Tangible Pixels

Interactive architectural modules for discovering adaptive human swarm interaction

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Abstract. *In this paper, we design and implement 40 identical modular architectural blocks, named Tangible Pixels, with swarm computing mechanism embedded. Each unit of tangible pixels is a customized, which has three functions─sensing, communication/ computing, and actuating abilities to collective reactions to its surroundings. We further arrange this set of tangible swarm into a public interactive installation to explore the potential research and design territories of human swarm interaction and adaptive artifact. Via a preliminary onsite observation, we prove that this adaptive interaction model did overturn the conventional space design and usage as well as user mental model.*

Keywords. *Tangible; adaptive artifact; human swarm interaction; modular robotic; programmable matter.*

INTRODUCTION

Following the digital architecture and generative design, interactive architecture has become a popular topic worth exploring in this decade. From the early smart environment with proactive detection and information integration capabilities (Brodey, 1967; Coen, 1998; Eastman, 1972; Mozer, 1999; Negroponte, 1970) to kinetic space formed by a dynamic structure in recent years (Fox, 1996; Fox, 2006; Senagala, 2005), many interactive space concepts have been developed in laboratories and are implemented in actual construction cases since related technologies have become advanced. In sensing and computing, researchers achieve timely space data by establishing sensors, together with a series of wireless network connections. The achieved data are integrated by the central control unit to calculate the pattern, so as to predict the demands of users and this becomes the basis for controlling the kinetic environment. In the actuation aspect, researchers either start with the design of the kinetic components to enable regular and rhythmic deformation of space elements through the combination of lever movement and power motor, or start with a module concept to cause kinetic deformation in the spatial form and function through movement and stacking of the space module (Bar-Cohen and Breazeal, 2003; Eldershaw et al., 2002; Frazer, 1995; Lipson, 2007).

The idea of "swarm computing," a computing mechanism for decentralized development comes from the concept of 'swarm intelligence' of biological systems (Bonabeau, Dorigo and Theraulaz, 1999). It denotes the attainment of an effective collective decision through signal-sensing of units, as well as propagation and communication in the computing mechanism even without a central control, by which a collective system achieves the purpose of adapting to the environment through self-evolution. Researchers have likewise physicalized the above mechanism. By integrating related technologies in robotics and materials science, researchers have proposed the idea of a 'programmable matter' which integrates sensing, computing and actuating into a physical module and this is minimized into a particulate material that is available for shaping. This minimized computing collective can sense the changes in the environment as well as communicate information with each other, thus creating a collective decision. It also acts like clay which takes different forms so as to achieve a dynamic purpose (Goldstein, Campbell and Mowry, 2005).

The current research studies related to programmable matters are focused mostly on algorithm design in "swarm robotics" and micro-electro-mechanical system (MEMS) (Aksak et al., 2005; Duff et al., 2001; Murata et al., 2002). Due to technical limitations, the micromation of particles has not been achieved. Therefore, the ability to use this type of substances to produce everyday artifacts and explore "human swarm interaction" between humans and collective particles has been temporarily simulated by computer, while the application and verification processes are not achieved (Pillai and Campbell, 2006; Weller et al., 2011). Architecture is one of these artifacts and it is also the medium contacted by humans (users). Therefore, the development of programmable matters in architecture dimensions can create a new type of interactive space and at the same time, enable users to have living experiences of it. Related topics focusing on human swarm interaction are further explored and discussed in this research.

DESIGN CONCEPT

A pixel constitutes the most basic unit of a flat panel display. Designers are free to structure static images or dynamic images by controlling the color of pixels. However, the graphics limited to the two-dimensional space on the screen are also constrained to the users' application range. Fortunately, the research on tangible media has presented interesting cases of physicalization of visual pixels. It has also suggested the possibility of applying the concept of pixels to a three-dimensional space (Lee et al., 2009; Zigelbau and Coelho, 2011). Based on this premise, we can further develop the programmable matter in the architecture dimension: tangible pixels.

A tangible pixels is a swarm with 40 identical modular units which can be freely arranged by users to form a desired shape for constructing a floor or wall. Each tangible pixel has sensing, communicating and actuating capabilities. In addition to collecting data on peripheral environment and user information, it identifies behaviors and predicts demands of users through communication. Finally, it provides dynamic functions through its actuating capacity in hopes of modifying the traditional interactive mode between artifacts and users and creating a brand new interactive space with new form.

For example, when a user wants to sit down, he / she normally finds a chair to sit on. Now, he / she only needs to perform the intuitive action of sitting down and the tangible pixels will sense the user's actions through the distance sensor installed above. The data are then collected through the communication ports found at the bottom and adjacent tangible pixels. These will predict the user's intention and drive the actuating units near the user immediately which are then lifted and formed into a shape of a chair that fully meets the user's posture and height (Figure 1).

IMPLEMENTATION

Appearance

The tangible pixels consist of 40 identical modular units. Each unit is a cube column of 150 mm x 150 mm x 400 mm and is divided into two parts which are stretch and base parts. The stretch part which can extend 120 mm upward consists of light-emitting and non-light-emitting portions. The light-emitting part is a cube column of 50 mm x 150

Figure 1
Simulation of chair and table application.

mm x 50 mm, with an opening of 40 mm x 40 mm at the surface center. It is equipped with a built-in 3-color LED light strip which can emit colored light. The inner section of the opening is embedded with an infrared distance sensor, which can detect objects above within a distance of 1000 mm. The base portion is a cubic column of 150 mm x 150 mm x 50 mm, with 8 small round points on four sides for communicating and transmitting signals (Figure 2).

Sensing

When the system boots up, the light-emitting portion's embedded sensors would continuously detect the upper space of the cube column. Once an object is detected, the system calculates the distance of the object. Based on the distance of the object, the system further determines the corresponding state, for example, it changes the color of the light-emitting part into the user's visual feedback, or it changes the length of the stretch part to provide function (Figure 3).

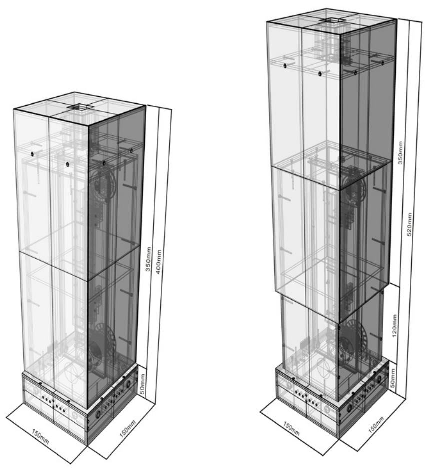


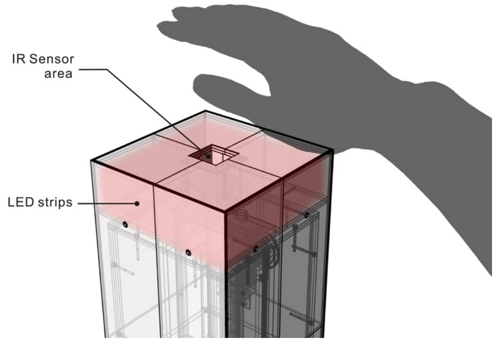
Figure 2
The diagram and dimensions of the stretch mechanism.

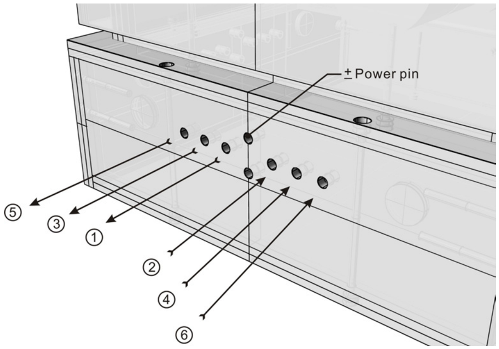
Communication

After the system obtains the environmental data (the distance of the object), it transmits and exchanges these data with the connected adjacent units through the base's communication port. Point 1 and point 2 are used to detect connection to the adjacent unit. If there is connection to the adjacent unit, Point 1 would provide a voltage of 5 V to the adjacent unit, while point 2 would detect whether the voltage of 5 V provided by the adjacent unit is achieved or not. Once the system detects the voltage signal, it performs the handshaking task through point 3 and point 4. At this moment, point 3 sends a randomly produced signal to the adjacent unit, and point 4 would detect whether the response of the adjacent unit is received or not. Once a received response signal meets the original signal sent by point 3, the handshaking task is completed. Next, the signal is transmitted through point 5 and point 6, whereby point 5 is responsible for transmitting the signal and point 6 is responsible for receiving the signal (Figure 4).

Computing

In addition to communicating signals, the communication ports can also perform signal coordination, which achieves a collective decision by means of communication. In the system, we have designed an algorithm for achieving a collective decision. When multiple tangible pixels detect environmental data





at the same time, they would compute for the data difference among them through communication. If the data difference is less than the set value X, each of them would regard the adjacent units as an identical swarm, so that the synchronization of behavior can be carried out next (Figure 5).

Actuating

The actuation of tangible pixels consists of the color change of the light-emitting part as well as the extension and retraction of the stretch part. Each light emission is embedded with 36 three-color components of SMD LED. The inner structure of the extension consists of a DC motor, pulley and belt, which are used to produce a vertical stretch movement (Figure 6). When a swarm of tangible pixels detects the environmental data, each pixel would display a different color according to the detected distances of the obstacles. Once a collective decision is achieved through communication within the swarm range, the tangible pixels with different colors originally emitted from the swarm, would display the same color to indicate that they belong to the same swarm, and produce a synchronized stretch movement which extends to a height required by users (Figure 7).

OBSERVATION

After the implementation of tangible pixels, we participated in an exhibition for an on-site observation and understanding of the user experience which enabled us to further explore the subject of human swarm interaction. We decided to join the "2011 Taiwan Designers' Week" for our observation and evaluation. For one week, we observed and interviewed more than 500 visitors, including the elderly, adults, adolescents and children (Figure 8).

This study involved two observation methods; namely, initiative guide and free exploration. With the initiative guide, we directly introduced the

Figure 3
The diagram of the light-emitting portion's sensing mechanism.

Figure 4
The design of communication ports.

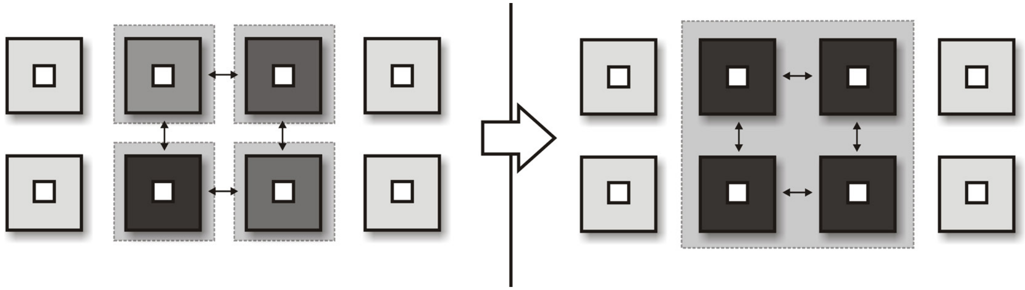
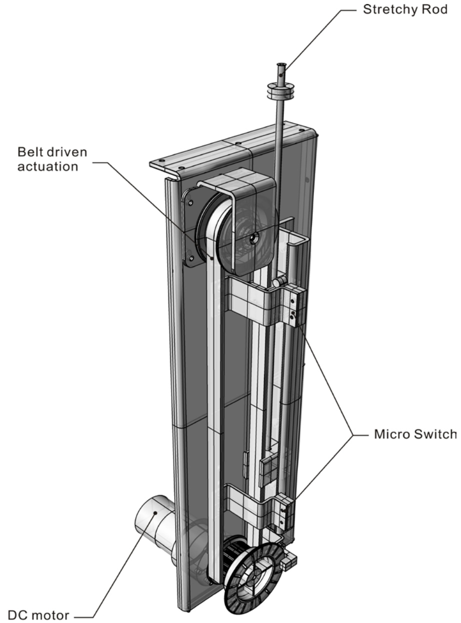


Figure 5
The diagram of algorithm coordination.

Figure 6
The design of the motor structure.



equipment and demonstrated the method of operation. After that, users could freely experience the mechanism. With the free exploration, there was no demonstration or explanation; users were allowed to freely explore. After the completion of each method, we conducted a brief interview with the users. However, when users encountered problems during the observation process, we answered their questions and provided recommendations as necessary.

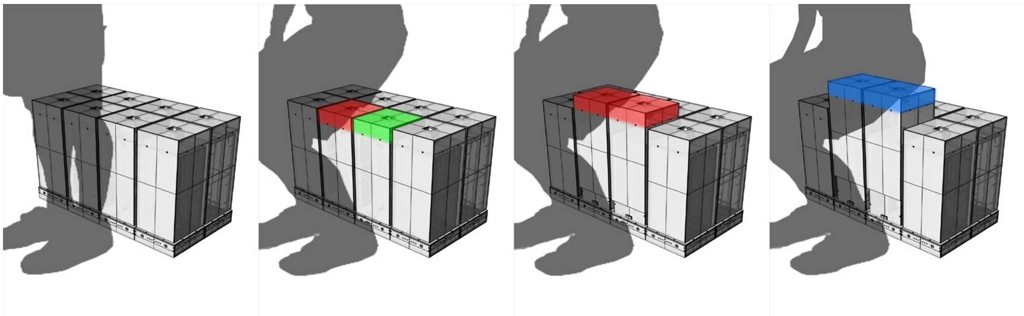
In terms of the layout of the experimental environment, the space elements of the architectural space were formed into pixels in order to create a space with tangible pixels. In addition to placing 40 prototype groups of tangible pixels at the center of the site, we used many paper prototypes with the same sizes and placed them on the floor and on the wall to allow users to immerse themselves in the experiment (Figure 9).

RESULTS

After obtaining 500 observation materials, we have summarized our research as follows:

1. With the initiative guide method, users could quickly understand the process and actively interact. In contrast, with the free exploration method, about 1/3 of the users did not know how to operate the equipment and gave up on mere remote observation, while 2/3 of the users enjoyed the interactive experience after undergoing a trial and error process.
2. One-third of the users who gave up and left were mostly adults and the elderly. The remaining 2/3 of users were young people and children.
3. The elderly and adults who stayed for the experiment were prone to ask questions when confronted with problems. However, the young people and children were more likely to find answers through trial and error, as well as rely on similar cases they have observed.

Figure 7
Storyboard of the interaction mechanism.



4. With the free exploration method, the users were able to gradually understand and manage the features and functions. However, some users suggested the use of a color code of light for overall function.
5. The elderly and adults believed that the adaptive feedbacks could help ease discomfort of the waist when sitting down, and suggested having modifications on the surface texture to make it more comfortable.
6. The young people observed that the equipment could be freely arranged to form a shape. They also found the fluctuation of deformation and the effect of the light interesting. The equipment could be used as a decorative building material. However, it is too heavy to move and its assembly is not easy.
7. The children showed great interest during the operating process. On several occasions, they treated the mechanism as a desk for placing toys or bags, which created a variety of color blocks. They even expected to hear sounds or music.

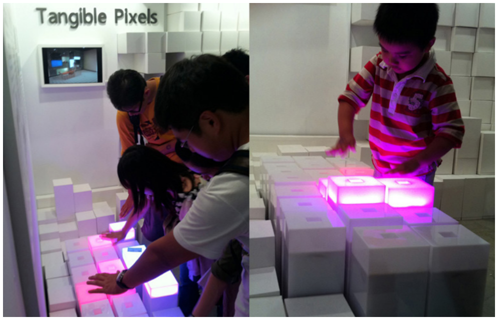


Figure 8
Photos of children and young people exploring the mechanism.

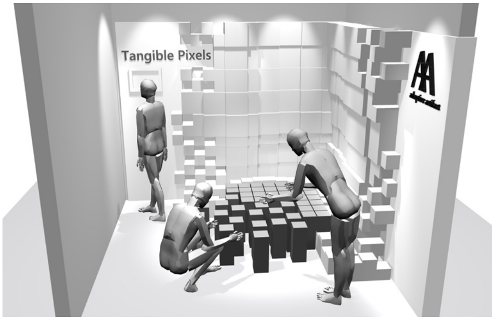


Figure 9
Simulation of experimental environment design.

CONCLUSION

This is a preliminary study wherein we created elements of architectural space into pixels and made programmable substances in a spatial dimension, so as to determine the preliminary phenomenon of human swarm interaction in the interactive space, and further propose the idea of designing and modifying this model type.

Based on our observations, we have reached the following conclusions: First, the adaptive behaviors of tangible pixels offer a new experience; therefore, some users were hesitant to explore and eventually gave up when they failed to obtain any result or even before they could fully understand the operation. Second, once the users overcame their shyness, the deformation response achieved by the tangible pixels from initiative sensing could actually provide adaptive user reactions in real time. However, technical limitations and composite materials of the pixel unit resulted in insufficient and unsuitable functions. Third, the decentralized communication and computing does not only enable users to change the composition relationship among units in real time and to dynamically create different attributes of the swarm, but also enhance the computing speed among units. However, due to the actual weight of the structures, moving them would be more inconvenient. Fourth, through the communication among multiple identical artifact units, a swarm with collective decision can be formed. The users can determine the height and color according to the number of blocks placed by objects. But because of the limitation of the sensor's current configuration and unit size, the resolution is constrained. Fifth, we suggest the possibility of adding other reactive effects, such as sound to provide a variety of user feedbacks; and use the characteristics of the five senses to enhance the degree of use and expand the application.

This study is a preliminary exploration which acts as a preparation for developing programmable substances to explore the interactive construction and human swarm interaction. It also serves as a phenomenon that provides a basis and direction for the next generation of exploration of details and behaviors. Since there is no precedent to be followed, many details are omitted and several experimental conditions lacked effective control. These details will be discussed in future research. The conclusions mentioned above will be the basis for future studies so as to develop tangible pixels with more adaptability.

REFERENCES

Aksak, B, Bhat, PS, Campbell, J, Derosa, M, Funiak, S, Gibbons, PB, Goldstein, SC, Guestrin, C, Gupta, A, Helfrich, C, Hoburg, J, Kirby, B, Kuffner, J, Lee, P, Mowry, TC, Pillai, PS, Rister, BD, Seshan, S, Sitti, M and Yu, H 2005, 'Claytronics: highly scalable communications, sensing, and actuation networks', *Proceedings of the 3rd international conference on Embedded networked sensor systems*, San Diego, California, USA, pp. 299-299.

Bar-Cohen, Y and Breazeal, CL 2003, *Biologically Inspired Intelligent Robots*, SPIE Press, Florida.

Bonabeau, E, Dorigo, M and Theraulaz, G 1999, *Swarm Intelligence: From Natural to Artificial Systems*, Oxford University Press, New York.

Brodey, WM 1967, *The Design of Intelligent Environments: Soft Architecture*, Landscape.

Coen, MH 1998, 'Design Principles for Intelligent Environments', *Proceedings of the Fifteenth National Conference on Artificial Intelligence*, Madison, Wisconsin, pp. 547-554.

Duff, DG, Yim, M and Roufas, K 2001, 'Evolution of PolyBot: A modular reconfigurable robot', *Proceedings of the Harmonic Drive Intl. Symposium*, Nagano, Japan.

Eastman, C 1972, 'Adaptive-Conditional Architecture', *Proceedings of the Design Research Society's Conference Manchester*, Academy Editions, London, pp. 51-57.

Eldershaw, C, Yim MH, Duff, D, Roufas, K, Zhang, Y 2002, 'Modular Self-Reconfigurable Robots', *Proceedings of Robotics for Future Land Warfare Seminar and Workshop*, Adelaide, Australia.

Fox, MA and Architecture, M. I. O. T. D. O. 1996, *Novel Affordances of Computation to the Design Processes of Kinetic Structures*, Massachusetts Institute of Technology, Department of Architecture.

Fox, MA and Hu, C 2003, 'Starting from the Micron: A Pedagogical Approach to Designing Responsive Architecture', *Proceedings of the 8th International Conference on ComputerAided Architectural Design Research in Asia CAADRIA 2003*, Bangkok, Thailand.

Frazer, J 1995, *An evolutionary architecture*, Architectural Association, London.

Mozer, MC 1999, 'An Intelligent Environment Must Be Adaptive', *Intelligent Systems and their Applications*, *IEEE*, 14(2), pp. 11-13.

Goldstein, S.C., Campbell, J.D. and Mowry, T.C. 2005, 'Programmable matter', *IEEE Computer*, 38(6), pp. 99-101.

Lee, J and Kakehi, Y and Naemura, T 2009, 'Bloxels: glowing blocks as volumetric pixels', *Proceedings of the SIGGRAPH 2009 Emerging Technologies*, New Orleans, Louisiana.

Lipson, H 2007, 'Principles of Modularity, Regularity, and Hierarchy for Scalable Systems', *Journal of Biological Physics and Chemistry*, 7(4), pp. 125-128.

Murata, S and Yoshida, E and Kamimura, A and Kurokawa, H and Tomita, K and Kokaji, S 2002, 'M-TRAN: self-reconfigurable modular robotic system', *Mechatronics*, *IEEE/ASME Transactions*, 7(4), pp. 431-441.

Negroponte, N 1970, *The architecture machine*, M.I.T. Press.

Pillai, P and Campbell, J 2006, 'Sensing and reproducing the shapes of 3D objects using claytronics', *Proceedings of the 4th international conference on Embedded networked sensor systems*, Boulder, Colorado, USA, pp. 369-370.

Senagala, M 2005, 'Kinetic, Responsive and Adaptive : A Complex- Adaptive Approach to Smart Architecture', *Proceedings of SIGRADI 2005 international conference*, Lima, Peru, pp. 1-13.

Weller, MP and Gross, MD and Goldstein, SC 2011, 'Hyperform specification: designing and interacting with self-reconfiguring materials', *Personal Ubiquitous Comput.*, 15(2), pp. 133-149.

Zigelbau, MJ and Coelho, M 2011, 'Six-Forty by Four-Eighty: an interactive lighting installation',*Proceedings of the CHI Extended Abstracts*,Vancouver,New York, pp. 485-485.