The usBot and Programmable Self-Assembly

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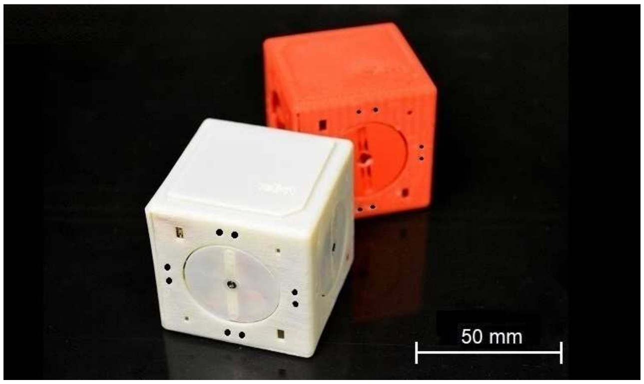

Fig. 1. usBots: Modular, programmable self-assembly robots.

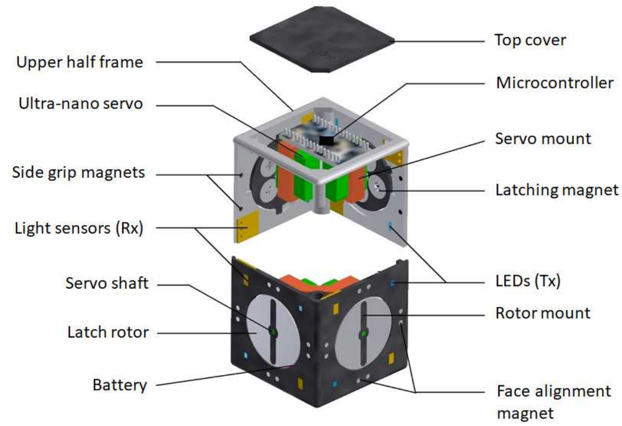

Fig. 2. usBot: Programmable self-assembly robot internal systems.

I. Background and Motivation

Self-assembly refers to the origin of patterned structures, that emerge from the collective behavior of simpler participating elements, acting autonomously. The intrinsic motivation for a great deal of research in this area is two fold. First, to understand self-assembly in general, to improve our knowledge of the natural self-assembling processes. Second, which is our intention as well, is to design, and develop intelligent modular robots, with the potential of demonstrating programmable self-assembly. Working along the same lines, we have developed a new self-assembling robot, the usBot, a passive magnetic latching robot, with a novel release mechanism, capable of demonstrating autonomous, and distributed self-assembly in 2D (see Fig. 1).

The applications and prospects for programmable self-assembly could be enormous. Some applications are already out there; for example, self-reconfiguring modular furniture [1]. Most of these existing systems emphasize on the locomotion capabilities of the robot, which often overshadows the goal of designing simple modular robots, which can self-assemble, or self-reconfigure in a truly decentralized, and autonomous fashion. In addition, most of the existing modular systems either use mechanical latching [1], or Electro-permanent magnets (EPMs) [2], which pose well known difficulties in design, as well as operation. Permanent magnets are known for their splendid latching strength [3], as well as for their usefulness in many important applications [4]. Some modular robots [5], do utilize permanent magnets for bonding, but they require a complex inertial actuator, to overcome the strong attraction of passive bonds, which is power consuming. Although, such a system is capable of self-reconfiguration in 3D, it is of little importance to be considered as a test bench for self-assembly algorithms; because of its small battery life, and uncertainties in performance. Instead, we come up with a novel, power efficient, and scalable release mechanism, for breaking the passive magnetic bonds in usBots.

II. Objectives

Our intent is to build on the recent work on stochastic self-assembly, in order to realize the promising prospects, which result from its reduction to a local-coordination problem [6]. The goal is to address the long asked question, that how we can enable the various agents in a modular system, to achieve a global objective, using only local interactions. We extend this concept towards a hardware implementation, by building an autonomous robotic platform with novel features, that can demonstrate the potentials of self-assembling behavior via strictly local interactions, only with the neighboring agents. We translate the proven guarantees from theory, into realistic hardware constraints. These can be narrowed down to: (1) small robot size, (2) on-board autonomy, (3) self-assisted and high strength bond formation, (4) self-assisted and instantaneous bond breakage, (5) the ability to refuse bonding without any communication i.e. avoidance, and (5) the ability to communicate with neighbors. The usBot conforms to all these challenging constraints, and yet is shown to have a remarkably simple design (see Fig. 2).

An important point to note here is that we intend to investigate the phenomenon of distributed self-assembly in a modular system, with a large number of agents. Our

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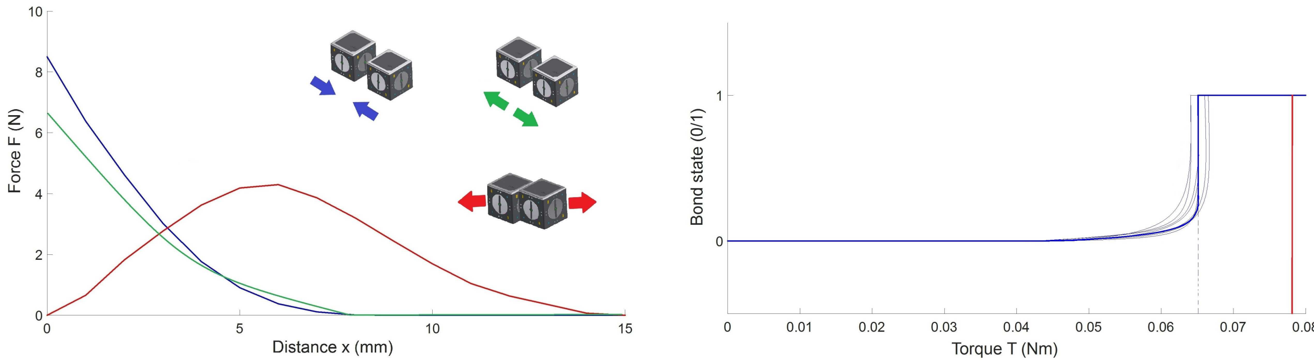


Fig. 3. The magnetic bonding strength for the cases of attraction, repulsion, and slide (left), and the relationship between the bond state and the release torque: State (0) means the bond holds while state (1) means it is successfully broken.

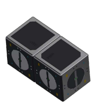
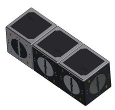
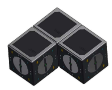
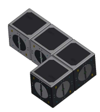
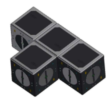
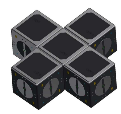
Assembly								
Attempts	30	20	20	20	20	15	10	10
Successes	100%	100%	100%	100%	100%	100%	100%	100%
Approx. Time	15 sec	35 sec	20 sec	~1 min	2-3 min	2-5 min	5-10 min	2-12 min

Fig. 4. Experiment results for various assembly formations with the total number of attempts, success rates, and the approximate range for time elapsed.

emphasis is not on the locomotion capability of usBot, but to utilize it as a tool for inducing self-assembling behavior in the system. Thus, the current version of usBot does not possess a self-locomotion capability, and uses an external-actuation platform for its movements.

III. Results and Prospects

So far, we have shown that the proposed modular system has the potential to demonstrate autonomous self-assembly, by characterizing its hardware (Fig. 3), and validating its primitive self-assembly behaviors (Fig. 5). Also, the novel release mechanism of usBot, is found to be well-qualified for the the task of stochastic self-assembly.

Extensive testing and multiple target assembly experiments with various algorithms need to be performed. Despite the remarkable success, we have observed during the preliminary self-assembly experiments (see Fig. 4), there remain however, decent challenges as well. Occasional avoidance failure, and repetitive deadlocks among the partial self-assemblies, result in considerable time loss for the system to achieve the desired configuration.

Self-locomotion would be a desirable feature to add in the second generation of usBots. We are working on a novel self-actuation technique, that could enable the future usBots to perform distributed self-assembly in 3D. So far, we have only considered homogeneous modules. We are also interested in heterogeneous self-assembling modules, specialized for certain tasks, such as grasping, manipulation, and perching. Developing better algorithms for particular applications of interest, is also on the list.

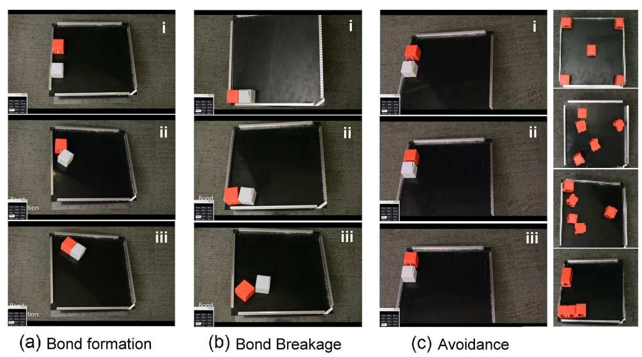


Fig. 5. Primitive self-assembly behaviors in usBots.

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