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Automatic contact gel application for robotic ultrasound scanning systems

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Abstract

Robotic Ultrasound Systems are an emerging technology. Autonomous systems, which are not yet on the market, comprise detection of the scanning area, the ultrasound scan and image processing. However, contact gel application is performed manually. This work proposes a concept for an autonomous contact gel applicator to contribute to a full automation of robotic ultrasound scanning systems e.g. for 3D-imaging of the knee.

1 Introduction

Over the last decade several Robotic Ultrasound Systems (RUS) have been presented in literature. The aim of these systems is either to bring ultrasound experts in rural areas by using telemanipulated robotic ultrasound or to relieve and assist experts by using collaborative or autonomous systems. For the latter there can be assisting tasks such as an optimization of probe orientation for high quality images or autonomous scanning procedures where the system finds the region of interest and performs the scan. (Haxthausen et al., 2021; Li et al., 2021; Phlippen et al., 2023) A task which lacks in the autonomous procedure is contact gel application which is essential for acoustic coupling (Hennersperger et al., 2017). In case of fully autonomous robotic ultrasound systems the user still needs to apply contact gel. This work proposes an adapter for automatic contact gel application during scanning. The authors are aware of only one concept in literature where a silicone ring around an ultrasound probe was used to keep gel with the probe (Zeiler & Smielewski, 2018). The concept has been developed in the context of a robotic ultrasound based 3D-imaging of the knee for TKA surgery (Phlippen et al., 2023).

2 Material & Methods

The concept includes the attachment to a wireless linear probe with an array length of 50 mm (L15HD, Clarius, Vancouver) and the possibility of starting and stopping the gel application by the robotic ultrasound system. For storage of ultrasound gel a tank of plastic foil was selected with maximum volume of 60 ml, which is according to practical tests sufficient for a scanning area of 0.7 m^2. A peristaltic pump (peristaltic pump 12 V, Funduino, Nordhorn) with a maximum flow rate of 1.5 ml(gel)/s is used for gel transport which is powered by a 9 V battery and controlled with a microcontroller with Bluetooth® interface (Nano Every, Arduino, Monza). For gel application two concepts were designed. The first concept comprises a nozzle with a narrow slot to emit gel along the width of the probe array (Figure 1). The second concept is inspired by (Zeiler & Smielewski, 2018) by using a silicone ring around the probe (Figure 1). The cavity can be filled by a tube which is connected to the pump.

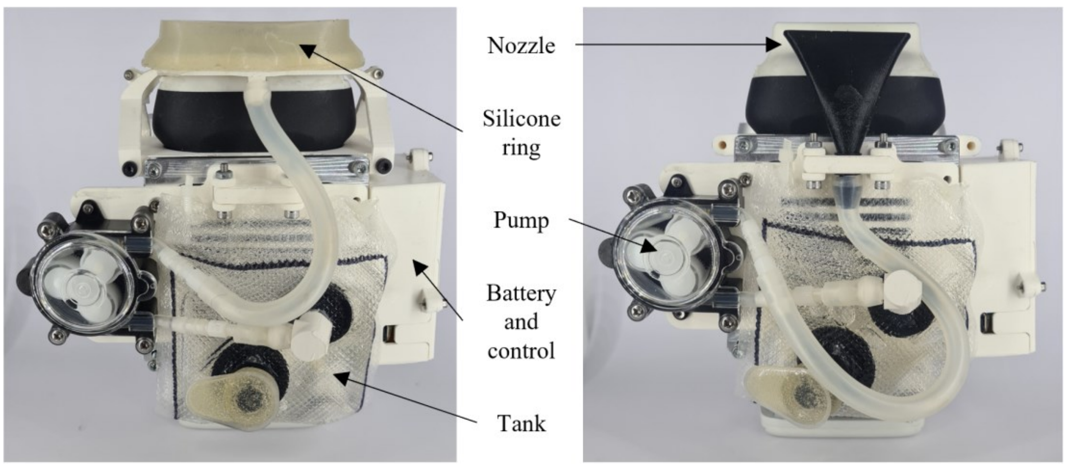

Figure 1: Gel application concept with silicone ring (left) and nozzle (right)

Control of the gel applicator is realized over Bluetooth® connection to the central control unit of a robotic ultrasound system. A software is implemented in Python and used with ROS (ROS Noetic, Open Source Robotics Foundation) which receives current states of the gel applicator such as battery charge and tank level. Furthermore, it controls the pump cycle by mapping the poses in space where gel was already applicated. This prevents gel ejection on areas where gel was already applied and saves gel consumption.

3 Evaluation

For evaluation of both concepts the probe with the gel applicator is attached to a lightweight serial robot (Panda, Franka Emika, Munich). For each concept the probe is moved with a contact force of 5 N perpendicular to a horizontal positioned upper leg of a proband with a speed of 2 cm/s over a distance of 24 cm. During the movement the applicator ejects gel with a flow rate of 0.35 ml/s, in case of the silicone ring concept the cavity is prefilled, which comprises 8 ml of gel. Ultrasound images are recorded during the scan and evaluated for the range of sound contact across the image width. Each scan is performed 5 times.

The results for the nozzle are a complete sound coupling in all tests after approximately 2 seconds. Excess gel is pushed in front of the probe during the feed, with some of it escaping to the side. In case of the silicon ring complete sound coupling is given from the beginning. During the scan there is also gel escaping to the side.

4 Discussion

Both proposed concepts for automatic ultrasound gel application show that they can successfully provide gel for a complete sound coupling. This would close the gap for autonomous robotic ultrasound systems for full automation (Hennersperger et al., 2017).

Comparing both concepts, the concept with the nozzle has the drawback of influence of the orientation on the mode of operation. Tests showed that gel is still applicated even in an overhead scanning but a huge amount is lost due to gravity. For the silicone ring gel doesn't stay in the cavity as expected. Also more gel is consumed for the initial filling of the cavity. An improvement to prevent loss of gel during the scan may be achieved with other hardness of the silicone or another shape with an additional lip to pull the gel along. The results do not agree with (Zeiler & Smielewski, 2018) where a scanning of 4h is reported with a silicone ring which was only filled initially with contact gel. However, the study is about a transcranial Doppler for monitoring of traumatic brain injuries, with the circular probe remaining in the same location for the examination.

Finally, the proposed concept of automatic ultrasound gel application is an approach towards a fully automated robotic ultrasound scan without the user needs to worry about applying gel to the right areas and saves time for the assistant. Nevertheless, maintenance work such as refilling the tank and cleaning the probe is required, which may require further considerations.

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