DOI: http://dx.doi.org/10.7551/978-0-262-32621-6-ch086

# Applying Self-Assembly and Self-Reconfigurable Systems for Printer

Masayoshi Mitsui[1], Atsushi Masumori[1], Ryo Asakura[1] and Hiroya Tanaka[1]

[1]Keio University
mitsuimasayoshi@gmail.com

## Abstract

We demonstrate the application of self-assembly system for human manufacturing processes at meso- and macroscale in order to pursue and expand the engineering applicability. First, we implemented a prototype referred to as self-assembly printer which can generate a dynamic, transformable, two-dimensional molding and reuse the units that compose the printed objects. Secondly, noteworthy technological components to explain our prototype system is introduced in this paper. Lastly, some potential application based on the system such as "Self-Assembly Electronic Circuit (SAEC)" is implemented and proposed. As a result of these researches, our system attains scalability and alleviates the need for complex and accurate movements of assembler in traditional manufacturing system.

## Introduction

Human manufacturing systems typically require high complexity that can only be achieved by top-down or laborious manual assembly. As technologists pursue smaller and more complex structures, traditional manufacturing schemes will not be able to meet such demands, because they are limited in their scalability, robustness, and complexity. As a solution to this problem, applying Self-assembly to human manufacturing process has been a long sought goal in many fields of both academia and industry (Griffith (2004)). Self-assembly has been used to create structures at the nano- and micro-scales using techniques such as chemical bounding, geometric interactions, and magnetic field. Even at the meso- and macro-scales, many techniques and basic theories to design self-assembling and self-reconfigurable systems has been proposed and implemented in the field of robotics (Cheung et al. (2011)). Although these robotic systems are impressive and are approaching functionality, they offer little hope in terms of scalability for large applications or complex structures, because of its high application cost, failure of electronics and miscommunication between machines. Therefore, this paper focuses on physical properties and geometric forms of units and implements Self-Assembly Printer which applies self-assembly system to manufacturing processes. In detail, we implemented simple designed units and an assembler. And then we constructed a mathematical model based on this designed units. Consequently, self-assembly printer system was proposed and implemented. Moreover, some potential applications based on the system such as SAEC (Self-Assembly Electronic Circuit) will be proposed here.

## Self-assembly printer

Self-assembly printer system consists of 22 types of minimum units, a mathematical model, and a simple designed assembler. First, an output shape at seven-segment display is determined through a graphical user interface. Second, a programmed software analyses the given shape in order to find the most appropriate Hamiltonian path and inform the assembler of the accurate order of units. Third, the assembler rotates to bring the units to the front of the extruder and pushes them out through it. By completing these steps, the self-assemble printer system can print some character or number at seven-segment display (see figure.1).

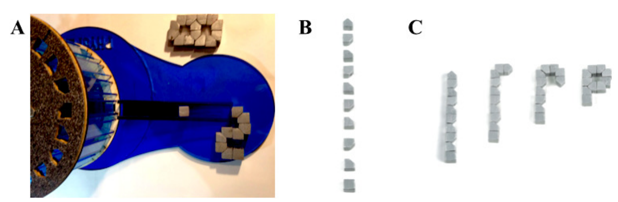

Figure 1: "(A) an assembler which rotates and allocates units. (B) a line of units allocated to form character "p". (C) an example process of character "p" being printed as a seven-segment display on self-assemble printer system".

### Design of minimum units

In this part, we will introduce a prototyped unit and a way of infusing binary codes into them as a genetic code. First, we focused on the geometric forms and the direction of magnetic flux embedded within the units, and associated the physical properties with binary codes as seen the figure.2. Second, we prototyped each units which have only four relative patterns (with Objet260: 3D Printer) although we had to fabricate 22 types without considering their geometric symmetry. Third, we introduced catalyst unit which will come off the printed object in order to achieve the required shape and to assemble units more efficiently (the details are shown below).

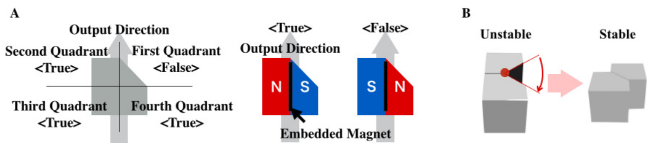


Figure 2: "(A) Minimum unit's code which is compatible with genetic code. (B) Interaction between units".

### Bridge-Method

As we understand how any shape is printed with only single path, we confront Hamiltonian path problem. There is an effective mathematical method proposed by (Bachrach et al. (2009)) to find a Hamiltonian path in any two- or three-dimensional shape. However, in the method, the number of vertices of given the graph are forced to be quadrupled in two-dimension case and thus the scale of the object becomes bigger. Therefore, we developed new method called "Bridge-Method" to create a Hamiltonian path with catalyst units. First, our method searches all odd points in a given graph not serially but parallel. Second, our method determines two points and bridges them with catalyst units in order to make an Euler path. If there are more than two odd points, our method would evaluate multiple solutions with an evaluation function. Finally, Bridge-Method is proposed as a more efficient method to make Hamiltonian path to achieve the goal more efficiently for our system.

## Experimental Result

We have implemented self-assembly printer system and demonstrated how it prints various shapes. First our system was able to print all characters and numbers at seven-segment display as seen the below figure.3. However, sometimes our system fails to print the required shape because of influence of friction force. For the same reason the system is unable to print large numbers of units. Second, we introduce "SAEC: Self-Assembly Electronic Circuit" as a potential application of our system in the below part.

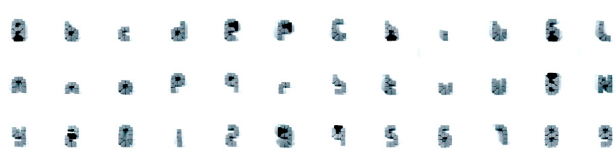

Figure 3: "All characters and numbers printed by self-assembly printer".

### Self-Assembly Electronic Circuit

We implemented SAEC as a potential application with the self-assembly printer. In detail, SAEC units are designed with copper foils in the same pattern for each units, and an electronic circuit is accomplished just after constructing the object. Most fabrication of microelectronic devices is carried out by photolithography and is unable to reuse or replace its components. SAEC offers a possibility to restore itself to its original condition or extend its function locally. As a future work, we propose "DSAEC: Dynamic SAEC" composed of more intelligent units. Like the SAEC, DSAEC units are all designed in the same pattern, however, they are embedded with different electronic components such as LED, battery, and sensor. We will implement units that are constructed through static self-assembly in our system, and moreover, will become agents and interact with other agents dynamically.

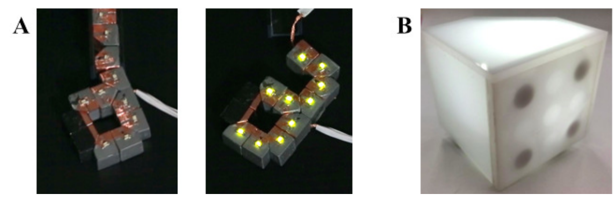


Figure 4: "(A) Self-Assembly Electronic Circuit as a potential application of self-assembly printer. Each units are designed with copper foils in the same pattern. (B) an early prototype of Dynamic SAEC'.

## Conclusion

The self-assembly printer system and an example of application was implemented and proposed here. The self-assembly printer system attains scalability to enable the assembler to print an object even if the scale is bigger than the size of the assembler. The system also alleviates the need for complex and accurate movements of assembler compared with top-down human manufacturing system. As our future work, we will develop the self-assembly system which can construct arbitrary three-dimensional forms. And also, we will apply this system for constructing small and complex structures of electronic circuit boards without highly-precise-assemblers.

## References

Bachrach, J., Zykov, V., and Griffith, S. (2009). Folding arbitrary 3d shapes with space-filling chain robots: Folded configuration design as 3d hamiltonian path through target solid.

Cheung, K. C., Demaine, E. D., Bachrach, J. R., and Griffith, S. (2011). Programmable assembly with universally foldable strings (moteins). *Robotics, IEEE Transactions on*, 27(4):718–729.

Griffith, S. T. (2004). *Growing machines*. PhD thesis, Massachusetts Institute of Technology.