Switchable Glass: A possible medium for Evolvable Hardware

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Abstract

The possibility of using switchable glass (also called smart windows) technology for Evolvable Hardware tasks is suggested in this paper. Switchable glass technology basically means controlling the transmission of light through windows by using electrical power. By applying a variable voltage to the window we can continuously vary the amount of transmitted light. Three existing technologies are reviewed in this paper: Electrochromic Devices, Suspended Particle Devices and Liquid Crystal Devices. An Evolvable Hardware application for a light-based device is described. The proposed device can be used for solving an entire class of problems, instead of one problem only as in the case of other dedicated hardware.

1 Introduction

Intrinsic Evolvable Hardware (EHW) employs the Darwinian principle of evolution directly into hardware. Several devices have been used so far in this purpose: Field Programmable Gate Array [16], Field Programmable Transistor Array [15], Field Programmable Analog Array [3] and Liquid Crystal [11, 12].

In this paper we suggest the use of switchable glass (commercially known as smart windows) for Evolvable Hardware purposes. Because switchable glass affects only the transmitted light, we can used this technology for light-based computations only.

In the area of light control, there are three main technologies: Electrochromic Devices, Suspended Particle Devices and Liquid Crystal Devices. Electrochromic Devices technology is based on chemical reactions whereas Suspended Particle Devices technology uses field effects. These technologies are widely used to manufacture smart windows [9]. These types of glass can be automatically controlled to adjust the amount of light passing through them.

Suspended Particle Device refers to rod-like particles suspended in a fluid. With no applied voltage, the particles are randomly oriented and block light (dark state). When a voltage is applied, the particles align with the electric field and let light though (light state). By varying the applied voltage, we can continuously vary the amount of transmitted light.

Electrochromic glass becomes translucent when voltage is added and are transparent when voltage is taken away. Like suspended particle devices, electrochromic windows can be adjusted to allow varying levels of visibility.

Liquid crystal glasses become transparent when a voltage is added and have an opaque behavior when there is no electrical power applied. However, liquid crystal glass has only 2 states: opaque and transparent with no other degrees of visibility.

The paper is structured as follows: The properties of intrisic EHW systems are briefly described in section 2. Section 3 reviews the current directions in the field of switchable glasses. A possible EHW application of switchable glass is presented in section 5. Conclusions and further work directions are given in section 6.

2 Properties of EHW devices

According to [12] there are several characteristics that a material should have in order to become a possible candidate for EHW tasks:

- the material should be configurable by applying some electrical power or any other source of energy (such as light),
- the material should affect an incident signal (optical or electronic),
- the material should be able to be reset to its original state.

In this paper we suggest the possibility of using switchable glass as a platform for EHW tasks. This kind of material has all the properties required by the EHW tasks:

- the switchable glass can change its degree of opaqueness by applying some electrical power,
- the switchable glass affects the quantity of light that pass through it,
- the switchable glass is able to be reset to its original state by removing the source of power.

Because switchable glass affects only the transmitted light, we can used this technology for light-based computations only.

3 Overview of the switchable glass technology

Three existing technologies in the field of switchable glasses are briefly described in this section. These technologies are: Suspended-particle devices, Electrochromic devices and Liquid crystal devices.

3.1 Suspended-particle devices

Suspended Particle Devices (SPDs) [7, 19], also called *light valves* use either a liquid suspension or a film within which droplets of liquid suspension are distributed. Light-absorbing microscopic particles are dispersed within the liquid suspension. The liquid suspension or film is then enclosed between two glass or plastic plates coated with a transparent conductive material. The mechanism behind SPD is similar to that of the dielectric in a parallel-plate capacitor which means that the atoms of the dielectric are polarized by the electric field. When an electrical voltage is applied to the suspension via the coatings, the particles are forced to align.

This allows a range of transparency where light transmission can be rapidly varied to any degree desired depending upon the voltage applied.

An example of how SPD works is given in Figure 1.

The way in which SPD glass works is very simple, if one thinks of SPDs as light valves. In a SPD window, millions of SPDs are placed between two panels of glass or plastic. When electricity comes into contact with the SPDs via the conductive coating, they line up in a straight line and allow light to flow through. Once the electricity is taken away, they move back into a random pattern and block light. When the amount of voltage is decreased, the window darkens until it's completely dark after all electricity is taken away.

3.2 Electrochromic devices

Electrochromic windows [4, 9, 13, 19] are made of special materials that have electrochromic properties. *Electrochromic* basically describes materials that can change color when energized by an electrical current. Electricity generates a chemical reaction in this material. This reaction (like any chemical reaction) changes the properties of the material. In this particular case, the reaction changes the way the material reflects and absorbs light. In some other electrochromic materials, the change is between different colors. In electrochromic windows, the material changes between colored (reflecting light of some color) and transparent (not reflecting any light).

At its most basic level, an electrochromic window needs this sort of electrochromic material and an electrode system to change its chemical state from colored to transparent and back again.

Electrochromic glass is made by sandwiching certain materials between two panes of glass. Figure 2 shows the materials inside one basic electrochromic window system and the way in which this system works.

In the design shown in Figure 2, the chemical reaction at work is an oxidation reaction – a reaction in which molecules in a compound lose an electron. Ions in the sandwiched electrochromic layer are what allow it to change from translucent to transparent. It's these ions that allow it to absorb light. A power source is wired to the two conducting oxide layers, and a voltage drives the ions from the ion storage layer, through the ion conducting layer and into the electrochromic layer. This makes the glass opaque. By shutting off the voltage, the ions are driven out of the electrochromic layers and into the ion storage layer. When the ions leave the electrochromic layer, the window regains its transparency.

With an electrochromic smart-window, it only requires electricity to make the initial change in opacity. Maintaining a particular shade does not require constant voltage. One only needs to apply enough voltage to make the change, and then enough to reverse the change.

3.3 Liquid crystal devices

Polymer Dispersed Liquid Crystals (PDLCs), [8, 19] or Liquid Crystals Devices (LCDs) are another major application in the field of switchable windows.

An example of how LCD works is given in Figure 3.

In the opaque state, the glass diffuses direct sunlight and eliminates 99 percent of the ultraviolet rays.

LCDs operate on the principle of electrically controlled light scattering. They consist of liquid crystal droplets surrounded by a polymer mixture sandwiched between two pieces of conducting glass. When no electricity is applied

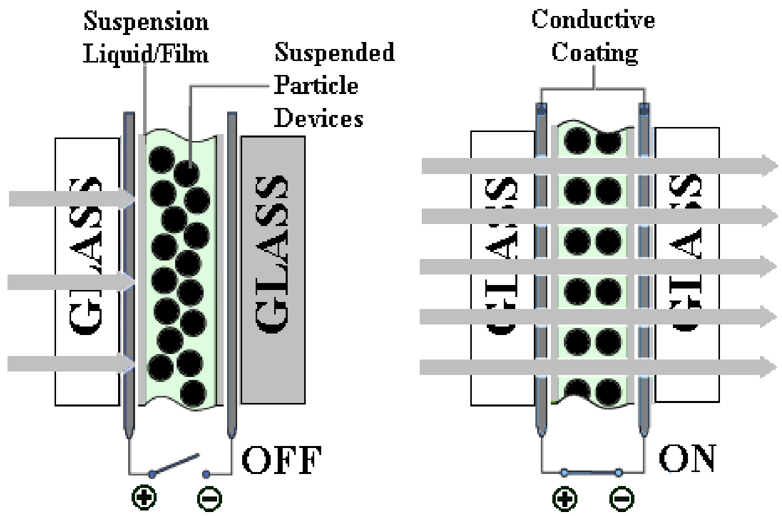

Figure 1. The materials within a SPD-based glass (from left to right): glass or plastic panel, conductive material - used to coat the panes of glass, Suspended Particle Devices - millions of these black particles are placed between the two panes of glass, a second glass or plastic panel. We have kept the glass panels in order to show how this technology works. When the SPDs are switched on, via the conductive coating, they line up in a straight line and allow light to flow through. When switched off the SPDs move back into a random pattern and block light.

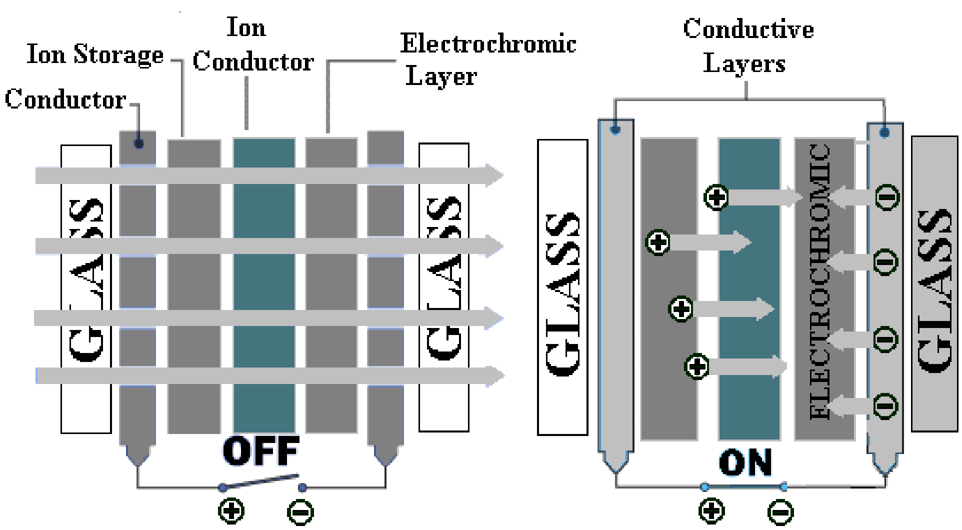

Figure 2. The materials within a ECD-based glass (from left to right): glass or plastic panel, conducting oxide, electrochromic layer, such as tungsten oxide, ion conductor/electrolyte, ion storage, a second layer of conducting oxide, a second glass or plastic panel. We have kept the glass panels in order to show how this technology works. When switched off, an electrochromic window remains transparent (left side). When switched on, a low volt of electricity makes the electrochromic window translucent (right side).

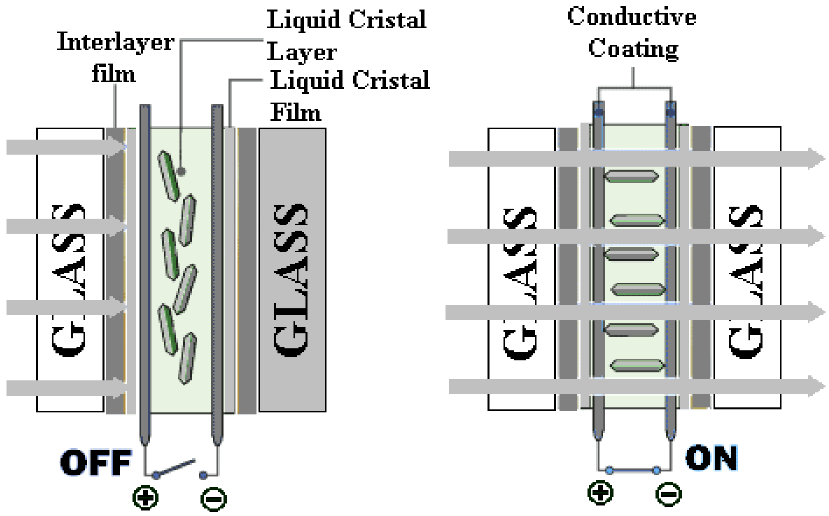

Figure 3. The materials within a LCD-based glass (from left to right): glass or plastic panel, interlayer film, liquid crystal film, a conductive coating, liquid crystal layer, a second conductive layer, a second liquid crystal film, a second interlayer film, a second glass or plastic panel. We have kept the glass panels in order to show how this technology works. When switched off the liquid crystal droplets are randomly oriented, creating an opaque state. When switched on the liquid crystals align parallel to the electric field and light passes through, creating a transparent state.

the liquid crystal droplets are randomly oriented, creating an opaque state. When electricity is applied the liquid crystals align parallel to the electric field and light passes through, creating a transparent state.

LCD windows can only be in one of the two states: transparent or opaque. There is nothing between these states, regardless how much electrical power is applied.

4 Advantages and weaknesses

A comparison of the features of the switchable glasses technologies is given in Table 1.

An important advantage of Suspended-Particles Devices and Electrochromic Devices is their ability to continuously vary the amount of transmitted light based on continuous variations of the applied electrical power. This feature makes SPDs and ECDs very suitable for a large number of problems whose parameters are real-valued. By contrast, Liquid Crystal Devices are of ON-OFF type: they can have only 2 states.

A possible drawback is the speed of performing the changes. As a general remark, the speed is directly connected to the glass surface. A bigger surface requires more time to change its state than a smaller surface. However, for EHW tasks the required surface can be microscopic, which requires less than 1 microsecond to perform a complete cycle (in the case of SPDs).

Because ECDs depend on ion injection and chemical reactions, the process is inherently slow. However, SPDs depend on a field effect, thus responding in very short time. As the technology advances we can expect to have smart glass which will respond faster to the applied electrical power.

5 Applications

In this section we describe an application for solving the 0/1 knapsack problem [2, 10]. For this purpose we have designed a special system which consists in two main parts:

- A computer which runs a standard Evolutionary Algorithm (EA) with binary encoding and
- an evolvable hardware light-based device for computing the fitness of a chromosome.

A schematic view of the proposed system is depicted in Figure 4.

5.1 The knapsack problem

In this problem we have a set M of n items. Each item has its own weight w_i. We also have a knapsack of capacity C. We have to fill the knapsack using some objects in the set M so that:

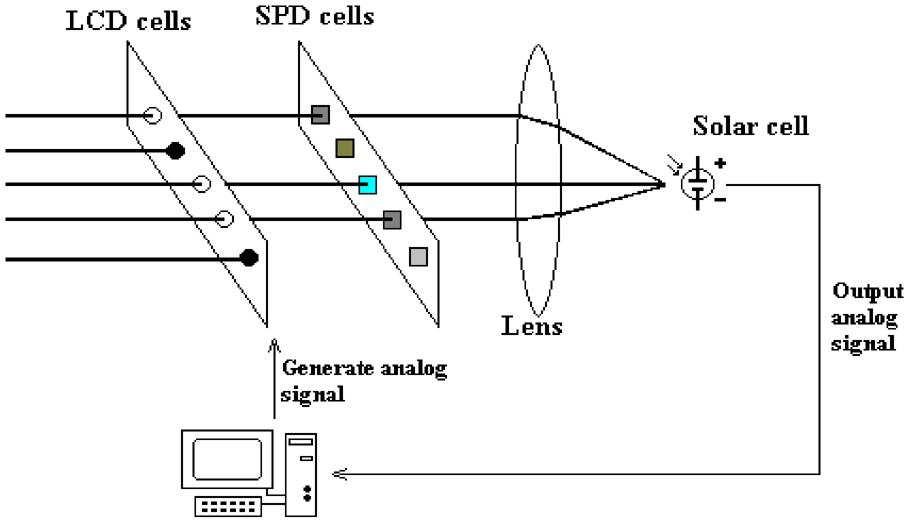

Figure 4. A schematic view of a light based-computer which performs a EHW task for solving a knapsack problem with 5 items. The weight of each item is encoded by the SPD array of glass pieces. The LCD array encodes the structure of the chromosome (the light is blocked if the corresponding gene x_i has value 0 and the light is allowed to pass if the corresponding gene x_i has value 1). When a source of light is applied, the first two arrays perform $x_i * w_i$ operation. The biconvex lens will focus all rays into a single spot which is equivalent with computing the sum $x_1 * w_1 + ... + x_n * w_n$. Finally a solar cell will convert the light into electrical power which will be sent back to the computer

- the total weight of the objects in the knapsack does not exceed the given capacity C,
- the difference between C and the sum of the weights of the objects in the knapsack is minimal.

Without losing the generality we may assume that each weight is a real number between 0 and 1. Otherwise we can scale them to that interval.

The knapsack problem belongs to the class of NP-Complete problems [2, 6]. No polynomial-time algorithm is known for solving it. Evolutionary algorithms have been extensively used for solving this problem and its countless variants [1, 5, 18].

5.2 Evolutionary Algorithms for the knapsack problem

We use a standard representation of a chromosome: a binary string x of length n. Each position x_i is filled with either 1 (meaning that the object is in the knapsack) or 0 (meaning that the object is not in the knapsack). The fitness is equal to the difference, in absolute value, between C and the sum of the objects in the knapsack. If the capacity C is exceeded, the corresponding chromosome will have the fitness equal to ∞. The fitness of a chromosome is computed by the EHW device (see section 5.3).

5.3 The EHW device

The EHW device (used for computing the fitness of a chromosome) consists in 5 main parts:

- several continuous sources of light. Their number is equal to n (the number of objects in the set M).
- an array of n LCD cells. Each cell is an reconfigurable LCD glass which lets or does not let the light to pass through. This array has the same structure as the structure of the chromosome whose fitness is computed: 1 - the light is not blocked and 0 - the light is blocked. This array will be reconfigured (by applying a predefined electric power) by the computer everytime when the fitness of a chromosome needs to be computed.
- an array of n SPD cells. Each cell is an SPD glass which allows a variable degree of light to pass through. This array encodes the weights of the given objects. When we have defined the problem (see section 5.1) we have imposed a restriction that each weight is between 0 and 1. Thus each SPD cell is configured to let $w_i * 100\%$ of the incoming light to pass through. If $w_i = 1$ it means that the corresponding glass is fully transparent allowing to pass 100% of the incoming light. When w_i is near to 0 means that the corre-

sponding glass blocks almost all of the incoming light. This array of SPD cells actually encodes the problem to be solved. This is why it should be kept fixed during a run. However, when the problem is changed (i.e. the weights of the objects are changed) we can reconfigure this SPD array too. This feature gives us a great generalization ability.

- The effect of these arrays (LCD and SPD), when a light is applied, is equivalent to performing, for each object, the multiplication $x_i * w_i$. For computing the sum of the previously generated values we can use a biconvex lens. This lens will focus all rays in a given point also called focal point. The lens is a very important piece of this device, because it can compute a sum of numbers in O(1) time. The conventional devices (electrically powered) can do this operation in O(n) time.

- The light is then captured by a solar cell (photo cell) which transforms it into electric power, which is later sent to computer as a analog signal. The computer will calculate the actual fitness based on the differences between C and the value generated by the EHW device.

5.4 How the system works?

The system works as follows (see also Figure 4):

- The SPDs cells are reconfigured at the beginning of the search in order to encode the knapsack problem (i.e. the weights of the objects). These cells are not reconfigured anymore during the current run. They are kept fixed until a new knapsack problem will be solved.

- A computer runs an Evolutionary Algorithm for solving the knapsack problem as described in section 5.2.

- When the fitness of a chromosome needs to be computed its structure will be downloaded into the LCD array. This means that the LCD array will be reconfigured (by applying/removing some electrical power to each of its cells) in order to reflect the structure of the chromosome. The light rays will pass through a cell only if the corresponding object is in the knapsack (according to the current chromosome).

- When the light rays will pass the second layer (SPDs array), they will have a power which reflects the degree of opaqueness of each cell (which actually encodes the weight of each object).

- Finally, the light rays are focused by a biconvex lens and the resulting ray will be captured by a solar cell. The signal, which is sent back to the computer, by the solar cell encodes the sum of the weights of the objects in the knapsack.

Table 1. The differences between the compared smart glass technologies. Second column shows when the glass is transparent. *Switched ON* **means that an electrical current is applied to obtain the transparent state. Third column shows whether the glass can be kept in other states between opaque and transparent. Fourth column shows whether glass requires power in order to maintain its state after an initial electrical power has been applied for changing the state**

Material	When is transparent?	Continuous states between opaque and transparent?	Requires power to maintain the state?
Suspended Particle Devices	Switched ON	YES	YES
Electrochromic Devices	Switched OFF	YES	NO
Liquid Crystal Devices	Switched ON	NO	YES

- The computer calculates the fitness by comparing value C with the sum of the objects in the knapsack.

5.5 Advantages

Because of its two levels of reconfigurability, this EHW device has an important advantage: it can be used for solving an entire class of knapsack problems, without changing the device. The second array (the array of SPD cells) allows us to reconfigure the weights, thus permitting to encode and solve all knapsack problems which have no more than n objects. However, the maximum number of objects, for a given device, cannot be modified.

Another important advantage is given by the use of the biconvex lens. This type of lens allows us to compute the sum $x_1 * w_1 + x_2 * w_2 + ... + x_n * w_n$ in O(1) time by focusing the entire light to a single spot. Note that a standard computer needs O(n) steps to do this operation.

6 Conclusion and future work

The possibility of using switchable glass for Evolvable Hardware tasks has been suggested in this paper. Three commercially available technologies in the field of smart windows have been reviewed. Strengths and weaknesses of these technologies have been deeply presented.

A potential application of these technologies for evolution *in materio* tasks has been described.

Further efforts will be focused on two directions:

- implementing the proposed hardware,
- finding new applications which are suitable for this model,
- applying the switchable glass to reversible computing [14]. This task could be possible because the glass is able to restore its original state after removing the source of energy.

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