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Design and preliminary evaluation of a bio-inspired steerable needle

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1. Introduction

High accuracy and precision in reaching target locations inside the human body are necessary for the success of percutaneous procedures, such as biopsy and localized drug delivery. Flexible steerable needles may allow the surgeon to reach areas deep inside solid organs while avoiding sensitive structures (e.g., blood vessels) [1].

Steering of a needle can be achieved by means of a pre-defined needle shape, such as a bevel-tip or a pre-curved needle shaft [2], or by means of an actuator embedded in the needle body, such as cables or a shape-memory alloy [3]. Rotation around the longitudinal axis of a bevel-tip allows steering in multiple directions, albeit at a possible cost of tissue damage. Actuators allow steering to all directions, but they are often cumbersome, limiting the possibilities for miniaturization of the needle diameter.

This work presents the design and experimental evaluation of a biologically inspired multi-part needle prototype with diameter of 1.2 mm, able to steer without the need of rotation around its longitudinal axis or the use of actuators embedded in the needle body.

2. Methods

Female parasitic wasps of the Hymenoptera family have a thin and flexible needle-like structure, called ovipositor, used for laying eggs inside larvae (Figure 1). The ovipositor consists of three longitudinal segments, called valves, that can be actuated independently of each other by musculature located in the abdomen of the insect. The valves themselves do not possess muscles. The ovipositor advances into the substrate by reciprocally sliding the valves along each other. One valve is moved forward at a time, whereas the other two valves are pulled backwards, anchoring against the substrate thanks to their toothed surface. This mechanism allows the wasp to penetrate deep into solid structures (e.g., wood or fruits, inside which host larvae are located) without buckling. Moreover, the wasp is able to steer the ovipositor along curved trajectories, without the need for rotatory motion. Instead, the offset between the sliding valves defines the steering direction of the tip [4].

Inspired by the anatomy and the steering mechanism of the wasp ovipositor we designed and fabricated a multi-part needle prototype, in which each body part is actuated independently. Both straight and curved trajectories (in 2D) were tested in gelatine by varying the actuation sequence of the body parts.

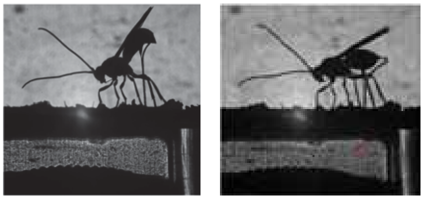

Figure 1: Parasitoid wasp (*Diachasmimorpha longicauda*) ovipositing on transparent gelatine. Red arrows indicate the ovipositor inside the gelatine (Courtesy: Uroš Cerkvenik, Wageningen University).

3. Results

Preliminary experimental evaluation indicated that the prototype can follow a straight path with limited push force. Steering was also possible, with steering curvatures up to 0.0184 cm^{-1} (radius of curvature 54.3 cm).

4. Discussion & Conclusion

This work is focused on the design and experimental validation of a steerable needle inspired by the ovipositor of parasitic wasps. The prototype was able to move forward and steer without rotation through gelatine simulating soft tissue.

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