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Topic : Novel Disaster Mitigation Engineering Toward Future

Smart disaster mitigation based on novel structures/materials

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Abstract

The author proposed to use novel technologies/materials such as smart structures/materials and related technologies to enable revolutionary prevention/mitigation of disasters. A typical example is the deployable breakwater which can be used daily for energy harvesting, small enough not to be an obstacle, as well as a smart breakwater autonomously deployable by the force/energy and material of tsunami or high wave. The author discussed with Furuya and Nonami on new reliable approaches to cope with disasters, which intends to enable sustainability as well as disaster mitigation, and they named it as “Disaster Mitigation and Sustainable Engineering.” The author et al. are establishing a research committee as a part of JSME M&P Division. In this paper, new ideas and developments for smart disaster mitigation toward future especially based on smart structures/materials are described. To explain the proposed concept more comprehensively, two examples, that is, an artificial forest and a novel deployable structure based on honeycomb to be used against flooding are introduced. Many other smart challenges and products are also introduced and future directions are discussed. Several projects are mainly undergoing by the author and/or his collaborators. Various outstanding challenges have been also done in industries and some are already commercialized. Disaster Mitigation and Sustainable Engineering has to be brushed up to become a basis for the above introduced emerging field with more variety of disasters to be smartly overcome or rather utilized.

Keywords

disaster, tsunami, flooding, sustainability, deployable structure, energy harvesting, daily use

1. Introduction

In recent years, more serious disasters occur around the world than in the past, and a large number of people are lost in spite of the rapid advancement of science and technology. In order to solve this problem, the author et al. have proposed a new concept “Disaster Mitigation and Sustainable Engineering” which enables sustainability as well as disaster mitigation, effectively and economically. It is emphasized that this novel concept can be effectively realized by the innovative field “Smart Materials and Structures.” The

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number of presentations in this field at JSME (The Japan Society of Mechanical Engineers)annual meeting (MECJ) has been increasing, and it has also become a nucleation site for developing new innovative fields. A couple of research committees have been managed for many years, and as one of them, "Active Material Systems" Technical Section which belongs to the M&P (Materials and Processing) Division of JSME has been playing an important role to support and activate the field. Its major applications have been explored in mechanical, electronics, civil, architecture, aerospace, automobile, transportation, biomedical, and so on. But, since the Japanese earthquake and tsunami disasters on March 11, 2011, Asanuma et al. had proposed the new concept briefly mentioned above and have been exploring a completely new and effective direction for disaster mitigation.

2. Disaster mitigation and sustainable engineering

The new concept "Disaster Mitigation and Sustainable Engineering" can be briefly explained using the typical examples shown in Figure 1 and Figure 2. Serious disasters may occur today or may not for a long period of time. The structures necessary for disaster mitigation need vast amount of construction and maintenance costs. So, we better think of using them daily to produce something useful such as energy. The generated energy can be used for their monitoring, maintenance, corrosion suppression, repair, and many other purposes such as lighting, charging drones, and so on. The disaster mitigation devices and structures have to be available even if disaster occurs once for hundred years. For the overwhelming period without disasters, they are not necessary from disaster mitigating point of view, so their compactness is very useful from daily and aesthetic point of view. In addition, a "Smart Furniture" to protect valuable products from falling from shelves etc. at the time of earthquake has been considered. Asanuma et al. introduced the concept etc. at the Chiba Univ. symposium on Jan. 26 and also at the MECJ-12 on Sep. 11, 2012 [1, 2]. In addition, several invited talks etc. such as keynotes at MECJ, MRS-J and PT-PIESA 2013 have been delivered by Asanuma [3, 4 and 5].

Asanuma and Furuya are establishing a research committee with Nonami, Maeno, Yamazaki, Igarashi, Kudo, Takahashi, Shimazu, Sumantyo, Kubo, Maruyama, Tanaka, Lu, Takei, Koyama, Okawa et al. from Chiba Univ., and Su (NASA), Shahinpoor (Univ. of Maine), Paolozzi, Felli (Sapienza Univ. of Rome), Nejhad, Hihara (Univ. of Hawaii at Manoa), Aimmanee, Ekkawatpanit (King Mongkut's Univ. of Tech. Thonburi), Adachi (Chubu Univ.), Yanaseko (Kogakuin Univ.), Vendittozzim, Santilli (Univ. of Brasilia), Dry (Natural Process Design), Yan (Missouri Univ. of Sci. and Tech.), Kishimoto (NIMS), Furukawa (Yamagata Univ.), Nakao (Yokohama National Univ.), Kosaka (Kochi Univ. of Tech.) et al. are also extending it to be more active and international one.

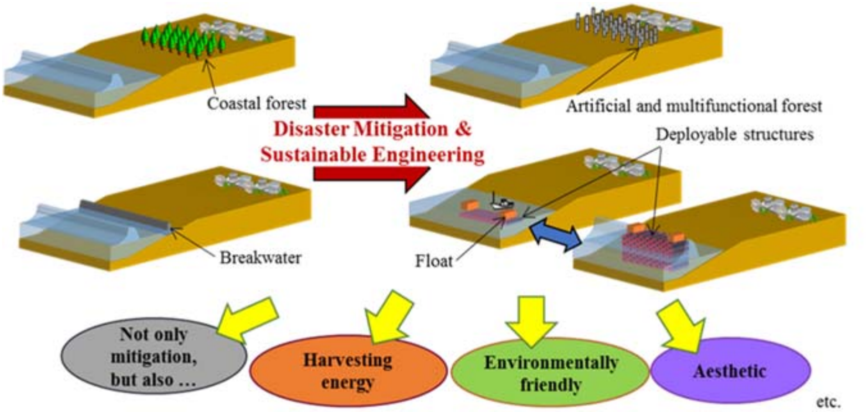


Figure 1. Typical examples to show the concept of "Disaster Mitigation and Sustainable Engineering."

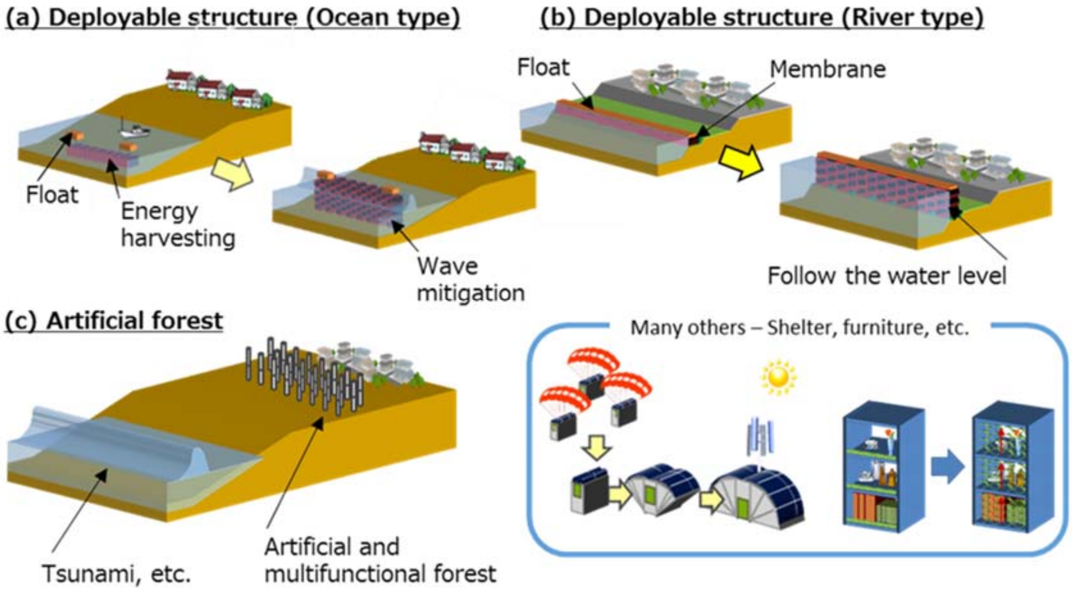


Figure 2. Examples to realize the concept.

First of all, in order to explain the concept more comprehensively, two examples having been experimentally done are mainly introduced and discussed. As the first example, an artificial forest has been developed, which are intended to have better capability of high wave or tsunami mitigation than actual ones [6, 7], by optimizing various parameters such as configuration, density and material. Natural forests have many problems such as low fraction of trees, low visibility of ocean waves, low strength, long time to grow, and so on.

The first two experimental parameters have been mainly examined by using a water channel set-up prepared for this research. Multifunctional design is also described. As the second example, a new smart structure based on honeycomb like one to be used against flooding etc. is proposed and demonstrated to show the possibility of autonomously deployable due to increase of water level as external environmental change. This autonomous height-controlled river or anti-flooding bank system can be regarded as a smart structure. Energy harvesting materials and systems are under consideration and development to make the system much smarter and fully realize the concept.

Secondly, several challenges toward future mostly done by the authors, and several smart products from industries and projects are introduced, and finally, the content is summarized

3. Experimental and future works

3.1 Artificial forests [8]

An aquarium as shown in Figure 3, consisting of 300 mm wide and 4500 mm long waterway and hydraulic bore water tank, was used, and an artificial forest model, consisting of 4 mm diameter and 300 mm long columnar bars, was arranged as shown in Figure 4, where lattice spacing S and number of rows N were changed. It was placed in the range of 2780 to 3180 mm from the gate of water tank. Stage type wave was generated by setting the initial water height of the waterway h_o = 30 mm and the initial water height of the water tank H = 240 mm, and opening the gate. In this case, the generated hydraulic bore is the state of supercritical flow, of which flow rate is 1.5 m/s and Froude number is 1.5 at the front edge (tank side) of the model.

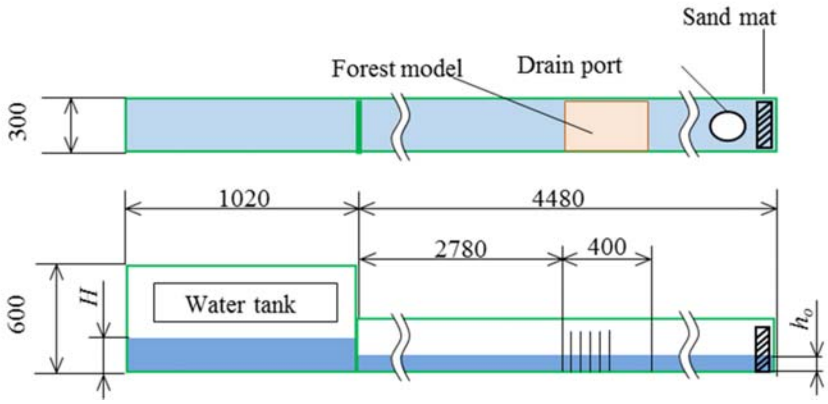


Figure 3. Schematic of experimental waterway.

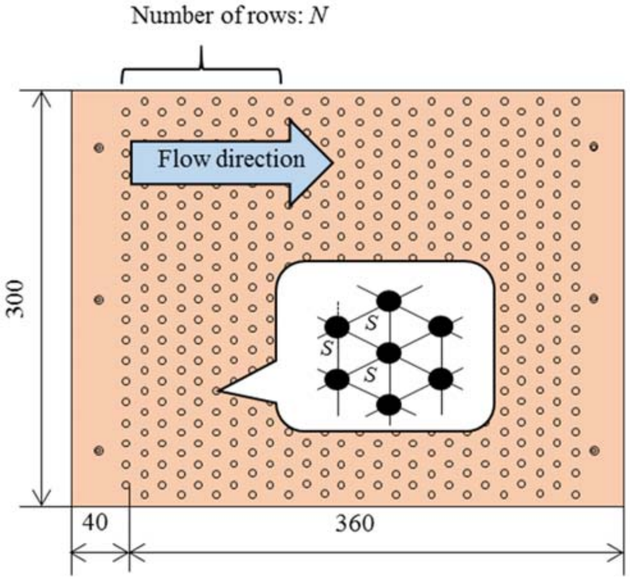
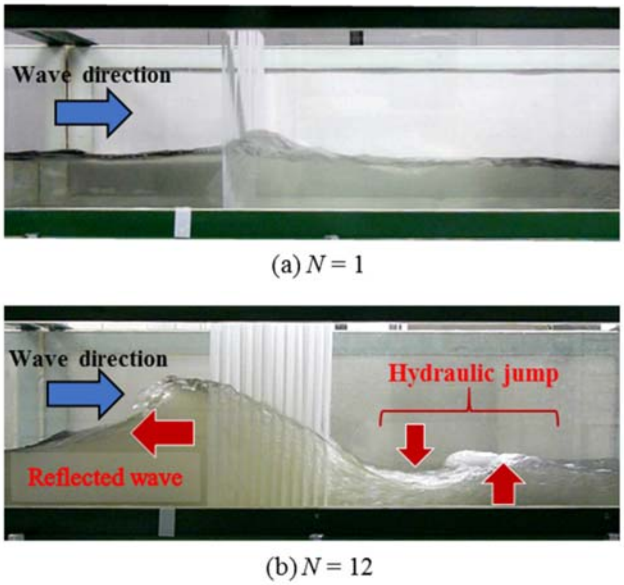


Figure 4. Schematic of metal plate to arrange cylinders.

To observe the state of flow passing through the artificial forest model, photos were taken from the above and the side positions with a digital camera. Then, by using an image processing software, flow rate and water level at the front and the end of the cylinder group model were measured, and reduction of those were used to evaluate wave mitigation effect .

From the preliminary studies [9], the arrangement shown in Figure 4 is better than square one, and smaller spacing S is also better. Therefore, the effect of type of material, that is, polyacetal (POM) and stainless steel (SUS304) were compared as a function of number of rows N from 1 to 12 at the minimum and constant S (= 15). In Figure 5, the water flow interacting with the artificial forest model made of POM cylinders is shown. In the case of N = 12, remarkable reflection of the incident wave can be observed in front of the model, and remarkable reduction of the water level and hydraulic jump phenomenon can be observed behind it.

In Figure 6, reduction rate of water flow velocity as a function of number of rows is shown. According to the figure, the reduction rate increases with increasing number of rows for both materials, and those of POM are generally higher than those of SUS304 except N = 1 and 2. This tendency is considered to be caused due to the difference of Young's moduli of the materials, that is, POM having lower Young's modulus can absorb



(a) $N = 1$

(b) $N = 12$

Figure 5. Side views of water flow experiments using POM cylinders of number of rows (a) *N* = 1 and (b) *N* = 12.

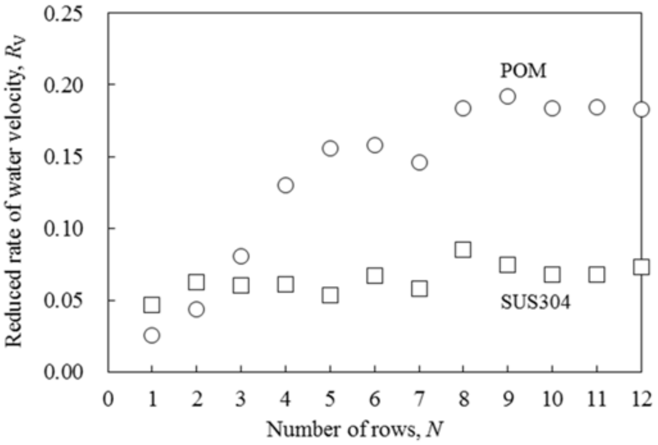


Figure 6. Effect of number of rows *N* on reduction rates of water velocity R_V for the cases of POM and SUS304.

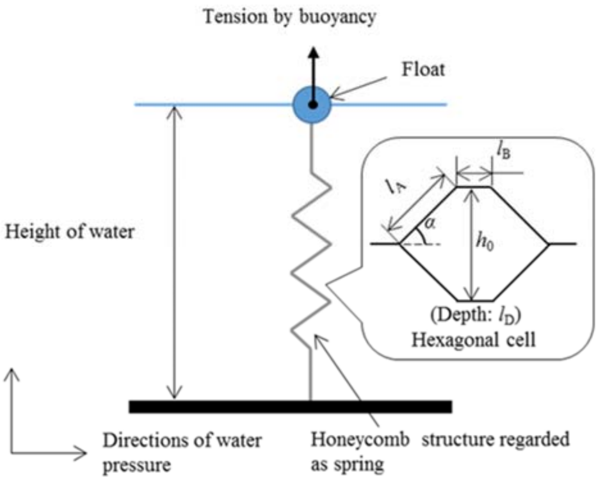
the kinetic energy of water flow.

As the next step of this research, the poles are planned to be integrated with voltage generation or energy harvesting function using vibration of the poles due to air flow and/or water flow. To realize this, electroactive polymers, piezoelectric materials, etc. are under investigation to be applied, or conventional electro-mechanical systems can be used for a while.

3.2 Deployable structure [8]

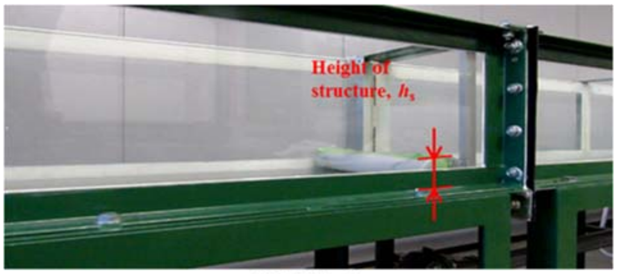
In Figure 7, a schematic drawing of the deployable honeycomb structure model is shown. In this study, the cell shape was designed based on the assumption that the cell is made of 0.2 mm thick aluminum (A1050-H24) and can elastically deform up to the double of its original height. The actual model designed to follow the height of water level with a float (POM cylinder) to lift the model and a membrane (PVC) to stop water flow, which are attached to L-shape aluminum frames on both vertical sides of the structure to obtain higher stiffness in the direction of water flow. This model was set in the same water channel as used for the artificial forest experiment and water was supplied at the rate of 1.3 l/s up to 150 s where overflow started. Then the water flow was stopped and the water level reduced. The heights of the water level and the top of the structure were measured.

In Figure 8, the actual model is shown at the initial and the successfully deployed states. Above this level, the supplied water overflowed. This system can be regarded as a smart structure because its height is found to be in autonomously proportion to the water height and its change as an environmental state in the experimental range. As the next steps of this research, the authors are trying to embed functional materials such as piezo-composites and IPMCs to make the structure multifunctional and smarter.

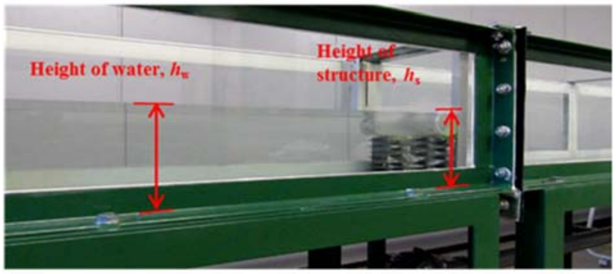


t /mm	0.2
α /deg	5
h_0 /mm	10
l_A /mm	50
l_B /mm	20
l_D /mm	10

Figure 7. Schematic of deployable structure model.



(a) Initial state



(b) Deployed state

Figure 8. The actual deployable structure model at (a) initial and (b) deployed states.

3.3 Challenges toward future

The following researches are mainly undergoing by the authors et al.

1) Applications of Piezoelectric Polymers in Electrical Power Generation Using Ocean Waves [10].
2) Dynamic Deployment of Smart Inflatable Tsunami Airbags (TABs) for Tsunami Disaster Mitigation [11].
3) A Novel Underwater Inflatable Structures for Smart Costal Disaster Mitigation [12].
4) Structural Health Monitoring of Pipelines for Environment Pollution Mitigation [13].
5) The Contribution of LARES to Global Climate Change Studies with Geodetic Satellites [14].
6) Smart Disaster Mitigation in Italy [15].
7) Smart Disaster Mitigation in Thailand.

The following one is also undergoing. In order to cope with tsunami, rigid and fragile structures are not suitable, and rather strong, light and flexible structures are preferred, Asanuma et al. have started to develop a multi-layered flexible and deployable structural material system to diminish the force of tsunami and dissipate its energy by separating water flow and letting them conflict with each other as briefly shown in Figure 12 [16], which was presented as a part of the plenary lecture at the International Innovation Workshop on Tsunami, Snow Avalanche and Flash Flood Energy Dissipation (January 21-22, 2016, Lyon, France) where lots of innovative ideas and challenges such as offshore mega-floating structures with energy harvesting function as well as dissipation function were introduced and future works were discussed [17].

4. Products from industries and projects

Various challenges have been done in industries and some are already commercialized. In Figure 13, one of the products successfully developed by Hitachi Zosen Corporation is schematically shown. The neo RiSe® (no energy, no operation, Rising Seawall) land- mounted movable flap-gate type seawall can be autonomously deployed by using the force of tsunami [18, 19].

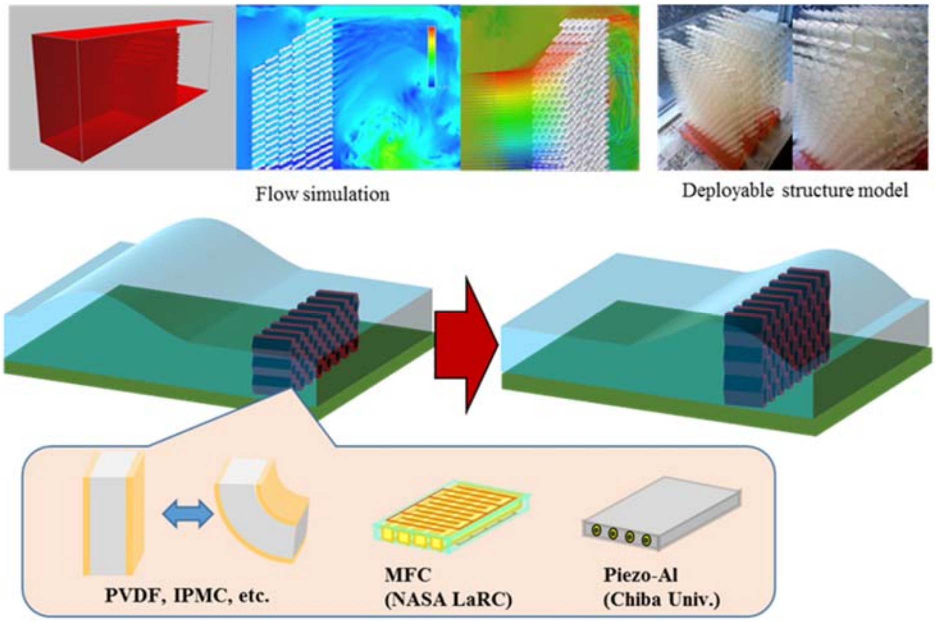


Figure 9. A new design of tsunami barrier using computational fluid dynamics (CFD), and its next plan to be multifunctional.

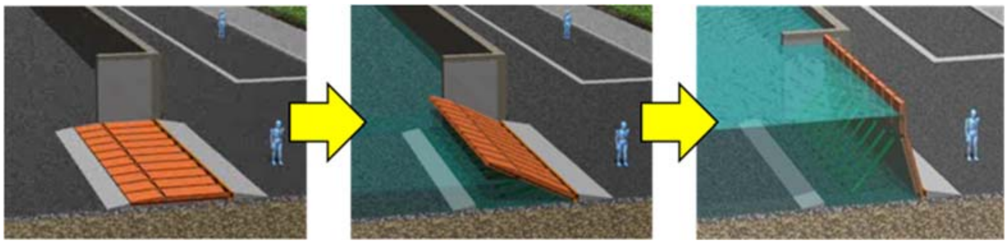


Figure10. The neo RiSe land-mounted flap gate embankment system (Courtesy of Mr. K. Nakayasu (Hitachi Zosen Corporation)).

Project MOSES, Aqua Dam, Inflatable Flood Barriers, Inflatable Rubber Dam, Water-Gate are also attractive examples.
In addition to the above mentioned products, Takenaka Corporation proposed innovative "Breakwater and breakwater group [20]."

5. Summary

New ideas and developments for smart disaster mitigation toward future especially based on smart structures/materials are described in this paper. The proposed concept "Disaster Mitigation and Sustainable Engineering" is the key and explained more comprehensively. Two examples having been tried experimentally to realize the concept are shown. As the first example, artificial forests are examined to have better capability of high wave or tsunami mitigation by changing various parameters such as configuration, density and material. Multifunctional design is also mentioned. As the second example, a novel deployable structure based on honeycomb to be used against flooding etc. is proposed and demonstrated to be autonomously deployable due to increase of water level. This autonomously height-controlled river or anti-flooding bank system can be regarded as a smart structure. Energy harvesting materials and systems are under consideration and development to make the system smarter and fully realize the concept. Many other smart challenges and products are also introduced and future directions are discussed.

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