Programmable Matter - Claytronics

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ABSTRACT- "Claytronics" is a developing field of electronics reconfigurable nano-scale robots ('claytronic atoms' or catoms) designed to form much larger machines or mechanisms. Also known as 'Programmable matter', the catoms will be sub-millimeter computers that will eventually have the ability to move around, communicate with each other, change color, electrostatically connect to other catoms to form different shapes. The shapes made up of catoms could mutate into nearly any object, even replicas of human beings for virtual meetings.

The design for the Claytronics model is extremely on scalable modular robotics developed as part of the Claytronics Project. This concept foresees multi-million-module robot outfits which are able to change into three-dimensional prospects, eventually with sufficient conformity so as to persuade that the visions are for real. This project involves coordination and communication of sensing and actuation across such large ensembles of independent units.

This paper talks about the need to understand and develop the hardware and software necessary to create programmable matter, a material which can be programmed to form dynamic three dimensional shapes which can interact in the physical world and visually take on an arbitrary appearance and thus replicate to an item using mini-computers.

According to Carnegie Mellon's Synthetic Reality Project personnel, claytronics are described as "An ensemble of material that contains sufficient local computation, actuation, storage, energy, sensing and communication" which can be programmed to form interesting dynamic shapes and configurations. Claytronics technology is currently being researched by Professor Seth Goldstein and Professor Todd C. Mowry at Carnegie Mellon University, which is where the term was coined.

This technology is not only effective in many skilled disciplines from engineering innovativeness, education and healthcare to entertainment and leisure activities such as video games but it a step which can lead the world towards an innovative revolution. The main purpose of this technology is to improve human-to-human communication even when they remain considerably far away.

A beautiful example to depict the worth of this technology is the video conferencing which makes the 2-D image to be transferred from one place to another but being impossible to transfer a 3-D image.

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Using claytronics, the physical presence of the person sitting beside can be felt continents away. This system could also have a role in telemedicine, allowing a patient and doctor to be miles away and examining the patient with claytronics emulations. Thus, this is the next unparalleled entity towards a Future World.

INTRODUCTION

Atoms combine to form molecules and the micro or nano scale devices can combine to form the shapes of physical entities. This concept known as "programmable matter" can collaborate to a material called Catoms or "Claytronics atoms". These Catoms are the ones that contain sufficient local computation, actuation, storage, energy, sensing and communication which can be programmed to form interesting dynamic shapes and configurations. Claytronics is the way of bringing this idea into reality. With claytronics, millions of tiny individual devices- "claytronics atoms" or "Catoms" would assemble into macro-scale objects, connecting and disconnecting as they move.

The innovation in this field combines the concepts of nanotechnology along with telepresence. Small robots or 'Catoms" of the size of a few millimeters (or a few nanometers) organize themselves into a shape that is determined remotely. For example, an individual located at a remote location have a 'claytronic' model of himself move, gesture and generally mirror all of his actions. It would be as if a solid image is projected of him. This technology would consent surgeons to perform intricate surgery on enlarged claytronic replicas of organs at the same time the actual organs are being worked upon by a claytronic replica of the surgeon and would enable the engineers to work remotely in physically hostile environments.

The Claytronics seems to be a little unbelievable and more than a sci-fi, however work has already begun towards such technology. The current large proof-of-concept Catoms (measuring 4.4 centimeters) connect and move via magnets, much like the "replicating" robots, operating at scales where electromagnetic or electrostatic connections are used for reassembling. The Catoms could have LCD or LED sufaces able to produce a faintly glowing image, so that what appeared to be a model made of millions of tiny microbots. Backed by the microchip manufacturer Intel, first generation Catoms, measuring 4.4 centimeters in diameter and 3.6 centimeters in height have been developed. The main concerns for the development of this technology are to create the basic modular building block of claytronics known as the claytronic atom or Catom, and to design and write robust and reliable software programs that will manage the shaping of

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ensembles of millions of Catoms into dynamic, 3-dimensional forms.

These Catoms which are ringed by several electromagnets are able to move around each other to form a variety of shapes. Containing elementary processors and drawing electricity from a board that they rest upon. So far only four Catoms have been operated together. The idea is to have thousands and millions of them moving around each other to form whatever shape is desired and to change color, also as required.

A. CATOMS

The "Claytronic atom" or Catom would be similar to the look of an atom and is preferred to be spherical in shape. A Catom would have no moving parts and each of the Catoms will act as an individual and would be covered by electromagnets to attach itself to other Catoms.

Each Catom would contain a fairly powerful processor and the Catoms surfaces would have photocells to sense light and light-emitting diodes to allowing it to see and to change color. The researchers are presently trying to build a two-dimensional version, with each Catom being a cylindrical device a little more than an inch in diameter with its side encircled by 24 electromagnets. It would move by the rolling of the electromagnets one over the other.

A large moving object such as a human replica might have billions of Catoms. A system with a billion computer nodes is something on the scale of the entire internet. Unlike the real internet, our thing is moving. This will require new schemes for quickly organizing and reorganizing such a large computer network. A moving shape will make the Catoms to constantly and quickly change positions, breaking connections with one set of Catoms and establishing new connections with others.

B. HARDWARE

Claytronics hardware operates from macro scale designs with devices that are much larger than the tiny modular robots that set the goals of this engineering research. Such devices are designed to test concepts for sub-millimeter scale modules and to elucidate crucial effects of the physical and electrical forces that affect Nano scale robots. Catoms created from the present research to populate claytronic ensembles will be less than a millimeter in size, and the challenge in designing and manufacturing them draws the CMU-Intel Research team into a scale of engineering where have never been built. The team of research scientists, engineers, technicians and students who design these devices are testing concepts that cross the frontiers of computer science, modular robotics and systems nanotechnology.

i. Planar catoms test the concept of motion without moving parts and the design of force effectors that create cooperative motion within ensembles of modular robots.

ii. Electrostatic latches model a new system of binding and releasing the connection between modular robots, a connection that creates motion and transfers power and data while employing a small factor of a powerful force.

iii. Stochastic Catoms integrate random motion with global objectives communicated in simple computer language to form predetermined patterns, using a natural force to actuate a simple device, one that cooperates with other small helium Catoms to fulfill a set of unique instructions.

iv. Giant Helium Catoms provide a larger-than-life, lighter-than-air platform to explore the relation of forces when electrostatics has a greater effect than gravity on a robotic device, an effect simulated with a modular robot designed for self-construction of macro-scale structures.

v. Cubes employ electrostatic latches to demonstrate the functionality of a device that could be used in a system of lattice-style self-assembly at both the macro and nano-scale.

The Carnegie Mellon-Intel Claytronics Hardware Lab has prepared the path for development of a millimeter scale module that will represent the creation of a self-actuating Catom- a device that can compute, move and communicate at the nano-scale. With the millimeter scale modular robot, the Claytronic Hardware Lab will demonstrate the feasibility of manufacturing Catoms in the quantities needed to produce dynamic 3-dimensional representations of original objects.

B. 1. PLANAR CATOMS

The self-actuating, cylinder-shaped planar Catom tests concepts of motion, power distribution, data transfer and communication that will be eventually incorporated into ensembles of nano-scale robots. It provides a test bed for the architecture of micro-electro-mechanical systems for self-actuation in modular robotic devices. Employing magnetic force to generate motion, its operation as a research instrument build a bridge to a scale of engineering that will make it possible to manufacture self-actuating nano-system devices.

The planar Catoms operates on a two-dimensional plane in small groups of two to seven modules in order to allow researchers to understand how micro-electro-mechanical devices can move and communicate at a scale that humans cannot yet readily perceive -- or imagine. These are approximately 45 times larger in diameter than the millimeter scale Catom for which its work is a bigger-than-life prototype.

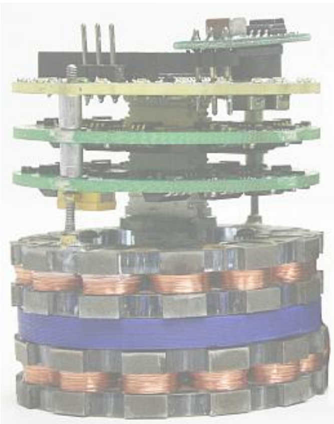

Fig. 1 Planar Catom V8

The view of the stack of control and magnet-sensor rings of the Plnar Catom V8 is shown above. Its solid state electronic controls ride at the top of the stack. An individual control ring is dedicated to each of the two rings of magnet sensors, which ride at the base of the module. Two thin threaded rods extend like lateral girders from top to bottom through the outside edge to brace the rings. A central connector stack carries circuits between control and magnet rings, enabling easier handling and maintenance of components while also providing internal alignment and stability along the cylinder's axis. At the base of the planar catom, the two heavier electro-magnet rings, which comprise the motor for the device, also add stability. To create motion, the magnet rings exchange the attraction and repulsion of electromagnetic force with magnet rings on adjacent catoms. From this conversion of electrical to kinetic energy, the module achieves a turning motion to model the spherical rotation of millimeter-scale catoms.

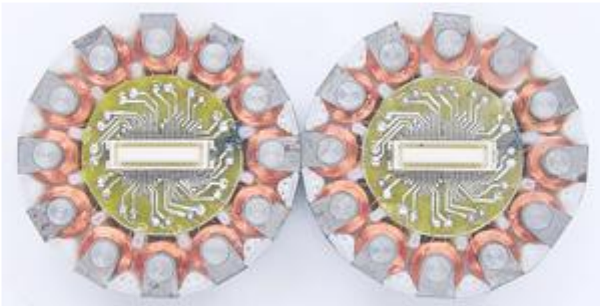

Fig. 2 Magnetic Rings from Planar Catom V7

The above picture shows two magnet rings from Planar Catoms displaying the arrangement of their 12 magnets around individual driver boards and the coil design for horse-shoe magnets.

A Catom sustains a clockwise or counterclockwise motion by a continuous transfer of electro-magnetic force to achieve the opposite motion in the other Catom. The planar Catom faces unique issues from alignment and friction, which this image suggests.

Fig. 3 Planar Catoms with LED

The picture above displays a planar Catom controller ring with light emitting diodes (LEDs) arranged around its perimeter. This board directs the two magnet driver boards embedded in the magnet rings.

The custom design of the electronics achieves a very high level of capacity to guide the module’s performance. Built with the smallest components commercially available, each controller board contains 5 layers of embedded microcircuits on 45 mm diameter acrylic boards. At this density of circuit design, wach of the two controller rings provides approximately 40 times the embedded instrumentation of a standard robotics controller package in 2/5th the space. The resulting capacity of its boards enables the module to carry on board all devices needed to manage its firmware, drivers and 24 magnets.

B. 2. ELECTROMAGNETIC LATCHES

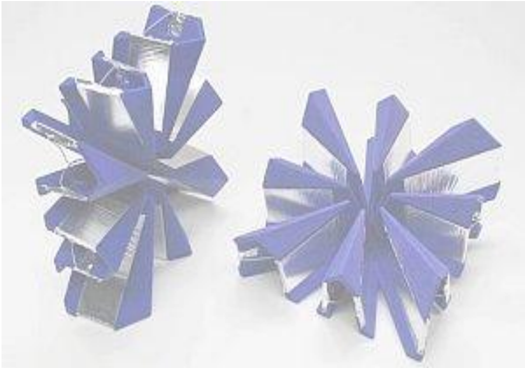

Fig. 4 Electrostatic Latches

It incorporates many innovative features into a simple, robust device for attaching adjacent modules to each other in a lattice-style robotic system. These features include a parallel plate capacitor constructed from flexible genderless electrodes of aluminium foil and dielectric film to create an adhesion force from electrostatic pressure. Its physical alignment of electrodes also enables the latch to engage a mechanical shear force that strengthens its holding force.

Currently, the electrostatic latch is being tested on a modular Cube that is 28 cm on a side. Each star-shaped face supports passive self-alignment of the link with a 45-degree blade angle at the top of each comb on the face. The design also supports easy disengagement with a five-degree release angle along the vertical lines of the faces.

B. 3. STOCHASTIC ATOMS

The module makes its decision by evaluating the relation of its form in the instance of the contact location to the ensemble's overall goal for a predetermined shape. Based on this evaluation, the module either forms a bond or continues in motion. Computations within the electronic module follow a simple program, known as a graph grammar, which enables each stochastic catom independently to determine its location in relation to other catoms in the ensemble - and in relation to a predetermined shape into which the catoms locate their positions from random motion.

B. 4. GIANT HELIUM CATOMS

A Giant Helium Catom (GHC) measures eight cubic meters when its light Mylar skin fills with helium to acquire a lifting force of approximately 5.6 kilograms. This lift is necessary to elevate a frame of carbon fiber rods and plastic joints, which contains the balloon and carries electronic sensors and a communication package to actuate the catom's motion and engage it with other GHCs.

The Giant Helium Catom provides researchers a macroscale instrument to investigate physical forces that affect microscale devices. The GHC was designed to approximate the relationship between a near-zero-mass (or weightless) particle and the force of electro-magnetic fields spread across the surface of such particles.

B. 5. CUBES

A lattice-style modular robot, the 22-cubic-centimeter Cube provides a base of actuation for the electrostatic latch that has also been engineered as part of this program.

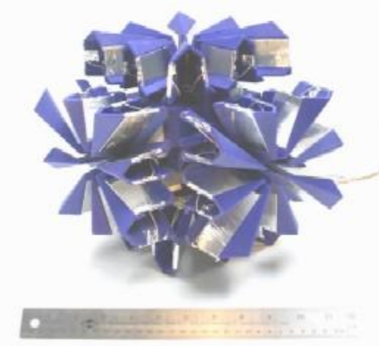

Fig. 5 Cube Catoms

The Cube also models the primary building block in a hypothetical system for robotic self-assembly that could be used for modular construction and employ Cubes that are larger or smaller in scale than the pictured device.

The design of a Cube, which resembles a box with starbursts flowering from six sides, emphasizes several performance criteria: accurate and fast engagement, facile release and firm, strong adhesion while Cube latches clasps one module to another. Its geometry enables reliable coupling of modules, a strong binding electrostatic force and close spacing of modules within an ensemble to create structural stability.

C. SOFTWARE

In a domain of research defined by many of the greatest challenges facing computer scientists and roboticists today is perhaps the creation of algorithms and programming language to organize the actions of millions of sub-millimeter scale Catoms in a claytronics. As a consequence, the research scientists and engineers have formulated a very broad-based and in-depth research program to develop a complete structure of software resources for the creation and operation of the densely distributed network of robotic nodes in a claytronic matrix. A large, moving shape such as a human replica might contain a billion Catoms. A system with a billion computer nodes is something on the scale of the entire Internet. Unlike the real Internet, our real thing is moving.

A notable characteristic of a claytronic matrix is its huge concentration of computational power within a small space. For example, an ensemble of catoms with a physical volume of one cubic meter could contain 1 billion catoms. Computing in parallel, these tiny robots would provide unprecedented computing capacity within a space not much larger than a standard packing container.

Because of its vast number of individual computing nodes, the matrix invites comparison with the worldwide reservoir of computing resources connected through the Internet, a medium that not only distributes data around the globe but also enables nodes on the network to share work from remote locations. The physical concentration of millions of computing nodes in the small space of a claytronic ensemble thus suggests for it the metaphor of an Internet that sits on a desk.

In the Carnegie Mellon – Intel Claytronics Software Lab, researchers address several areas of software development.

C. 1. PROGRAMMING LANGUAGES

Researchers in the Claytronics project have also created Meld and LDP (Locally Distributed Predicates). These new languages for declarative programming provide compact linguistic structures for cooperative management of the motion of millions of modules in a matrix.

C. 2. INTEGRATED DEBUGGING

In directing the work of the thousands to millions of individual computing devices in an ensemble, claytronics research also anticipates the inevitability of performance errors and system dysfunctions. Such an intense computational environment requires a comparably dynamic and self-directed process for identifying and debugging errors in the execution of programs.

C. 3. SHAPE SCULPTING

The team's extensive work on Catom motion, collective actuation and hierarchical motion planning addresses the need for algorithms that convert groups of Catoms into primary structures for building dynamic, 3-dimensional representations. Such structures work in a way that can be compared to the muscles, bones and tissues of organic systems.

C. 4. LOCALIZATION

The team's software researchers are also creating algorithms that enable Catoms to localize their positions among thousands to millions of other Catoms in an ensemble. This relational knowledge of individual Catoms to the whole matrix is functional to the organization and management of Catom groups and the formation of cohesive and fluid shapes throughout the matrix.

C. 5. DYNAMIC SIMULATION

The simulated world of DPRSim manifests characteristics that are crucial to understanding the real-time performance of claytronic ensembles. Most important, the activities of Catoms in the simulator are governed by laws of the physical universe. Thus simulated Catoms reflect the natural effects of gravity, electrical and magnetic forces and other phenomena that will determine the behavior of these devices in reality. DPRSim also provides a visual display that allows researchers to observe the behavior of groups of Catoms.

D. APPLICATIONS

i. This technology would enable engineers to work remotely in physically hostile environments.

ii. Surgeons to perform intricate surgery on enlarged claytronic replicas of organs, whilst the actual organs are being worked upon by a claytronic replica of the surgeon.

iii. A 3-D Fax machine is a new approach to 3-D faxing. A large number of sub millimeter robot modules form intelligent clay which can be reshaped via the external application of mechanical forces. The clay can act as a novel input device, using inter module localization techniques to acquire the shape of a 3D object by casting.

The process of remotely reproducing a facsimile of an object requires three phases: Acquisition, Transmission and Reproduction. In the first phase, the system senses the object and creates a digital representation of the visible, external structure. The shape information is then transmitted to the remote site. Finally, using the transmitted date, a facsimile of the object is reconstructed at the remote site.

Building a moving, sensing, color changing replica of each person out of nanotech robots makes every meeting a face-to-face meeting. This is the 3D Video conferencing. We feel that the person, continents away, as sitting right beside you.

iv. 3D TVs and movies may also be possible using this claytronics.

v. It might be useful for producing 3D shapes in the computer-aided design process.

vi. Claytronics cell phone might grow a full-size keyboard, or expand its video display as needed.

E. DISADVANTAGES

i. With so many Catoms, the system will have to compensate for the inevitable failure of individual Catoms. Computers don't deal well with failure.

ii. Algorithm and programming the combined motion of Catoms to form a 3D shape is a very ridiculous task.

iii. Even the nodes of the Internet have some addresses and accessing them is hard. Accessing each Catom without any address is a very difficult task.

iv. At present, only four individual Catoms are made to communicate with each other. But, the thought of making billions of Catoms to communicate may take a few decades.

v. Even though the mentioned applications are possible, the cost involving the manufacturing of these Catoms may not be affordable.

F. CONCLUSION

Unpredictable is the future though, changes in the technology trends prepares everybody for tomorrow. Biotechnology, Genetics, Space Science, Nanotechnology, Material Science, Robotics and many more fields of technology managed to make their way out from science fiction in last 4 to 5 decades. Claytronics is an exception as it never existed in science fiction as a science or technology until recent years, and yet here we are discussing the possibilities if programming matter.

According to Moore's Law, the transistors count in an Integrated Circuit almost doubles every year. This shows the rapid development in the electronics in the recent decades. If this continues the concept of Claytronics will not be hard to achieve.

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