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IOT AND SENSOR NETWORKED SMART PRODUCT

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Abstract. *The adoption of Internet of Things (IoT) and Wireless Sensor Network (WSN) is crucial for the realization of smart product and service. IoT and WSN are interrelated and work together in this process. Smart connectivity with existing networks via wireless sensor network resources is an indispensable part of IoT. The purpose of this research is to develop IoT and WSN-based smart product. For the problem domain, a vending machine is adopted which is widespread and easily accessible in the office and campus building. Customer requirements through user complaint analysis are analyzed and research directions are derived. Four major improvements such as error detection, display improvement, safety mode design and fine dust removal are extracted and implemented using IoT and WSN environment. A prototype is developed and tested in a similar working condition.*

Keywords: Internet of Things (IoT), Wireless Sensor Network (WSN), Smart product, Vending machine, Cloud computing, Error preventive design

1. **Introduction.** The Internet of Things (IoT) and machine-to-machine networks are highly connected and implemented on the Internet protocol. The IoT describes a system where objects, sensors and software are connected to the Internet via wireless and wired network. It enables added value and service by exchanging data with the manufacturer, operator and/or other connected devices. ITU (International Telecommunications Union) defines IoT as a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies [1,2].

The IoT generates a paradigm where everything is interconnected and redefines the way people interface with machines and the way they interact with the environments. As the IoT is generating an unprecedented amount of data, companies need cloud computing infrastructure to alleviate the data storage pressure. Cloud computing enables all the connected devices to work together. There are differences between cloud computing and IoT. Cloud computing delivers data, applications, photos, videos, and more over the Internet to data centers. IBM has proposed cloud computing as Software as a Service (SaaS), Platform as a Service (PaaS), Infrastructure as a Service (IaaS), public cloud, private cloud, and hybrid cloud. Including all the above, they can be summarized as Everything as a Service (XaaS). Meanwhile, the IoT refers to the connection of devices to the Internet [3].

Recently, as most competitive product combines additional product service on top of the basic function through the rapid development in the IoT and cloud computing, smart product should equip with intelligent, adaptive and network capabilities. Mostly, the adoption of IoT has mainly focused on infrastructure such as smart city, smart home, smart banking project, to name a few. The adoption of IoT and Wireless Sensor Network

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(WSN) is crucial for the realization of smart product and service. IoT and WSN are interrelated and work together in this process. Smart connectivity with existing networks via wireless sensor network resources is an indispensable part of IoT.

The purpose of this research is to review the state of the art of IoT and WSN. Then we propose a smart product realization process based on IoT and WSN. A vending machine is chosen as an implementation domain for the proposed system. Section 2 reviews the IoT and error preventive design scheme. Section 3 describes the methodologies and implementation. Section 4 shows the results of the proposed research. Section 5 summarizes conclusions and future research directions.

2. **IoT and Error Preventive Design.** The idea of IoT and wireless sensor networks has been developed following a similar process. While IoT does not assume a specific communication technology, WSNs will proliferate many applications and many industries. The small, rugged, inexpensive and low powered WSN sensors will bring the IoT to even the smallest objects installed in any kind of environment, at reasonable costs. Integration of these objects into IoT will be a major evolution of WSNs [4]. In the IoT and WSN environment, when embedded system, mobile and cloud are implemented on the service, it resulted in IoT-based new product as shown in Figure 1.

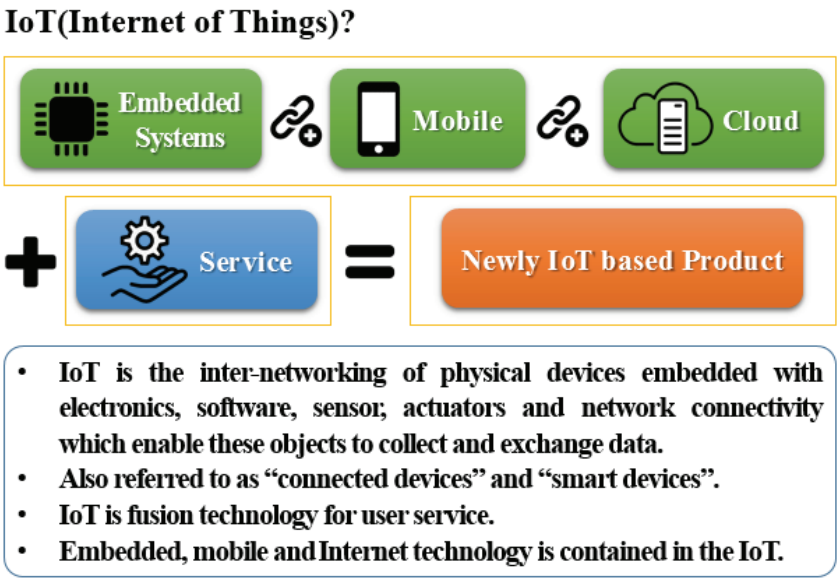


FIGURE 1. IoT-based new product development scheme

For the future vision of IoT, the computing paradigm needs to go beyond traditional mobile computing scenarios that use smart phones and portables, and evolve into connecting everyday existing objects and embedding intelligence into our environment. Smart connectivity with existing networks and context-aware computation using network resources is an indispensable part of IoT [5]. Porter and Heppelmann have proposed that smart and connected products share three core elements: physical components, smart components and connectivity components [6].

A working system operated by human and machine is defined as man-machine system. Many errors in the machine system are related with the interface between man and machine. Thus, we can reduce many errors focusing on the interface of man and machine. Figure 2 shows the man-machine interface system.

When a new product is developed, the concept of error preventive design is applied to reducing the possible error which may be caused by human error or machine malfunction. The error preventive design is based on compatibility, action inducing, consistency and acceptability. In the error preventive design, four kinds of design approaches are adopted.

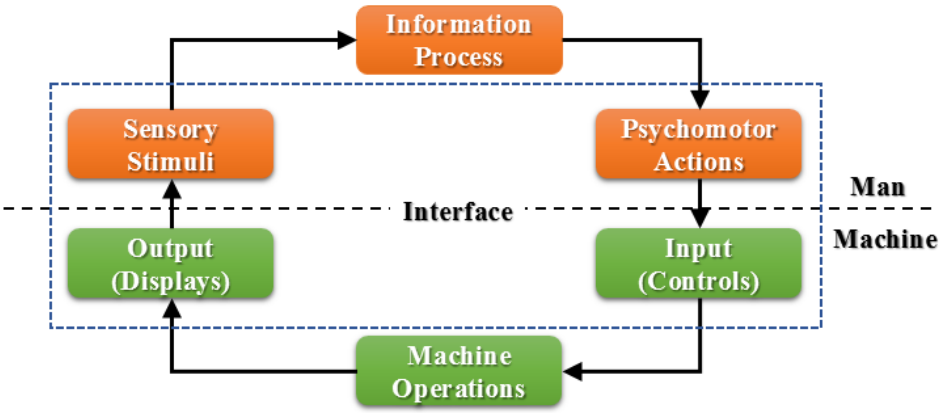


FIGURE 2. UI in the man-machine system

Manufacturer	Donggu CO. LTD.
Model Number	VEN701
Available drinks	2 mixes
Raw material container	1kg 2EA
Cup capacity	60EA (6.5oz)
Water supply	- 2.7 liters of internal water bottle - Able to mount on the upper water tank
Product size (HWD)	596 × 280 × 460(mm)
Weight	12kg
Price	500$
Built-in sensor	- Water level sensor - Cup sensor

FIGURE 3. A coffee vending machine

They are error clearance design, error reducing design, safety equipment installed design and warning system.

Nowadays, not only cellular phone but also most devices become more intelligent and smart. Even cleaning robot used in carpet cleaning is very smart with self-recognition and identification capability. A vending machine has been used widely for its unmanned system and auto control mechanism. In case of coffee vending machine, we can find everywhere in business office, bus terminal, lounge or campus building. With the advent of smart world, the user requirement for the vending machine is higher compared to decades ago.

The error type in the vending machine is analyzed as three cases. Firstly, a paper cup is not supported from the machine even though the paper cup is stored in the machine. This is not a frequent case because a sensor is equipped in the vending machine already. Secondly, only water is provided without coffee powder. This happens when there is not enough coffee powder or it is hardened through old usage. Thirdly, components are not mixed as planned because one of the components is missing or out.

In order to solve these problems, various sensors are attached to every component of vending machine, which can monitor the volume and properties of components. IoT and machine-to-machine network are implemented to tackle these problems. An exemplar photo and specification of coffee vending machine used in this research is shown in Figure 3.

3. **Methodologies and Implementation.** The reference architecture of IoT system has been proposed in the form of architecture patterns [7]. They are three-tier architecture pattern, gateway-mediated edge architecture pattern, edge-to-cloud pattern, etc. The three-tier architecture consists of edge, platform, and enterprise tiers connected by proximity, access, and service networks. In the edge-tier, data are collected through the proximity network, and then forwarded to the platform tier. The networks utilize a combination of enabling wireless and/or wired technologies such as RFID, Bluetooth, Cellular, ZigBee, Z-Wave, Thread, and Ethernet. The platform tier uses the service network to communicate with the enterprise tier, and generates data transform and data analytics.

IoT and sensor networked smart product are bi-directional communicating objects which observe their environments and are able to make decisions depending on the application and based on the information extracted from the physical world. Smart products are designed as miniaturized, low power microelectronic systems based on micro controllers, transceivers, sensors and low energy supply operated under IoT and cloud platform.

The method/approach for the smart product is wireless sensor networks as they provide the communication platform and the sensors. In this paper, we propose a reference architecture composed of three layers, which are communication layer, service layer and application layer. This corresponds to edge, platform, and enterprise tiers in the three-tier architecture pattern.

For the IoT network, LoRa is adopted for its low power and wide area network. LoRa is a new transmission standard between distributed devices and distributed gateways. LoRa has an extremely low channel capacity, a very low power consumption and a very high link budget.

In order to achieve the research goal, implantation process has been proposed as Figure 4. The process follows the research methodology composed of three layers described above.

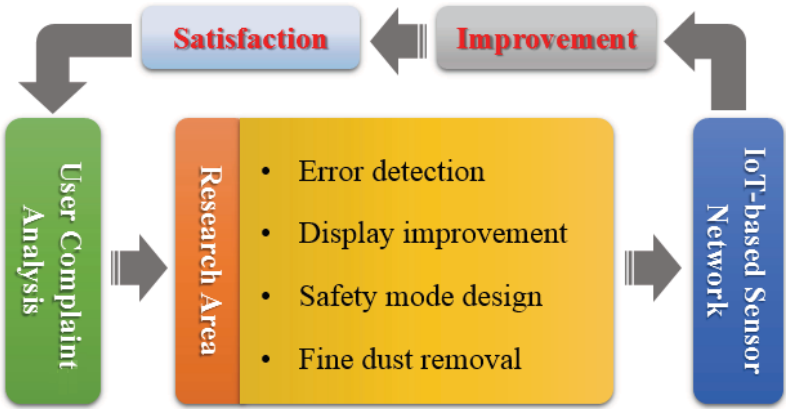


FIGURE 4. Implementation process for solving vending machine error

Firstly, user complaint analysis has been performed to get customer requirements. Secondly, several approaches have been tried to solve various problems. Machine error detection mechanism, display improvement, safety mode design, and fine dust removal for environmental solution have been proposed, devised and applied. These methods combined with IoT can lead to WSNs to solve user complaints. A feedback loop system is constructed to solve user complaints.

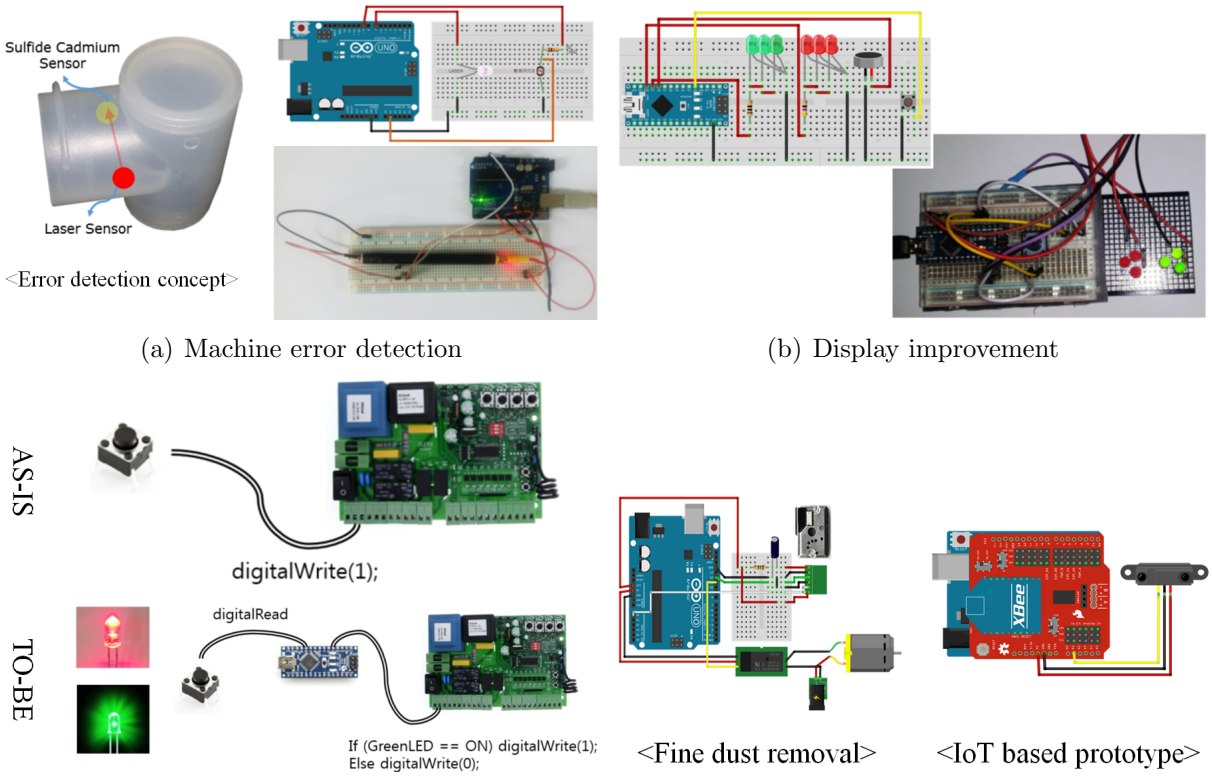
Four areas to solve the user complaints of a coffee vending machine are explained in the following.

(1) Error detection system: For the identification of resource material (i.e., coffee powder) in the vending machine, laser sensor, sulfide cadmium cell and Arduino board are used. Using the laser, the resistance of sulfide cadmium cell is measured, and by the resistance value, the existence of coffee powder is identified.

(2) Display improvement: The display in the vending machine should show the exact status of inside of the system. However, the present machine cannot identify the correct status of the machine. This does not meet the "concept compatibility" property in the man-machine system. Through the error detection system, when the coffee powder is below the limit, red LED light is blinking on the PUSH button. When the user inserts money in the vending machine with malfunction, the money is returned with a kind comment such as "coffee is out, please try later".

(3) Safety mode design: By returning the money when coffee powder is not available, safety mode is included in the vending machine. In order to recognize machine status easily, display design is improved and revised in visual and audio mode.

(4) Fine dust removal: Recently, fine dust is a big issue globally. Users of vending machine are worried about the cleaning and hygienic status of the machine. The status of fine dust near the vending machine should be measured and monitored regularly. Four devised modules to implement these ideas are shown in Figure 5.



(a) Machine error detection

(b) Display improvement

(c) Safety mode design

(d) Fine dust removal & IoT based prototype

FIGURE 5. Approaches for solving customer complaint

4. **Results.** In order to develop the proposed system, software development environment is set up in the laboratory level. The environment for software development is as the following.

- Windows 10 Home 64bit
- Hardware: tablet Notebook (CPU Intel ® Atom x5-z8300, RAM: 4G)
- Program: MS Visual Studio Express 2012 Windows Desktop
- RAD (Rapid Application Development)_tool

To implement IoT and WSN in the vending machine, a unique ID is given to each vending machine. The measured data of the existence of coffee powder and the volume of fine dust are transferred to the vending machine control cell via wireless sensor network and IoT. According to the data value, corresponding warning display or mechanism can

Vending MC ID	Cartridge1 Inventory	Cartridge2 Inventory	Cartridge1 Status	Cartridge2 Status	Dust Concentration	Cartridge1 Sales volume	Cartridge2 Sales volume	Cartridge1 Opportunity cost	Cartridge2 Opportunity cost

FIGURE 6. Application protocol

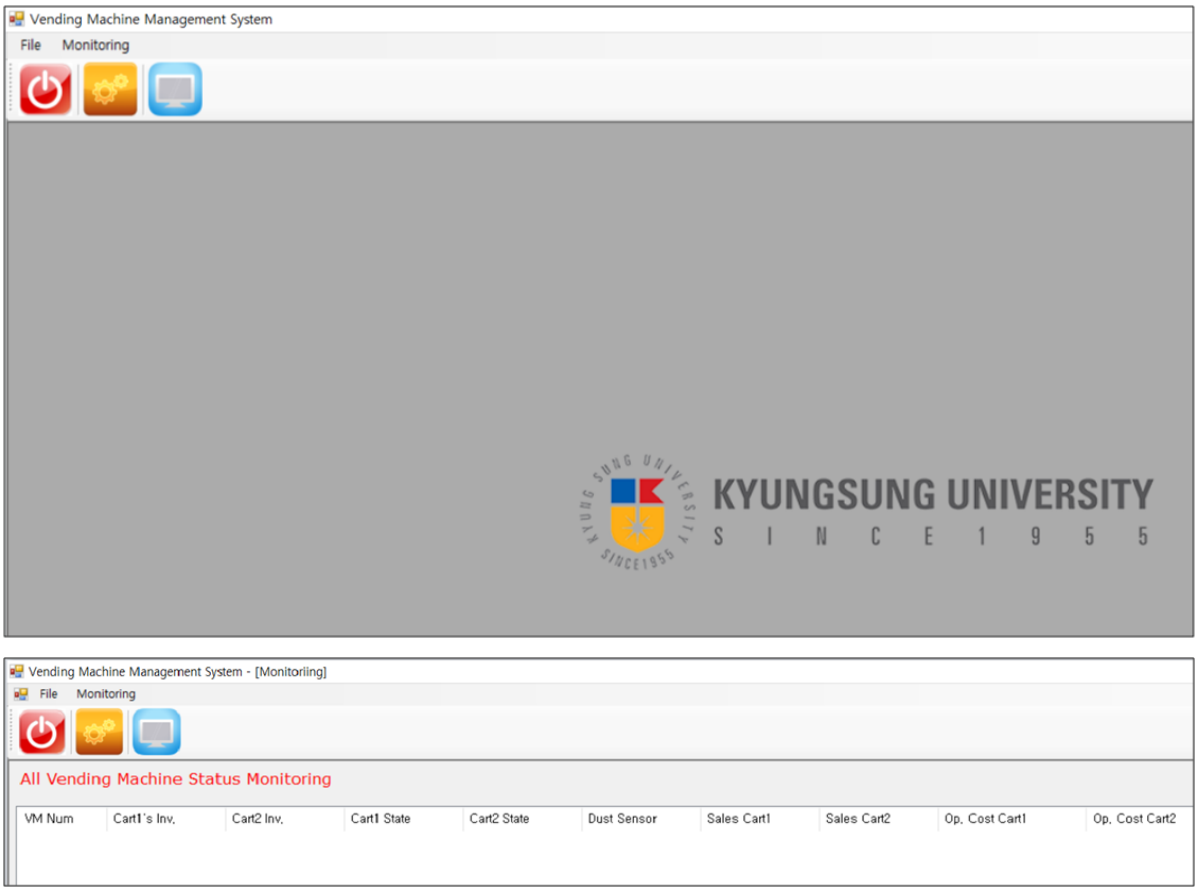


FIGURE 7. Implementation result of vending machine monitoring software

be performed. Figure 6 shows the application protocol of vending machine control cell and Figure 7 shows implementation result of vending machine monitoring software in IoT environment.

The concept of modularization is adopted to implement the system. Modular system means that each separated sub-system can play its function independently. It can be easily assembled and disassembled with sensor and Arduino board using "Pin Header" and "Jump Wire". Figure 8 shows the modularization of each component. The sensor with the same voltage value can be assembled with Arduino via "Pin Header". Those which cannot be assembled directly are developed as modular system. Figure 9 shows sensors to be installed inside the machine to solve the customer complaints. Laser sensor and laser generating equipment can be connected with Arduino because they all use 5 voltage. As visual display and sulfide cadmium cell require low voltage, they are modularized and connected to the Arduino.

The academic contribution of this paper relies on the implementation of smart product realization process. In the IoT and WSN areas, there are huge ideas and suggestions in various domains. However, an actual working prototype has been reported in limited cases for the suggested ideas. In this regard, this paper tried to propose research methodology and developed a prototype for an actual product in the real life.

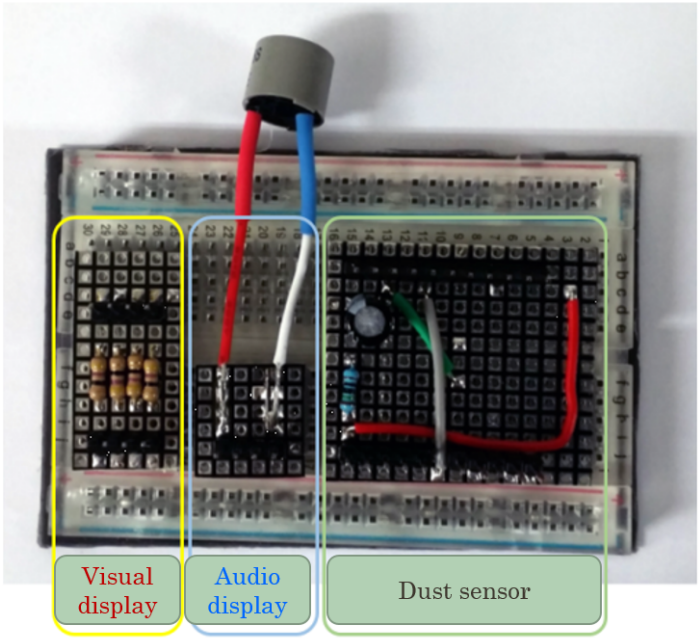


FIGURE 8. Modularization of each component

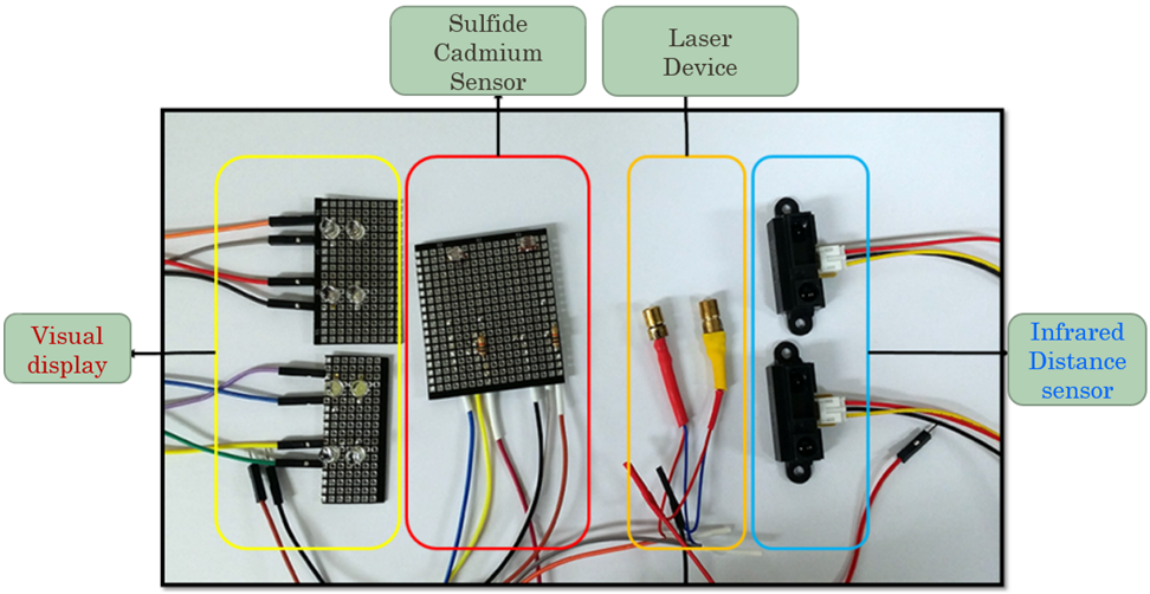


FIGURE 9. Modularization connecting via Arduino

5. **Conclusions.** This research has proposed IoT and WSN system to realize the concept of smart vending machine. The concept of IoT and WSN is reviewed for this purpose. For the problem domain, a vending machine is adopted which is widespread and easily accessible in the office and campus building. Customer requirements through user complaint analysis are analyzed and research directions are decided. Four major improvements such as error detection, display improvement, safety mode design and fine dust removal are extracted and implemented using IoT and WSN environment. A prototype is made and tested in a similar working condition.

Future research directions are as follows. Even this research shows a good use case of smart product realization using IoT and WSN, a more generic methodology needs to be developed which can be applied for other cases. Additionally, IoT is a hot topic which is adopted so often in many areas these days. The IoT supported objects need to be Plug

and Play smart objects which can be deployed with an interoperable backbone allowing them to blend with other objects.

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