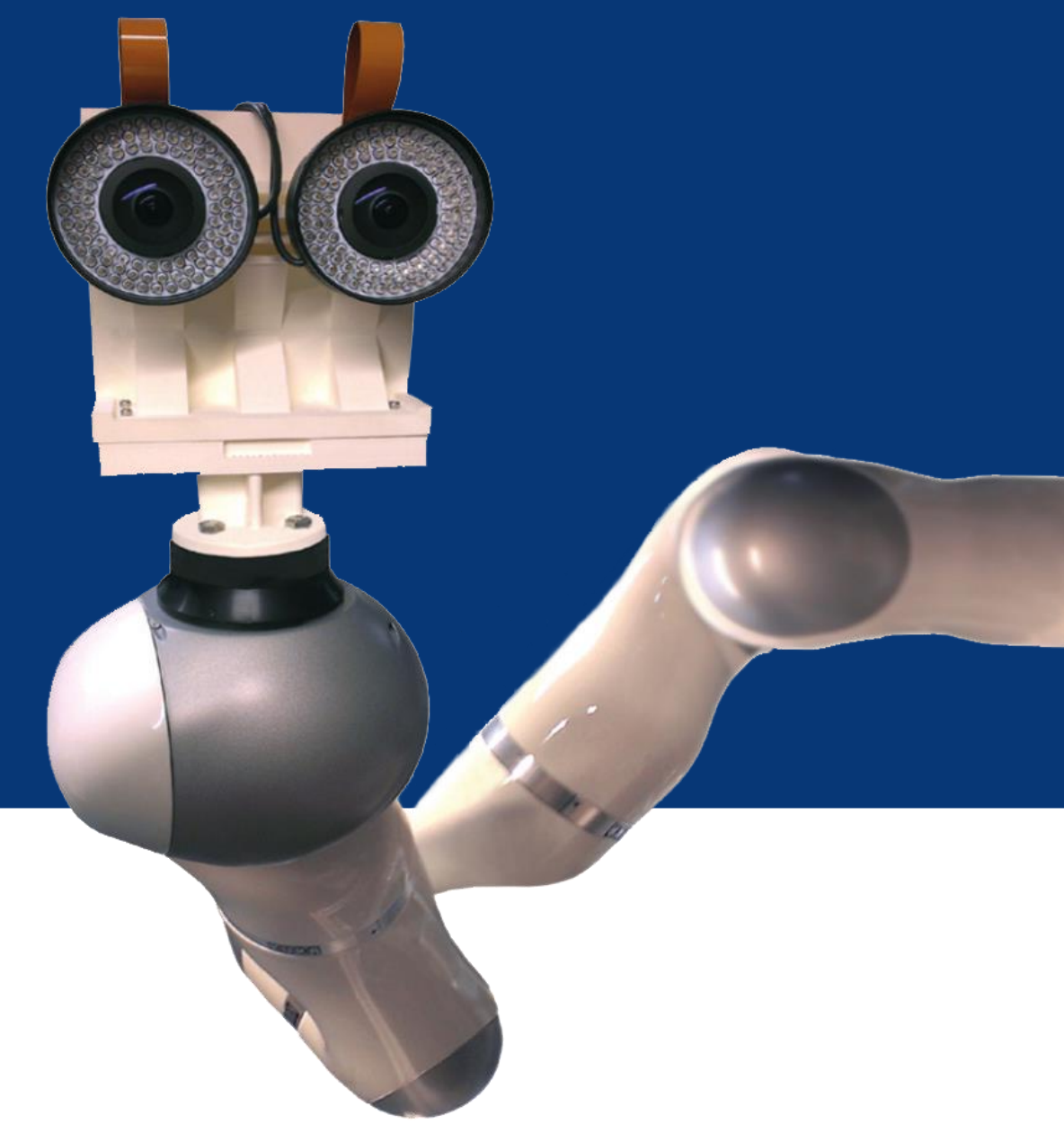




# A Stereo Vision Approach for Cooperative Robotic Movement Therapy

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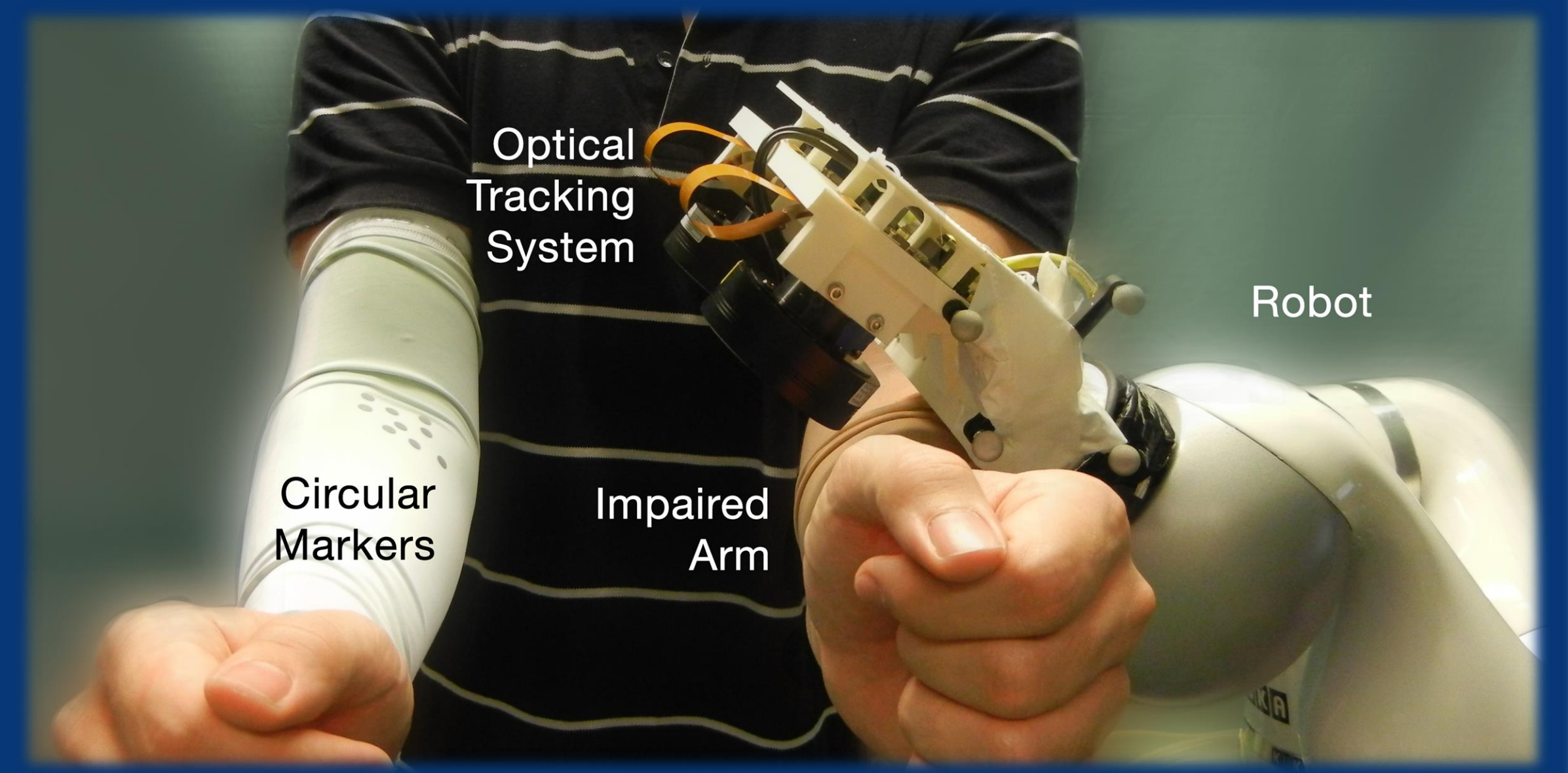
1. Computer Aided Medical Procedures, Technische Universität München, Germany
2. FRAMOS Imaging Systems, Germany
3. Computer Aided Medical Procedures, Johns Hopkins University, US



## Robot-assisted rehabilitation system

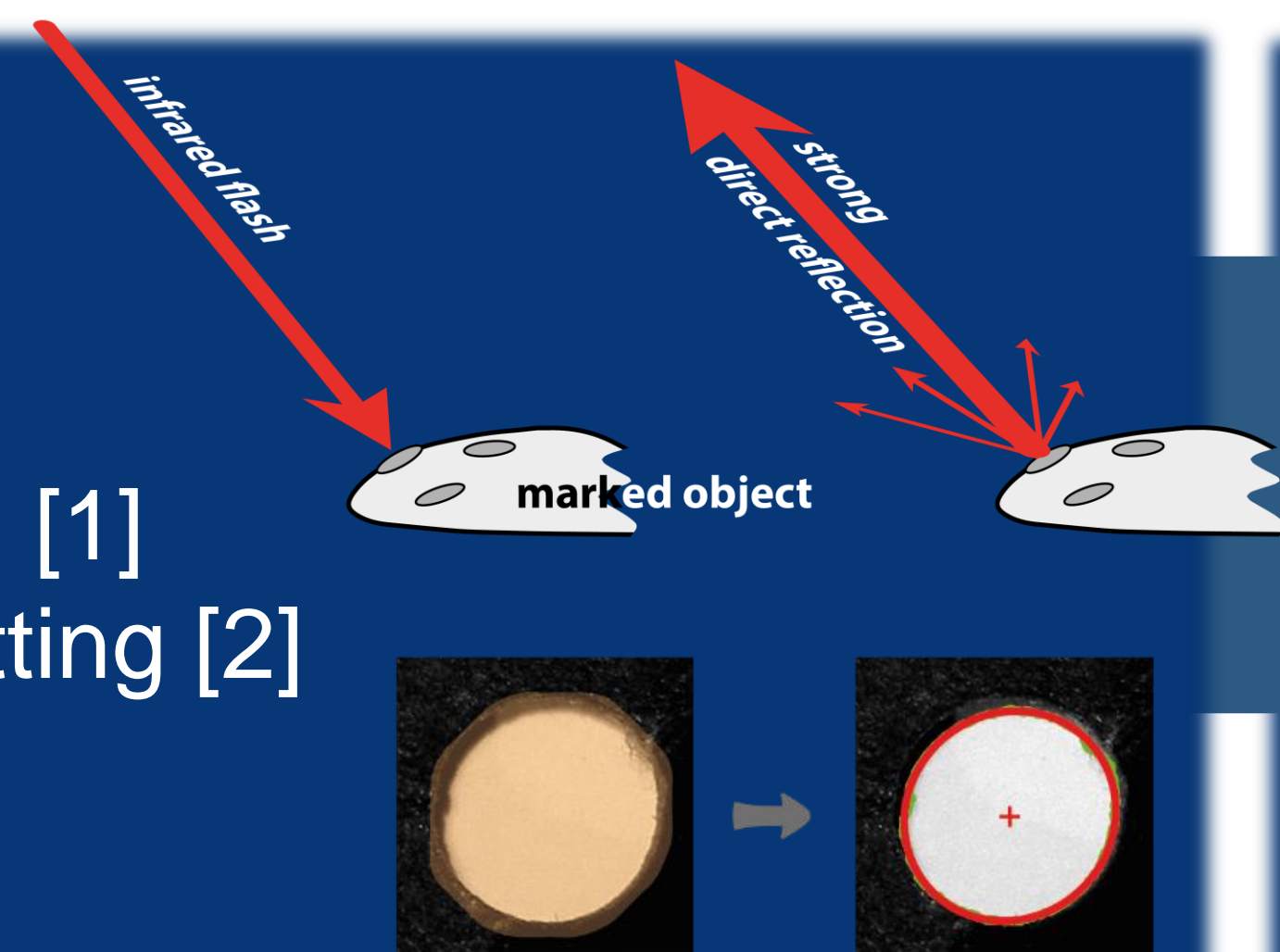
Movement therapy is an integrating part of stroke rehabilitation. We present a device for the re-education of upper limb movements in hemiparetic patients where a light-weight robotic arm follows the movements of the healthy arm that wears a sleeve equipped with flat round reflective markers.

The marker position is detected by a stereo camera system and a robust and real-time algorithm provides the tracking.

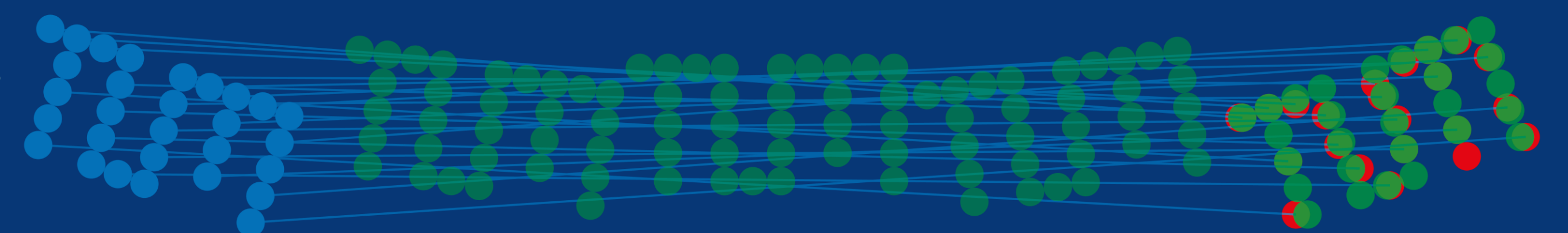


## Image Processing

1. Acquire images
2. Find object markers (ROIs) [1]
3. Subpixel precise contour fitting [2]
4. Compute centres
5. Triangulate 3D points



## 3D Computer Vision



Sparse Point Cloud Registration

Minimize Energy Functional

$$E(\mathbf{M}, \mathbf{R}, \mathbf{t}) = \sum_{j=1}^J \sum_{k=1}^K m_{jk} \|\mathbf{y}_k - (\mathbf{R}\mathbf{x}_j + \mathbf{t})\|^2 - \alpha \sum_{j=1}^J \sum_{k=1}^K m_{jk}$$

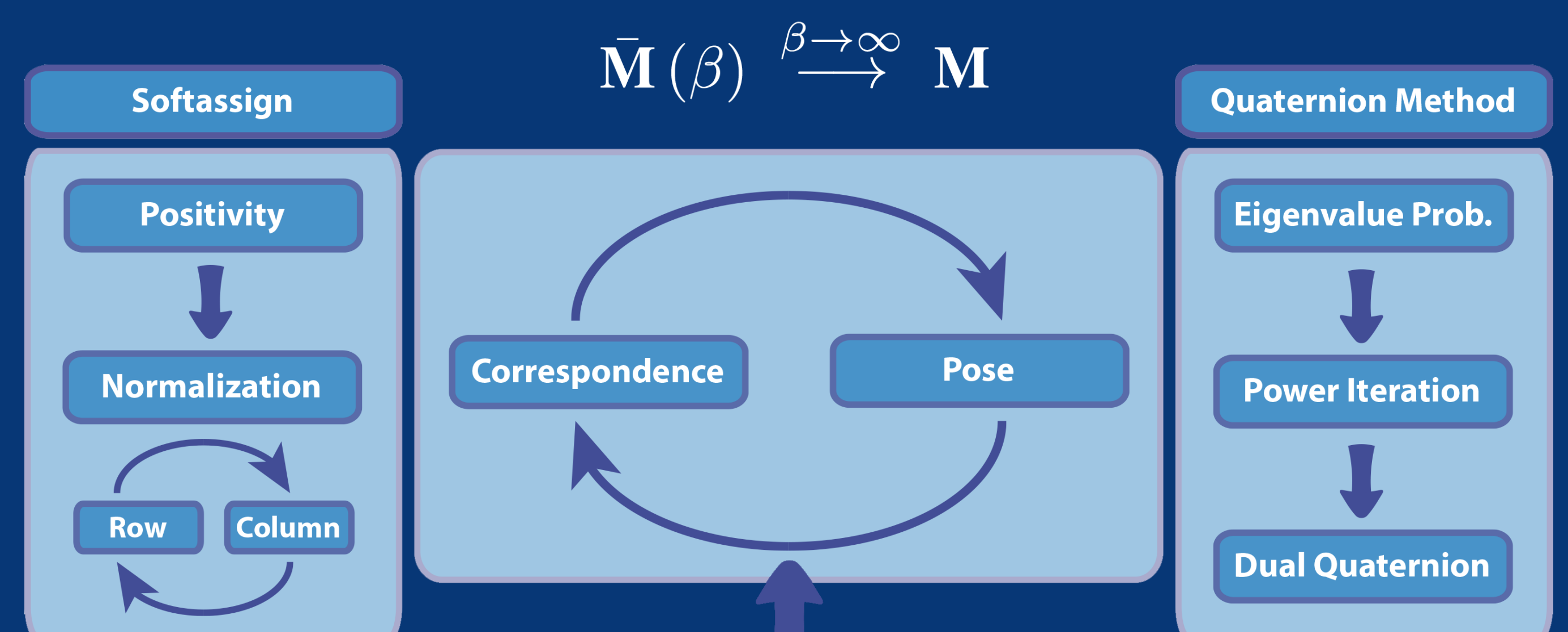
Constraints

$$\sum_k m_{jk} \leq 1 \quad \forall j \in \{1, 2, \dots, J\}$$

$$\sum_j m_{jk} \leq 1 \quad \forall k \in \{1, 2, \dots, K\}$$

$$m_{jk} \in \{0, 1\} \quad \forall j \in \{1, 2, \dots, J\}, k \in \{1, 2, \dots, K\}$$

Algorithmic Solution: Mutual Approximation Updates



- Individual set-up
- Online teaching

- Robust recognition
- Real-time tracking

## Processing Pipeline

### Calibration

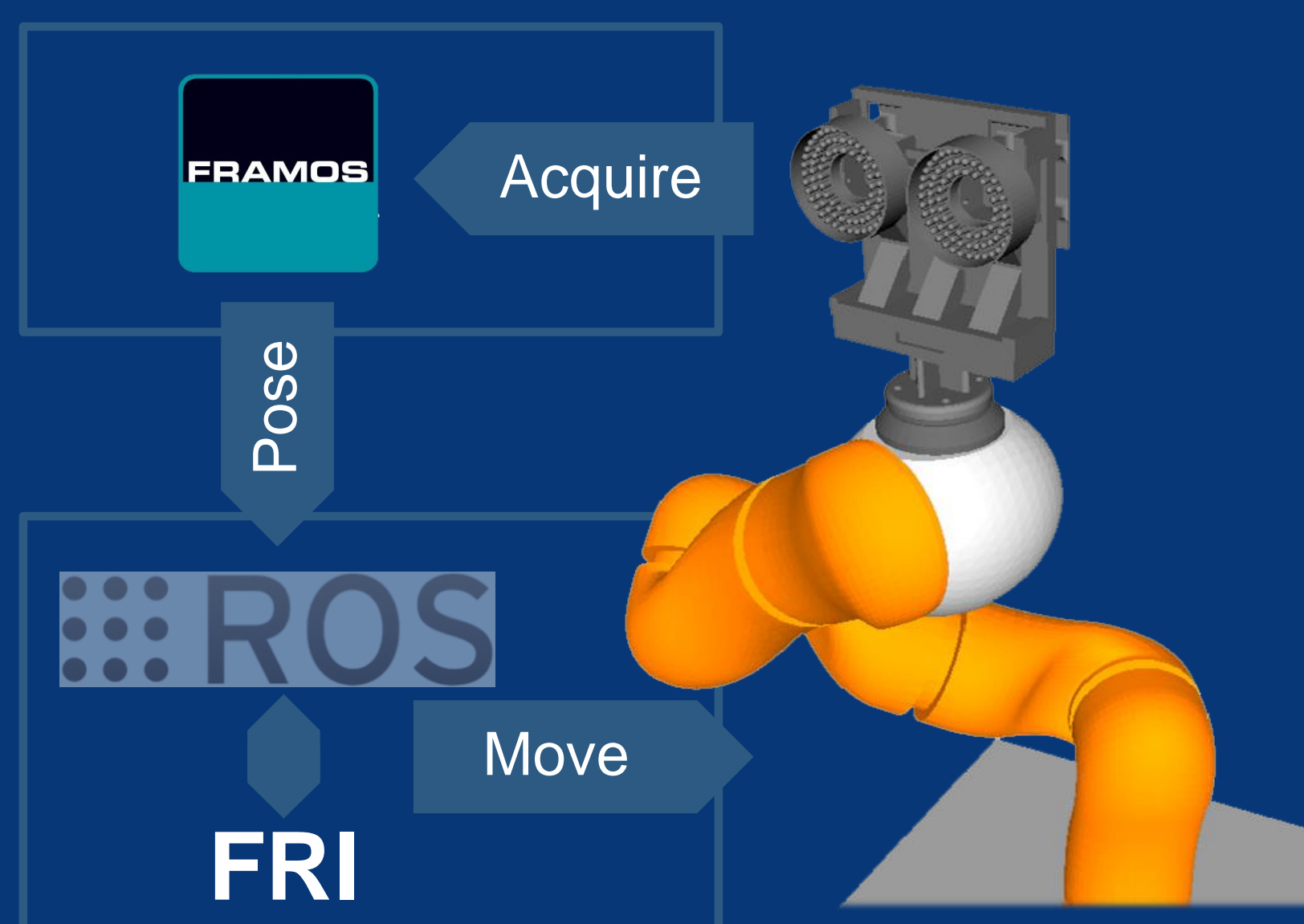
- Camera Params
- Hand-eye [3]

### Communication

- OpenIGTLink [4]

### Robot Path Planning

- RRT-connect [5]



## Quantitative Evaluation

### Accuracy in working volume

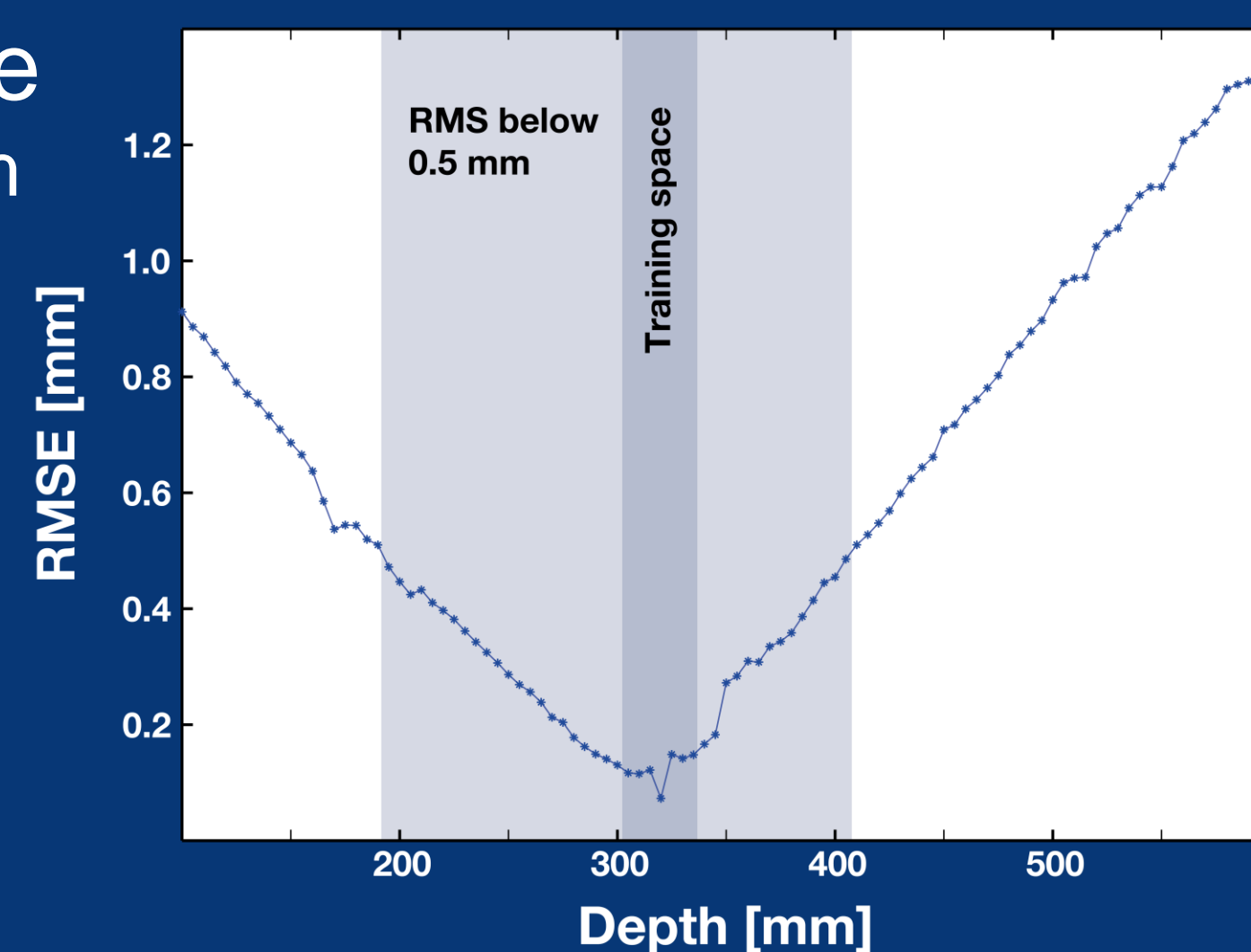
- Total translation error 0.5 mm

### Partial Occlusion

- Up to 50% occlusion

### Computation Time

- Tracking 9.42 ms ± 1.44 ms
- System latency 318.70 ms



## Conclusion

We introduce a robust real-time marker-based tracking algorithm that provides the necessary information to reproduce the movement of the healthy arm with the impaired one. First trials with healthy subjects show the feasibility of this approach. Finally, this work opens the way towards gesture-controlled robots in rehabilitation.

[1] T. Lindeberg. Edge detection and ridge detection with automatic scale selection. CVPR 1996.

[2] P. O'Leary and P. Zsombor-Murray. Direct and specific least-square fitting of hyperbolae and ellipses. Journal of Electronic Imaging 2004.

[3] R. Tsai and R. Lenz. A new technique for fully autonomous and efficient 3D robotics hand/eye calibration. TRA 1989.

[4] Tokuda, Junichi, et al.: OpenIGTLink: An open network protocol for image-guided therapy environment. MRCAS 2009.

[5] J.J. Kuffner and S. M. LaValle. RRT-Connect: An Efficient Approach to Single-Query Path Planning. ICRA 2000.