Embedding Intelligence into *Smart Tupperware* Brings Internet of Things Home

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Abstract

The *Internet of Things* (IoT) has been rapidly growing in recent years and is seen as a key enabler in a wide variety of applications such as manufacturing, transportation and healthcare. Home automation, in fact, has been a major market for both hobbyists and early adopters of IoT technology. Even a wave of smart kitchen appliances has been released such as a refrigerator with a built-in screen on its door or internet-enabled coffee maker. While green activists may applaud the appearance of tiny cameras inside our refrigerators to avoid the power loss of opening the door, displaying such images on a brilliant, 200W LCD monitor is not the "killer app" that many of us believe has the power to re-shape our every-day lives.

Instead of the technology-push exemplified above, we have been examining the potential demand-pull of adding convenience to the lives of consumers with a focus on kitchen automation as in many cultures, the kitchen is the functional and social nerve center of the home. *Smart Tupperware* and *Tuppy*, an intelligent app and personal assistant, is our information-centric gateway to the 21st century household. We describe an appliqued container, over-molding of electronics and a printed polymer circuit into *Smart Tupperware* containers. However, the true power of *Smart Tupperware* comes from the network that connects *Smart Tupperware* with other smart appliances such as smart refrigerator or smart cooktop in the kitchen. We propose a new IoT architecture, *TupperwareEarth* that forms an extended network of IoT-integrated appliances and infer to each other to potentially re-shape your every-day life in your kitchen by bringing convenience.

Introduction

The term, *Internet of Things* (IoT) was first introduced about 20 years ago with the idea of using Radio-Frequency IDentification (RFID) tags from Auto-ID Labs [1]. However, the concept has been extended to the wide use of the sensors, actuators and other wireless network systems using Bluetooth or Zigbee embedded in the environment [2]. The extension of the IoT is alongside the growth in the number of devices connected to the Internet. The research shows that there will be 50 billion of the Internet-connected devices and each person will own about six of the Internet-connected devices by 2020 [3]. These would include smartphones, a smart product that is already commonly used by people, PCs and other possible future things that could become smart with the IoT technology in the future. The definitions of "things" has changed over the growth of the technology and virtually any objects could become "things". However, the main goal of making a computer sense information without the aid of human intervention stays the same in the modern applications of the IoT [2].

The term first started with the context of supply chain management [4], but the concept has been rapidly implemented into different applications including homes, healthcare, transportation and automation. For example, the buildings have sensors for attempting to save energy or industrial plants are connecting to Internet for the automation [5]. In fact, one of the biggest area of the IoT-integration is in our homes, the domestic places which are the spaces for our daily lives and activities with the rise of the services such as *Air-BnB*, which have made IoT-controlled locks, thermostats and smoke alarms valuable – though, perhaps, not indispensable -- from a business case perspective. Smart home is on the top three largest sales of smart products in the market since 2011 [3] and this also has been seen in *Consumer Electronics Show* (CES) which was a spectacle of the smart home appliances in 2015 [6]. Almost a quarter of the show was focused onto the smart home appliances and many new smart products were released that tie coffee makers to the *World Wide Web* and allow us to browse the internet while standing, half-naked, at our refrigerators. The power of the IoT-integration into the home appliances comes from the impact it will have on different aspects of everyday-life and behavior of the users [7]. However, there are questions of whether these home appliances actually bring any impacts to our every-day life. Why do we enable the Internet to a coffee maker to remotely control? We do not need to turn the coffee maker on unless we are in the house and it does not take too much time to go and physically press the button on the product.

The concept of smart home is not a completely new idea, but has been visualized ever since the electronics occupied the house. Our house is full of electronics such as TV, refrigerator or microwave, and they used to be categorized into either "time-saving" goods or "time-using" goods [9]. For example, Harper defined a television as a time-using good, which occupies discretionary time and improve its perceived quality, but a washing machine as a time-saving good, which can potentially increase discretionary time by reducing the time needed to carry out a task [8]. However, with the growth of domestic technology, the distinction between time-saving and time-using goods are becoming unclear and the integration of the

IoT technology adopts the time-using features to all appliances.

The interest of in wiring homes for increased functionality started from the 1960s by the home hobbyists, but the commercial interest of home automation began in 1980s with the development of digital systems [8]. The integration of the IoT technology emerged with the smart home concept in modern days to connect the appliances to the Internet. The question is, what make the appliances "smart"? The answer lies in the value creation from the IoT integration. Fleisch describes the IoT-product-services logic with thing-based function and IT-based function [10]. For example, a thermostat's thing-based function is measuring the temperature of the space from its sensor. This function comes from the physical body of the thermostat, but when the technology adds an IoT stack onto this function, it creates an IT-based function which is an automated temperature control. The integration extends the functionalities and services of the thing, thus creates a new value into the product [11]. The "smartness" not only comes from the extension of the functionality, but also from the enhancement of the functions by connecting to related products [11]. For instance, Amazon's *Echo* could access your calendar and notify the thermostat to heat up or cool down the house based on the weather in advance to your arrival. This ties into how a network of the smart appliances could create a new knowledge and perform a cooperative task that establishes the smart system of the house.

Harper claimed in his book released more than 10 years ago that there had been yet no smart home technology that is largely independent of the household income and there is a question of whether the smart home appliance is the "must have" appliance [8]. The claim is still valid until today, as we still have not seen a killer app despite the enormous number of appliances released in the current market. For instance, voice-controlled smart speaker is one of the hot area in the home appliance market and a big competition is followed by the tech giant such as Amazon's *Echo* and Google's *Home Mini* [13][14]. The nature of smart speakers is to help the customers control wide variety of home automations through a voice-control. However, the survey from the NPR and Edison Research shows that 90% of people use Amazon's *Echo* for listening to music, 87% for asking questions with voice and 63% for setting alarms, and because of those uses, 45.9% of the smart speakers are used in a living room [15][16]. Smart speakers certainly have a great potential to become an assistant to control the home automation, but in fact they are mostly used for the entertainment and remain as information cloud, instead of leading to an "activity tornado" that enhances the kitchen automations.

To tackle the drawback of the smart home appliance, we have been working on developing *Smart Tupperware*, an intelligence-embedded container to build a smart system at a micro-level in your kitchen. Kitchen is a nerve center of many households and a heart of the house where many activities are occurring on a daily basis, not only limited to cooking, but other non-food related activities. It is a place for social activities, household management, relaxation and recreation [12]. The survey on kitchen activities of American households shows that the eight most practiced non-food related kitchen activities include eating, planning meals, talking on telephone, conversations, entertaining guests, paper works, reading newspapers and watching televisions [12]. Since the kitchen revolves around food preparation as a social, artistic and sustaining activity, we believe the gathering, organizing, storing and use of pantry items and associated utensils is a meaningful place to start. Recognizing the variety of activities happening in the kitchen, our goal of *Smart Tupperware* is to enhance the convenience and quality of life through exploring different methods of embedding an intelligence into a standard *Tupperware* container.

Appliqued Electronics

We often refer *Tupperware* to plastic containers, though *Tupperware* is a name of the company that produces plastic containers in various sizes and shapes [17]. Known as a company that focuses on kitchen and household products, Tupperware Brands Co. is changing the standard image of their products by transforming typical plastic containers into an intelligent container over past decade through exploring various design.

Figure 1. Early Prototype of LCD Mounted Tupperware Container. [18].

Smart Tupperware's design is centered around a microcontroller that collects the data from sensors and communicates with the App through a Bluetooth wireless network. Previous designs integrated with built-in sensors that can sense the sight, weight and volume to monitor the food contents inside *Tupperware* containers in real-time. Power consumption is a key as people would not like to have a high power electronic device everywhere in the kitchen. *Smart Tupperware* actually minimizes the power consumption by controlling active and sleeping modes to make the microcontroller control the flow of power [18]. Earlier prototypes shown in Figure 1 had a LCD screen mounted on the container, but the project is moving into integrating a thin flexible display that consumes lower power for displaying information on its screen. The screen will show the information based on type of food, amount of food left, expiration date and most importantly alert the users when there is a low amount of food is left or expiration date is passed [18]. However, the users do not need to look at each container's screen to check all information. *Smart Tupperware* offers a smartphone App that connects to all the containers for gathering information and makes it convenient for the users to keep track of the containers in the kitchen.

What *Smart Tupperware* App offers to the users is more than just checking the information of each container. Knowing the information on type, amount and expiration of food in all container, the system can expand its services to bring more conveniences to our daily lives. It can automatically generate a shopping list by checking the list of food at low amount or alert the users on expiring food by checking the expiration dates [18]. The system also knows the availability of the food in your kitchen and can suggest a menu for dinner based on the ingredients you have. By gathering the data of what type of food you like to eat, *Smart Tupperware* will learn your preference and eating habit. This would allow the system to suggest your favorite menu or a healthier meal plan based on the patterns.

Figure 2. *Smart Tupperware* and *Tuppy*.

Smart Tupperware can offer the services from the IoT network built between the containers, but also able to expand the network by connecting to other smart devices in the kitchen. For example, what if *Smart Tupperware* can be connected to FirstBuild's *Paragon Induction Cooktop*? First, *Smart Tupperware* analyzes the availability of ingredients in your house and checks your eating habit. The system suggests you a pasta because you have all the ingredients in your kitchen and you tend to cook a simple menu on Monday after you get back from your work. Upon your agreement on the suggestion, *Smart Tupperware* will talk to *Paragon Induction Cooktop* to start heating up to a temperature for boiling a noodle. Imagine that many Smart Tupperware reside with other smart electronics and they communicate with each other through IoT network in your future kitchen. *Smart Tupperware* will blend convergence technologies such as suggesting menu, pulling up recipes from online or displaying cooking tips on Smart Refrigerator that will enhance the kitchen actuation and establish a smart system in the kitchen.

Over-molded Components

The earlier prototype of a conventional rigid LCD *Smart Tupperware* was a good exploration of the possible design and system, however there were several limitations identified. The product comes in as two parts of the plastic container itself and the display, thus there were questions of how the assembly would play a role in the product commercialization and how it would appeal to the potential customers. The question arose from this exploration was, "Can we directly embed the electronics into the plastic?" We have explored various designs and concepts of over-molding the electronics to more directly embed the intelligence into *Smart Tupperware*.

Over-molding process requires high temperature and pressure and our main concern was whether the electronics would survive in these harsh conditions. We explored a concept of the barcode cups, shown in Figure 3 that was simpler and easier to tackle this problem. The barcode label was successfully over-molded into a transparent cup, so the barcode was visible and able to be scanned for the information it contained. The barcode cups work like the RFID tagging system. Each barcode contains an identifiable information about the content and the cup, but required an external device to access and read the information. With the barcodes, the containers became live and active to provide the information to the customers. However, the concept identified a clear limitation that the information on the barcode was not able to be updated with a new information.

Figure 3. Barcode Cups

One of the user interactive part that *Smart Tupperware* consists of was the E-Ink displays. The E-Ink displays were great for low power consumption as they only required a power when updating the displays and maintained at almost a zero-power for the rest of the times. This would build a safe environment in the kitchen and resolve the concerns of having a high power electronics in the pantry, refrigerator and kitchen. Our main concern was whether the displays would survive from the harsh conditions of high temperature and pressure of over-molding process. One of the experiments we tried was encapsulating the E-Ink display in Epoxy. Figure 4 shows a successful sample of embedded E-Ink display in Epoxy and demonstrating that the display was still able to be actuated by updating.

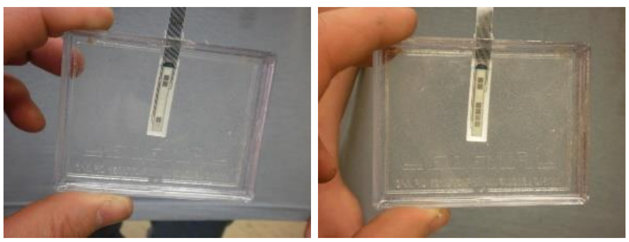

Figure 4. Embedded E-Ink Displays in Epoxy. Before (Left) and After the Display Actuation (Right)

Another test we conducted was over-molding the E-Ink displays to embed them directly into the plastic containers. 275-ton Windsor injection machine was used to over-mold the E-Ink displays in 216 psi of injection pressure and 400^{o}F of nozzle temperature. Figure 5 shows a successful sample of the E-Ink displays over-molded in the plastic container and was able to actuate the display for the update even after the over-molding process.

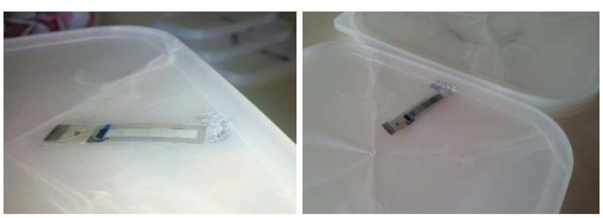

Figure 5. Over-molded E-Ink Displays. Before (Left) and After the Display Actuation (Right)

Though the over-molding of E-Ink displays showed a promising result, the failure rate remains for the improvement in the future and there are other components of the electronics need to be tested for the over-molding. The electronics compose of the PCB (printed circuit board), E-Ink displays and a thin film battery. The PCB is made of polyimide, a flexible polymeric film which will operate upto 300 ^{o}C of temperature rating, however the test of over-molding is still necessary to experiment whether the PCBs will survive under the conditions of over-molding. The batteries also need to be tested for over-molding to check on the survival rate.

Printed Polymer Circuits

Over-molding process successfully embedded the intelligence into the plastic, but not all attempts on embedding electronics were successful and the survival rate of electronics remained as a big concern for the process. The over-molding process was combining two different materials together, however the new idea came from embedding the intelligence directly into the material by printing a polymer circuit.

The idea of building an intelligent meta-material has been conceived by different research applications such as building a neuromorphic architecture in a polymer or embedding an artificial neural network (ANN) [19], [20]. The intelligent meta-material have benefits of flexibility and re-configurability that could customize *Smart Tupperware*. We would like to produce *Smart Tupperware* in different shapes, sizes and purposes, however, over-molding will require us to re-configure differently each time. If we print a polymer circuit to form an intelligent material, we could re-configure at a micro-level to personalize *Smart Tupperware*.

We started with printing the light-emitting diode (LED), one of the most common parts of the electronics that operate as an important user indicator. The polymer circuit was printed on a highly flexible substrate that the device characteristics are not affected by the bending of the material as shown in the picture on the left in Figure 6. With the chemical composition of an active layer, which is a light-emitting layer on the polymer circuit, an organic light-emitting diode (OLED) was lighted up with a light green color shown from the picture on the right in Figure 6.

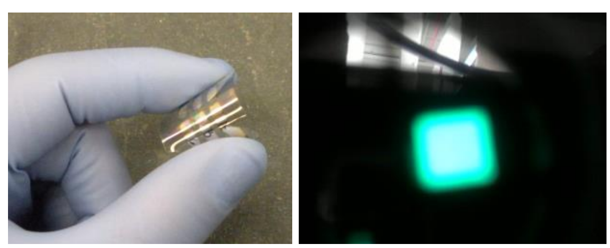

Figure 6. Bendable Substrate (Left) and OLED (Right)

There is also a possibility of printing other components of the electronics such as sensors as a part of the polymer circuit. The density of sensing is important in the IoT network and *Smart Tupperware* uses several different sensors such as color sensor and strain gauges. If the sensors are printed in a polymer circuit, forming an intelligent material that builds the plastic container out of, *Smart Tupperware* will benefit from the flexibility of the design in using the intelligent materials as configurable blocks. With different shapes and sizes of the container, the material can be re-configurable and personalize different *Smart Tupperware* for different purposes.

Networked Tupperware

There could be tens of *Smart Tupperware* reside in your kitchen and forming a network between each other, but this network can be extended by connecting *Smart Tupperware* to other smart appliances in the kitchen. *Smart Tupperware* collects enormous amount of data collected from the contents inside the containers and stores the information to the cloud, however what *Tuppy* could offer to the customers is limited to being an information cloud that pulls out an information from the Internet. An extended network, *TupperwareEarth* of connecting *Smart Tupperware* with other smart appliances can enhance the kitchen automation from sharing the data between the appliances.

The concept *TupperwareEarth* is referred from *RoboEarth*, a semantic engine that connects the robots around the world for sharing the knowledge by exchanging and reusing the data between the robots [21]. *RoboEarth* provides a language that allows to describe actions, object recognition and articulation models, as well as semantic environment maps and provide different methods of reasoning about the information given to the robot [22]. Though *RoboEarth* was built for connecting the robots and showed a promise in applying the architecture to the robotics world, this type of architecture is what a smart kitchen needs to build a semantic network between the IoT-integrated kitchen appliances to reach the goals of inferring between the appliances, understanding the context and performing the task through a certain logic of inferring one to another.

Imagine that you are in a house full of smart appliances, how do you envision your version of smart kitchen? A microwave, stove, blender, coffeemaker… the list goes on, but we cannot skip a refrigerator from this list. If your kitchen is a heart of a house, your refrigerator can be a heart of your kitchen. *Samsung Family Hub* has a built-in touchscreen on the door and connects to your smartphone. The latest model of *Family Hub* is equipped with a voice-control and focuses on offering ‘personalized’ services to the customers with the algorithm of understanding the food preference or arranging a healthier meal plan [23]. Now, imagine that *Smart Tupperware* can share the data with *Family Hub* and collaborate through a network. For instance, *Smart Tupperware* shares the collected information about the availability of ingredients in each container and *Family Hub* could suggests a dinner menu and provide a recipe on its built-in screen to the users. With *Family Hub*’s algorithm, different menu and recipes can be suggested each day and personalizes the needs of individual user as the kitchen is a place for every member of the family.

What about the appliances that help your cooking in the kitchen? FirstBuild produces a various kind of kitchen and home appliances such as *Opal Nugget Ice Maker* and *Paragon* Induction Cooktop to integrate a smart system into our daily cooking styles [24]. Cooking is a part of our daily activities, but some recipes need a special handling such as a temperature control. FirstBuild’s *Paragon Induction Cooktop* offers a sensor that monitors the temperature in real-time to make it more precise for cooking [25]. The temperature precision is within one degree of Fahrenheit and the users can choose between the probe for liquid temperature and the mat for pan temperature [25]. Adding *Paragon* to the network of *Smart Tupperware* and *Family Hub*, the system can help the preparation and the cooking of the meal. *Smart Tupperware* identifies the available ingredients, *Family Hub* suggests a menu and pulls a recipe on its screen and *Paragon* heats up the pan to a certain temperature based on the recipe. The chains of inferring from *Smart Tupperware* to *Family Hub* to *Paragon* extended the capabilities of what individual appliances could offer and enhance the kitchen activities.

With the network of multiple smart appliances in the kitchen, imagine your smart speaker in the kitchen controlling those appliances and being a kitchen assistant. 45.9% of the smart speaker is used in a living room, however the kitchen is almost as important as living room for the users as 41.4% of them are used in the kitchen [15]. It is still about four percent behind the race, but the networked kitchen appliances predict that the kitchen will become more suitable space for the smart speaker and it win the race in near future. The common uses of smart speaker for the users is quite focused on the entertainment, however, the kitchen automations such as preparing and cooking for a meal are what the smart speaker can focus in the kitchen.

We vision that *TupperwareEarth* will form an IoT network in the kitchen to connect those appliances together and expand to provide an activity tornado with the unlimited services. Through *TupperwareEarth*, the value creation is occurring not only limited to the individual appliance, but to the collaboration of multiple appliances together. The value creation is heavily based on what is available on the database, the density of sensing and actuation of gathering data and the system of rules to link the logics together [5]. With the increase of number of smart appliances in the kitchen, *TupperwareEarth* will handle the large scale of devices and meet the need of logical system that links them together.

Discussion

Each way of embedding the intelligence to *Smart Tupperware* had different advantages and limitations. In order to develop *Smart Tupperware* at a product level, other factors need to be considered such as the cost and manufacturing compatibility with the current production of the plastic containers. Yet, the ideas of embedding the intelligence and extending the capabilities of what the plastic containers can do remain the same. The logic of how *TupperwareEarth* infers and connects the appliances across the different platforms and the demonstration of the conveniences brought to the customers stay as important parts of the future work.

Conclusions

The IoT-integration into the home appliances have pushed the release of products for various types and purposes in the market, but we still have not found any killer app that has re-shaped our every-day life yet. The current appliances such as an Internet-enabled coffeemaker or monitor-enabled refrigerator did not convince the customers on what the conveniences of using them compared to the original products and why they need to have those appliances for their houses. However, we explore the concept of *Smart Tupperware* on brining the convenience to the customers to overcome the current drawback of the IoT-integrated appliances in the market.

We have described different ways of embedding the intelligence into *Smart Tupperware* and shared the vision of how *Smart Tupperware* and *Tuppy* could form a *TupperwareEarth* network of the smart appliances in the kitchen. While we continue to explore different methods of embedding the intelligence and conduct more tests on over-molding the other components of the electronics, we also continue to refine the architecture of *TupperwareEarth*. Through the development of *TupperwareEarth*, we aim the smart kitchen to be ready to handle the large scale of smart appliances around *Smart Tupperware* and re-shape our every-day life in the future.

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