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Computing on the verge of chaos: classical and quantum reservoirs

Didier Felbacq^a, Emmanuel Rousseau^a, and Emmanuel Kling^b

^aUniversity of Montpellier, France

^bSafran Electronics and Defense, Massy, France

ABSTRACT

We propose the use of a periodic set of dielectric rods considered in the high frequency regime as a reservoir for computing. We show that such a system presents a chaotic behavior that can be analyzed within the K.A.M. approach, with the formation of tori in phase space. The conditions for which the system can be used to encode information is then addressed. Finally, we try to extend these ideas to quantum metamaterials and investigate the possibility of using these structures for quantum reservoir computing.

Keywords: reservoir computing, quantum chaos

1. INTRODUCTION

The idea of reservoir computing is a type of machine learning technique where the main ingredient is a ?reservoir? which is a system with a large system of states. Several physical reservoirs have been used in practice. One of the most surprising being surely the surface of a bucket of water¹! Recently, it was proposed to use optical reservoir such as a scattering medium.² In the present work, we propose the use of a periodic set of dielectric rods considered in the high frequency regime. We show that such a system presents a chaotic behavior that can be analyzed within the K.A.M. approach, with the formation of tori in phase space. The conditions for which the system can be used to encode information is then addressed. Finally, we try to extend these ideas to quantum metamaterials and investigate the possibility of using these structures for quantum reservoir computing.

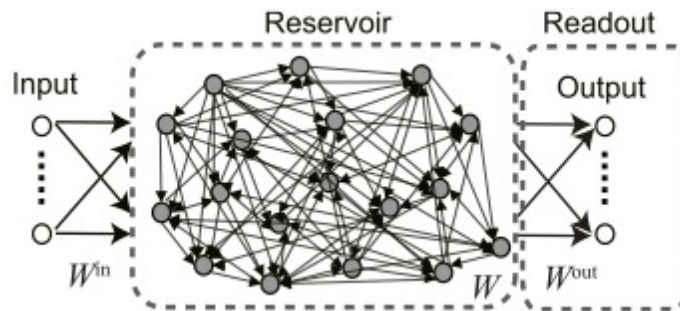


Figure 1. Modulus of the Fourier coefficients of the density σ .

2. RESERVOIR COMPUTING

The idea of reservoir computing is to consider an untrained Recurrent Neural Network as a system hosting a very large number of modes and that can be used as a memory to encode and store an output signal.³ Once the input signal is encoded, an output can be produced and a layer of artificial neurons can be trained to link the input signal to the encoded signal, see fig. 1 for a schematic representation of the system. Several systems, from Recurrent Neural Networks to all-optical systems or even skyrmions have been proposed to work as a reservoir^{1,2}

Further author information: (Send correspondence to D.F.)

D.F. : E-mail: didier.felbacq@umontpellier.fr

3. CHAOS IN A PHOTONIC CRYSTAL

A possible physical system for designing a physical reservoir is a set of scatterers. This was considered in,² where a strongly scattering medium is used. We propose instead to use a perfectly periodic medium: a 2D photonic crystal. When such a structure is considered in the very frequency regime, it displays chaotic properties that were analyzed in the framework of ray optics in⁶ and also from the point of view of quantum chaos in.⁷ The ray

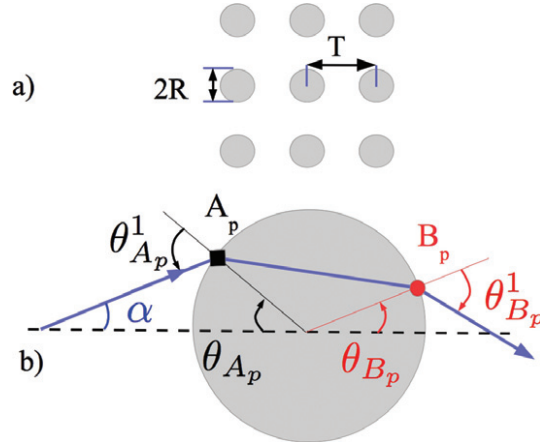


Figure 2. Scheme of the structure (a) and ray tracing analysis of a 2D photonic crystal (b).

tracing analysis is displayed in fig. 2 together with the structure into consideration. Inside the chaotic sea, it is possible to identify the tori as predicted by KAM theory.

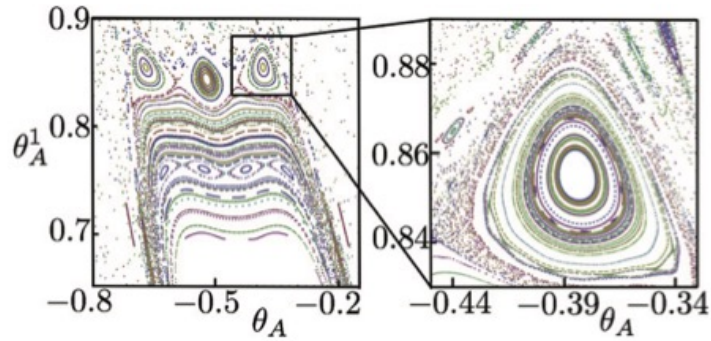


Figure 3. Phase space of the 2D photonic crystal. The stability regions can be identified inside the sea of chaos.

In fig 4, we give the map of the field for an incident beam. The point is to demonstrate the mechanism leading to the regions of chaos and stability in phase space. When entering a scatterer, the beam is split into several beams, both refracted and reflected. The beams that remain in the direction of the original beam are slightly deviated but the other ones are rapidly diverging from the original direction indicates the sensibility to initial conditions.

In fig. 5, we give the map of the field inside the photonic crystal for an incident plane wave, in the high frequency regime. It turns out that the repartition of the field presents elaborate structures that are quite sensitive to the angle of incidence resulting in a high dimensional space of modes. This allows the encoding of a signal into the modes of the system.

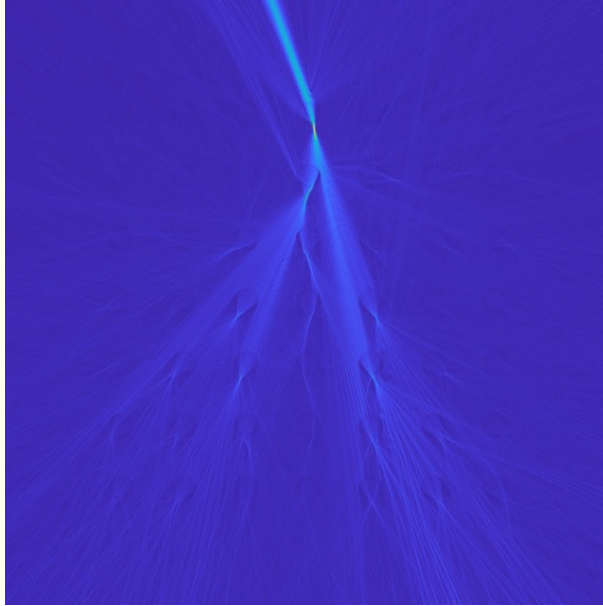


Figure 4. Map of the field for an incident gaussian beam.

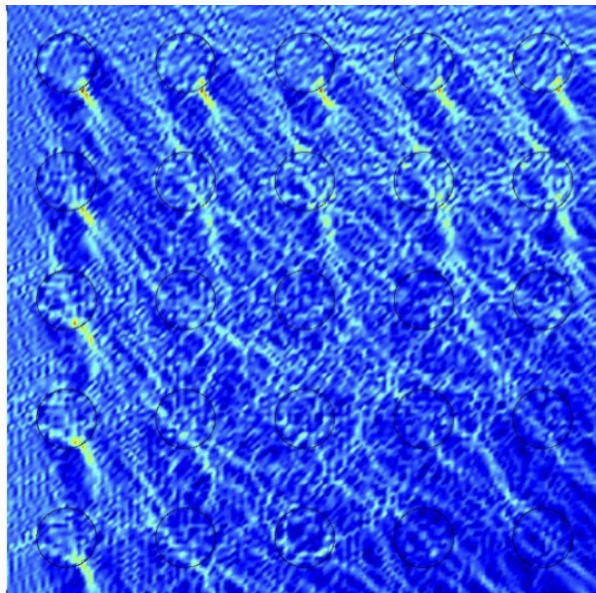


Figure 5. Map of the field inside the photonic crystal, when illuminated in the high frequency domain by a plane wave.

4. CONCLUSION

We have proposed to use a periodic 2D photonic crystal as a reservoir for the implementation of classical reservoir computing. The extension to optical quantum reservoir computing is now studied, in the framework of the QRC-4-ESP research network <https://www.qrc-4-esp.eu>. It could be implemented by inserting quantum point defects (under the guise of substitutional centers or quantum dots), in order to create a quantum superlattice, within the photonic crystal.

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