SmartStorybook: An Internet of Things Augmented Environment Coordinator for Storytelling

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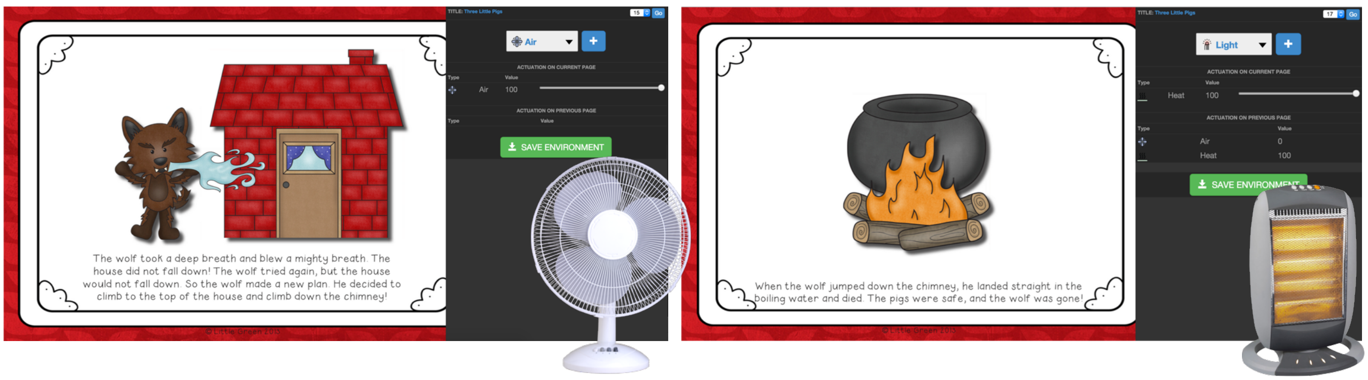

Figure 1. Example story pages augmented with SmartStorybook. (a) As the Big Bad Wolf huffs and puffs, a connected fan is triggered in the environment. (b) When the situation comes to a boil, a nearby heater warms the room.

ABSTRACT
Reading stories and experiencing storytelling is formative to a child's development and a critical tool for sense-making. As the Internet of Things develops, we see new opportunities to expand the aesthetics of storytelling. We introduce SmartStorybook, an augmented environment (AE) application that controls the rich multimodal environment enabled by IoET to create interactive, engaging reading material. Smart Storybook contributes a content creation tool that synthesizes output with storylines. Upon reading time, the tool polls devices in a room for story enhancing capabilities (e.g. providing light, sound, smell). The desired story telling environment is resolved dynamically, providing a unique storytelling experience based on available devices and services.

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internet of things, storytelling

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INTRODUCTION
As reading technologies continue to develop, we have a new opportunity to alter and enhance the story-telling experience. Story-telling is fundamental to modern culture as a means of passing down knowledge and as a tool for sense-making. Interactive stories (the content) and interactive story books (the object) have been a long sought goal for human-computer interaction researchers to realize a vision of long-term engagement and critical thinking. Due to the wide variety of publication mediums (print, digital, verbal) and a tension between traditional storytelling modalities, this has proved difficult. In particular, the spectacle of an augmented story book often overpowers the content and affects the learning value of the story itself.

We present SmartStorybook, a digital storybook that polls for IoT-connected devices and triggers actions based on story content. Our approach enhances the physical environment rather than imposing a virtual one. We show how this type of interface provides a seamless interaction with the storytelling experience and present novel application scenarios for improving sense-making and creating a dynamic story telling experience for repeat engagement with stories.

BACKGROUND
The "magic book" is a common object of study for virtual and mixed reality research. Billinghurst, et al., proposes the magic book enables three spheres of interaction: the tangible object, the mixed-reality universe, and the virtual universe [2]. Several technologies have been used to operate in each of these spaces: refined computer vision techniques have been used to prove the feasibility of an augmented re-

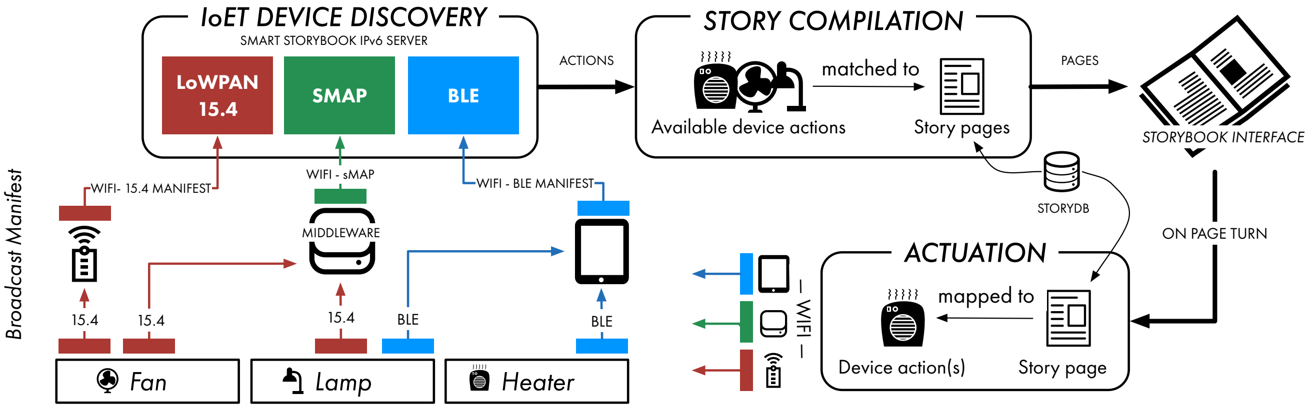

Figure 2. SmartStorybook architecture. Devices in a room broadcast available services through supported physical communication (Bluetooth, IEEE 802.15.4) in a IoET device discovery phase. A device-action list is then matched to desired actions in a story page. This story is pulled down by a storybook interface which publishes its page location. On a page turn event, the bound actions are actuated via its appropriately.

ality storybook free of machine-readable markup [9]; camera free approaches, such as Fujinami's augmented book cover and bookmark, detect page flips and offer a more mobile detection routine [4]. More instrumented approaches used head-mounted displays to create immersive *virtual* visual environments [8]. Unlike mixed-reality initiatives that augment physical artifacts with virtual elements, Smart Storybook uses a digital storybook application to interface with devices and directly alter the *real* representation of the environment.

Other research has focused on added new interactivity to story books. Through simple energy harvesting, Karagozler, et al., demonstrated that powered devices can be embedded directly onto the pages of a story book [6]. A rubbing action is used to generate charge to drive LEDs and power e-paper displays and enable dynamic animations and hidden messages. Similarly, multimodal output have been integrated into printed artifacts [5] seen primarily in greeting cards. SmartStorybook similarly expands this space by operating in a heterogeneous interactive system and leveraging the naturally multimodality of connected actuators to not only add visual feedback, but provide feedback to the other senses.

The enhanced storybook has also been examined as a method of creating a more collaborative story telling experience and enhancing the learning value of these books. Raffle, et al., demonstrated how Internet-connected storybooks could be used to create telepresent story-telling between children and distant relatives [7]. The character Elmo was used to facilitate the remote interaction; however this caused attention issues since children were more prone to engage with the digital cartoon. SmartStorybook has a similar "WOW" factor characteristic of many new media storybooks, however we show how this is not merely a superficial element but can be designed so children directly engage with the story content.

SYSTEM DESIGN

The system architecture is depicted in Figure 2 and consists of three steps: discovery devices and services, mapping services to pages in a storybook, and actuating the necessary device through the appropriate protocol. A middleware server was used as a global device manifest, book repository, and for content creation.

IoET Device Discovery

Several protocols exist for discovering devices in an environment. To allow for interoperability, we created a central repository that interfaces with three different device profiles for Internet of Things devices GATT-BLE[1], SVCD-15.4[2], sMAP[3].

In this paper, we focus primarily on the actuation component of sMAP, which provides a specification for commonly used actuation patterns: binary two-state, discrete n-state, any-integer, and continuous-value actuation. A sMAP registered connected device publishes its available services to a middleware server, subscribes to a socket, and listens for incoming requests. The server provides a RESTful API to get/set actuator state, while offering some rate-limiting control.

This sMAP pattern was extended to devices published through 15.4 and Bluetooth. Metadata was added to the published manifest for each device describing each action and its corresponding modality. Modality is described in terms of physical and sensory characteristics as follows: ⟨ light, air, sound, smell, heat, taste, motion ⟩. Each action was ascribed an amplitude (on $\rightarrow$ 100), and a distance attribute was added to each environment for locality. Lastly, a RESTful API set/get point was assigned to each device.

Story compilation

In order to allow story developers to author interactive content into existing storybooks, we created a IoT story composer that assigns a high-level description of a desired environment to a story page (Figure 3). For each page, a story developer can specify the intensity of each modality along a continuous

[1] Bluetooth Generic Attribute Profile

[2] 802.15.4 6LoWPAN - Low power Wireless Personal Area Networks - a IPv6 protocol that enables small devices to have Internet-connectivity

[3] The Simple Measurement and Actuation Profile (sMAP) is a specification for transmitting physical data to and from sensors and actuators [3].

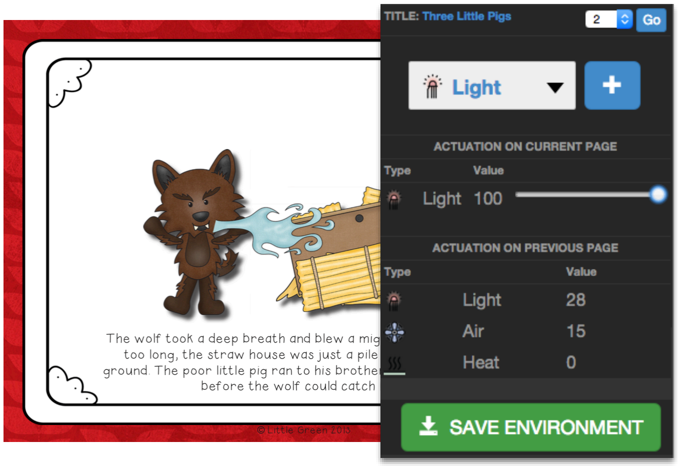

Figure 3. SmartStorybook composer. Modalities are assigned to each page in the storybook to create a desired ambiance. Active page actuations are displayed to remind content authors of current conditions.

range from 0 to 100. For usability, active actuations (triggered from previous pages) are displayed alongside the desired environment.

Matching

Two matching schemes were constructed to resolving devices to desired environmental or interactive conditions.

- Least-squares - takes the difference in desired environment and the permutation of IoT device actions and finds the closest optimal fit.
- Greedy - Finds the closest modality strength value and actuates n equivalent actions (e.g. $\langle$light, 100, $n\rangle \rightarrow$ turn on n light actuators).

A tuple containing the UUID of the device and the name of the action was bound to the appropriate page in the story.

Actuation

Finally, a previously developed iPad application (StoryBubbles) was used to view story content. StoryBubbles retrieves storybook information from a server. The storybook is treated as a button stream, where each page turn is treated as a button press event which publishes its current page number. The server subscribes to this stream, looks up linked device actions, and actuates each respective device. The server communicates with each protocol using a base station that "speaks" the language of the device. For instance, BLE devices are actuated using an iPad or other BLE device as a relay. All device actuation logic exists in the middleware layer.

APPLICATIONS

Novel interactions exist from integrating IoT actuators to story content. In this section, we detail example scenarios for augmenting the content and experience of a story.

Augmented Environments

Compared to purely visual animations common in screen-based applications, Smart Storybook interacts with a wider range of sensory experiences. By connecting to IoT devices, SmartStorybook can control environmental conditions such as humidity, temperature, smell. These types of actions are generally slow actuations, taking several minutes to achieve a discriminable change. We foresee these as chapter-based interactions; whereas as more immediate changes such as air flow and ambient noise can be triggered to simulate the narrative's environment.

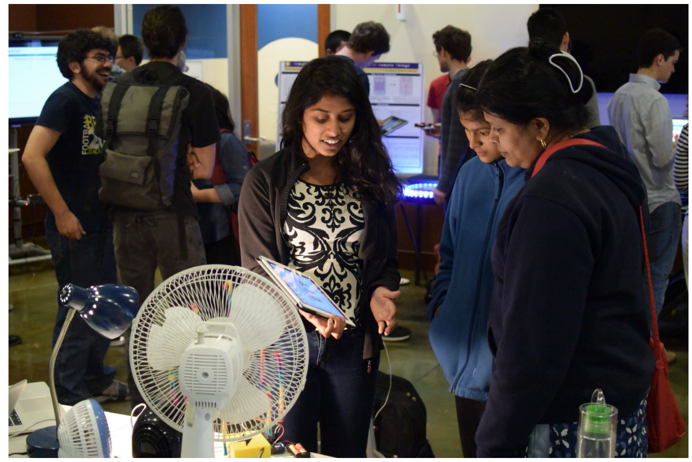

Figure 4. Spectators are invited to hear and interact with the SmartStorybook.

Character Enhancement

Through Smart Storybook's content creation tool, character actions can be bound to actions or to the devices themselves. In our favorite example, the wolf in the Three Little Pigs blows down the house alongside an actuated fan. These cues add theatricality to the story, a key component of engagement. Furthermore, binding an character to a device can be used to signal character presence to young readers for a more *embodied* interaction. For instance, in the story of *Aladdin*, the genie is either within his lamp or outside of it. A lava lamp can be bound to this condition, giving user's an indication of the genie's state and likely develop empathy through the course of the story for the genie's plight as they realize the amount of time the genie spends in his lamp. The release of the genie at the conclusion of the story could likely be signaled by a more spectacular event (such as all lights turning on and flashing).

Dynamic Storytelling and Interactivity

In each environment, Smart Storybook queries to find what devices are available to contribute to the storytelling experience. This means that each room has its own storytelling capabilities slightly changing the story with each new environment. For instance, the story Goodnight Moon, where a reader bids goodnight to the inhabitants of a room, can be made interactive such that each "good night" turns off an IoT device. This story would change in each room of a house, and function similarly in other locales. By retaining the novelty of stories through different augmented environments, Smart Storybook can facilitate continued and repeated engagement with readers.

EVALUATION

This following example story was tested informally in a public demonstration (Figure 4). The audience was invited to participate in a personal reading or as a oral group reading.

In a mock IoET storytelling environment, our system discovered up to seven connected devices. The devices included a 4-state sMAP/15.4/BLE fan and a sMAP smart powerstrip with binary control to 6 devices: 3 lights, a personal heater and fan, and a scent diffuser.

Story: The Big Bad Wolf

Our testing story consisted of a 19-page full-page illustration of The Three Little Pigs by Little Green. Device interactions are composed in the story as follows:

- Firstly, a 4-state connected fan is mapped to the "huff and puff" of the Big Bad Wolf. As the wolf visits each respective pig's home, the fan is actuated to a higher intensity.
- At the introduction of each of the piglet's construction ideology, a light is turned on; this tracks the rhetorical repetition common in children's stories. For the child, this presents an opportunity to have multiple external representation (MER) important to sense-making [1].
- Furthermore, each light is mapped to the presence of each piglet throughout the book. This acts as a cue to which characters are "on the stage".
- At the climax of the story, the wolf is thrown into a boiling pot of water. We trigger a personal heater to turn on and remain heating the environment until the conclusion of the story.

Results

Due to the unexpected co-use of devices by other demonstrators, we refined the list of available devices to a single fan. Our system was able to create an augmented story with the same prior definition as above. When a heater was later added to the device manifest, it was appropriately dynamically linked to trigger based on story events.

In a personal reading setting, we quickly found that synchronousness was fundamental to the interaction. Delays in actuation would dissolve a user's "suspension of disbelief", or the suspension of the implausibility of the narrative. We suspect a more private setting would aid with the delay effect since evaluation of public demonstrations is more subject to its spectacle value.

In a group setting, where one of the project authors facilitated the reading of the story, we observed that IoT actuations provided a more engaging storytelling experience especially in an audience of adults highly familiar with the story content.

LIMITATIONS AND FUTURE WORK

Ultimately, ascribing relevant metadata remains the chief deterrent to widespread applicability. For instance, proximity and context information is highly important to the semiotics of the interaction (a back heater is very different from a space heater). While the sMAP definition provides some flexibility, there is inherently a lack of proximity information and the granularity needed for storytelling. SVCD can provide better proximity data through RSSI, or resolving devices can be made a user-process.

Furthermore, richer actuator control is limited by connectivity. For instance, a lightning behavior (a lamp turning on and off rapidly) is subject to the throughput of the server. Lastly, during the demo, several groups were using similar devices. A similar case would likely occur in the wild; access control needs to be added to devices to prevent unwanted behavior (such as actuating a thermometer of a building).

CONCLUSION

Smart Storybook provides an alternative viewpoint to the IoT narrative.This project touches on issues of discovery management and ensemble creation, and presents a vision of a novel dynamic, interactive, and *multimodal* storytelling experience enabled by IoT devices. We uncover the importance of synchrony of actuation to storybooks in "suspending disbelief" and highlight the added engagement of augmented environment to social storytelling.

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