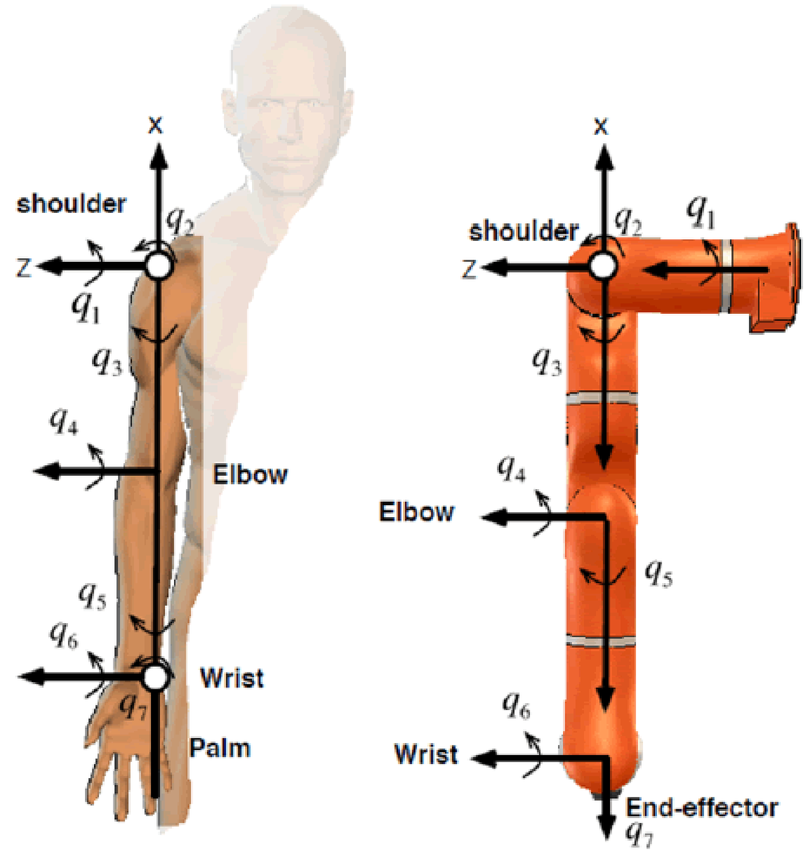
Programming by Demonstration Using Two-Step Optimization for Industrial Robot

Mikhail Ostanin, Dmitry Popov, Alexandr Klimchik
Innopolis University
{m.ostanin, d.popov, a.klimchik}@innopolis.ru

Motivation

- While teaching/demonstrating people make movements that are optimal for them, but these movements will not be optimal for a robot with another kinematic structure.
- Each demonstration is slightly differs from previous.



Sources: doi:10.4172/advances-robotics-automation.1000110

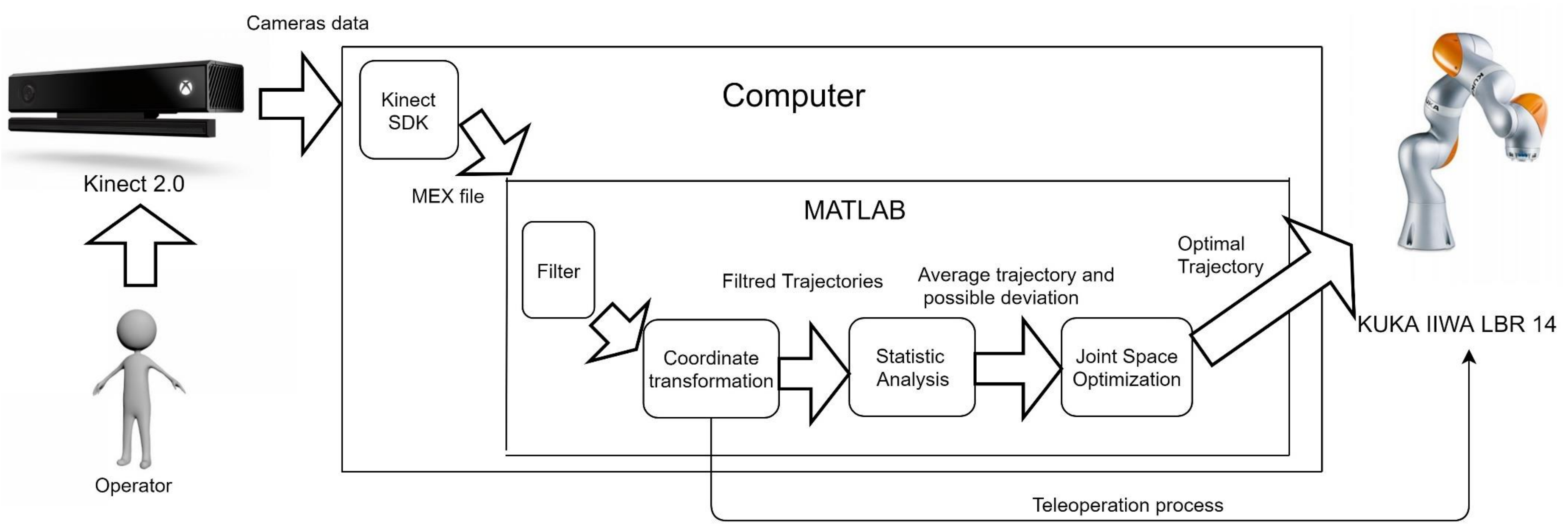
- Develop a system for Programming by Demonstration based on the teleoperation.
- Use a statistical data analysis and optimization techniques to program a robot based on multiple human movements.
- Minimization of the total execution time or the energy consumption.

Hardware:

- Kinect 2.0
- Desktop computer
- Robot Controller
- KUKA IIWA LBR 14

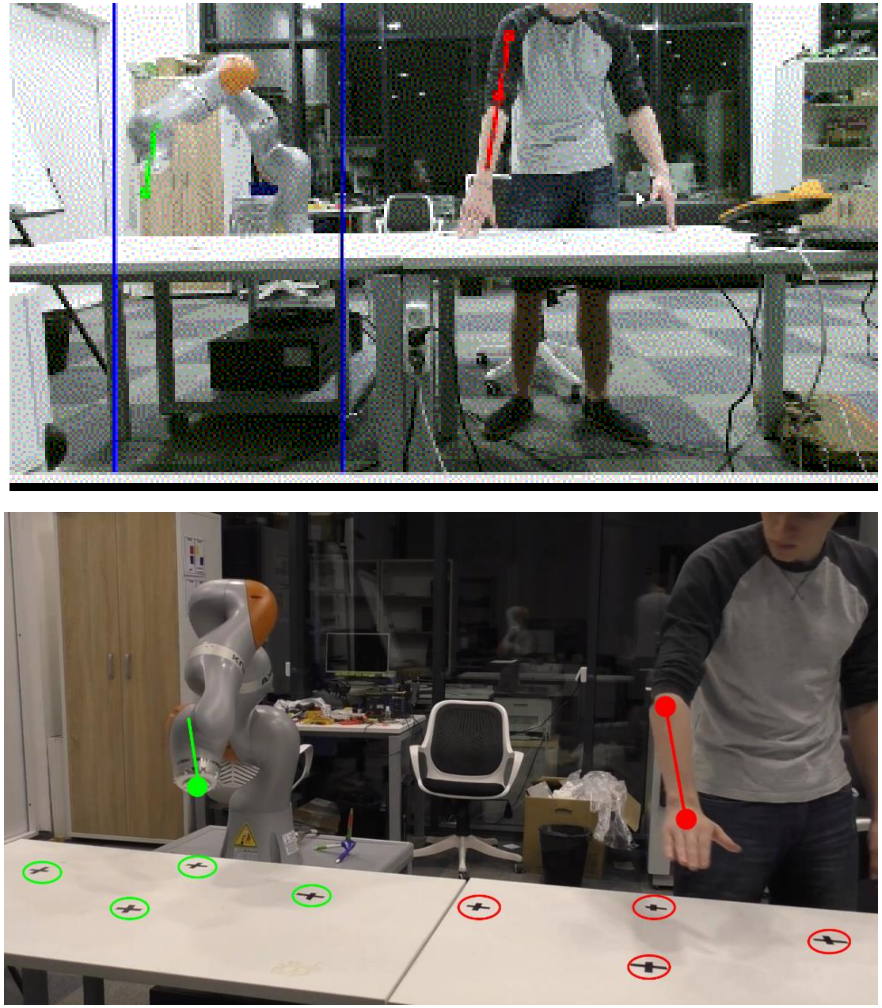
Software blocks:

- Kinect SDK
- Data processing
- Trajectory Statistics Analysis
- Trajectory Optimization



Manipulator - 7 DOF
Human hand - 6 DOF

The coordinates of the human wrist (x_w, y_w, z_w) are corresponding to the coordinates of the manipulator EE. The orientation of the EE (θ, φ, ψ) could be found as a vector directed from the elbow (x_e, y_e, z_e) to the wrist.



KUKA IIWA and human tracking markers with calibration points

Trajectory statistical analysis

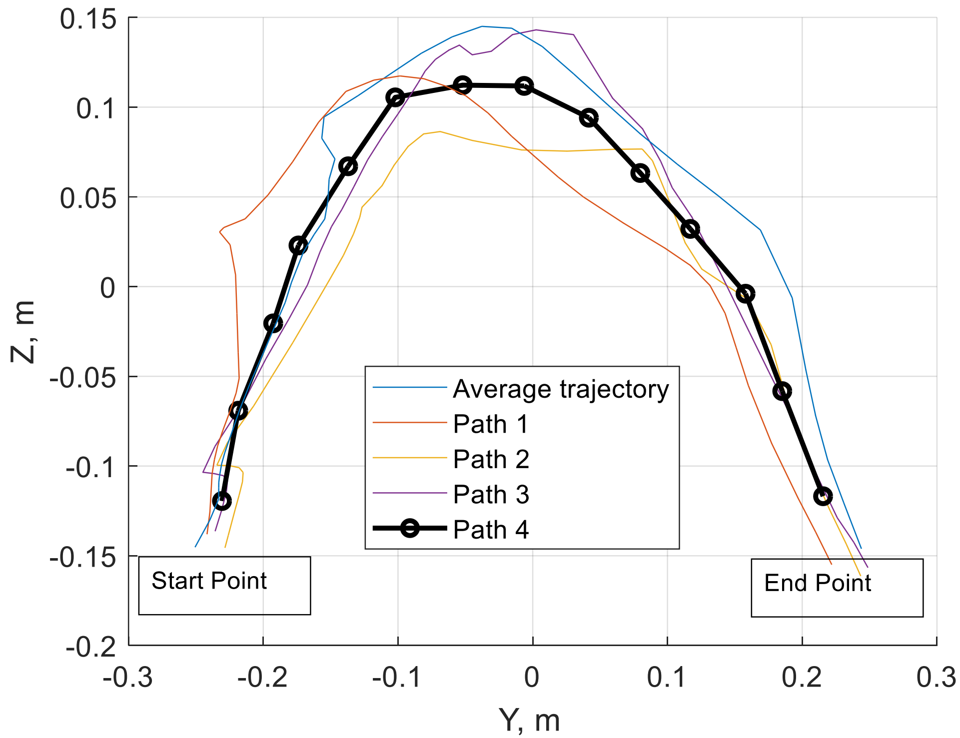
Algorithm:

1) User shows Start and End points.

2) User repeat action several times.

3) Normalization of the obtained trajectories.

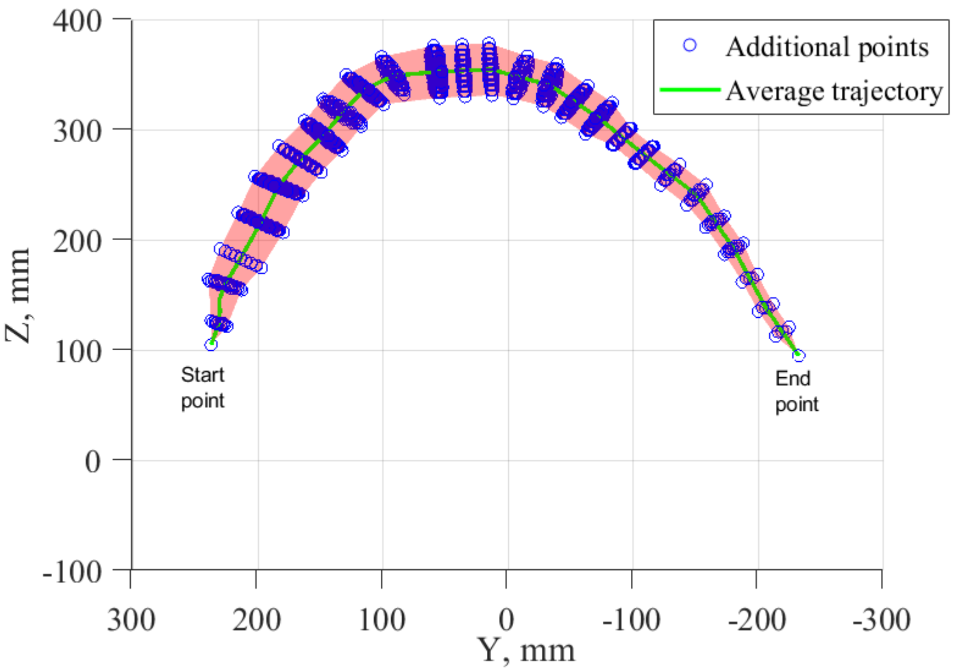
4) Computation of a midpoint and standard deviations for each discrete part.



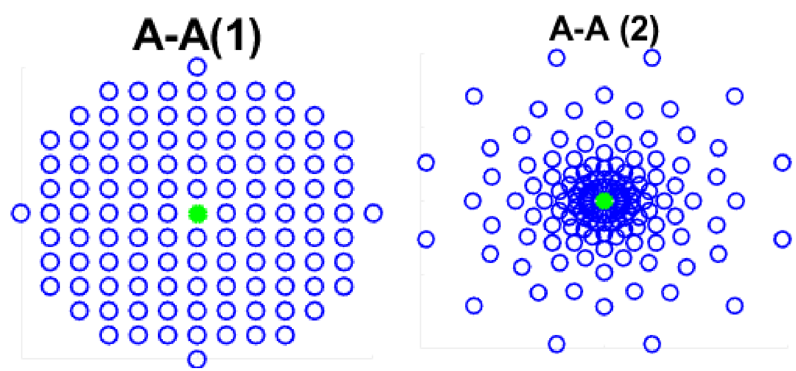
The result of statistical analysis for four times repeated trajectory (Front view).

Joint space optimization

Create additional points

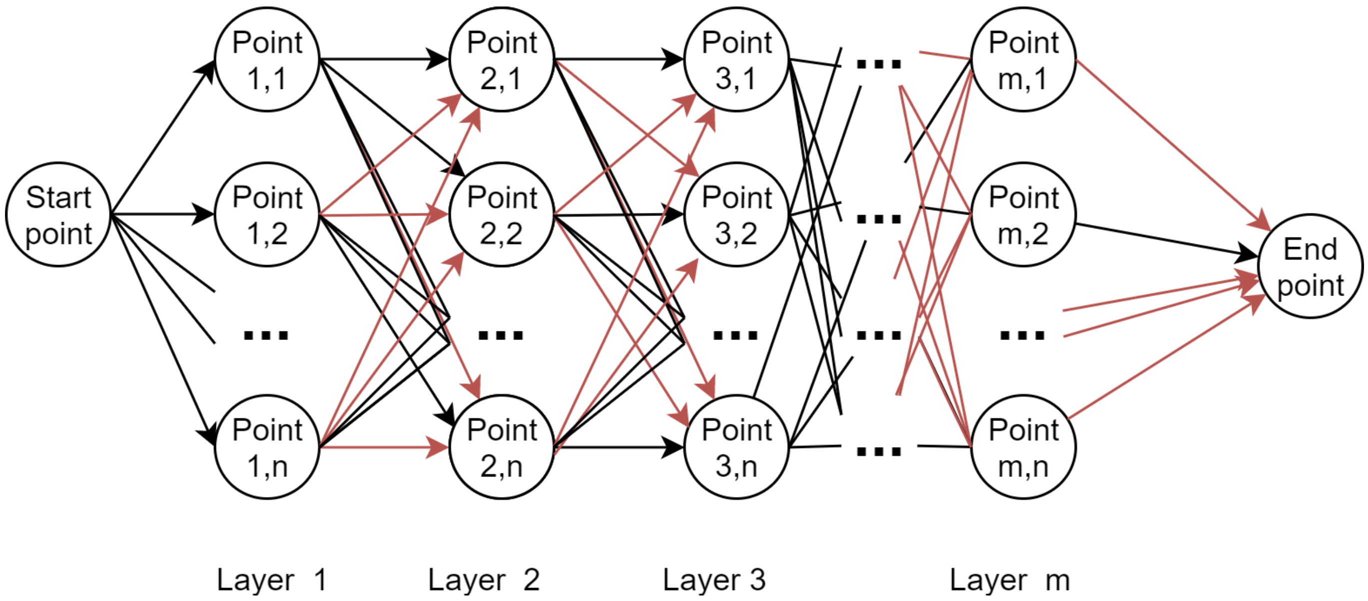


Average trajectory with additional points



1) Additional points that are evenly spaced around the midpoint.
2) Additional points that are distant from the center by the logarithmic law.

Create the graph



Redundancy – a large number of configuration.

Black arrow – accepted transformation, Red arrow – rejected transformation.

Calculate weights

Weighting functions:

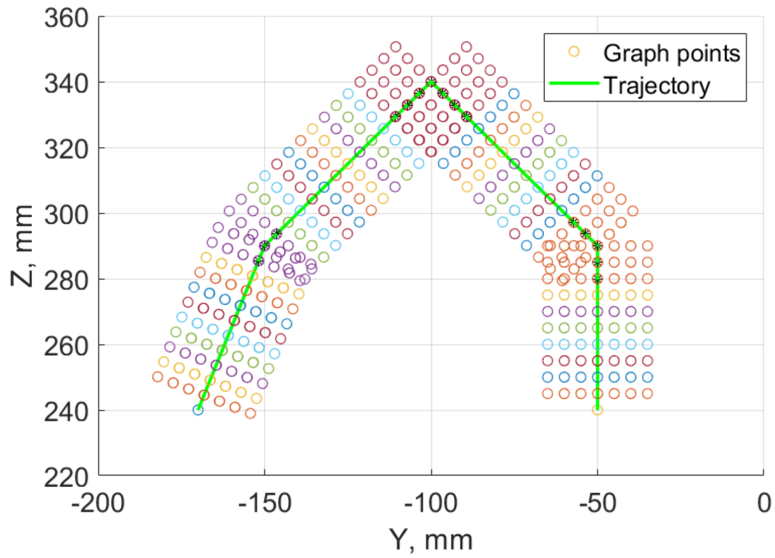
1) Execution time

2) Energy consumption

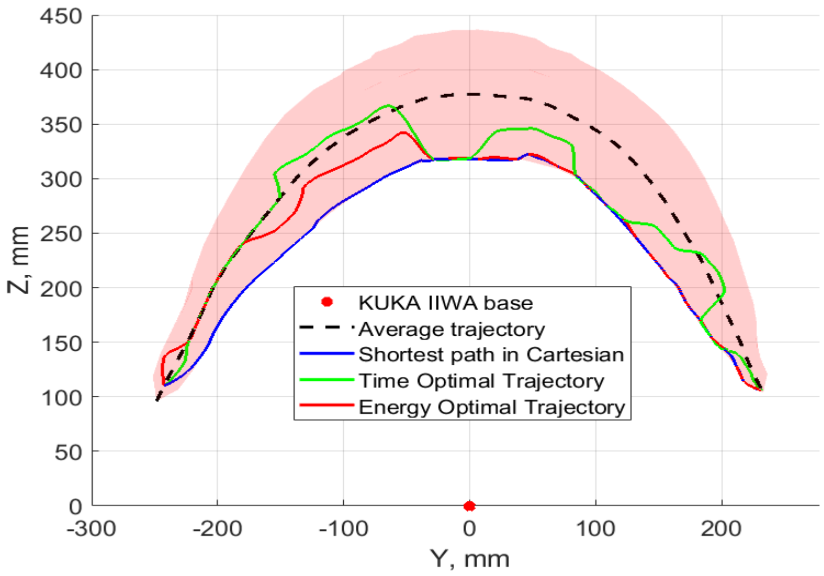
$$W = \sum_{t} \sum_{i=1}^{7} \tau_i \cdot \Delta q_i \, ,$$

3) EE displacement in the Cartesian space

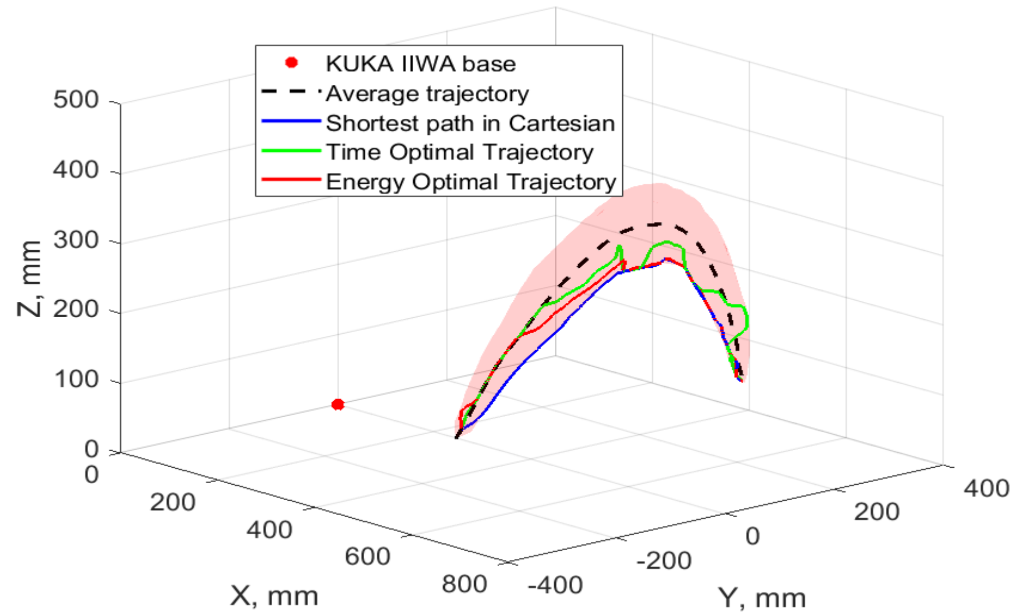
Methodology problem:



Example of the trajectory with intersecting graph points (2D case)



Trajectory for different cases. Front view.



Trajectories.

Trajectories evaluation

Criteria	Σ Δq, rad	Max (Δ q), rad	T, sec	Energy, J
Average trajectory	9.64	2.01	5.03	40.14
Shortest path in the Cartesian space	9.05	1.94	4.72	35.47
Total Execution time	9.01	1.77	4.25	39.2
Energy consumption	8.77	1.86	4.49	33.9

The time optimal trajectory is 15.5% lower than the average trajectory.
Energy optimal case shows 15% improvement.

	Initial		Higher points density		Lower points density		½ deviation		Log distribution	
Criteria	Time	Energy	Time	Energy	Time	Energy	Time	Energy	Time	Energy
Energy, J	39.2	33.9	42.26	34.28	46.95	38.56	42.03	37.77	37.95	34.16
T, sec	4.25	4.49	4.42	4.51	4.91	4.90	4.70	4.76	4.23	4.87
Max (Δ q), rad	1.77	1.86	1.80	1.89	1.90	1.97	1.97	1.99	1.85	1.97
Σ Δq, rad	9.01	8.77	9.26	8.82	9.99	9.49	9.69	9.35	8.85	9.12

- Increasing or lowering point density does not improve time or energy criteria.
- For a half of deviation trajectories, total execution time increased by 10.6%. The energy value was higher on 11.4%.
- The results with uniform point distribution are slightly better than with logarithmic distribution.

- The detection accuracy depends on the tracking system precision.
- In statistical analysis deviation is applied to all directions around the trajectory.
- The optimized trajectories are significantly better than the initial average trajectory.
- The logarithmic distribution law does not improve the performance.
- Collision avoidance, just exclude graph nodes.

- Kinect based teleoperation for the different robot systems with redundancy and without.
- Trajectories could be optimized by the two-stage algorithm.
- Optimization is performed using discrete methods, with minimization of time or energy criteria.

- Developing trajectory optimization with another criterion and multifunction optimization.
- Design a more accurate teleoperation system by using the multi-Kinect system.
- This work will be integrated to interactive robot programming system based on Mixed Reality.