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THE ROLE OF IMPROVER MANUFACTURING TECHNOLOGY INTHE DESIGN OF MEAGRE TRANSDUCER ARRAYS

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Abstract

Large two-dimensional (2D) arrays offer verypromising prospects as an analysis tool due to their capability toobtain information of volumetric spaces. However, this kind ofdevelopment has major drawbacks. The main challenge comesfrom the large number of elements required to achieve anacceptable image quality. The sparse arrays have been proposedas a compromise solution between the number of active elementsand dynamic range. Although we can find in the literature a lotof examples about sparse arrays models, there is a significantlack of experimental prototypes. The main reason for this is thatthe manufacturing process is expensive and complex. In order toaddress this problem, the capabilities to develop structural partsof sparse arrays of manufacturing process based on AdditiveManufacturing technology have been analyzed in this paper.

INTRODUCTION

Nowadays, it is widely accepted that large two-dimensional(2D) arrays offer very promising prospects as an analysis tooldue to their capability to obtain information of a volumetricspace. However, to avoid grating lobe formation, the distanceetween transducers in the array element distribution is limitedto _=2. Therefore, large 2D matrix apertures involve a highnumber of elements. This issue leads to some challengesat several levels: (i) manufacturing level, because the largenumber of elements involves also cables, shield, matchedfilters, etc; (ii) signal conditioning level, because the smallsize of the elements, the contribution of individual elementsis very low and offers poor SNR (low radiation area andlow sensitivity); (iii) system control level, because of thecomplexity of acquiring, processing and managing a largevolume of data; and finally, (iv) the economic level, because ofthe high cost associated with the transducer and the systems.Although, micromachined and microelectronic manufacturingtechniques reduce some of the manufacturing problems,allowing the development of high densely populated apertures[1], some of the challenges identified are still unsolved orinvolve a huge bunch of resources. In any case, some solutionto these issues involves a high cost and a high degree ofuncertainty that makes it difficult to be justified.

Consequently, there is a reduced offer of both commercial2D transducer and associated instrumentation. Furthermore,the systems identified in the literature are mainly laboratory instruments. In this sense the reduction of active elements inthe aperture, by sparse array design is an interesting solutionfor the development of volumetric imaging systems. Therefore,the main challenge in array design is determined by thenumber of elements necessary to achieve acceptable imagequality. In the literature we can find a lot of examples ofsparse arrays [2], [3]. However, the number of experimentalprototypes is very low [4]. The main reason for this is that themanufacturing process is expensive and complex.In order to address this problem, the capabilities to manufacturestructural parts of sparse arrays based on AdditiveManufacturing technology [5] and the consequences in thetransducer behavior have been analyzed in this paper. Theresults show that Additive Manufacturing gives an opportunityto array designers to develop low cost and risky proof ofconcept.

Additive manufacturing (AM), or 3D printing, builds objects layer by layer using 3D modelling data. AM has been explored from rapid prototyping to tooling that leads to direct production. More importantly, AM can be used to integrate with CAM (computer-aided manufacturing), CNC (computer numerical control) and CAD (computer-aided design) for 3D printing objects.[1–4] AM is applied everywhere from biomedical applications to aircraft design and is being slowly explored for applications in the oil and gas industry. The materials used in AM include polymers, metals, ceramics and their composites; however the materials for AM are still limited. For instance, in some cases CNC machining is needed as, sometimes, the dimensions of the spare parts to be built can be larger than available AM printers can cope with. Rapid prototyping may not be a good answer for all instances as CNC machining could also be required.[3–5] In the past few years, AM has played a key role in the oil and gas industry by promoting the engineering nozzles produced by the GE company.[6] Although AM has significant opportunities in the oil and gas industry, the truth is that real companies have become slower to take them. However, major oil and gas service companies have invested in AM and have completed some successful pilot projects.[7,8] AM is potentially capable of enabling the design of products with complex structures with reduced cost and waste and could also reduce the overheads associated with documentation and production planning.[9] AM technology produces parts with fewer materials compared to conventional technologies and provides a quick response to demand for spare parts.

Proposed method

The main challenge comesfrom the large number of elements required to achieve anacceptable image quality. The sparse arrays have been proposedas a compromise solution between the number of active elementsand dynamic range. Although we can find in the literature a lotof examples about sparse arrays models, there is a significantlack of experimental prototypes. The main reason for this is thatthe manufacturing process is expensive and complex. In order toaddress this problem, the capabilities to develop structural partsof sparse arrays of manufacturing process based on AdditiveManufacturing technology have been analyzed in this paper.

Methodology

II. SPARSE ARRAYS DESIGNED FOR PROTOTYPING

At first, a sparse array is designed to accomplish the specifications,which are related to lateral resolution, dynamic rangeor number of active elements. However, in order to develop asolution suitable for manufacturing some other considerationshould be done, like cable distribution and the supportingstructure. In this sense it is important also take in accountthe manufacture procedure that is going to be followed.

Fused Deposition Modeling (FDM) techniques are suitableto produce cost-effective structural components. The materialsused by these techniques are plastics that can be manipulatedeasily and, in order to implement arrays, show interestingmechanical properties. For this case we have considered acrylonitrilebutadiene styrene (ABS), polylactic acid (PLA) andthermoplastic polyurethane (TPU).Nowadays, 3D printers have good link with ComputerAssisted Design tools that help to design tridimensionalstructures. Basically, the arrays element is constituted bythree components: the piezoelectric component, the cable thatprovides electrical connection and the backing.A. Array element structureThe Figure 1 describes the structure of a single element.

The manufacturing process is divided in two stages printedas separated parts. The first stage is where the piezoelectriccomponent, the cable and the electric contact are located. The manipulation degree required at this stage is very high. In thesecond stage, the main part of the backing structure is placed,optionally including a dispersal space.

Two piezoelectric component have been considered for thetesting purposes: 1MHz PZ27 ceramic (FerropermTM) and1.5MHz 1-3 piezocomposite (SmartmaterialsTM, 851 material,Dice and Fill 65%). These two components were diced inorder to achieve the element dimensions and their electricalimpedances were evaluated .The results showthat piezocomposites maintain its resonance response meanwhilethe PZ27 has reduced its resonance frequency.

The cable is located near to the element and guided througha channel across the aperture structure to the outer shell ofthe plastic structure. To place it, we made use of supportingpoint and heat to fix it. In order to make contact betweenboth elements, conductive epoxy was used. This epoxy layerconstitutes the first part of the backing structure. Therefore,backing epoxy is doped with tungsten to match the impedanceof the conductive layer. If the backing column needs to bemore loaded, conductive epoxy could be replaced by silverconductive paint.

The material used to manufacture the first stage can be usedto minimize the mechanical crosstalk between elements. Ingeneral, all materials used (ABS, TPU and PLA) show goodmechanical response. However, TPU is less capable to avoidlateral oscillation. ABS has been discarded because of the wideuse of acetone to clean epoxy.

SPIRAL SPARSE ARRAYS

To analyze the capacities of FDM to develop structurescapable of enclosing a dispersed matrix, a simple set ofspecifications have been considered as proof of concept: lateralresolution less than 1:5_, no more than 64 elements, operationfrequency of 1.5MHz and a dynamic range higher than 30 dB.If the Fermat spiral distribution is analyzed for a diameter of48_ and 64 elements, three different angles provide solutionsaround them than can be considered as viable: 84_, 95_and 140_. Therefore, in this case the selection is addressedby manufacturing considerations like cable location, routingand how backing columns are distributed. In this sense, toFig. 2. Top: electrical impedance of 1:5 _ 1:5 mm PZ27 (1MHz). Bottom:Electrical impedance of 1:5_1:5mm 1-3 piezocomposite (851 material, Diceand Fill 65%, 1.5MHz)reduce as much as possible the mechanical interaction betweenelements it is interesting to isolate each backing columns.

These considerations point to the angle 140_ as the moreadequate for our purposes.The simulated pulse-echo response of the aperture showsa lateral resolution of 1:2_ and a dynamic range of 33 dB(Figure 3 Bottom).

Results

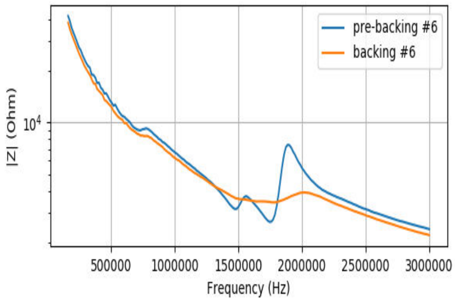
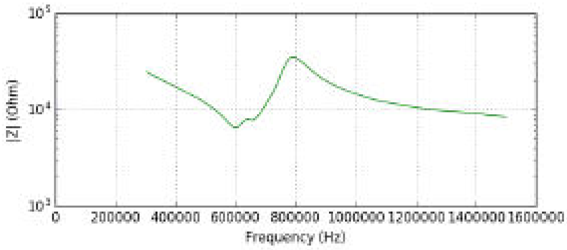


Fig. 8. Electrical Impedance of the element number 6. In blue previous tothe backing insertion. In orange after the backing insertion.



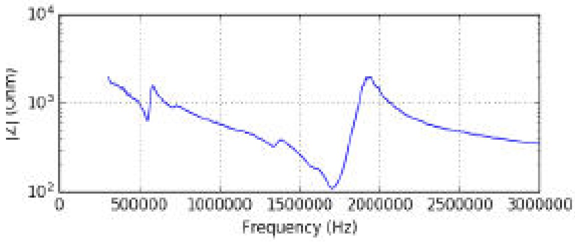


Fig. 10. Temporal response and Power Spectral Density of four elements ofthe aperture. Left: elements 34 and 62. Right: elements 6 and 16.

CONCLUSIONS

In this work a sparse array of 48_ diameter and 64 elementsbased on a Fermat spiral distribution has been designed andmanufactured. In order to make it, a novel technique has beendeveloped based on FDM. This technique has shown to bevery versatile and cost effective. In this sense this techniqueseems to be adequate for the development of risky proof-ofconceptand can support an improvement of the arrays designtools.

Future scope

As a matter of fact, AM has brought many innovations and opportunities in various industries, mainly medical, aerospace, and automotive. AM helps effectively with cost and time-saving, reducing complexity, rapid prototyping, and highly decentralized production. However, besides the several advantages of AM technology, there are also some barriers against its quick growth, such as size limitation, production time, limitations of materials, and machine and production costs. AM is also in the group of sustainable and efficient production processes in the field of manufacturing which helps with resource-saving and environmental protection. The sustainability studies show a considerable reduction in material waste and fuel consumption as two principle benefits in AM. In fact, eco-design in AM provides this opportunity that the environmental issues fundamentally be considered in each design and fabrication stage, accordingly, various eco-design tools, e.g., life cycle analysis (LCA), can be applied for evaluating the environmental impact of products

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