Manipulating with excitations: Waves or gliders?

Ioannis Georgilas*, Andrew Adamatzky and Chris Melhuish

Abstract— **Excitable media are classical examples of unconventional computing devices. Using waves to represent information and wave interactions to represent information processing, excitable media achieve computation versatility comparable to traditional techniques. We aim to use waves in a discrete excitable media to create a controller for a novel smart surface manipulator. The manipulator uses these waves as control signals for an array of actuators to transfer, orient and aggregate objects. We present results of scoping experiments on distributed manipulating of objects with omni-directional waves and travelling localised excitations (gliders).**

Index Terms— **Excitable Media, Cellular Automata, Smart Surfaces**

I. Introduction

Excitable media as computational systems can solve complicated problems utilising natural aspects like massive parallelism and reconfiguration for optimal utilisation. These features are widely used in image processing, computational geometry and optimisation on graphs. Non-linear systems, like Reaction-Diffusion[1], BZ reactions [2], Physarum Polycephalum simulations [3] and Cellular Automata [4] show that information can be transferred along the medium and under proper condition can be used for computational tasks. Pieces of information can be easily and intuitively modelled as waves. Processing of information is done in the form of interaction of waves [5], such as collisions, annihilation, addition and formation of solitons, can represent operations between these bits of information.

Control of a robot is the process of acquiring information from its sensors and processing it to generate specific actions. The use of wave-based collision processing in non-linear media has been proposed, [6], [7], [8], [9], as an alternative to more classic robot control approaches.

Within this context, the current work develops our ideas about an excitable medium, namely a Cellular Automata (CA), controller for smart surfaces. Smart surfaces are distributed manipulators implemented for industrial environments as part of assembly lines in the distribution and manipulation of objects, specially in the micro/nano scale. Also, smart surfaces can be used in the creation of molecules using a mechanical assembly process rather than a chemical interaction process. The characteristics of a smart surface are: simple hardware design to allow ease of construction, robustness of operation, failure of some cells will not affect overall system performance, and decentralised distributed architecture which allows for maximum scalability. The proposed CA control theory will employ the ideas of object manipulation by means of spreading and growing patterns, diffusive wave-fronts, waves of excitation and solitons.

Utilising omnidirectional waves and wavelets in the sub-excitable 2^+-medium is an optimal approach for the controller of the smart manipulation surface, [10] . With this work we will investigate how the generation and propagation of different wave types can affect the operation of the smart surface. We will present how simulation data of the two wave types compares with previous research in transferring and orienting objects in our novel proof-of-concept prototype [11] and the current work will provide a qualitative discussion on the different types.

The structure of the paper is as follows, in section II a description of excitable media will be given In II-A the difference between omni-directional waves and wavelets will be presented. In II-B the process of selecting the 2^+-medium as the appropriate cellular automaton will be given and how the two types of waves are generated. Finally, in III a discussion of the operation of omni-directional waves and wavelets in a simulated environment and on the real smart surface will be given.

II. Excitable media

An excitable medium is any non-linear system with specific states that after an original state set, i.e. excitation, it will change from state to state periodically. A further excitation signal will not be applicable until the medium gets to a refractory state. The change of states can be perceived as waves of state-fronts travelling the medium.

The waves created in excitable media can easily and intuitively model information. More specifically, in a system with strictly specified periodic waves and given wavelengths, a binary system can be implemented by the existence (1) or not (0) of a wave at the predefine interval, and information creation is the original excitation of the medium. Based on the specific system dynamics, appropriate excitation patterns can create streams of information that will propagate in the medium. Processing of information then can be done in the form of interaction of waves, such as collisions, annihilation, addition and formation of solitons representing boolean operations between these bits of information.

A. Omnidirectional Waves vs. Wavelets

The form of waves in an excitable medium is usually omni-directional, originating from a point in the medium and travelling in every direction. Depending on the type of the medium, the amplitude of the waves shrink proportionally

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to the distance from the source, or retain their strength until they encounter an obstacle, an other wave or the boundaries of the medium. Omni-directional waves are a “broadcast” mode, transmitted from a source to all available “receivers”. It can be effective when one piece of information must reach multiple targets, but can be considered as a waste of medium bandwidth. In the topic of information processing, the “broadcast” mode renders precise computation tasks difficult since the exact origin and interaction pattern of specific bits of information are noisy due to the abundance of information, omni-directional waves. In the context of manipulation omni-directional waves generate enough energy to transport heavier or multiple objects but at the same time are energy inefficient given that parts of the medium are excited without being involved to the manipulation task.

On the other hand wavelets can be focused to transfer information to specific targets, representing peer-to-peer communications. Since the packet of information is explicitly defined processing of the carried information is simpler and the possibility of data loss due to noise in the medium is highly decreased. None the less, they lack the energy payload to manipulate objects effectively.

B. Cellular Automata

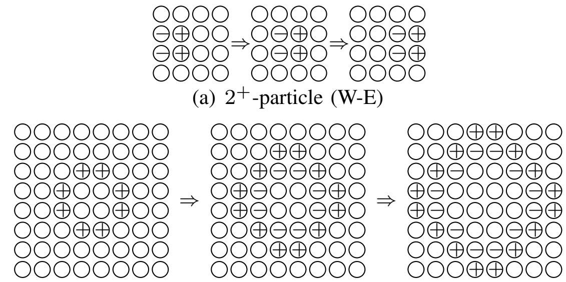
As our medium we are going to use cellular automata and for reasons of uniformity a rule-set that produces both omni-directional waves and wavelets. For the latter, the medium must be sub-excitable with dissipating solitons; hence waves can retain amplitude and form along the path of distribution creating a “focused” beam of information. Based on research undertaken by the authors in [12] regarding robot controllers and in [13] on the simulation of theoretical smart surface hardware, the 2^+-medium, also known as an excitable lattice, will be used.

The 2^+-medium is the appropriate medium mainly due to three factors; *a*) number of cell states, it has three states as do motor actuators, rotating clockwise, rotating counter-clockwise and turned off; *b*) glider shape and directionality, they have the minimum size and be able to travel horizontally and vertically; *c*) glider interaction patterns, which do not always dissolve when interacting.

C. The 2^+-medium

The 2^+-medium is widely studied and its various localisation patterns extensively analysed. One interesting characteristic of this medium is that there are no static structures, i.e. oscillators, making it suitable for wave-based computation and manipulation.

1) The rules of 2^+-medium.: For a two-dimensional lattice A, each cell x takes three states, resting($\cdot$), excited ($+$) and refractory($-$). A resting cell is excited if the number of excited neighbours is exactly two. An excited cell takes refractory state and a refractory cell takes a resting state unconditionally. Its notation is $B2/S-/3$ and in (1) is given as an update function of state x^{t+1} .



(a) 2^+-particle (W-E)

(b) Omni-directional wave (N, S, E, W)

Fig. 1. Wave-like self-localisations in 2^+-medium. (a) The 2^+-particle moving in horizontal or vertical directions and (b) omni-directional waves moving in all four directions

$$x^{t+1} = \begin{cases} +, & x^t = \cdot \text{ and } \sum_{y \in u(x)} \chi(y,+) = 2 \\ -, & x^t = + \\ \cdot, & \text{otherwise} \end{cases} \tag{1}$$

where $\chi(y,+) = 1$ if $y = +$ and 0, otherwise.

2) Mobile self-localisations in 2^+-medium.: The 2^+-medium is a deterministic automaton, therefore the mobile self-localisations keep their shapes indefinitely. The most useful for computation tasks is the smallest possible, the 2^+-particle. It has a wave-front, consisting of two $+$ states, and a refractory tail, consisting of two $-$ states, Fig. 1(a). It strictly moves horizontally or vertically with a linear speed of $1 \frac{cell}{generation}$.

3) Omni-directional waves in 2^+-medium.: In the 2^+-medium it is also possible to create omni-directional waves with a specific focus centre. The pattern for the generation of the wave can be seen in Fig. 1(b). It is essentially four gliders, one facing each of the cardinal directions, with their “wings” joined. The propagation speed of the wave front towards all directions is $1 \frac{cell}{generation}$ like the 2^+-particle.

III. Discussion on Wave-based Manipulation in Smart Surfaces

In order to evaluate the performance of the two wave types in manipulation tasks, first a simulation of the 2^+-medium was carried out, and given the intermediate results, a series of experiments with the prototype hardware were contacted.

The simulation environment used is APRON (Array Processing enviRONment) developed by the University of Manchester [14]. APRON can model array interactions and interface with a 3D physics engine to model a smart surface. The actuation method of the smart surface is the use of linear actuators in the form of square pins.

Two sets of simulation experiments were carried out, initially four objects were displaced using omni-directional waves, Fig. 2(a), and secondly a single object using linearly propagating wavelets, Fig. 2(b). In the latter experiment only one object was used given the narrow focus of the glider. The trajectories of the objects were recorded and are presented in Fig. 2(c) and 2(d) respectively.

As can be observed for the omni-directional waves the “broadcast” mode renders the trajectories of the objects

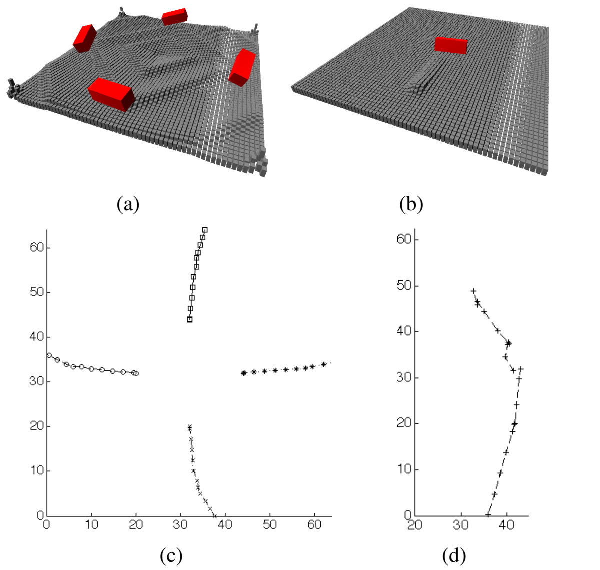


Fig. 2. (a), (b) Simulation frames of omni-directional and wavelet propagation respectively, (c),(d) The relevant objects trajectories (x,y-axis in simulator distance units).

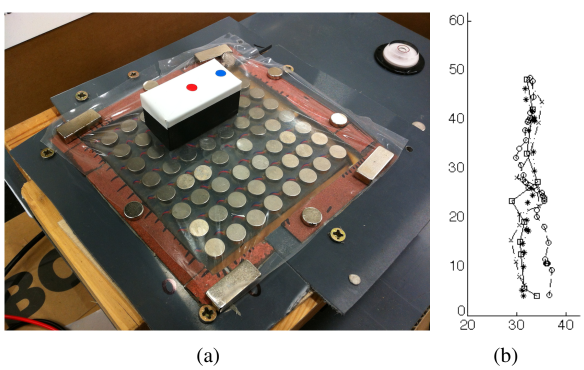


Fig. 3. (a) Hardware prototype and manipulated object, (b) four experimental trajectories (x,y-axis adjusted to simulator distance units).

coupled. They need to move in a connected way that is not suitable for clustering operations, where individual manipulation is necessary. Moreover, as seen from the screen shot, Fig. 2(a), the delivered energy is leading to the vertical displacement of the objects, "hoping" effect. On the other hand, the wavelet manipulation operates as expected. There is a parabolic motion that can be attributed to the specific dynamics of the simulation engine.

For the prototype experiments the object depicted in Fig. 3(a) was manipulated by the smart surface described in [11]. Omni-directional wave experiments were not undertaken based on the simulation observations, that the coupled trajectories are not suitable for the specific application domain. For the wavelet type experiments four different trajectories were produced and are presented in Fig. 3(b). Although each trajectory is slightly different due to mechanical variations of the prototype, the overall pattern is as predicted in the simulation experiment. Another interesting observation is that the different actuation approaches, linear actuators in APRON vs vibrating motors in the hardware, do not significantly affect the results.

IV. Conclusions

With this work an initial discussion for the use of wave-based control in smart surfaces is presented. The use of excitable media as unconventional controllers for smart surfaces, namely the 2^+-medium, and how waves can be formed and model information, to be used for manipulation tasks is discussed. Simulation and experimental data is provided to evaluate the use of each type and the results for wavelet-based method is consistent between simulation and prototype.

Future work can involve the investigation of different types of actuation and the impact of a bigger prototype in the dynamics of manipulation. Also, different forms of CA can be investigated and wavelet interaction for processing tasks can be examined.

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