Electromechanical Design of a Miniature Tactile Shape Display for Minimally Invasive Surgery

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Abstract

*A design of a new tactile shape display to be used in Minimally Invasive Surgery (MIS) is presented. It consists of 32 micro brushless motors in a 4-by-8 configuration, and the total size is 27 mm * 20 mm * 18 mm. The main restrictive design parameter is the size of the display because it should be attached to a laparoscopic grasper. Another important design parameter is modularity, as it is desirable to do experiments with several actuator pins. Each actuator has 3 mm indentation and can provide 1.7 N at a frequency of 2 Hz at full excursion. The pin spacing is 2.7 mm with a pin diameter of up to 2.65 mm.*

1 Introduction

Tactile displays have a wide variety of applications, one of them being MIS. Minimally invasive techniques have come a long way, and are now common in many surgical procedures, mainly because they have the advantage of smaller scars and faster recovery, making it a winning proposition for patients. Although complications in MIS are lower than in traditional surgery, it does have disadvantages, such as lack of the tactile sense which limits the surgeon's abilities to examine and palpate internal organs. We want to design a device that can be attached to a laparoscopic grasper and serve as an extension of the surgeon's fingers. One of the main challenges when making such a device, is to design a tactile display which stimulates the skin to generate a sensation of contact and has a size that is compatible with the size of the grasper handle.

The complexity of the tactile sense and the fact that there are still many unanswered questions about human perception, have put restrictions on the research on tactile displays, and a satisfactory solution has yet to be found. Most tactile displays use an array of actuators in contact with the skin to stimulate the mechanoreceptors in the finger tip. Previous designs include use of shape memory alloy [1], pneumatics [2], piezoelectricity [3], voice coils [4] and electrical stimulation [5]. Use of motors in tactile displays has also been tested earlier showing good performance [6], but for the purpose of MIS this device is limited by its size. The main advantage with our design is the small size combined with a relatively high resolution of the actuator pins.

2 Principle and Design

The motors we use are of type SLB-06H1PG79 from Namiki Precision Jewels. Each motor measures 2.4 mm in diameter and 12 mm in length (including gear and shaft), see figure 1. For this first version of the display, which indents the finger vertically, the principle is to attach a tiny screw to the gear head shaft which screws a top up and down when the shaft rotates, see figure 1.

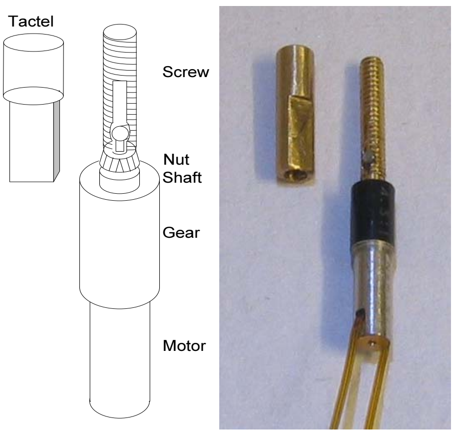

Figure 1: Integration of tactel and motor.

According to [2] the force required is estimated to 1 N per tactel (TACTile ELement) when the actuator density is 1 per mm^2, with up to 2 mm indentation and a bandwidth $>$ 50 Hz in an ideal tactile display.

An experiment showed that a motor with gear head reduction ratio of 1:79 could lift a load of 177 g at a velocity of 11.4 mm/s [7].

2.1 Tactel Mechanism

The mechanism used to attach the screw to the shaft is shown in figure 1. It consists of a small cylinder that has a diameter of 0.8 mm and a length of 1 mm, and a screw with a diameter of 1.4 mm. Through the cylinder we drill a hole such that it can be threaded onto the motor's shaft. The screws have a split running about halfway through them in the vertical direction, and a hole with a diameter of 0.9 mm in the horizontal direction. In this way, the screw can be clicked into place on the cylinder attached to the shaft. Finally a small nut around the screw helps secure the connection. The advantage of using this mechanism over glue, is that it is more flexible, and hence will not necessarily damage the motor if it is exposed to destructive forces.

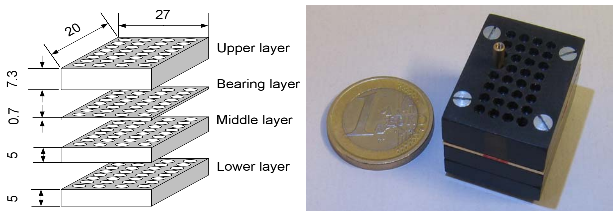

Figure 2: Overall design and measures of display and display housing with one tactel.

To the left in figure 1, the tactel top is shown. The upper part of this top has cylindrical shape, while the lower part has a rectangular cross section. This rectangular cross section shape is the key to translating the rotational movement of the motor into the linear movement of the tactel. With this design, the tactel top can also easily be replaced, allowing for testing with different shapes, heights and sizes.

2.2 Display Housing

The overall design of the display housing and the current version of it is shown in figure 2. Each hole in the display housing corresponds to a cylinder that is designed to house the tactel mechanism described in section 2.1. One of the major challenges of designing the display is to make it mechanically stable without damaging the gears, which are encapsulated in plastic and only loosely attached to the motors. We therefore need a design that will not put pressure on the gear, in either direction, because this might destroy the gear wheels [7]. Our design consists of several layers stacked together, where each layer is carefully fitted to the different parts of the motor and screw mechanism. Another reason for using several layers in the design, is that it makes it easy to replace one of them in case we want to do testing with other mechanisms.

The lower and middle layer's hole dimensions match those of the motors and the gears respectively. The bearing layer is intended for the nut in the screw mechanism to rest upon, such that pressure from the finger will be absorbed by the bearing layer instead of the gears. The upper layer's inner workings has a split in the lower part and cylinders in the upper part. The split fits the rectangular cross section shape of the tactel top, and ensures the linear movement needed to indent the finger vertically.

2.3 Drive Circuit

The drive circuit designed to operate the motors is a 3-phase sensorless drive circuit and is shown to the right in figure 3. As 32 of these circuits will be too big, a control strategy which integrates the 32 driver circuits in one block has been made (left part of figure 3). It consists of several cards stacked together. Each card controls 8 motors and contains an FPGA together with driver circuits, RS485 transmitter and connectors for the motors. Set points for position and acceleration are easily set by the user. Commutation of the motors is controlled by a state machine which compares current position with reference position. In the current design, position feedback is not provided, but optical position sensors can be included.

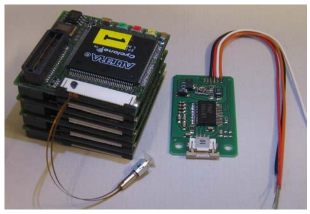

Figure 3: The specially designed driver circuit for 32 motors and the original single driver circuit.

3 Performance

Important data for the display is shown in table 1.

Table 1: Technical data for the display.

Property	Value
Positioning resolution	0.02 mm
Max. tactel force	1.7 N
Max. tactel velocity	11.4 mm/s
Tactel excursion	3 mm
Size	27 mm * 20 mm * 18 mm
Weight (display and circuit)	96 g

Acknowledgments

The research is funded by the Research Council of Norway, grant 147830/V50. The authors would like to thank Dr. Ronald Mårvik at St. Olavs Hospital for useful discussions related to MIS. We would also like to acknowledge the engineering workshop at the Dept. of Engineering Cybernetics and Torgim Gjelsvik at Sintef IKT for help with mechanical and electronic designs.

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