# IoT Stickers: Enabling Lightweight Modification of Everyday Objects

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## ABSTRACT
Internet-of-Things (IoT) devices promise to enhance even the most mundane of objects with computational properties by seamlessly coupling the virtual world to the physical. However, IoT's associated costs and cumbersome setup limits its extension to many everyday tasks and objects, such as those in the home. To address these issues, my dissertation work will enable IoT Stickers—a book of inexpensive, battery-free sensors and composition patterns—to support customizing everyday objects with software and web services using stickers. Using RFID-based paper mechanisms, IoT Stickers integrates common sensors and web services with interactive stickers through a trigger-action architecture. This integration enables computational services to be tailored to everyday activities by setting parameters to be passed to the sticker's actions and composing the stickers together. Thus, IoT Stickers demonstrates a way to associate IoT services with a dramatically wider set of objects and tasks.

## Author Keywords
Paper computing; tangible interfaces; battery-free; Internet of Things

## CCS Concepts
•**Human-centered computing** → **Interactive systems and tools;** *Interaction techniques;* Ubiquitous and mobile computing systems and tools;

## INTRODUCTION
The ubiquitous computing vision extends computing beyond the desktop to the everyday objects that make up our physical world: like desks, offices, other people, the weather, trees, and even chance encounters [22]. In service of this vision, Internet-of-Things (IoT) devices promise to enhance mundane objects with computational properties so that the virtual world of computing becomes seamlessly coupled with the physical. Once embedded in everyday objects, the bits of computing become directly manipulable. This takes advantage of fine tuned human skills capable of sensing and manipulating objects in the environment [11]. By coupling IoT services with the everyday objects people are already adept at manipulating, computing has the potential to fade into the background so that people may focus on their goals and not the computing technology itself [22].

However, current IoT devices are costly and are correspondingly "heavy weight" in how they are deployed and linked to (often proprietary) services. This limits their use for many common household objects such as laundry, groceries, cat bowls, medicine bottles, and bike tires. For example, many IoT devices tend to cost at least 10's if not 100's of $US [4], and this makes them ill-suited for one time interactions like notifying the user that their supply is depleted. Beyond financial costs, there are many social costs for even those IoT devices that manage to drive the price point down to make their extension to replaceable items—like lightbulbs—viable [23, 24]. Replacement contributes to waste, and if electronic, can be especially damaging [12, 18]. Further, discarding possessions to make room for new ones means owners must let go of their attachments to these objects and eliminate the entrenched routines and practices sustained by them [2, 16]. New objects mean users need to acquire new skills [5], and so, renders their existing skills obsolete. Thus, adopting today's IoT carries many hidden costs for the home.

Instead, an upcycling approach to IoT could extend computing to everyday objects by adapting computing capabilities to existing possessions. Everyday objects would not need replaced with internet-enabled equivalents if upcycling could support their renewal by retrofitting them with the latest computing capabilities. A class of technologies that I call *IoT Stickers* makes this approach possible [23]. They enable battery-free, wireless sensing using low cost—and in some cases do-it-yourself—fabrication methods of custom traces on a flexible substrate like sticker paper. When this hardware design is coupled with machine learning enabled sensing and backscatter recognition techniques, attaching computing capabilities to an everyday object can be made as simple as sticking it on the object. Although still requiring some fixed infrastructure (akin to the current widespread deployment of home wireless networking), an important part of this advance is that the price point of individual interactive devices can be at least two orders of magnitude less than typical current devices and that


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social costs can be minimized by enabling IoT to be retrofitted to existing possessions. This means that they can be treated in a much more “light weight” fashion for a much wider range of everyday tasks.

In my dissertation work, I will show how custom IoT services could be associated with a dramatically wider set of objects and tasks by exploring and enabling an upcycled approach to domestic IoT. This approach changes how we enable ubiquitous computing by centering the user within the fabrication process. On this view, the user selects the primary material and form for a smart object, transforms their possessions into a new kind of object, and shapes the capabilities that upcycled object will have. Instead of supporting installation and maintenance of the smart home, an upcycled approach shifts the focus to supporting creative reuse of everyday objects with computing services.

## RESEARCH QUESTIONS

In my dissertation, I explore ways embedded systems could facilitate the selection and transformation decisions users will need to make to upcycle their possessions within the context of the smart home. I realize these ideas by creating the systems for families wanting to adopt IoT in their home and verifying whether these designs succeed by asking users to employ them on their own or collaboratively. I focus on the following research questions.

1. **What interaction techniques enable non-expert users to author and compose embedded computing applications using their everyday objects?** Trigger-action programming has become widely available in commercial systems through services like IFTTT [1]. This approach uses graphical user interfaces (GUIs) to encapsulate control flow constructs like if-then conditions in easier to use abstractions like form filling [8, 17]. Yet, non-experts largely do not use them to author their own recipes [21]. Problematically, they naively rely on experts to compose the IoT services they do use [21]. Further, studies of end-user programming in the home find that these earlier, rule-based approaches are ill-suited to the processes and sequencing needs for embedded computing in the home [4, 3]. These findings underscore a need for alternative abstractions and interaction techniques that enable non-experts to author control-flow statements for domestic IoT.

2. **What physical computing techniques facilitate alignment of non-expert users' application ideas with the expressiveness of end-user programming languages for embedded systems?** Shape successfully conveys affordances of end-user programming languages in GUIs by constraining what expressions can be composed to those that are permissible in the language [19, 7]. Yet, GUIs are malleable materials that displace the rich, integrated practices people have [13, 11], and this kind of displacement is especially problematic for domestic IoT [23, 24]. Instead, tangible user interfaces (TUIs) can use form to constrain what can be expressed while encouraging non-experts to tinker and experiment with physical artifacts to develop expertise [19, 13]. In particular, on an upcycled approach, non-experts could download and reuse functional TUI expressions that realize their computing ideas and remix them with their existing possessions to begin authoring their own embedded applications (see [6] for the importance of reuse and remixing). This approach calls for the design of physical computing techniques that facilitate the selection of appropriate TUIs and their remixing through their affordances.

3. **How might embedded systems sense and impact a small group of users'—like a family's—social field?** Many domestic IoT systems sense home dwellers' behavior so that a system might intelligently augment the home (*e.g.*, [14]). However, the artifacts of the home carry layers of social meaning and are sites of negotiation between family members [23, 24]. To make these domestic systems ‘intelligent’ within this social context, we would need AI-complete systems, and families would have to be willing to accept and defer to these ‘intelligent agents’ within their interpersonal negotiations (both, dubious assumptions). Instead, by centering family members within the IoT fabrication process, family members could choose what should be sensed within the home. Further, they may retain discretion over how to programmatically manipulate any related symbolic meaning the artifact may have as appropriate for the rest of the family instead of delegating it to AI interpretation. Artifact features like ownership, location within a room/home, and the degree that it roams throughout the home's territory cue other family members to social norms [24]. These findings demonstrate an opportunity to imbue IoT systems with social context and enable programming it, without requiring a system actually understand that context.

## PRELIMINARY WORK

I have created a tangible user interface that can be used to remix control flow abstractions with everyday objects. Using off-the-shelf RFID tags and a long-range RFID reader (see [9] for how these could be installed within a lightbulb form factor), I structure interactions around a book containing RFID augmented stickers using pop-up book style mechanisms to encapsulate programming constructs like setting variables, reading data from a sensor, wrappers, if-then statements, and for loops. The book makes programming composition approachable to non-experts by using the codex form factor to scaffold introduction of these concepts and constrain how expressions can be authored and composed. I use paper-engineering techniques from pop-up books, architectural prototyping, commercial stationary, graphical design, and scrapbooking. I use these recognizable motifs to aid user selection and discrimination when composing an expression and constrain TUI remixing. Importantly, the sticker form factor attaches these tangible compositions to everyday objects (see [15, 20] for sticker proof-of-concept). Thus, users can associate their programs with the object of their choice or even remix an already functional program whose construction has been scaffolded with TUI constraints.

### Book Construction and Mechanism Design

The book is subdivided into sections according to sticker type, with a progression from simple to more complex capabilities.

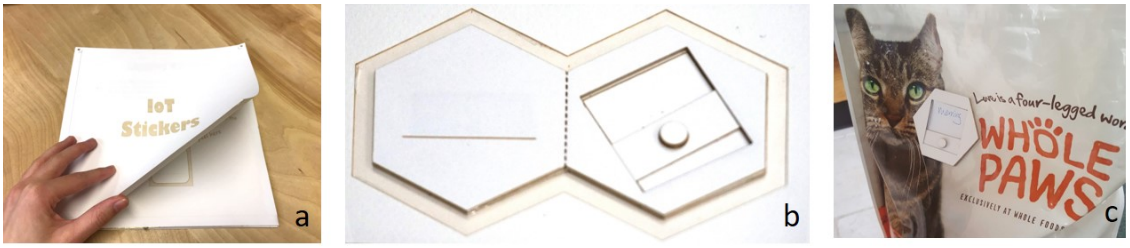


**Figure 1. We introduce IoT Stickers: a book of inexpensive, battery-free sensors and interaction patterns to support linking everyday objects to software and web services using stickers (a). To use, a sticker is first peeled off from the book (b) and attached to a desired everyday object (c). Stickers can be customized during setup and composed with others to create more expressive applications.**

In each section, there is an introductory page describing how the sticker works, followed by a few pages with example sticker applications.

Each page is a folded piece of paper with the open ended sides bound at the spine. The interior of the folded page is lined with gold foil to prevent the RFID sticker from being read by the reader before initialization is desired. Each page has cutouts for any contained stickers and stores a wax paper backing for the sticker to adhere to while still uninstantiated. The book supports five main sticker types implementing different basic interactions: a button, toggle switch, list, dial, and wrapper.

#### *Button Sticker*
Button stickers are the most basic sticker type in our system. Buttons produce a single trigger and are invoked by covering the button sticker with the hand. A person activates the button sticker by peeling the sticker from the page which initiates the sticker setup process.

#### *Toggle Switch Sticker*
The toggle switch sticker has two states. A trigger for the switch is activated by moving the switch cover to newly reveal the tag beneath it while at the same time covering (and disabling) another tag.

#### *List Sticker*
The list sticker consists in 6 RFID tags in a row covered by pop-up style flaps. This supports a user in individually associating an action with the tag and allowing for greater complexity in the relationship between those tags if the user desires. Since more than one RFID tag can be activated at a time with the list sticker, more complex situations can be managed with this tag. For example, partially fulfilled tasks could be managed and tracked with the list sticker.

#### *Dial Sticker*
The dial sticker consists of up to 6 RFID tags fanned out in a circle and selectively activated when covered with a moving arm lined with foil. The dial sticker supports interactions that require a selection between a small set of values or states. This could include controlling the place of play in a video/audio file, manipulating rotation of a 3D object, or scrolling. Dial stickers are also supportive of cases where alternatives describe social relationships rather than the system's objects, such as identifying who in a set of people is responsible for a set of actions to be undertaken.

#### *Wrapper Sticker*
The wrapper sticker consists of a larger shaped sticker that contains an area big enough for a button sticker. This supports user in composing together wrappers and stickers to provide additional control and functionality over a sticker's actions. Wrappers can help with scheduling future behavior as with a timer, or creating a multiplicative effect such as increasing the magnitude of a counting action.

The setup process of sticker types varies with the sticker according to whether it is a pre-programmed sticker, pattern sticker, or blank sticker. The pre-programmed sticker is meant to cover cases where the sticker's functionality provides value by enabling an existing service to be linked to the physical world. We envision that manufacturers may want to make their products available to users through Stickers, but would want to limit their support of end-user customization to cover only a small number of predictable cases. The pattern sticker links button Triggers to specific Actions, but leaves customization open by supporting end user specification of button variables or parameters. Blank stickers support choosing which supported pattern to associate with the sticker, and then customizing that pattern further as desired.

### Supporting Collaborative End User Programming
I conducted a formative study to understand what kinds of objects families would want to modify with IoT Stickers and how they might make lightweight modification of everyday objects in the home with computing capabilities. Using participatory design, I asked 10 households to enact the process of modifying their home objects by attaching stickers to their possessions and speculating as to how to endow those objects with computing capabilities over the course of 7 days.

Modifying an object with IoT begins with coming up with an idea. At times, family members used the object itself as the source of inspiration. However, households also used other sources such as caring for a family member or wishing to completely change a room. When generating an idea, families decide which objects are appropriate interfaces for IoT. Our dataset revealed 17 different rooms and 267 objects as candidates for IoT interfaces. Participants designated a total of 219 objects to leave unmodified with IoT. The largest number of objects to modify were in the bedroom (53), bathroom (52), living room (42), kitchen (35), and office (18). These 5 rooms contained 74.9% of all modified objects and 77.2% of all unmodified objects (see Figure 2 for a breakdown of

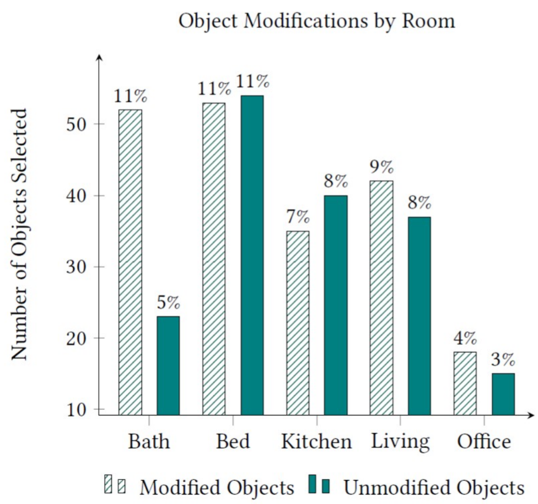


**Figure 2. The bar graph shows the distribution of objects across the five rooms with the most number of selected objects from participants. Each room shows the comparative number of objects participants wished to modify with IoT capabilities to those they wished to remain as they are, apart from an IoT network. Percentages above each bar show the percentage of the total object inventory from the study found in each room.**

objects for each room). Nine rooms were chosen by only one or two households: guest room, baby's room, dining room, door/doorway, hallway, outdoors/porch, sewing room, TV room, and storage. These rooms fell into three categories: liminal spaces, such as hallways and doorways; dedicated activity spaces, such as rooms for sewing or watching TV; and spaces for other people, such as a baby or guest.

These results and details from family modification patters inform a set of pre-programmed sticker patterns. These patterns are designed to support users with envisioning how they might realize their IoT ideas using Stickers. In line with our results, we focus on sticker application ideas for the top 5 rooms identified by our participants and the common household tasks they support like claiming food and warning others not to disturb a person in the bath. We reveal these patterns using laser cut icons on paper stickers and walk the user through the instantiation process using a phone app triggered when the sticker is peeled from the book page.

## PLANNED RESEARCH

I will evaluate the IoT Stickers system in 2 ways. First, I will conduct a set of user studies to assess how well the IoT Sticker book facilitates non-expert programming composition using everyday objects. Second, I will develop a novel IoT Sticker to facilitate sensing of activities currently unsupported by the variety of IoT Stickers that have been developed.

### Evaluating IoT Stickers

I will conduct two studies—a controlled study and a field study—to evaluate the success of the IoT Sticker system. I will use a controlled study to examine how well users are able to select and compose sticker programs using the IoT Sticker book. Specifically, I will test whether users are able to set parameters like string/number values or sensor readings, use wrappers to augment an object, and use control flow constructs like if-then statements or for loops. I will use a field study to assess how well the sticker system senses and affords manipulation of the home's social field. Over the course of a week, I will ask household members to construct simple programs to upcycle their possessions to better fit their household arrangements or to envision how their household might work differently.

### Developing a Microfluids Sticker

Prior work turned to both origami techniques and pop-up mechanisms to fabricate low-cost paper sensors for microfluids [10]. Observing that conductive ink is hydrophylic and wax is hydrophobic, the researchers created a two step process that controlled the path of conductive ink's trace on paper so that two-sided paper channels, or vias, could be created. This then allowed the researchers the ability to create a conductive path between layers of paper when stacked on top of one another or folded over. It also allowed the researchers the ability to insulate layers from one another so that they could selectively create a three dimensional path between the paper layers. Using this method, they demonstrate 1) how conductive traces for LEDs could be layered at a criss cross over one another without interference and 2) how an accordian style fold could support a self-sufficient paper battery with enough power to light an LED. While this research is primarily concerned with applications to low cost medical testing, the techniques could be readily extended to everyday tasks in the home.

Building on the techniques I developed for the IoT Sticker book I will design a set of stickers that take advantage of chemical reactions through selectively opening and closing microfluid channels by using pop-up mechanisms. This would allow for timeouts to be pre-programmed based on chemical behavior so that a sticker would change state after a chemical reaction has finished. For example, a water channel could be opened onto a salt chamber so that a salt bridge could be created between two electrodes. This would create a conductive path between an anode and cathode where there previously wasn't any and realize a galvanic cell. The battery could then power the sticker until the water had evaporated off and the salt bridge no longer held.

The microfluids sticker would enable a set of tasks to defer computing until some later time as set by the chemical timeout. Although, wrappers can currently program timeouts in the sticker system, that information remains stored by the system. A microfluids sticker would allow for the delay interval and the fact that an action will fire at a future time to be stored wholly offline. This would allow for the user to hide the action until ready for it to be triggered.

## CONCLUSION

In summary, my dissertation work explores and enables an upcycled IoT for the home. This work transforms how we design for ubiquitous computing by supporting non-experts with creating and composing their own smart home.

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