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Abstract

Design and evaluation of a paste applicator for laser tissue soldering

C. Gathmann[1, *], M. Rolfs[2], O. Cipolato[3]

[1] *Study program Robotics and Autonomous Systems, Universität zu Lübeck, Lübeck, Germany*
[2] *Fraunhofer IMTE, Fraunhofer Research Institution for Individualized Medical Technology and Engineering, Lübeck, Germany;*
[3] *Nanoparticle Systems Engineering Laboratory, ETH Zurich, Switzerland*
[*] *Corresponding author, email: carl.gathmann@student.uni-luebeck.de*

Laser tissue soldering (LTS) is a sutureless wound closure technique for robot-assisted minimally invasive surgery (RMIS) in which a solder paste is deposited along wound margins and thermally activated by laser illumination [1]. Controlled extrusion of such thermosensitive pastes is a key challenge shared with bioprinting [2]. The paste used here, based on bovine serum albumin and gelatine with embedded nanoparticles, forms a gel at room temperature and becomes extrudable only within a narrow, elevated temperature range. This work presents the design and evaluation of a thermally controlled extrusion prototype [3].

We first validated extrusion feasibility on a CELLINK BIO X6 bioprinter, then developed a custom prototype. A hexagonal aluminium thermal mass surrounds the syringe barrel for homogeneous heating. Peltier elements provide bidirectional temperature control via PID regulation on an ESP32-C6 microcontroller, and a stepper motor coupled to a lead screw drives mechanical extrusion. We characterised the prototype through two experimental test suites: an extrusion yield test quantifying extruded paste mass across a range of temperatures, and a gravitational flow test evaluating paste stability on a 45° inclined surface.

We identified an optimal operating window of 26–28 °C. Within this range, paste extrusion was consistent (mean mass 0.147 g, coefficient of variation $\leq$ 4.4 %) and the deposited paste remained stationary on the incline. Below 26 °C, extrusion became clumpy and unreliable, with frequent nozzle clogging. Above 28 °C, the paste became free-flowing: at 30 °C it ran freely down the incline, making controlled deposition impossible.

The prototype achieved stable temperature regulation (steady-state accuracy of ±0.03 °C, settling time of 55 s) and homogeneous paste heating through its aluminium thermal mass, enabling repeatable paste deposition within the identified operating window. A water-cooled variant is under development to enable miniaturisation towards an RMIS-compatible end-effector integrating paste deposition and laser activation. Current limitations are bench-only evaluation, a single paste formulation, and a non-miniaturised form factor.

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