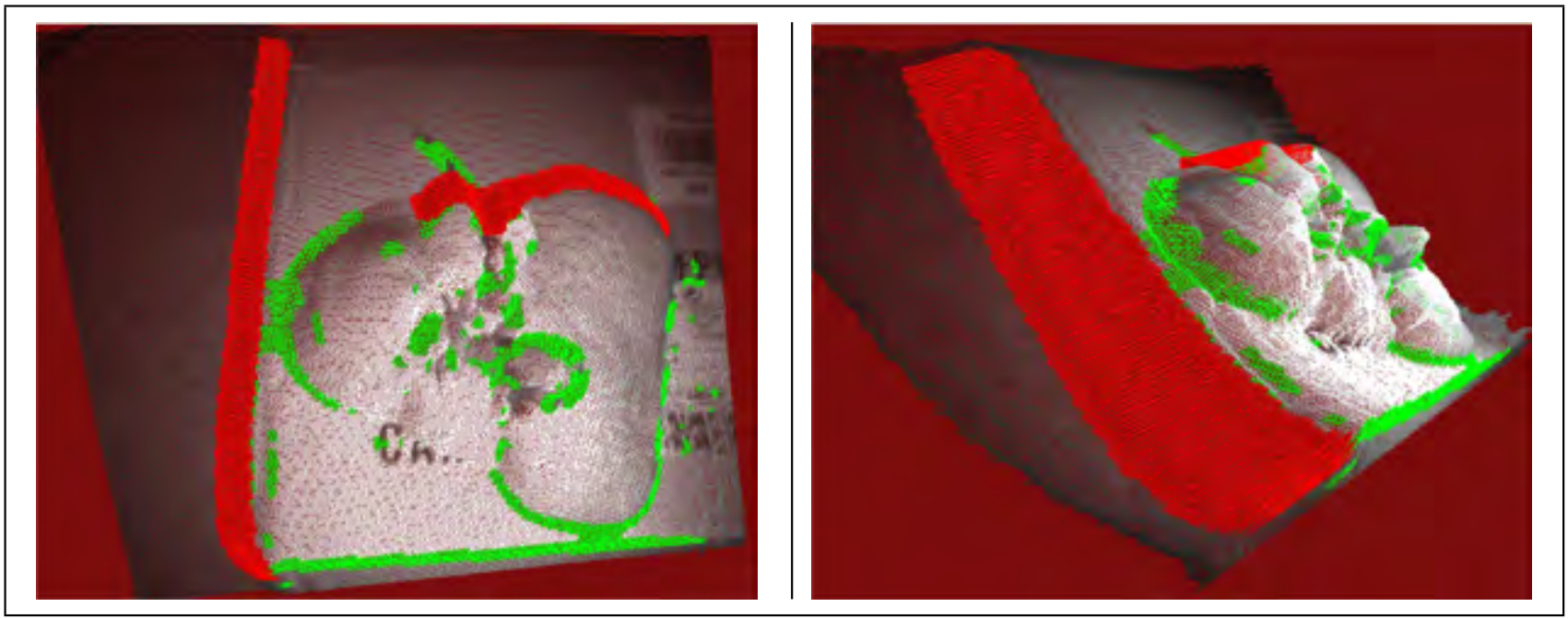
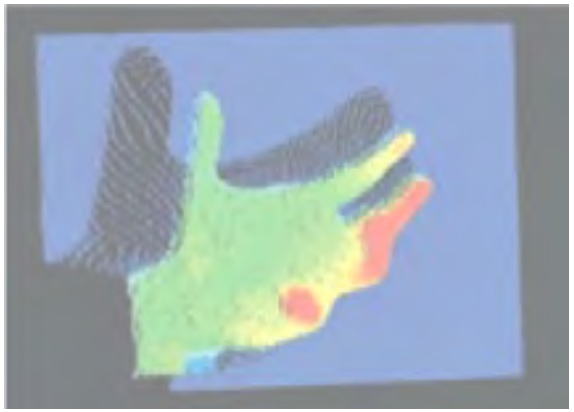


Figure: 3D surface reconstruction. Test scenario: liver model. Both images show the features detected in amplitude data (green) and 3D points (red).

Overview



Laser diodes

Advantage over a LED array

- easier coupling into illumination chanel
- high power
- fast modulation
- narrow-band, ambient light suppression

$$\text{Accuracy} \sim \frac{1}{f_{mod}} \cdot \sqrt{\frac{P_{mod} + P_{amb}}{P_{mod}^2}}$$

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Experimental setting

with laser powered illumination

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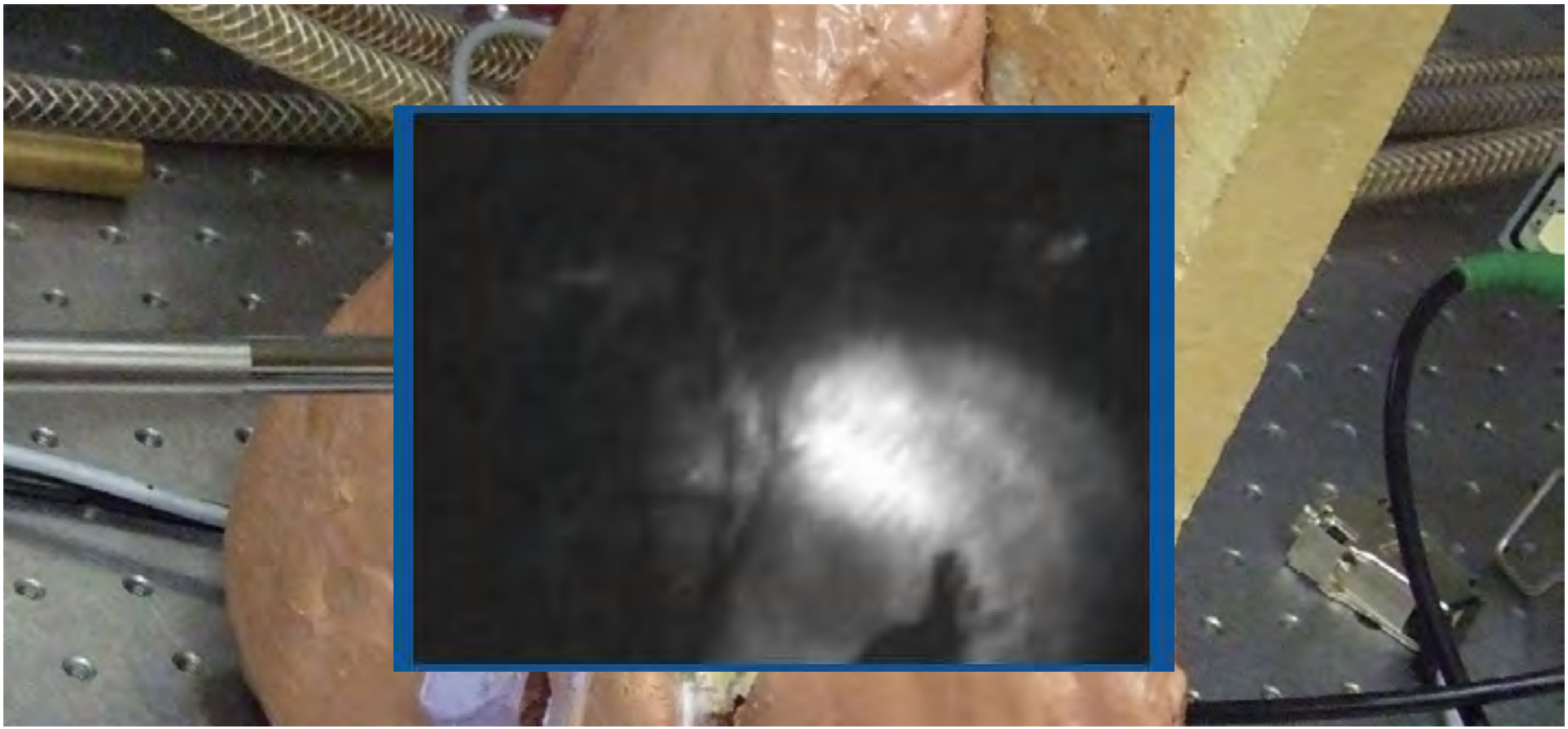

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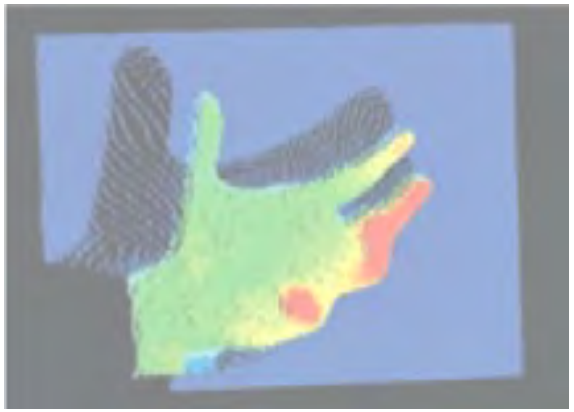


Summarize

Applications and Challenges

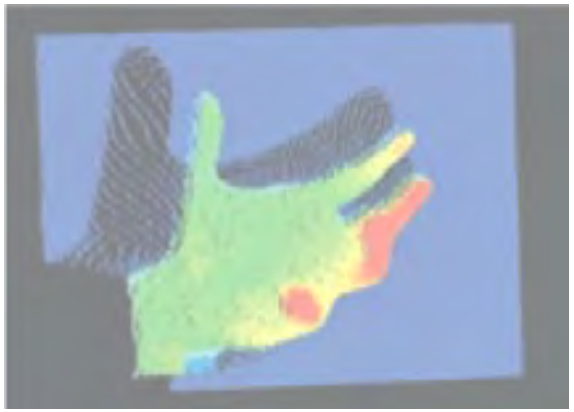
Supporting problems of NOTES will be THE application:

- Access to peritoneal cavity
  - Registering online optic 3-D data with preoperative MR or CT visualized by Augmented Reality
- Maintaining spatial orientation, distance values or other 3-D data
  - collision prevention, motion compensation and automatic positioning of surgery tools
  - reconstruction of static scenes (3-D mosaicing)

Research to make MUSTOF technology more precise:

- modulation frequency and temperature depending offset
- integration time, modulation frequency and reflectivity depending errors
- high power laser illumination

Overview



Outlook

Next steps:

- Spectra and power optimization of the MUSTOF system
- Receiving data from animal laboratories (porcine model)
- First results of Paketantrag 'Towards NOTES^{3D}'

The End

- Thank you for your attention!
- Any further questions?