A Novel Sensor to Measure Surface Deformation and Contact Shape Using Stereo Vision

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***Abstract*—In this paper we describe a novel sensor that enables the detection of different types of contact using a deformable surface whose deformation is measured in 3D based on stereo vision. The sensor was developed using a NanEye Stereo camera to capture images of the inside of a deformable dome whose shape is approximately hemispherical. These cameras are very small (2.2x2.0x1.7 mm) which makes them suitable for this application. Stereo is used to compute the 3D positions of points in the inner surface of the dome. The 3D reconstruction enables the measurement of the deformation of the surface. The images are preprocessed to remove vignetting and distortion and are rectified. The estimation of the 3D positions of a set of feature points allows the estimation of the deformation including the contact shapes and forces (which requires a pre-calibration). The results show that this simple sensor can be used to estimate the shape of the contact and also of the forces generating the deformation.**

I. Introduction

Tactile sensing is an important sensing modality for many applications, namely for Robotics. Manipulation and grasping, and especially fine manipulation require tactile sensing. This type of sensing is an inherent characteristic of the human body, being useful for object discrimination, mainly when there is no visual information available.

II. Related Work

Several sensors such as Gelsight[6] and TacTip[2] use concepts based on image analysis to estimate contact shapes, forces and torques (Gelsight). Gelsight recently released Gelsight Mobile which is a device capable of displaying and measuring the 3D topography of a surface. It uses a single camera coupled with an elastomeric sensor that comes into contact with a given surface, providing detailed analysis of its features.

III. The sensor

The use of stereo vision facilitates the estimation of the deformation of the surface that is used to evaluate the shape of the object in contact as well as of the relevant physical quantities (namely forces and torques). The main goal of the development of this device was an evaluation of the feasibility of the creation of a force/tactile sensor that should be easier to manufacture while requiring less complex vision methods and algorithms (due to the use of stereo). For that purpose a device capable of testing the capabilities and limitations of the method was designed and built. In order to do so, several materials were tested. 3D printing was used to manufacture the sensor and the materials were evaluated in terms of their ability to deform versus rigidity.

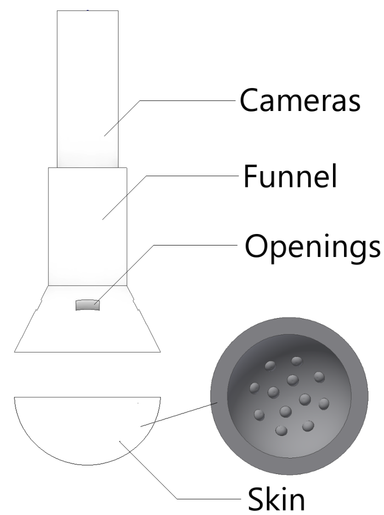

Fig. 1. Layout of the sensor.

We ended up with a functional prototype that is composed of 4 different parts, namely the *funnel*, the *membrane*, the cameras, and LEDs.

The assembled sensor can be seen in figure 2.

IV. Image Analysis

In order to acquire the images we used the NanEye Fiber Demo Kit, coupled with a pair of NanEye Stereo 2D cameras whose dimensions are 2.2 mmx 1.0 mmx 1.7 mm. The quality of the images has limitations and their resolution, distortion and issues with the video frame rate affects the accuracy of the results.

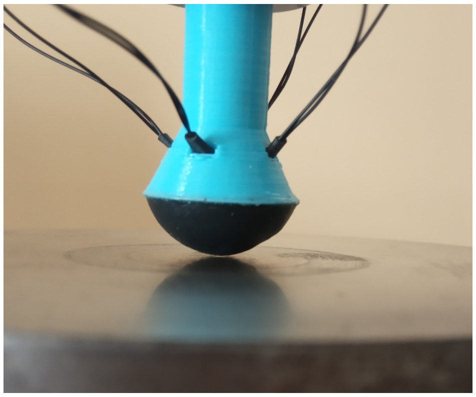

Fig. 2. Sensor before contact.

In order to find corresponding features across both images the sum of absolute differences is the one used in the current configuration of the system.

To allow for the estimation of the deformation, features have to be tracked so that the time variation of their positions can be computed. By labeling each visible feature the membrane, we were able to track and register them. When a feature eventually disappeared from the field of view due to the proximity to the cameras' lenses, it was considered to be located at the minimum depth.

V. Experimental Results

A. Methods

A set of experiments were conducted in order to evaluate the sensor measurements as a result of a contact with a surface, and also to calibrate the sensor response to applied forces. The experiments consisted in placing the sensor on a rack built specifically for it, while pressure was applied by a universal tensile tester with controlled displacement values. For that purpose forces of different intensities were applied to the surface of the deformable membrane. Stereo was then used to determine the 3D positions of features in the inner surface of the membrane,as a function of the intensity of the force applied on the outer surface. The machine used for these tests was a *Shimadzu Autograph AG-X 1kN*. A total of four experiments were performed, where the press was initially positioned immediately over the tip of the membrane, making sure that no contact was registered. Thenceforth, the press was moved downwards towards the membrane in controlled intervals.

1) First experiment - small intervals: The press was moved downwards towards the membrane in regular and discrete intervals of 0.01mm, registering the value of the force in each step. A total of 20 samples were gathered, for a total of 0.2mm of movement.

2) Second experiment - big intervals: In this experiment the displacements were increased. In this case, a total of 50 samples were gathered between 0.2mm and 2.7mm in 0.05mm intervals.

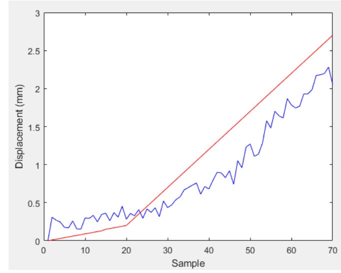

Fig. 3. Displacement per sample for the first two experiments. The red line represents the experimental data, and the blue line shows the results obtained from the sensor

3) Third experiment: The same setup as in the other experiments was used. The press was moved in regular intervals of 0.1mm, with the force intensity being registered, until the material breaking point was achieved.

4) Fourth experiment - tiny intervals: A fourth experiment was conducted to evaluate the non-linear behavior of the material that composes the membrane under extreme pressure, resulting in the gathering of force intensity values in close proximity to the breaking point. Therefore, the intensity of the force was applied in regular 0.01mm intervals between 4.5mm and 5.0mm.

B. Analysis

The first and second experiments show a linear behavior (relative to the applied forces) for small displacements values, meaning that the force intensity is directly proportional to the displacement at any given time, as shown by the red line in figure 3. The slope change at sample 20 corresponds to the end of the first experiment and to the beginning of the second, caused by the new sampling interval. On the other hand, the blue line, which represents the displacement values obtained using the sensor, shows a non-linear trend, with poor accuracy but acceptable precision, varying from 0 to 2.28mm. This can be explained as a result of the vision tracking algorithm, which can lead to inaccuracies due to poor picture quality.

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