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Technische Universität Berlin
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Methodology and optimization of a single incision laparoscopic surgical instrument's maneuverability

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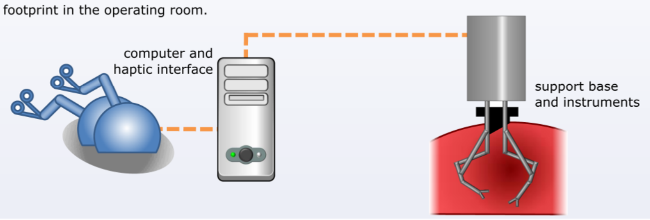
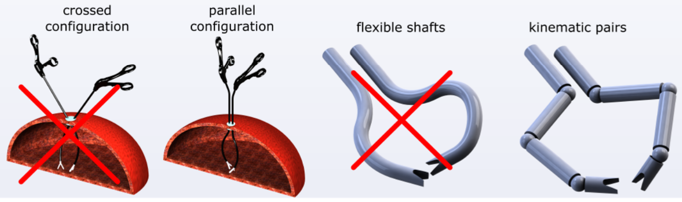
Concept

Within the "**AKIM**" research project, a **robot-assisted surgical system** for motor-enhanced articulate instruments has been developed. The telemanipulation master-slave system comprises a patient-side **support base** with **surgical instruments** and the **surgeon's console** where these are operated under visual control via a **haptic interface**. The instruments are individually connectable to the support base where the different motors for actuation are placed and which was specifically designed to have a small footprint in the operating room.

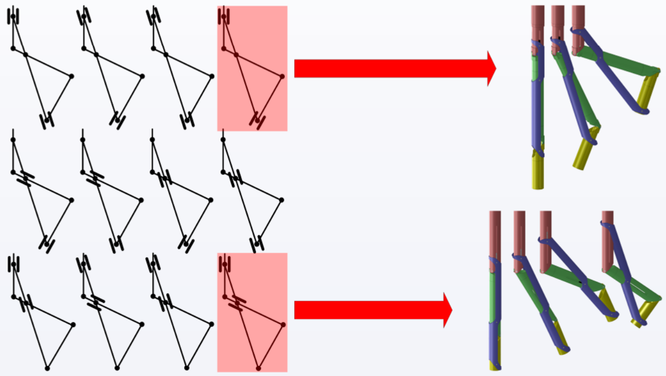


The "AKIM" system was designed as a **single port system**. In comparison to standard minimally-invasive surgical (MIS) procedures, which often rely on rigid shaft structures in a triangulating arrangement, the instruments offer multiple **additional degrees of freedom**. Instead of crossing them inside the trocar, they are **introduced parallel** and move apart before tilting toward each other to achieve a position similar to standard MIS. To avoid mechanically underdetermined wire-driven multi-segmented structures, which are subject to unintended displacement when forces are applied, the "AKIM" system features **joints serially connected with kinematic pairs**.

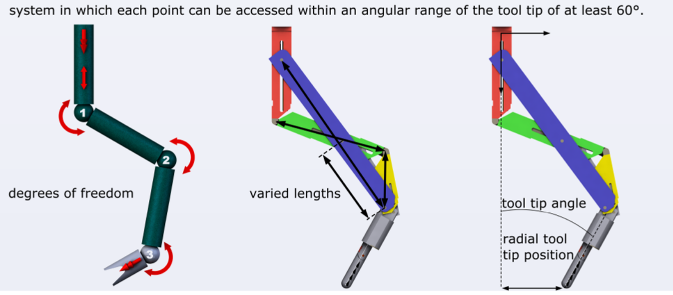


Instrument Design

Serially connected joints offer large workspaces but are more sensitive to external forces compared to parallel structures. Therefore, a **design study** of linkage mechanisms has been performed to find the optimal configurations. The arms' segments are coupled with an **enveloping semi-open shaft structure** that is closed in straight instrument position, but **self-supporting** when unfolded, thereby forming a framework of segments **reinforcing the joints**.

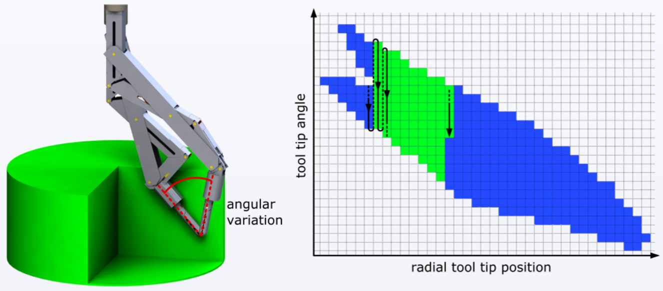


The pivotable and rotatable end-effector is serially coupled via joint 3 to the linkage mechanism. The whole instrument features **five degrees of freedom for positioning and orientation,** not counting the actuation of the tool tip. By varying several lengths and ratios of the arm, it is possible to maximize the reachable workspace and a volume of increased dexterity in a cylindrical coordinate system in which each point can be accessed within an angular range of the tool tip of at least 60°.

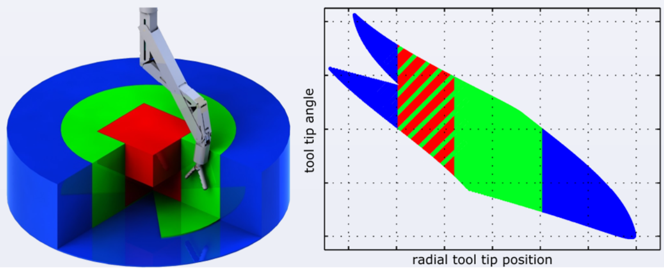


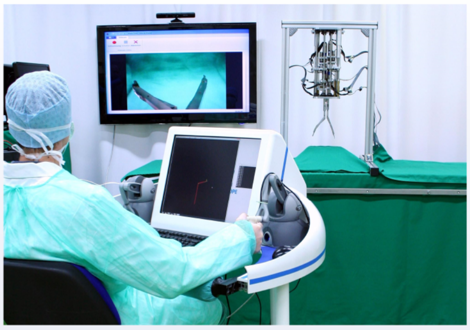
Optimization Algorithm

The length variations lead to millions of possible configurations of the instrument. Two parameters are determined to define the workspace: the **radial tool tip position** and the **tool tip inclination angle**. With the instrument being rotated and shifted along its vertical axis, the whole **reachable workspace** for each configuration is deduced by overlapping all possible positions. Both parameters are plotted in diagrams forming phase space areas which are divided into grids and analyzed column by column using **image evaluation methods**. A counter sums up all connected columns exceeding 60° angular variation at a certain point. The configuration of the largest "**area of dexterity**" (green) is chosen.



Prior to the development, a set of parameters essential for movability and dexterity inside the abdomen was drawn from porcine laparoscopic in-vivo tests, showing the instruments being mostly used in a so-called "**area of interest**" (red) with an edge length of 50 mm. By optimization, the "**area of dexterity**" **exceeds the** "**area of interest**" by a **factor 4.5**. The reachable workspace (blue) is nearly **12 times larger** than the "area of interest".



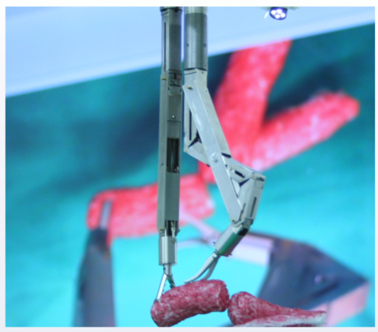


Conclusion

Both the search for an **optimal instrument arm design** and a maximized area of **increased dexterity** lead to an **optimized workspace** of a single incision laparoscopic surgical instrument's maneuverability. These instruments are part of a telemanipulation robot suitable for single port surgery and can be connected and detached from the support base independently from each other.

Several instruments have been developed, optimized and tested under laboratory conditions, successfully performing pick-and-place-tasks and working under load tests. Flexible drapes prevent the risk of accidently capturing organic material.

In sum, these new instruments feature sufficient strength, due to their innovative new self-supporting design, as well as high movability and dexterity.



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