Catoms: Moving Robots Without Moving Parts

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Abstract

We demonstrate modular robot prototypes developed as part of the Claytronics Project (Goldstein et al. 2005). Among the novel features of these robots ("catoms") is their ability to reconfigure (move) relative to one another without moving parts. The absence of moving parts is central to one key aim of our work, namely, plausible manufacturability at smaller and smaller physical scales using high-volume, low-unit-cost techniques such as batch photolithography, multi-material submicron 3D lithographic processing, and self assembly. Claytronics envisions multi-million-module robot ensembles able to form into three dimensional scenes, eventually with sufficient fidelity so as to convince a human observer the scenes are real. This work presents substantial challenges in mechanical and electronic design, control, programming, reliability, power delivery, and motion planning (among other areas), and holds the promise of radically altering the relationship between computation, humans, and the physical world.

Introduction

The past six decades have brought tremendous reductions in the physical scale of computing hardware. We envision a similar reduction in the scale of modular robotics, made possible by the extension of present high-volume manufacturing techniques (e.g., such as used in semiconductor fabrication). Millions of sub-millimeter robot modules each able to emit variable color and intensity light will enable *dynamic physical rendering* systems, in which a robot ensemble can simulate arbitrary 3D scenes and models. Such systems could have many applications, such as telepresence, human-computer interface, and entertainment.

The high complexity of existing modular reconfigurable robot systems and limits on the operations possible in bulk microfabrication make a simple downscaling of known modular robot designs very difficult. In particular, intricate assembly of complex, independently manufactured parts may be onerous or not cost effective at submillimeter scales. Common mechanisms such as latches, gears, shafts, and solenoids could also be problematic. Radical simplification and redesign of robot mechanisms is important to ease such radical downscaling. To enable this, we adopt a design principle which we term *the ensemble axiom:* a robot should include only enough functionality to contribute to the desired functionality of the ensemble. Each robot ("catom") must work cooperatively with the rest of the ensemble to move, communicate, and obtain power.

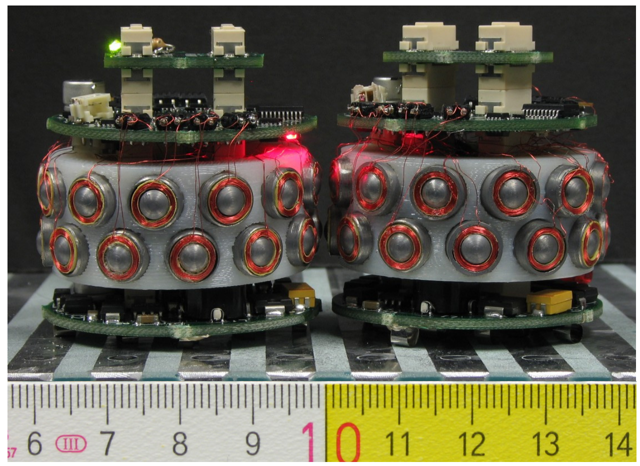

Figure 1: Cylindrical (2D) prototype catoms, each 44 mm in diameter. Reconfiguration/movement is accomplished by coordinated energizing of adjacent magnet coils. Over five single-step reconfiguration operations (rotation from one docking site / pair of magnets to the next) are possible per second even with open-loop control and no periodic resynchronization.

Demo Overview

In the demonstration, two catoms (Fig. 1) move relative to one another by cooperatively energizing pairs of magnets along their outer surfaces. Each catom carries 24 magnets and corresponding 24 channels of magnet drive circuitry, but at any given time only a single magnet is energized on each catom in the present demonstration. The time required for a “step reconfiguration”, from one pair of magnets to an adjacent pair, is on the order of 100ms.

Power to operate electronics and magnets is provided via pickup feet on the bottom of each catom. These feet make contact with conductive strips in the table, where strips connect alternately to +15VDC or ground. On-board rectification circuitry resolves the polarity of the power connections and an on-board DC/DC converter on each catom efficiently transforms the high voltage available from the table to 5VDC to power logic components. (The magnets are driven with unregulated power directly from the rectifiers.)

Each magnet is controlled by an H-bridge circuit, the H-bridges are in turn driven by outputs from serial-in-parallel-out shift registers, finally, the shift registers are loaded by a microcontroller. This approach increases the current available for driving the transistors in each H-bridge and reduces the size/pin-count of the microcontroller package.

Future prototypes will also incorporate a 32-bit microprocessor for high-level control, wireless (broadcast) and optical (nearest-neighbor) communications subsystems, and wired (unary) interconnects between catoms for use in power sharing via “virtual wires” (Campbell et al. 2005).

Related Work

A number of modular robotics efforts have focused on movement and locomotion (e.g., Yim et al. 1997; Murata et al. 1994;). The approaches have been frequently limited by slow docking/undocking speeds due to the need to precisely position modules before successful mechanical engagement. Others researchers have sought to apply modular robotics to shape formation (e.g., Murata et al. 2002; Winkler et al. 2004; Yim et al. 1997; Suh et al. 2002). These approaches have suffered from the large physical size of the modules involved, and relatively small numbers of modules envisioned (typically, thousands), which limits the spatial fidelity with which shapes can be resolved. Our work takes as a base assumption the need to support millions of cooperating catoms which should be capable of extremely high speed reconfiguration (i.e., no multiphase alignment procedures).

A further distinction in our work is the focus on radical simplification to the extent that moving parts and gendered and multiconductor connectors are entirely eliminated. Our module design is even less complex than prior work which, for similar reasons, has also aimed at module simplicity (e.g., Yim et al. 2000; Rus and Vona 1999).

Acknowledgements

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