Claytronics

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Abstract: ***Claytronics is a futuristic concept required to implement programmable matter. It involves materials which can be manipulated electronically in three dimensional space. Its a combination of nanobots and computer software to create unit entities of nano-sized computer systems called claytronic-atoms, or simply, catoms. Claytronics has various applications in the field of info-graphics, nano-medicine, telecommunication and gaming-entertainment industry.***

Keywords: catoms, ensemble, synthetic reality, nano

1. Introduction

Claytronics is a form of programmable matter, made up of three dimensional individual claytronic-atoms or catoms, whose primary objective is to move along space, and organize itself, dynamically taking desired shape of any object. The catoms adhere to each other either electrically or magnetically to maintain the required profile, and also share their state information.

Also termed as synthetic reality, this system has the ability to render its outer surface to synchronize with the visual appearance of the object it is replicating. The catoms form a network in an orderly manner, based on the state information. First, a series of snapshots is taken of the object at various locations and orientations, and also the various forces acting on it, its color and texture is determined. Then this information is broadcast to these cluster of catoms(ensembles), where each catom is provided a local/elemental plan to achieve the desired global shape.

Claytronics thus can be used even to replicate any physical artifact or even a person to such an extent that our senses can perceive these to be real. Unlike virtual or augmented reality, synthetic reality can interact with its environment on its own, without any use of augmented sensory devices.

2. Catoms

Catoms are analogical to atoms and molecules of physical matter. They are the smallest single unit of programmable atom which can function independently. Each of these catoms can receive and process information, manipulate electronic instructions and interact with other catoms. They are an integration of modular nanobots and computer program, capable of self assembly. A catom is similar to a computer, but in a nano-scale. It consists of various familiar components like a central processing unit, peripheral sensors, a power supply, a single pixel display, certain assistance system for its movement and any magnetic or electrostatic adhesion mechanisms.

3. Software

Let us consider the catoms are replicating a human in real time. Then an ensemble would easily contain millions of catoms would have to simultaneously coordinate and shape shift. It is not practical to individually code the program for each catom. Hence few advanced programming software are developed to provide instructions to the ensemble. They have created a complete structure of software resources which creates a distributed network of nodes in the Claytronics matrix, having a huge computational capacity within a very small space. They just provide one program and some constraints, which automatizes all the units which organize themselves following certain simple rules.

A few of the software development research going on at the CMU-Intel Claytronics Laboratory, are mentioned below.

3.1 Ensemble Programming Language

The programming languages are designed to accommodate parallel computing capability, where enormous processing power is confined to a very limited space. Two Major Claytronics Ensemble Programming Languages that are developed are: Meld and Locally Distributed Predicates (LDP).

MELD: It is a form of logical programming which concentrates on the overall performance of the catoms' matrix. It uses a heuristic solution to compute all the individual nodes. Meld is a declarative language based on P2, a logic designed for static topology, extended to the dynamic catoms.

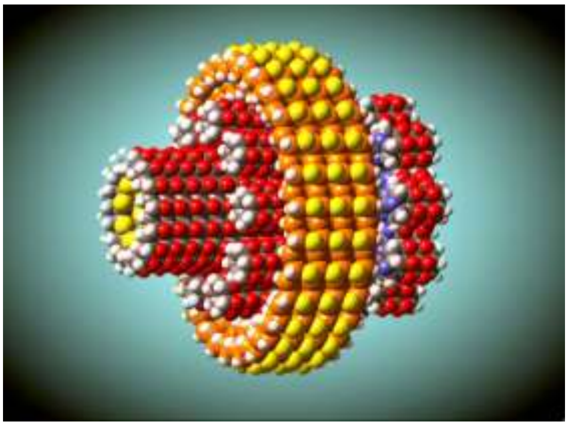
Locally Distributed Predicates (LDP): While Meld utilizes logical programming technique, LDP uses pattern matching instead. It provides a means of controlling the catoms by matching distributed patterns, where the program can control a group or module within the ensemble. This makes shaping of the matrix much simpler.

3.2 Distributed Watch-Points

While millions of tiny catoms are working together simultaneously, sharing vast information through threads, the chances of system failure due to bugs, exponentially increases. Thus for debugging, various mechanisms are used, one of which are the distributed watch-points. These watch-points concentrate on key nodes analyzing the functionality and configurations of separate modules. Thus due to modular approach, the debugging of the ensemble becomes much simpler, faster and efficient.

3.3 Shape Sculpting

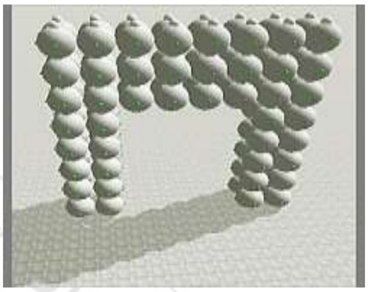
For the formation of the catoms, the ensemble should shape itself without the aid of any external force. To achieve this, the adjacent catoms use their power source to induce an electrostatic alignment or a latching effect. This increases the hold of one catom on those surrounding it, at a local level. Now at a global level, for the ensemble construction, we requires cranes and joints to support the structure.



Thus algorithms, like Collective Actuation, are used to design stable patterns of the structure which should be rigid enough against the effects of gravity. Thus complex shapes can be formed using this tool, which design geometric structures which can dynamically sustain motion and body forces.

3.4 Dynamic Simulation

Dynamic Physical Rendering Simulator (DPRSim) designs and tests modular bots in real world conditions. Its a LINUX based software which conceptually visualizes millions of ensembles, which helps the user to visually observe the nano-scale catoms in a magnified way. It also provides simulation of ensemble under physical phenomena such as power flow, magnetic, gravity and friction.

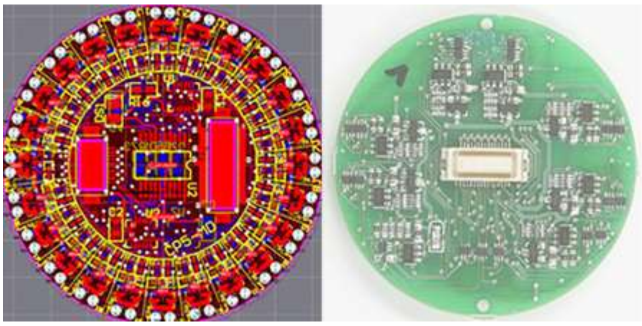


3.5 Localization

For a system of modular robots, one of most important constraints is to know the location of the modules, relative to one another. This information is gathered by the on-board sensors, like short-range IR sensors. Since the modules often form non lattice structures, sophisticated techniques are required to estimate the location, from the noise data of the surroundings. Thus a software is used to disintegrate the ensemble, into smaller components. The software also limits the data resource available to each module, allowing it to interact and share data only with its adjacent modules.

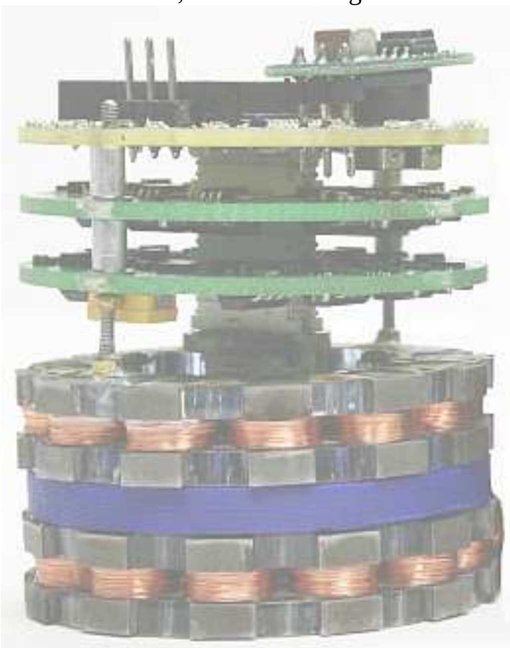
4. Hardware

The pioneers in designing the Claytronics Hardware are the research and development team of the Intel Corp-Carnegie Mellon University. They are testing the effects of various ambient scenarios on the micro mechatronic components. These components should be easily manufacturable, and should have self assembly capability. Right now they are testing on macro scale designs, trying to first master the self actuation and adhesion mechanisms. They have developed various prototypes, classified by their geometry and functionality. A brief description of this classification is given below.

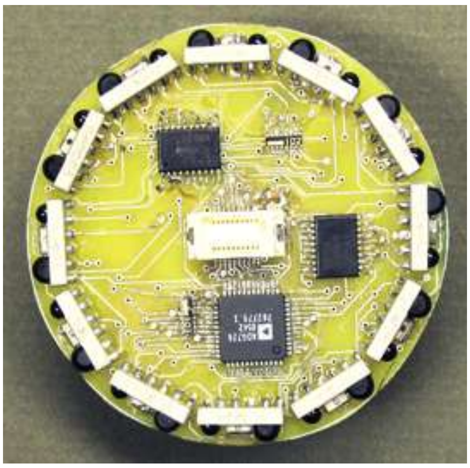


4.1 Planar Catoms

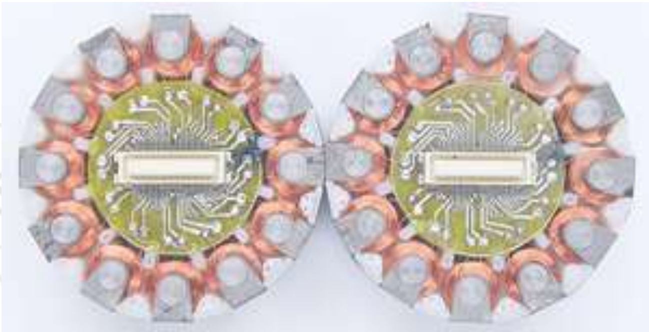
The Planar Catoms are cylindrical shaped macro sized prototypes of the actual micro electromechanical systems. They are used to test for the power distribution within the ensemble, self actuation mechanism using magnetism. All these are essential characteristics required for the proper working of the nano scale modular robots. Currently, eight versions of planar catoms have been developed, the latest being Planar Catom V8, shown in the figure below.



It is a macro scale prototype which weighs nearly 0.1 kg. It is a cylindrical stack of Planar control boards and magnetic rings. The control board transfers the data and instructions between adjacent modules. The controller board carries a microprocessor, registers, micro circuits, driver boards, light emitting diodes, and other such hardware. The drive boards control the magnetic intensity of the magnetic rings attached to it. Thus it can control the actuation and adhesion of the ensemble. The module also houses an infrared communication board for information interchange. They play a crucial role in debugging and in reprogramming large ensembles of catoms. A picture of a Planar Control Board is shown in the following image.

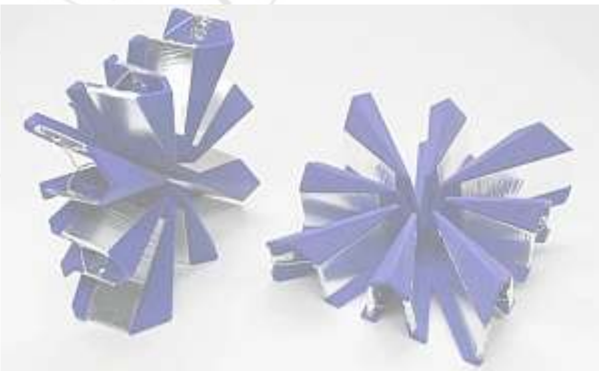


The motion of the catoms is achieved by the magnetic rings, on the planar catoms. The Planar Catom V7 and V8 can house up to 24 magnets, with two driver boards controlling 12 magnet rings each. The electromagnets, which act as force effectors, are arranged in such a way that the ring forms a 12 sided polygon with an acrylic base holding it together. Thus the planar catoms can only interact with other catoms on the same two dimensional plane. For motion, the electromagnets use magnetic attraction and repulsion, by effectively converting its electromagnetic energy into kinetic energy. The magnetic rings also have significant power loss in overcoming friction due to the contact of catoms and gravity due to its self weight. The top view of a pair of magnetic rings interacting is shown in the figure below.

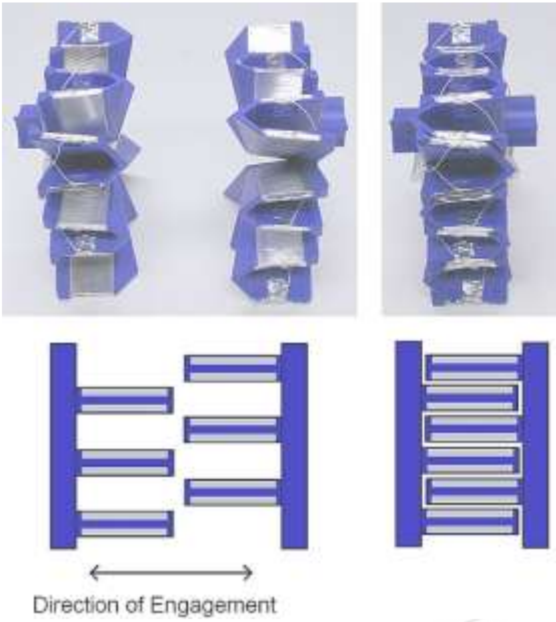


4.2 Electrostatic Latches

The electrostatic latch is a simple component used for adhesion of catoms. They have capacitor plates made of thin flexible electrodes made from aluminum foils and have a dielectric medium in between which creates an electrostatic pressure, which results in capacitance coupling. This latch is further enhanced by the mechanical shear force acting between the electrodes. The have a gender-less profile of these star shaped electrodes, which can latch without constraints.



The design of the latch should be in such a way that the adhesion is fast, flexible and accurate. It should also ensure that the bond is very strong, but at the same time should support facile release, as and when the ensemble is reprogrammed at computational speeds. These latches not only use capacitance, but also use friction to strengthen their latching force. The combs of the latches have a 45 degree inclination blades at their edges. After they bond, these blades act in such a way that they oppose peeling away over the surface, keeping them intact. This figure shows the schematic diagram of the working on the electrostatic latches.

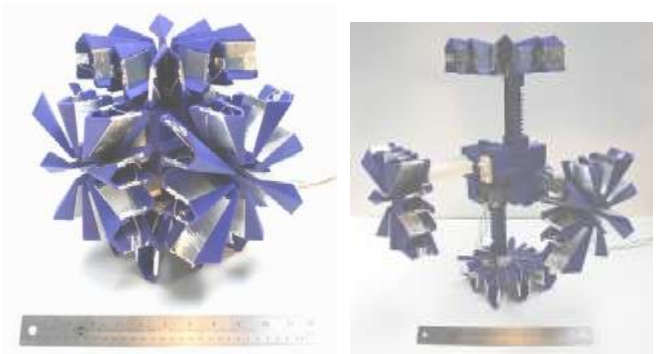


4.3 Stochastic Catoms

Stochastic Reconfiguration is a concept being tested at the MCU-Intel Corp Laboratory. The ideology of this reconfiguration is that, instead of limiting the actuation to electrostatic or magnetic forces, they have extended it external forces like, currents of air. Thus these catoms can undergo motion, also using buoyancy forces. The objective is to achieve the required shape with minimal power consumption. The students of the Carnegie Mellon University tested this concept using cube shaped catoms' prototypes using lightweight Mylar helium balloons. They have a very large size and relative negligible mass(near-zero-mass). This reduces the effect of gravity which now becomes relatively smaller compared to the electrostatic forces.

4.4 Cubes

The Cube is a lattice styled modular robot, developed by the Carnegie Mellon University. It uses electrostatic latches for its actuation. The cube satisfies that basic criteria of a good adhesion system which has strong bonds, quick release mechanisms, structural stability and close spacing. The cube has six latches on each of its side which are connected to a stem, as shown. These stems can extend or contract, enabling the cube to attach to another cube at its proximity.



The capacitance couple is not limited to only physical adhesion. It also activates real time data sharing, communication and power transfer. This enables communication between all catoms within the ensemble, and it can transfer power from a power surplus region to a deficient region, thus managing energy resources efficiently.

5. Applications

Claytronics is an emerging field with a global market valued at billions. The research and development of synthetic reality, is undertaken in several key regions, namely, North America, Europe, China, Japan, South East Asia And India. They are implementing the concept of programmable matter in various fields. The key players in Claytronics application in real life, are : Claytronics Inc., Intel Corp., Claysol Inc., and Claytronics Solution Private Limited. The fields to actively use this futuristic technology, in the near future are:

- Health care : Claytronics can be used for surgical instrumentation, diagnosis, pharmacokinetics and targeted drug delivery. It is also used to monitor vitals of the body.
- Aerospace And Defense : Synthetic reality enables the armed forced to attack sensitive enemy territories using ensembles which can shape shift and reach the target location, thus eliminating human casualties. Also the aircraft can control its color and external features, thus enabling a visual camouflage against its enemies.
- Entertainment : It is used in gaming industries for creating synthetic game-play, where the ambient map, and other players recreated. This is taking the current virtual reality gaming to the next level, where you can not only see, but also feel your immediate surroundings.
- Robotics And Automation : Claytronics gives the much required flexibility, structure and speed to robotics. Now humanoid robots can be designed to be even more realistic, with their look, feel and behavioral approach very close to that of actual human beings.
- Physical Data Transfer: In the technique called 3D faxing, the three dimensional model has to just accept the required information and the catoms assemble on their own to form a synthetic copy of the object whose configuration, orientation and dimensions are presented.
- Communication : Claytronics has taken communication to a whole new level with its concept called "pario". It is similar to an audio visual conferencing, but here the person can be replicated in three dimensions. So its very similar to physically interacting with the real person .

6. Drawbacks

Although claytronics has potentially great effects on various aspects of life, it does have some drawbacks which needs to be considered.

- Currently, only control of an ensemble having extremely small number of catoms is possible. This control has to extended to ensemble having millions of catoms in dynamic motion, which is extremely difficult.
- Designing a robust program to control each catom individually is complicated, since the visualization and developing the algorithm is confusing and time-consuming.
- Designing the nano scale modular robots having the same functionality as its macro scale prototypes is practically unachievable.
- The information of the catoms' location should be stored in the data cloud, with each node having an IP address, for easier access. Thus the range of communication of the catoms should be increased drastically, and not limit it only to the adjacent catoms.
- As the number of modules increase, the process of debugging becomes laborious. Also the chances of failure due to internal issues or external attacks increases with the number of catoms in the ensemble.
- Although Claytronics has wide applications, the cost of manufacturing of the catoms, as of now, is not justifiable.

7. Conclusion

Claytronics creates a bridge between human and computer interface, where the interactions are extended to physical nature. The computational power and nanotechnology advancement required to implement Claytronics today, is insufficient, but is practically feasible. Thus within the following couple of decades of innovation and research we can fully integrate our daily lives with synthetic reality.

8. Acknowledgment

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V Gautham Sai Natekar, Gnana Tejesh M and Sriram Srinivasan are all final year mechanical engineering students, pursuing their Bachelors in PESIT-South Campus, Bangalore. They have worked on various projects before, like SAE Collegiate Aero Design Test, ISIE Hybrid Vehicle Challenge, etc. Apart from academics, each of them have notable interests in other fields. Gautham is a pianist and a poet, Tejesh is a playback singer and Sriram is a runway model, who has won quite a few inter-collegiate competitions.