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Force Sensor for Robotic Graspers in Minimally Invasive Surgery

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Abstract : Robot-assisted minimally invasive surgery (RMIS) has been widely performed around the world during the last two decades. RMIS demonstrates significant advantages over conventional surgery, e.g., improving the accuracy and dexterity of a surgeon, providing 3D vision, motion scaling, hand-eye coordination, decreasing tremor, and reducing x-ray exposure for surgeons. Despite benefits, surgeons cannot touch the surgical site and perceive tactile information. This happens due to the remote control of robots. The literature survey identified the lack of force feedback as the riskiest limitation in the existing technology. Without the perception of tool-tissue contact force, the surgeon might apply an excessive force causing tissue laceration or insufficient force causing tissue slippage. The primary use of force sensors has been to measure the tool-tissue interaction force in real-time in-situ. Design of a tactile sensor is subjected to a set of design requirements, e.g., biocompatibility, electrical-passivity, MRI-compatibility, miniaturization, ability to measure static and dynamic force. In this study, a planar optical fiber-based sensor was proposed to mount at the surgical grasper. It was developed based on the light intensity modulation principle. The deflectable part of the sensor was a beam modeled as a cantilever Euler-Bernoulli beam on rigid substrates. A semi-cylindrical indenter was attached to the bottom surface the beam at the mid-span. An optical fiber was secured at both ends on the same rigid substrates. The indenter was in contact with the fiber. External force on the sensor caused deflection in the beam and optical fiber simultaneously. The micro-bending of the optical fiber would consequently result in light power loss. The sensor was simulated and studied using finite element methods. A laser light beam with 800nm wavelength and 5mW power was used as the input to the optical fiber. The output power was measured using a photodetector. The voltage from photodetector was calibrated to the external force for a chirp input (0.1-5Hz). The range, resolution, and hysteresis of the sensor were studied under monotonic and harmonic external forces of 0-2.0N with 0 and 5Hz, respectively. The results confirmed the validity of proposed sensing principle. Also, the sensor demonstrated an acceptable linearity ($R2 > 0.9$). A minimum external force was observed below which no power loss was detectable. It is postulated that this phenomenon is attributed to the critical angle of the optical fiber to observe total internal reflection. The experimental results were of negligible hysteresis ($R2 > 0.9$) and in fair agreement with the simulations. In conclusion, the suggested planar sensor is assessed to be a cost-effective solution, feasible, and easy to use the sensor for being miniaturized and integrated at the tip of robotic graspers. Geometrical and optical factors affecting the minimum sensible force and the working range of the sensor should be studied and optimized. This design is intrinsically scalable and meets all the design requirements. Therefore, it has a significant potential of industrialization and mass production.

Keywords : force sensor, minimally invasive surgery, optical sensor, robotic surgery, tactile sensor
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