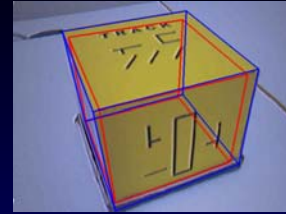


# Model-based Hybrid Tracking for Medical Augmented Reality



Jan Fischer<sup>1</sup>, Michael Eichler<sup>1,2</sup>, Dirk Bartz<sup>1</sup>, Wolfgang Straßer<sup>1</sup>

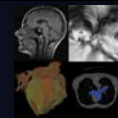
<sup>1</sup> WSI / GRIS – VCM, University of Tübingen, Germany

<sup>2</sup> Alpine Electronics, Inc., Germany

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<http://www.gris.uni-tuebingen.de>  
<http://www.janfischer.com>



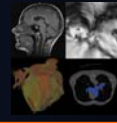
## WS GRIS Overview



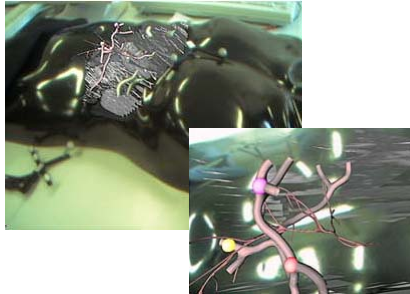
### • Introduction

- Medical AR based on Image Guided Surgery
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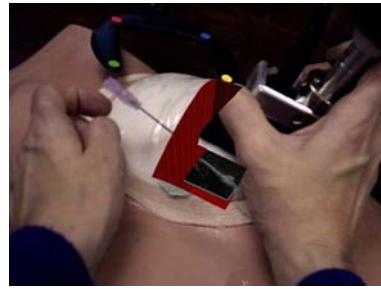
## ws GR/s Augmented Reality Support for Surgery



- Supporting visualization of **organs, risk structures**, etc.



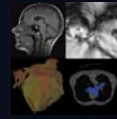
[TU Graz, liver surgery]



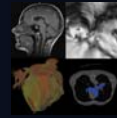
[UNC Chapel Hill, breast biopsy]

- Our project context: neurosurgery, maxillofacial surgery

## ws GR/s Related Work

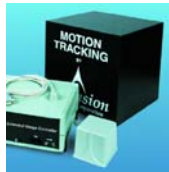


- **Ultrasound visualization** (UNC Chapel Hill)  
[Bajura et al. SIGGRAPH 1992; Fuchs et al. MICCAI 1998]
- **Augmented C-arm**  
[Navab et al. IWAR 1999]
- **Operating microscope** with graphical overlays  
[Sauer et al. ISAR 2001]
- Augmented reality for **liver surgery** planning  
[Bornik et al. SPIE Medical Imaging 2003]



- Utilization of **specialized** system components, e.g.

#### Magnetic trackers



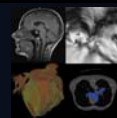
#### Optical trackers



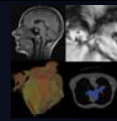
#### HMDs / Shutter glasses



⇒ Installation and usage can be difficult



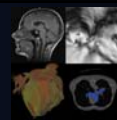
- Introduction
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- Design of a system for medical augmented reality **based on existing medical equipment**
- Approach: Utilization of **Image Guided Surgery (IGS)**
- IGS supports **almost all tasks** necessary for medical AR

⇒ **Augmented Reality based on Image Guided Surgery (ARGUS)**

[Fischer et al. EGVE 2004; Fischer et al. ACM VRST 2004; del Río et al. EGVE 2005]



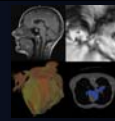
### Image Guided Surgery (IGS) system



- **Proven** technology, **certified** for medicine
- Accurate **infrared tracking**
- Provides methods for **patient registration**



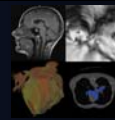
- Infrared **marker clamp**
- Attached to **AR webcam**
- **Marker clamp pose** received using local network
- **Custom calibration step**



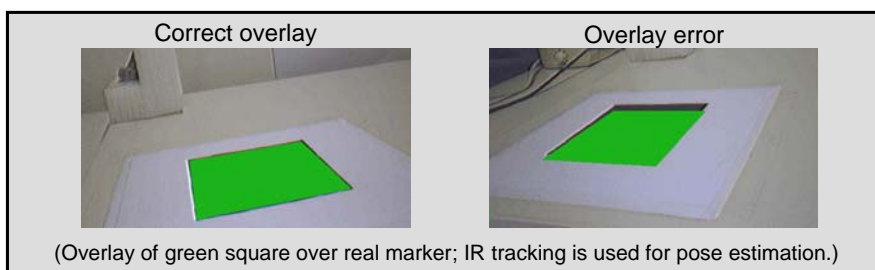
- Plastic skull, manually placed tumor model

Medical Augmented Reality based on  
Image Guided Surgery

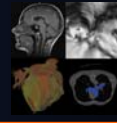
Overlay of manually placed tumor model



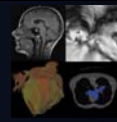
- Overlay accuracy **not always optimal**
- **Jittering** (video), tracking **lag**, calibration **errors**
- Causes: Imprecise **calibration**, inaccuracies in **IR tracking**



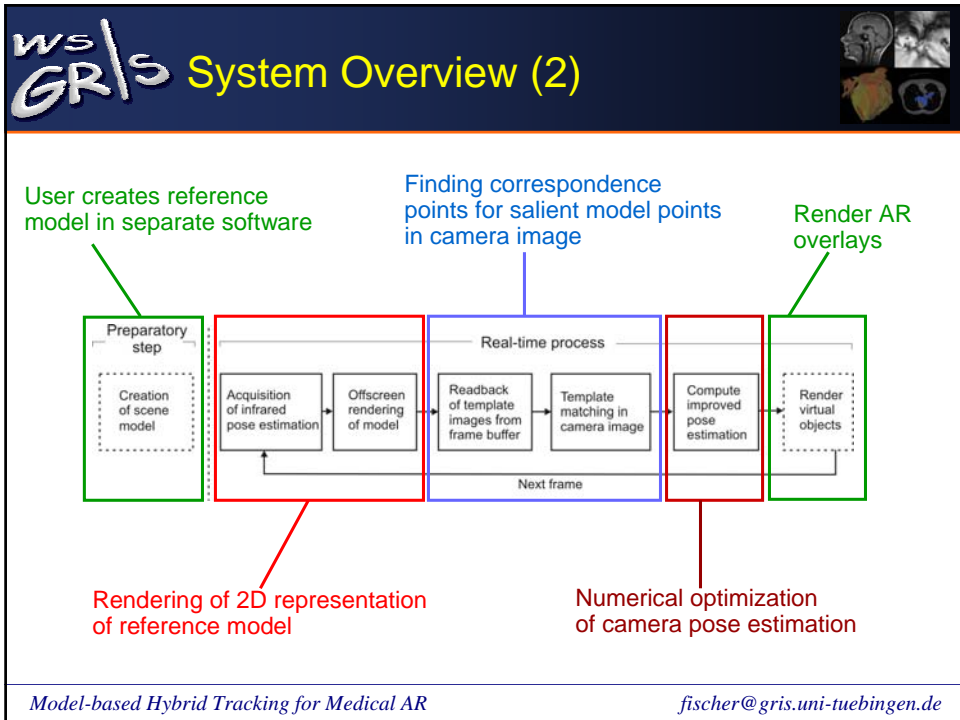
- **Task: Improve tracking without additional hardware**



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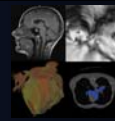


- **Hybrid** tracking method for medical AR
- **Combination** of tracking approaches
  - **Infrared** and
  - Markerless **vision-based**
- **Geometric model** of real object as reference
- Combination of complementary advantages
  - IR tracking: **Stability** (global pose every frame)
  - Vision-based tracking: Improved **accuracy**

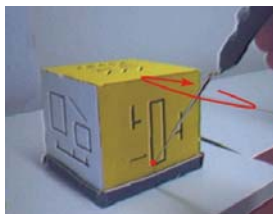


- ws GRIS Overview**
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  - Overview of Hybrid Tracking Method
  - **Description of Algorithm**
  - Results
  - Conclusion
- Model-based Hybrid Tracking for Medical AR* *fischer@gris.uni-tuebingen.de*

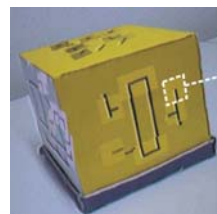
## ws GR/s Creation of Reference Model



- **Manual definition** in a separate software tool
- **Salient parts** of the observed model are defined



Point definition with tracked interaction tool

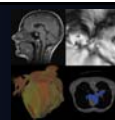


Template image for one reference point

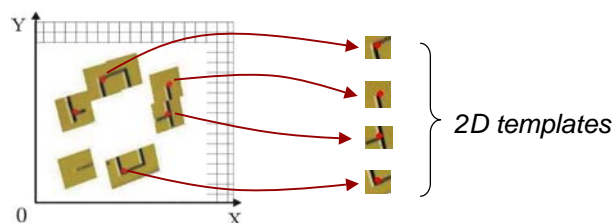
Data acquired for each **reference point**:

- 3D **position**  $r_i$
- **Template image** (grabbed from webcam)
- 3D positions of **template image corners**

## ws GR/s Offscreen Rendering

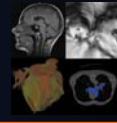


- **Current pose** estimation is acquired from **IR cameras**
- **Template images** are rendered
- Display in **back buffer** (invisible)

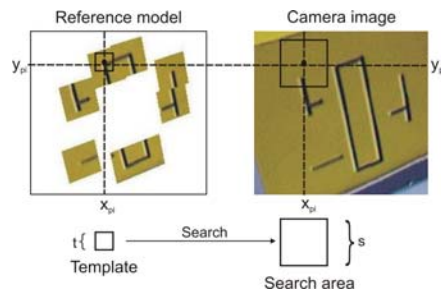


- **Readback** of rendered template images
- OpenGL function **glReadPixels()** is used
- Output: **2D template image** for each reference point

## WS GRIS Template Matching

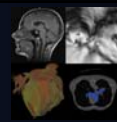


- Search **position of 2D templates** in camera image
- **Normalized correlation coefficient** for template matching

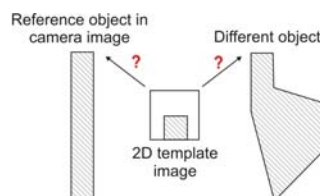


- Position of match: **Correspondence point  $c_i$**
- Quality of match: **Confidence value  $k_i$**

## WS GRIS Numerical Stability



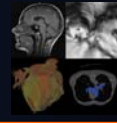
- Numerical optimization based on **correspondence points**
- Correspondence points may contain **errors**
  - **Insufficient match** (e.g., out of camera image)
  - **False positives** (e.g., repetitive patterns)



### Solutions:

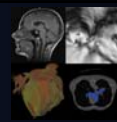
- Insufficient match  $\Rightarrow$  **Confidence value threshold**
- False positivies  $\Rightarrow$  **RANSAC algorithm** [Fischler 1981]

## WS GR/S Hybrid Pose Estimation



- Starting with **pose from infrared tracker**
- **Iterative improvement** of pose based on point correspondences:
  - **Reference points** (and their projections)
  - **Correspondence points**

## WS GR/S Iterative Optimization (1)



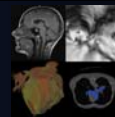
- Based on **Newton's method** for solving systems of nonlinear equations [cf. Trucco and Verri 1998]
- **Minimize reprojection error** using an error function E

$$E(\underbrace{t_x, t_y, t_z}_{\text{Camera translation}}, \underbrace{\phi_x, \phi_y, \phi_z}_{\text{Camera orientation}}) = \sum_i d(c_i, \text{proj}(M \cdot r_i))^2$$

$\Rightarrow \min_M \sum_i d(c_i, \text{proj}(M \cdot r_i))^2$

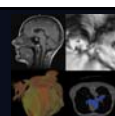
Point correspondences index  $i$     
 Euclidean distance  $d$     
 Correspondence point  $c_i$     
 Reference point  $r_i$

## ws GRIS Iterative Optimization (2)



- Goal: Approximate the **root (zero) of E**
- **Algorithm:**
  1. Compute residuals ( $proj(M \cdot r_i) - c_i$ ) for all correspondences
  2. Compute partial derivatives with respect to:  
 $T = (t_x, t_y, t_z)$  and  $\Phi = (\Phi_x, \Phi_y, \Phi_z)$
  3. Set up and solve equation system for  $\Delta T$  and  $\Delta \Phi$
  4. Update  $M$  with computed corrections  $\Delta T$  and  $\Delta \Phi$
  5. Repeat from 1. until convergence criterion is met

## ws GRIS Iterative Optimization (3)

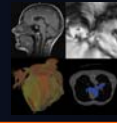


- Equation system set up **for each correspondence:**

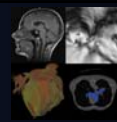
$$\begin{pmatrix} \frac{\partial x_i}{\partial t_x} & \frac{\partial x_i}{\partial \phi_x} & \frac{\partial x_i}{\partial t_y} & \frac{\partial x_i}{\partial \phi_y} & \frac{\partial x_i}{\partial t_z} & \frac{\partial x_i}{\partial \phi_z} \\ \frac{\partial y_i}{\partial t_x} & \frac{\partial y_i}{\partial \phi_x} & \frac{\partial y_i}{\partial t_y} & \frac{\partial y_i}{\partial \phi_y} & \frac{\partial y_i}{\partial t_z} & \frac{\partial y_i}{\partial \phi_z} \end{pmatrix} \begin{pmatrix} \Delta t_x \\ \Delta \phi_x \\ \Delta t_y \\ \Delta \phi_y \\ \Delta t_z \\ \Delta \phi_z \end{pmatrix} = \begin{pmatrix} \delta x_i \\ \delta y_i \end{pmatrix}$$

Computed from projected reference point coordinates (known)      Pose corrections (unknowns)      Residuals (known)

- Solve with singular value decomposition (**SVD**)
- Repeat until **E is small** or **maximum number of iterations** is reached
- Result: Improved, **hybrid pose estimation**



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Template side length $t$	16 pixels
Search area side length $s$	60 pixels
Confidence threshold $k_{min}$	0.9
Number of reference points (defined from 3 viewpoints)	23
Test duration	182 frames

Table 1: Parameters of experimental test run.

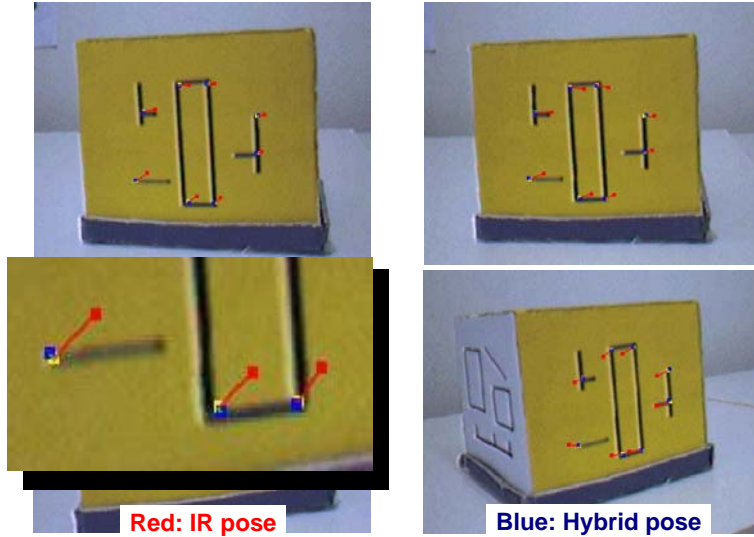
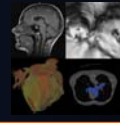
	Infrared pose	Hybrid pose
Min. Ø displacement (average per frame)	6.4 pixels	2.98 pixels
Max. Ø displacement (average per frame)	18.94 pixels	12.88 pixels
Overall Ø displacement (average of all frames)	11.74 pixels	7.89 pixels
Overall Ø frame rate	20.7 fps	13.5 fps
Number invalid frames	-	3

Table 2: Results of experimental test run.

Offscreen rendering	17.86 msecs	(27%)
Template matching	36.92 msecs	(57%)
Pose estimation	10.18 msecs	(16%)

Table 3: Runtime analysis of the individual algorithm steps.

# ws GR/S Result Images (1)



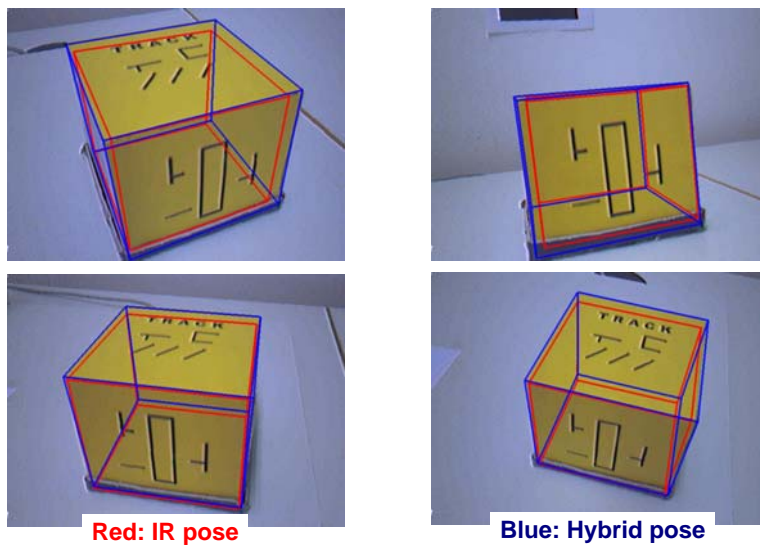
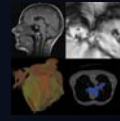
Red: IR pose

Blue: Hybrid pose

Model-based Hybrid Tracking for Medical AR

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# ws GR/S Result Images (2)

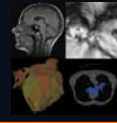


Red: IR pose

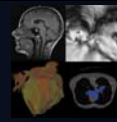
Blue: Hybrid pose

Model-based Hybrid Tracking for Medical AR

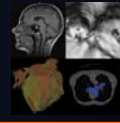
fischer@gris.uni-tuebingen.de



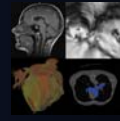
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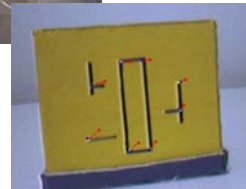
- **Hybrid tracking algorithm** for medical AR
- **No additional hardware** required
- **Combines advantages** of IR tracking (**stability**) and vision-based tracking (**accuracy**)
- Experiments show that it can **improve overlay accuracy**
  - Vision component **sensitive** to camera **image quality**
  - Reduced **frame rate**



- Transfer computation tasks to **GPU** (template matching)
- Adapt approach to more **application-oriented setting**
- For instance, track **fiducials** used during surgery



## Questions?



### Acknowledgements:

- Peter Biber, Sven Fleck
- Bernhard Thomaszewski
- German Research Foundation (DFG), SPP1124

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