Sparse Force Mapping System Based on Compressive Sensing

Lucas Hermann Negri, Aleksander Sade Paterno, Marcia Muller, and José Luís Fabris

***Abstract*— This paper reports the development and application of a reconstruction method based on differential evolution (DE) to solve an underdetermined tactile sensing system with quasi-distributed fiber sensors. The reconstruction relies on the coupled responses from eight fiber Bragg grating-based transducers. The sensing system is capable of locating and quantifying up to three loads simultaneously applied to a metallic plate divided into 16 regions. The signal reconstruction is performed using compressive sensing methods to infer the spatial distribution of the applied forces. A comparison between the implemented method based on DE and traditional sparse signal recovery schemes (LASSO, OMP, Robust-SL0, and CoSaMP) showed the better performance of the proposed algorithm in the demonstrated application.**

***Index Terms*— Compressed sensing, fiber Bragg gratings (FBGs), optical fiber measurement applications, optical fiber sensor, tactile sensing.**

I. Introduction

TACTILE sensors are used in different areas where the detection of distributed forces is required, as in the structural deformation sensing [1], [2], in medical applications [3]–[6], and in the development of robotic tactile systems [7]. Different strategies have been proposed in the literature for the tactile sensing of surfaces [8], [9]. Some of them use an array of transducers responsible for sensing specific regions of a surface [5], [9], [10]. In the work developed by Heo *et al.* [9], a system with 16 optical fibers forming a grid with 64 sensing points is described. The intensity-coded signal from each of the 16 fibers is used to map the forces applied on a surface. The detection system is simplified by using only 16 detection points; however, the response of the grid to a distributed force applied on the surface provided an ambiguous reconstruction of the input signal.

In general, when each transducer of the array detects at only one point, it is expected that the enlargement of the monitored area requires an increased number of transducers to maintain the system resolution. This situation would possibly limit the size of the area to be monitored, impairing the sensing system application in terms of cost and implementation. In addition, point transducers must not have coupled responses. However, if this coupling occurs, the development of systems with a reduced number of transducers might be explored [8].

Usually, tactile sensors incorporate electrical strain-gages or capacitive transducers in their configuration. Alternatively, fiber Bragg gratings (FBG)-based transducers have been used for this purpose [8]–[12]. In these systems, the FBG intrinsic sensitivity to strain and temperature is exploited [11], [13]. Other useful characteristics of the optical fibers as their reduced size, wavelength encoded multiplexing capability, easy installation, and immunity to external electromagnetic fields can also be useful for tactile systems. The tactile sensing system proposed by Cowie *et al.* [8] is based on the evaluation of deformations occurring on the surface of a flexible metal plate, allowing estimating the applied load at those points. In this scheme, a point load is applied on the plate and all the FBGs respond simultaneously to this perturbation, as a function of the distance between the FBG and the point of load application. With the help of artificial neural networks, up to two loads with previously known masses applied on the plate surface could be located [8]. The ability of a tactile sensor instrumented with FBGs to detect and discriminate loads was tested by Saccomandi *et al.* [10]. For the sensor characterization, a single load was systematically applied in different positions of a surface instrumented with nine FBGs distributed into a 3×3 array. A feedforward neural network was used to evaluate the system performance.

In the system proposed by Negri *et al.* [14], sparse forces applied on a metal plate divided into nine cells were determined by using the responses of nine transducers composed of FBGs installed in metal rings. The LASSO [15] method was used to solve the resulting underdetermined problem. A reconstruction error of 73.33% was achieved for tests with three loads applied simultaneously to the plate in distinct cells.

This paper shows results obtained with a new method implemented to reconstruct the signal in a tactile sensing system composed of a metal plate instrumented with FBG embedded transducers. The transducers responses are coupled and the spatial distribution of forces is sparse. As the compressive sensing (CS) theory [16] shows the possibility of solving an underdetermined system with sparse solution, a method for the signal reconstruction based on CS and differential evolution (DE) [17] was proposed and implemented. The performance of this method was assessed in a benchtop application with experimental data and its capacity of reconstruction was compared with already existent methods (LASSO, OMP, Robust-SL0, and CoSaMP).

Manuscript received July 11, 2016; revised September 12, 2016; accepted October 22, 2016. Date of publication February 14, 2017; date of current version March 8, 2017. The Associate Editor coordinating the review process was Dr. V. R. Singh.

L. H. Negri, M. Muller, and J. L. Fabris are with the Federal University of Technology–Paraná, Curitiba 80230-901, Brazil (e-mail: fabris@utfpr.edu.br).

A. S. Paterno is with Santa Catarina State University, Joinville 89219-710, Brazil.

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TIM.2017.2658078