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A Low-cost Soft Tactile Sensing Array using 3D Hall Sensors

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Abstract

Tactile sensors are essential for robotic systems to safely interact with the external world and to precisely manipulate objects. Existing tactile sensors are typically either expensive or limited by poor performance, and most are not mechanically compliant. This work presents MagTrix, a soft tactile sensor array based on four 3D Hall sensors with corresponding permanent magnets. MagTrix has the capability to precisely measure triaxis force (1 mN resolution) and to determine contact area. In summary, the presented tactile sensor is robust, low-cost, high-performance and easily customizable to be integrated into a range of robotic and healthcare applications.

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Keywords: Soft tactile sensors; Hall sensors; Magnetic field; Triaxis force sensors; Contact area; Noise suppresion

1. Introduction

Tactile sensors are essential for robots to safely interact with the external world and to precisely manipulate objects by providing force and contact information [1]. Existing tactile sensors are typically either expensive or limited by poor performance, and most are not mechanically compliant. Over the past two decades, research into deformable/soft tactile sensing systems has rapidly accelerated, spanning a broad range of target applications [2]. Existing systems [3] employ techniques including MEMS pressure sensors, conductive liquids, optical system, capacitive/resistive sensors, and piezoelectric/piezoresistive sensors. Originally proposed by Clark [4] in 1988, magnetic field based tactile sensing [5] has shown potential to achieve high performance at a reasonable cost and has been extensively investigated recently

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(driven by advanced 3D Hall sensor technology), but it remains a challenge to design and optimise these systems. Recently, we developed a general design methodology for magnetic field based tri-axis soft tactile sensors [6], enabling researchers to easily develop specific tactile sensors for a variety of applications. A single element soft tri-axis tactile sensor prototype—MagOne was developed as a case study, which achieved a resolution around 1 mN. Building on this work, we present a miniaturised tactile sensing array "MagTrix", with 2×2 tri-axis force sensing nodes, and here we test and assess the performance of the system, demonstrate its capability of precision tri-force measurement with noise suppression and contact area detection.

2. Design and Fabrication

With the same working principle described in [6], a 2×2 sensing nodes array (MagTrix) was designed. MagTrix comprises an elastomer with four embedded magnets, and a rigid base (PCB) with four surface mounted 3D Hall sensors. Compact 3D Hall sensors (MLX90393, 3×3×0.8 mm^3, Melexis, Belgium) with digital output via I2C bus were used to measure the movement of the corresponding magnets. The distance between Hall sensors is 6 mm in both *x* and *y* axis, as shown in Fig. 1 (b). As the 3D Hall sensor has 2 bits of address, four sensors (each has a different address, 00, 01, 10 and 11 for S1, S2, S3 and S4 respectively) share the same I2C bus to communicate with a real-time embedded controller (NI myRIO-1900).

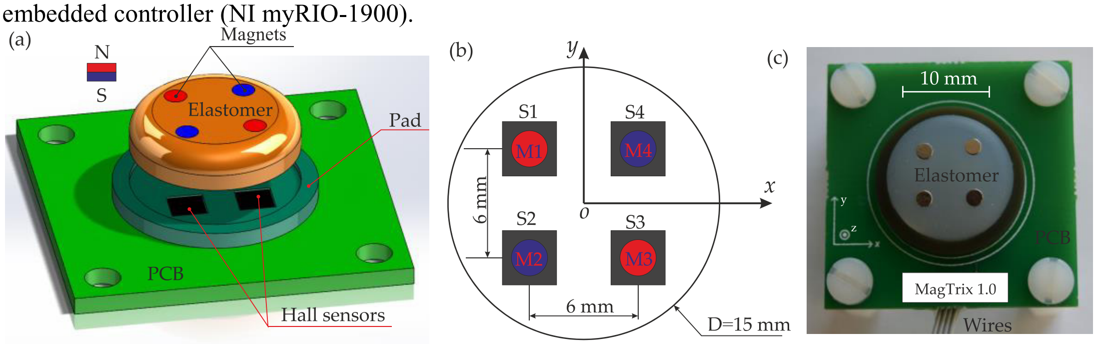

Fig. 1. (a) The schematic of MagTrix; (b) Configurations of Magnets and Hall sensors in MagTrix; (c) Photograph of MagTrix prototype.

An elastomer (15 mm diameter, 3.5 mm thick) was designed and fabricated with Ecoflex 00-30 (Smooth-on) using 3D printed mold. Four Neodymium magnets (N42, 2 mm diameter × 0.5 mm thick, First4magnets) were embedded in the elastomer and covered by a thin encapsulation layer on top. Any two adjacent magnets have opposite magnetic polar direction, as shown in Fig. 1(a). A pad with four square holes to locate the sensor chip was assembled in the PCB, and the elastomer was glued on the pad with Sil-Poxy (silicone rubber adhesive, Smooth-on). A photography of the fabricated MagTrix Prototype is shown in Fig. 1(c). A control program (NI LabView) was developed to configure the sensors and continuously read the magnet field data from the four sensors sequentially. The tri-axis magnetic field density from the four sensors were denoted by B_{ix}, B_{iy}, and B_{iz} (i=1, 2, 3, and 4, index of the Hall sensors).

3. Experiments and Results

The experiments and results of MagTrix prototype for tri-axis force measurement and contact area detection are shown and discussed in this section. Firstly, a test platform was developed to perform the characterisation experiments. As shown in Fig. 2(b), the platform comprises micro-positioning stages, a Force/Torque (F/T) Sensor, the MagTrix sensor and holding bracket. One of the motorized stage moved the MagOne prototype in *z* axis, the other motorized stage moved the F/T sensor and the indenting surface in *y* axis, and the manual positioning stage was used to adjust the *x* position of the F/T sensor. They were assembled and mounted on an optical table to minimise vibration during testing. A program was developed (using LabView) to control the movement of the motorized stages, acquire data from the F/T and MagTrix sensors, and to record data into a measurement file.

To obtain the correlation between the magnetic field and the applied force, a 2D (*y*/*z* axis) scanning process with a range of 1.5mm in *z* axis and 2 mm in *y* axis, was performed to collect the data set (F_x, F_y, and F_z, and the corresponding

B_{ix}, B_{iy}, B_{iz}). A sum of the magnetic field ($\boldsymbol{B}$=$\boldsymbol{B}_1$-$\boldsymbol{B}_2$+$\boldsymbol{B}_3$-$\boldsymbol{B}_4$) from four sensors was used to calibrate MagTrix as a tri-axis force sensor. Using moving-least-square method [6], a multi-variate homogenous polynomial (with an order of 5) was used to express the relationship between the magnetic field and the force. The calibrated normal and shear force test results compared with a commercial load cell (ATI Nano17) are shown in Fig.2 (d, e), which illustrates decoupling of the strong crosstalk effect between magnetic field signals (Fig.2 (b, c)). This version of MagTrix has a relatively large normal force (z axis) measurement range (circa 20 N) with a resolution of 14 mN and a high resolution (1.5 mN) in shear force (x/y axis) measurement.

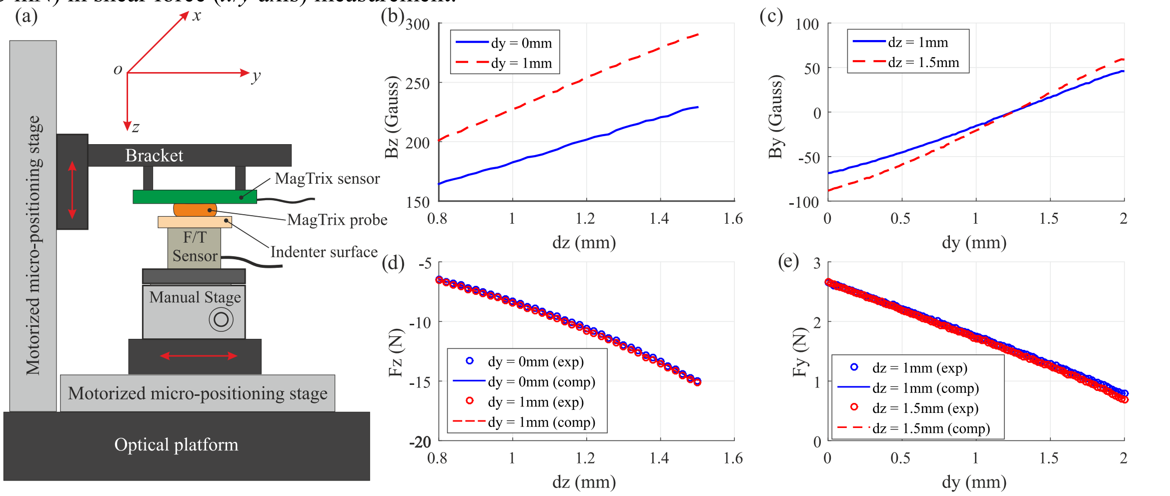

Fig. 2. MagTrix test platform and calibration results. (a) Test platform; (b) B_z during z axis indentation (applying normal force) with different shear forces applied; (c) B_y during y axis indentation (applying shear force) with different normal forces applied; (d) Normal force output during z axis indentation with different shear force applied (circle represents the reference force from F/T sensor nano17, line represents calibrated output from MagTrix);(e) Shear force output during y axis indentation with different normal force applied (same settings as c).

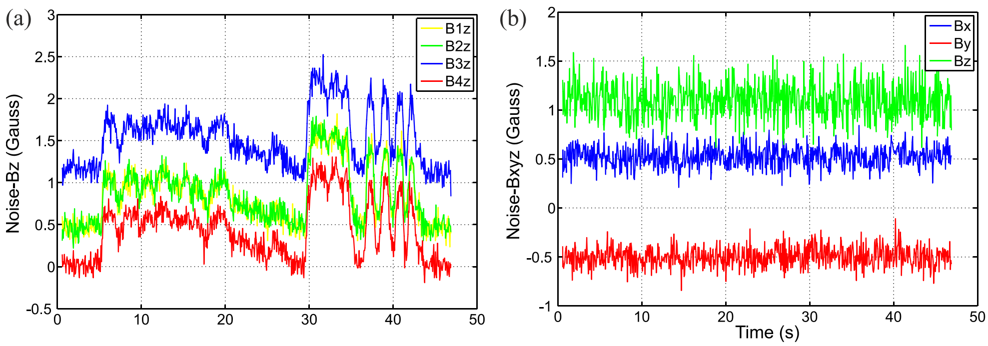

Fig. 3. (a) Magnetic field B_z from four Hall sensors; (b) Magnetic field used for force measurement after noise reduction.

As the four sensors are close to each other, they will measure the same variation of external magnetic field under most circumstances. Figure 3(a) shows that all z axis magnetic field from four sensors changed in unison when a large magnetic object was moved around the MagTrix. By using the sum of the magnetic field from all the four sensors, the magnetic field disturbance from environment is minimised to a negligible level, as shown in Fig 3(b). Although the external magnetic field introduced a maximum noise up to 1.5 Gauss, the compound magnetic field only has a noise of 0.18 Gauss in z axis, and 0.10 Gauss in x/y axis, which is only double that of the noise from each sensor without interference.

In addition, further signal processing of the magnetic field vectors from the four magnets enables estimation of the contact point on the sensor. Figure 4 shows the movement of the four magnets when MagTrix was indented by a small rod (2 mm diameter), which demonstrated that there is a strong relationship between the contact point and the resultant movement vector of the four magnets.

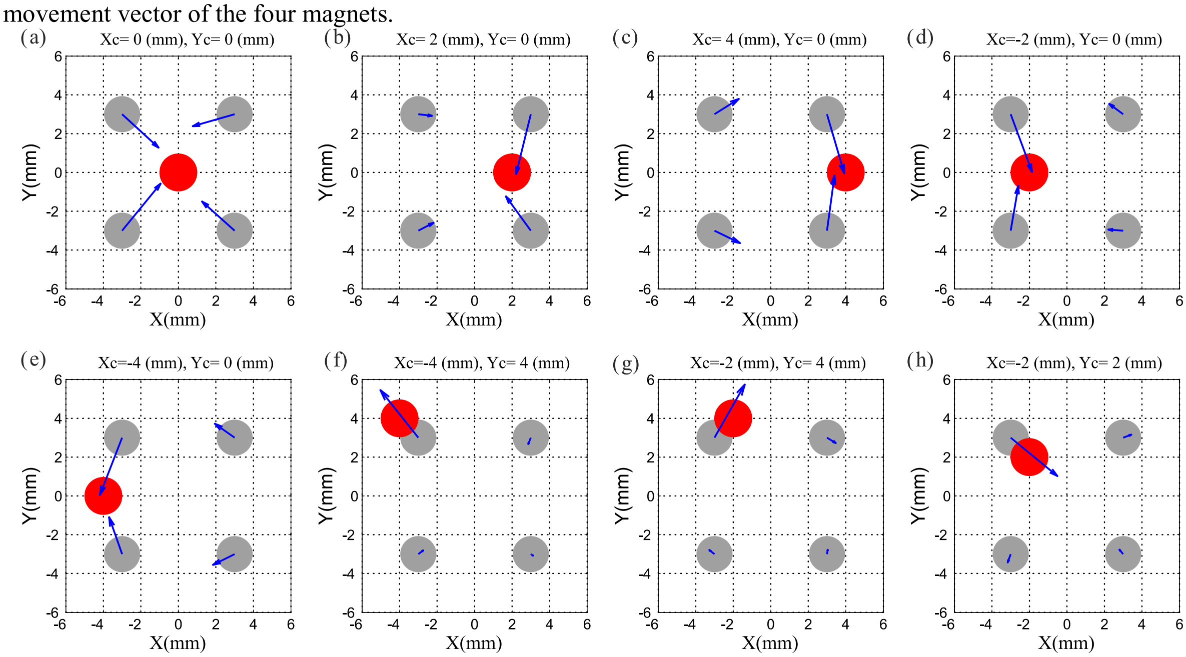

Fig. 4. Movements of the four magnets in XY plane when the MagTrix sensor was indented by a 2 mm cylindrical rod at different position (Grey circles represent magnets, the red circles represent the indenter).

4. Conclusion

In summary, MagTrix shows the capacity of magnetic field based tactile sensing array to deliver high sensitivity force measurements and contact area/point detection. They are well suited to robotic manipulation in their performance and robustness to environmental disturbances and have the potential for force feedback control and slip prediction and detection. Our future work will explore the fabrication, characterisation and optimisation of larger sensing arrays and their integration into structures such as an artificial fingertip. This will build on our previously reported design methodology work, combining finite element analyses and advanced signal processing techniques.

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