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Miyashita, S ; Casanova, F ; Lungarella, M ; Pfeifer, R

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Tribolon: Water Based Self-Assembly Robot with Freezing Connector (Video)

Shuhei Miyashita, Flurin Casanova, Max Lungarella, and Rolf Pfeifer

***Abstract*— We present a novel type of inter-module connection mechanism for waterborne modular robotic systems. The proposed mechanism exploits the thermoelectric effect to cool down and freeze the water between two modules thus causes them to attach to each other. We validate the feasibility of this mechanism by embedding Peltier heat pumps ($m = 0.8\,g$) in a cm scale self-assembly system. Our experimental results demonstrate that the proposed Peltier-based connector has (a) a high bond strength/weight ratio for a rather large range of temperatures and (b) is rather robust against misalignments between docking modules, making it a useful alternative to current connection mechanisms for small scale low autonomy self-assembly systems.**

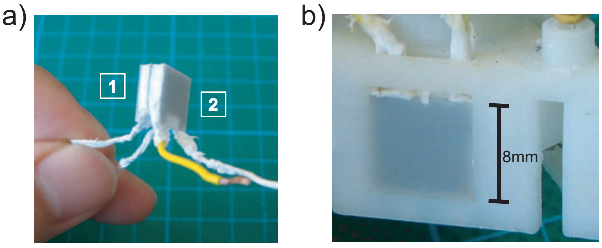

Fig. 1. Illustration of Peltier elements. a) Frozen Peltier elements (8 × 8 mm) sticking together. b) A Peltier element embedded into a module.

I. THE PELTIER CONNECTOR

The core of our connector is the Peltier heat pump – a double-faced cooling-heating device that can transfer thermal energy from one side of the device to the other, with consumption of electrical energy. We used the Peltier device to freeze (and thaw) the water between two modules and thus realize binding (and unbinding) between modules. The polarity of the current applied to the device defines which side is cooled down or heated up. The device consists of different types of semiconducting materials that are connected in series to take advantage of the so-called thermoelectric or Peltier effect. This effect is the direct conversion of an electric voltage into a temperature difference and *vice versa*, and allows the element to work as a heat pump. Peltier devices are available in various sizes. For our purpose we used an $8 \times 8\ mm$ element that weighs $0.8\ g$ (Fig. 1). Theoretically, the Peltier heat pump can induce a temperature difference of up to 72 $^\circ C$ while consuming approximatively $2.60\ W$.

One particular advantage of this type of inter-module connection mechanism is due to the absence of mechanical parts which makes it scalable. The fact that the connector is devoid of moving parts makes it also intrinsically less prone to failures. One disadvantage is that in order to sustain the connections, energy has to be supplied permanently to the heat pump. For the detachment process, however, there is no need to supply energy because the ice melts when it is not cooled down; moreover, the flow of heat from the hot surface supports the thawing process speeding it up.

II. IMPLEMENTATION TO SELF-ASSEMBLY ROBOTS

Followed by the feasibility of the connector idea, we embedded the Peltier-based connector into a stochastic modular robots.

The experimental setup was composed of a power supply, a metallic ceiling, a water tank, and six modules immersed halfway in water (Fig. 2). Each module consisted of a kite-shaped wedge made of durable plastic (acrylnitrile butadene styrene; ABS) spanning angles of 60 degrees and 30 degrees. The modules (H: 13 mm, L: 30 mm) contained a permanent magnet oriented orthogonally to their main axis to attract or repel other modules (Fig. 3 a). A vibration motor was used to endow the modules with a minimal locomotive ability which allowed the modules to move randomly around – vaguely reminescent of Brownian motion. Rather than using batteries, electricity was supplied to the modules through a pantograph that drew current from a metal ceiling. This solution not only led to lightweight modules ($m = 6.0\ g$), but it ensured that all modules received approximately the same amount of energy in a particular experiment.

When an electrical potential was applied to the metallic ceiling plate, current flowed through the pantograph to the vibration motor returning to ground via the electrodes (platinum) immersed in the water (8 % concentration of electrolyte (salt) was added to the water to make it conductive). To speed up the connection between two modules, the water in which the modules moved was cooled down to approximately -3 °C (due to the concentration of salt this was slightly higher than the freezing temperature). Two diodes were used to switch the direction of the current. Current flowed either through the Peltier element or the vibration motor depending on the direction of the voltage applied to the system (Fig. 2c, switch).

We first carried out experiments to test the reliability of the connector and to investigate the reconfigurability of our

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Shuhei Miyashita, Flurin Casanova, Max Lungarella, and Rolf Pfeifer are with the Artificial Intelligence Laboratory, Department of Informatics, University of Zurich, Zurich, Switzerland `miya@ifi.uzh.ch`

self-assembly system. The result is shown in Fig. 3. In the beginning of the experiment the modules were placed in the arena (Fig. 3 a) and arranged by hand to form a hexagonal shape (Fig. 3 b). Voltage was applied via the metallic ceiling (Fig. 3 c). After one minute, all six modules were connected to each other forming one unit (Fig. 3 d). We then flipped the polarity of the current supplied through the pantograph. The Peltier connectors stopped cooling and the vibration motors started to vibrate causing a disassembly of the hexagonal shape into 6 separate modules (Fig. 3 e). As a result of the vibrations of the motor, the modules moved around in the arena where they eventually got magnetically attracted by another module and started to form triangles (Fig. 3 f,g). The experiment was considered completed when the six modules had formed two triangles (Fig. 3 h).

We conducted the experiment several times. For sufficiently long waiting times T, we always observed two different ways of convergence to the final states: one is in Fig. 3h (two 3-clusters), the other is three 2-clusters (not on the picture, yield problem [1]).

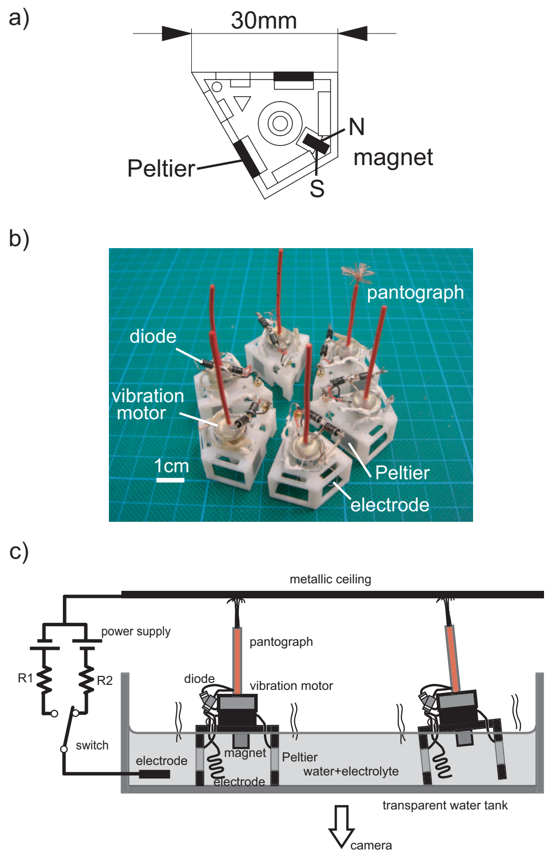

Fig. 2. Experimental setup. a) Schematic illustration of a module (bottom view). b) Picture of 6 modules. c) Experimental setup with 2 modules.

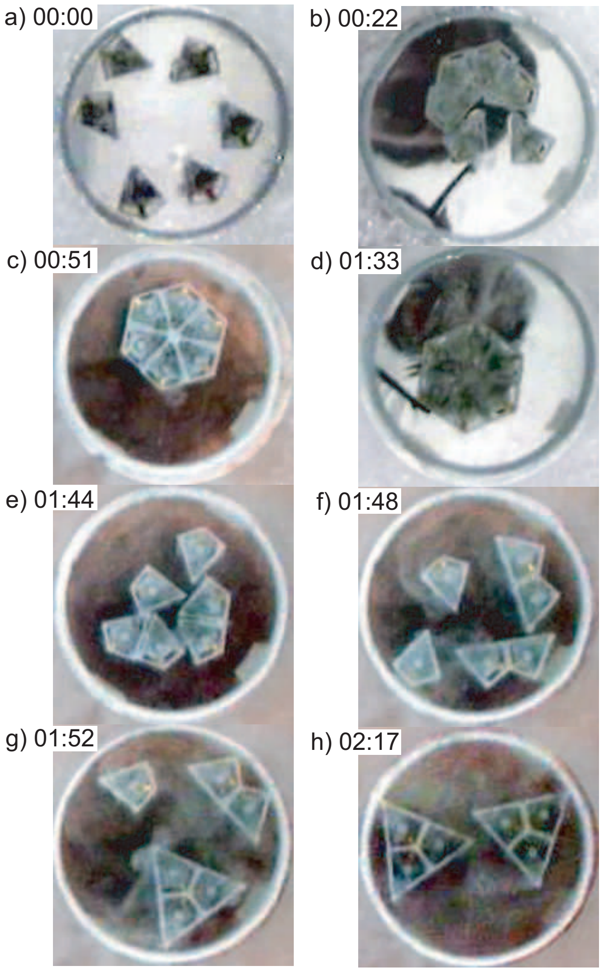

Fig. 3. Snapshots of the experiment.

III. CONCLUSION

We presented a novel type of connection mechanism for small-scale modular robotic systems. The mechanism exploits the thermoelectric effect to cool down the temperature and freeze water close to the modules and induce a strong bonding between modules. To test the connector, we embedded it into water-based modular robots. The results obtained in this research demonstrate the utility of the proposed connection mechanism for lightweight self-assembling systems, and open a door towards more resilient self-assembly system at smaller scales.

REFERENCES

[1] Hosokawa, K., Shimoyama, I., Miura, H.: Dynamics of self-assembling systems: Analogy with chemical kinetics. Artificial Life **1**(4) (1994) 413–427