Available online at www.sciencedirect.com

ScienceDirect

Manufacturing Letters 1 (2013) 17–20

www.elsevier.com/locate/mfglet

Research Letters

The haptic position measurement of soft or compliant objects using the magnetic tracking system

Roland K. Chen, Yancheng Wang *, Bruce L. Tai, Albert J. Shih

Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI 48109, USA

Received 16 April 2013; received in revised form 19 August 2013; accepted 20 August 2013
Available online 14 September 2013

Abstract

A novel haptic position measurement system (HPMS) utilizing a hand-held magnetic sensor is developed to measure the position and shape of soft/compliant objects. The magnetic senor, serving as a touch probe, is guided by hand to contact with the object. The haptic feedback from the contact between the sensor and object provides the guidance to the user for measurement. The HPMS is validated by measuring the diameter of a soft silicone phantom and shown capable to achieve 0.2 mm accuracy level. This result demonstrated the feasibility for HPMS as a new approach to measure the shape of soft and compliant objects.
Published by Elsevier Ltd. on behalf of Society of Manufacturing Engineers.

Keywords: Compliant; Coordinate measuring machine; Haptic; Magnetic sensor

Demands for accurate measurement of three-dimensional (3D) complex geometries of soft and/or compliant objects have increased in applications such as measuring the deflection of thin guide wire and needle insertion into soft tissue, deformation of tissue during surgical manipulation, and displacement of compliant mechanisms. It is difficult to accurately obtain the 3D geometry of soft tissue or flexible compliant mechanisms using conventional measuring systems, such as the coordinate measuring machines (CMM), due to a low contact force is allowed. Although CMM has advanced with the integration of fiber optic displacement sensor [1–2], multi-axis force sensor [3–4], microspherical probe [5], and virtual haptic [6], it is still technically challenging to measure soft and/or compliant objects. Many optical methods are also used to measure 3D geometry [7–8]. In general, optical methods require extensive alignment and image processing. The selection of optical methods depends on the feature or object size. Optical coherence tomography [9] and fluorescence microscopy [10] provide high resolution (<10 μm) for 3D reconstruction of small objects or area (about 2 mm). Holographic interferometry gives high resolution (<5 μm) for a large area (up to 1 m) but the high resolution is limited to a small range of depth variations (<500 μm) and is mainly used for surface measurement [11]. For large volume objects, laser triangulation is widely used but has lower accuracy compared to other optical methods (0.5 mm) [12].

Electromagnetic tracking (EMT) technology, utilizing generated magnetic fields and a magnetic sensor with coils to induce electrical current, has been developed to measure spatial position and orientation since 1970s [13]. EMT systems have been applied to several medical procedures, such as stereotactic radiotherapy localization [14], endoscopic guided surgery [15], real-time tumor tracking in proton therapy [16], and for tracking of ultrasound scanhead [17]. Several studies have been conducted to assess the positional accuracy of EMT systems and showed that sub-mm accuracy level can be achieved [18–20]. A recent study utilizing the laser interferometer measurement system for calibrating the positional accuracy has demonstrated that the performance of a direct current (DC) EMT system (TrakSTAR™ by Ascension Tech, Milton, Vermont, USA) with the miniature, 0.9 mm diameter sensor (Model

* Corresponding author. Tel.: +1 7348347798.
E-mail address: yancwang@umich.edu (Y. Wang).

2213-8463/$ - see front matter Published by Elsevier Ltd. on behalf of Society of Manufacturing Engineers.
http://dx.doi.org/10.1016/j.mfglet.2013.08.005

90, Ascension Tech) has 0.1–0.2 mm positional accuracy when the transmitter is oriented with its front surface facing the sensor [21]. The advantages that EMT has over optical methods are easy to setup and flexibility to measure both small and large features.

In this study, a magnetic sensor that is secured in a hand-held needle cannula as a miniature probe is used to touch an object and an EMT system is used to detect and record the position and orientation of this magnetic sensor. The contact between the probe and measured object is controlled by both haptic and visual feedback. This is an EMT-based haptic position measurement system (HPMS) for soft and/or flexible objects. The geometry of a soft silicone phantom is measured by the HPMS to demonstrate the feasibility of this approach.

1. Overview of HPMS

Figure 1(a) shows the overview of the HPMS based on Ascension Tech's DC EMT, including an electronic unit (TrakSTAR™), a transmitter (Mid-range transmitter), and a magnetic sensor (Model 90). The electronic unit synchronizes the transmitter and signals from the magnetic sensor to calculate the position and orientation of the sensor [13,21]. The digital data of three translational positions and three angular orientations of the magnetic sensor are recorded at 50 Hz. The transmitter has three orthogonally oriented coils that create magnetic fields using DC pulses. These three orthogonal coils are sequentially pulsed at 50 Hz frequency. As shown in Figure 1(b), the magnetic sensor is fixed inside the tip of an 18-gauge needle cannula with the tip of the sensor exposed from the cannula tip. This miniature magnetic sensor has an outer diameter of 0.90 mm and a length of 7.25 mm, as shown in Figure 1(c). The magnetic sensor also consists of coils that receive the magnetic field emitted by the transmitter and induce an electrical current signal, which is transmitted to the electronic unit via a thin (0.60 mm diameter) cable.

The sensor enclosed needle cannula is used as a touch probe to be visually guided and to touch the measured object. The probe is guided by the user's hand while coordinating by the user's vision and haptic sensation to touch the object. When the hand-held magnetic sensor is touching the object, the electronic unit records the position and orientation of the magnetic sensor as a measurement point either continuously (at 50 Hz) or by single point. The actual sensing point detected by the sensor locates at the center of sensor, as indicated in Figure 1(c). Therefore, in order to obtain the accurate position of the sensor, compensation of raw recorded data will be needed based on the sensor geometry and the orientation of the sensor when touching the object. When the side of the sensor is used to touch the object, the raw measurement data need to be compensated by the diameter of the sensor, while the tip of the sensor will be compensated by the length of the sensor. Potentially, a microscope can be incorporated with the HPMS to guide the human operator to determine the probe contact point and achieve better measurement accuracy.

2. System validation

To validate the HPMS, the diameter of a cylindrical silicone phantom was measured using this measurement system. This silicone phantom, as indicated as "Object" in Figure 1(a), is soft (24.9 kPa Young's modulus [22]) with a diameter of 35.446 ± 0.05 mm (measured ten times by a Mitutoyo Model 293-341 micrometer). The HPMS was used to determine the diameter of the phantom by measuring three circumferential points on the phantom top surface. Figure 2(a) shows the close-up view of the hand-held needle cannula and sensor tip touching the silicone phantom. These three points fit a circle and find the diameter. The recorded position is at the center of the magnetic sensor, and thus the fitted circle determined by the three measurement points needs to be compensated by the geometry of the sensor. The measurements were repeated for ten times (30 measurement points) and the average diameter was compared to the diameter measured by micrometer.

Figure 3 shows the measurement results and fitted circle compared to the circle determined by the micrometer. After deducting the sensor diameter (0.90 mm), the diameter of

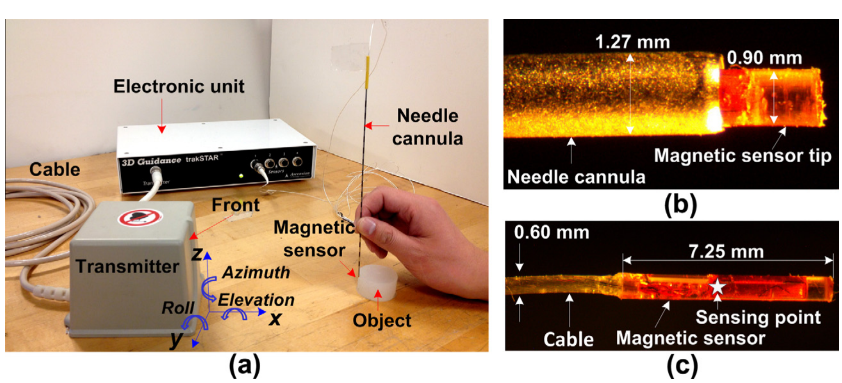

Figure 1. The HPMS (a) system overview, (b) microscopic view of the magnetic sensor enclosing in the needle cannula, and (c) microscopic view of the magnetic sensor.