Endoscopic 3 DoF-Instrument with 7 DoF Force/Torque Feedback

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Minimally invasive surgery (as previously discussed) is an operation technique advantageous for patients. However, surgeons have to contend with a number of disadvantages. With the development and commissioning of a robot supported, prototypic minimally invasive robotic surgery (MIRS) instrument the intracorporal manipulability as well as surgeon's immersion will be enhanced. This paper will give an outline of the endoscopic instrument consisting of 3 DoF actuation unit, 2 DoF joint, 7 DoF Force/Torque sensor, and functional end.

The distal end of the instrument (cf. Fig. 1) consists of a cable driven 2 DoF universal joint, a 6 DoF force/torque sensor for measuring instrument interaction forces/torques, and a gripping DoF with integrated, distal gripping force sensor (1 DoF). The cable driven universal joint allows a $\pm 40^\circ$ motion in two orthogonal planes. Together with the wrist rotational DoF of the supporting robot (MIRO see Fig. 2 [1]) the universal joint forms a spherical wrist with intersecting axes. Restoring two DoF articulation inside the patient eliminates movement restrictions in the workspace and therefore reestablishes full dexterity and increases manipulability. The drive cables form two closed loops which allow for coupled linear motion of the universal joint.

Minimally invasive suturing (intracorporal viscerosynthesis) is one of the most difficult and time consuming tasks in conventional MIS. To limit the number of instrument changes, MIRS instruments should have the ability to not only delicately grasp tissue, but also to strongly and securely hold needles. Kitagawa et.al. reported ideal knot tying forces between 1 N and 4 N for commonly used suture material [2]. Assuming a worst case friction coefficient of $\mu_0 = 0,1$ between needle and holder, a grasping force of up to 40 N is required. Currently, only a generic gripper shape exists. However more specialized geometries are being developed in cooperation with industrial partners.

The spatially separated arrangement of user input station and robotic manipulator prevents any direct haptic feedback from the operation site. In order to provide direct feedback of tissue manipulation forces to the surgeon, these have to be measured at the operation site. The measurement range should be larger than the knot tying force described above. However, physical constrains, particularly electrical noise, necessitates a tradeoff between resolution and measurement range. Tissue penetration forces of commonly used suture needles were studied in depth by numerous research groups (e.g. [3, 4]) to establish minimally required resolution of the manipulation force sensor.

The manipulation force sensor used in the MIRS instrument should resolve the force retardation at penetration which we measured to be in the 0,025 N range. Considering a desired range of ±10 N this results in roughly 10 bit desired resolution. The force sensor is a 6 DoF force torque sensor based on a Stewart Platform using flexural hinges [5]. It is placed between the functional end (gripper) and the 2 DoF joint (see Fig. 1). The diameter is 10 mm. The annular cross section allows for gripper mechanics and force sensing to be integrated tightly. Deformation of the Stewart Platform is measured with strain gauges in half bridge configurations. The electrical signal is amplified close to the sensor by signal conditioning electronics integrated in the instrument shaft, yielding 12 bit resolution with about 3 bit of noise at 500 Hz.

The proximal end (propulsion unit, see Fig. 1) is designed to be separable from the distal part for sterilization purposes: Since autoclavation (i. e. steam sterilization) is the standard sterilization method and most electrical/electronical components do not withstand autoclavation conditions, sensitive components are isolated in the propulsion unit. The distal part is in direct patient contact, therefore it is autoclavable. However, for the propulsion unit disinfection at room conditions is sufficient as it is not in direct patient contact.

Currently, a new propulsion unit is under construction enhancing range of motion, increasing motion dynamics, and being more compact at a reduced weight. The novel drive mechanism is divided into three decoupled propulsion modules, each for one DoF. The modules are exactly alike. Each of them consists of a brushless DC motor with a hollow shaft. The generated torque is directly transferred to a ball threaded spindle with excentrically attached poles. The dynamics is high enough to operate on the beating heart. Moreover, one single module (which weighs less than 250 g) has a driving power of 100 N. Mechanical failure probability is reduced.

Novel MIRS instruments as discribed above increase usability through intracorporal dexterity and feedback of manipulation loads, thereby, addressing two major problems of conventional MIS.

References

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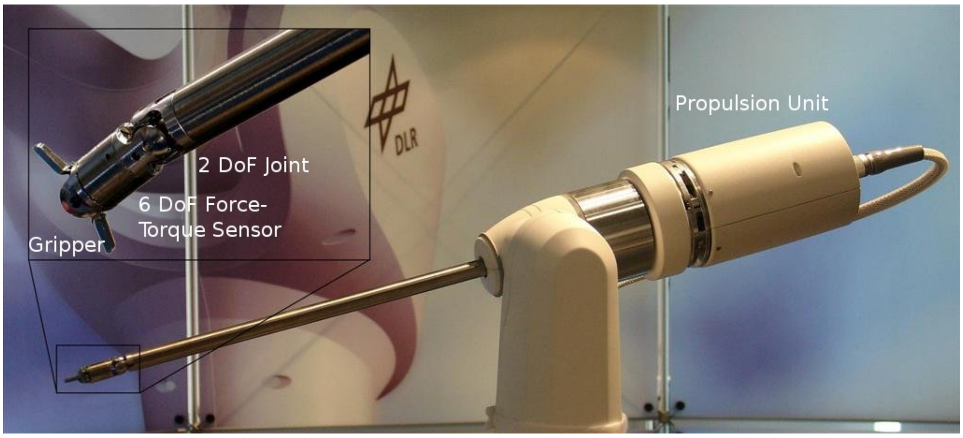

Figure 1: Instrument with detailed view of the distal end.

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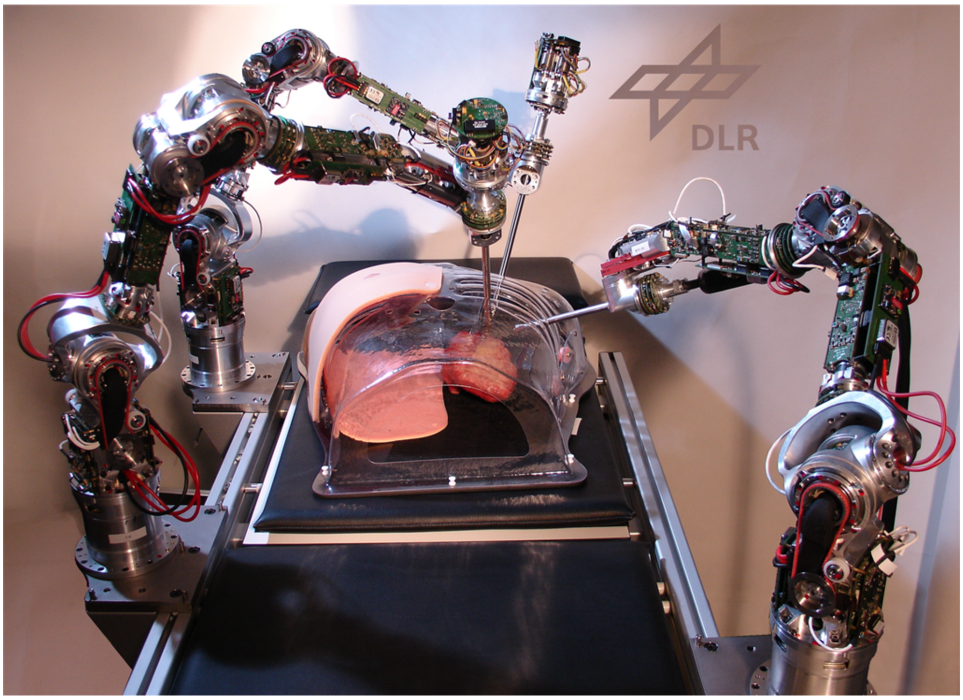

Figure 2: Complete DLR-MIRS scenario. Presentation without housings. Left side: robots carrying two instruments (left and right hand), right side: robot carrying an endoscopic stereo camera.