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Hardware Implementation for the Contact Force Reconstruction in Tactile Sensor Arrays

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Abstract : Reconstruction of contact forces is a fundamental technique for analyzing the properties of a touched object and is essential for regulating the grip force in slip control loops. This is based on the processing of the distribution, intensity, and direction of the forces during the capture of the sensors. Currently, efficient hardware alternatives have been used more frequently in different fields of application, allowing the implementation of computationally complex algorithms, as is the case with tactile signal processing. The use of hardware for smart tactile sensing systems is a research area that promises to improve the processing time and portability requirements of applications such as artificial skin and robotics, among others. The literature review shows that hardware implementations are present today in almost all stages of smart tactile detection systems except in the force reconstruction process, a stage in which they have been less applied. This work presents a hardware implementation of a model-driven reported in the literature for the contact force reconstruction of flat and rigid tactile sensor arrays from normal stress data. From the analysis of a software implementation of such a model, this implementation proposes the parallelization of tasks that facilitate the execution of matrix operations and a two-dimensional optimization function to obtain a vector force by each taxel in the array. This work seeks to take advantage of the parallel hardware characteristics of Field Programmable Gate Arrays, FPGAs, and the possibility of applying appropriate techniques for algorithms parallelization using as a guide the rules of generalization, efficiency, and scalability in the tactile decoding process and considering the low latency, low power consumption, and real-time execution as the main parameters of design. The results show a maximum estimation error of 32% in the tangential forces and 22% in the normal forces with respect to the simulation by the Finite Element Modeling (FEM) technique of Hertzian and non-Hertzian contact events, over sensor arrays of 10×10 taxels of different sizes. The hardware implementation was carried out on an MPSoC XCZU9EG-2FFVB1156 platform of Xilinx® that allows the reconstruction of force vectors following a scalable approach, from the information captured by means of tactile sensor arrays composed of up to 48 × 48 taxels that use various transduction technologies. The proposed implementation demonstrates a reduction in estimation time of x / 180 compared to software implementations. Despite the relatively high values of the estimation errors, the information provided by this implementation on the tangential and normal tractions and the triaxial reconstruction of forces allows to adequately reconstruct the tactile properties of the touched object, which are similar to those obtained in the software implementation and in the two FEM simulations taken as reference. Although errors could be reduced, the proposed implementation is useful for decoding contact forces for portable tactile sensing systems, thus helping to expand electronic skin applications in robotic and biomedical contexts.

Keywords : contact forces reconstruction, forces estimation, tactile sensor array, hardware implementation
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