Collaboratively Testing in Open-Source Hardware Communities

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Abstract
Open-source hardware communities face unique communication challenges when collaborating around physical prototypes. However, these communities use a heterogeneous set of software collaboration tools that were never meant for remote collaboration around physical objects, particularly objects whose designs are actively being re-defined. To better understand open-source hardware collaboration, we are studying email, forum, and video conferencing communications in a research and development team within the e-NABLE community, an open-source hardware community focusing on low-cost 3D printable prosthetic hands. We identified a series of real-world physical collaboration tasks, and particularly discuss how the R&D team communicates results from functional testing of physical prototypes. We believe that HCI research can contribute remote physical collaboration tools that support real-world, open-ended processes and communication goals of open-source hardware design teams.

Author Keywords
Remote Collaboration; Open-Source Hardware; Physical Tasks; Testing

Introduction
Online open source hardware (OSHW) communities collaborate and share design and fabrication files for physical

objects such as microcontrollers (e.g, Arduino [1]), scientific lab tools (e.g., Open Source Lab [3]), and prosthetics (e.g., e-NABLE Community [2]). OSHW communities are similar to open source software (OSS) communities, and sometimes use tools appropriate for online OSS collaboration (e.g., Github). However, OSHW presents unique challenges that tools from OSS cannot address. We studied communications from an R&D team within e-NABLE — an OSHW community for 3D printable prosthetic hands. We found that interactions with fabricated objects (e.g., prototype demonstration, print testing, functional testing) are not well-supported by remote collaboration technologies. HCI researchers have the opportunity to better understand and ultimately enhance collaboration practises unique to remote fabrication and physical design.

We particularly highlight the design and use of 3D printed objects to communicate physical prototype functionality during testing. In current communications within the e-NABLE research and development (R&D) group, members describe testing failures or successes through text, images or video demonstration. However, these media struggle to capture and communicate the complexity of physical testing of prototypes. We intend to explore why communicating physical testing is so challenging for OSHW communities, and how new tools might help collaborators provide better feedback on physical prototypes at a distance.

Background

e-NABLE is an OSHW community with thousands of members dedicated to the design, creation, and distribution of low-cost hand prosthetics, particularly for kids and people in developing countries. As a group, they match recipients in need with volunteers who are willing to print, assemble and ship hands to those recipients. Through various online community channels (e.g., Facebook, Google+) e-NABLE connects people interested in open-source prosthetics. While many community members are 3D printing enthusiasts who volunteer to print prosthetic hands, only a small subset of the community (40-50) contribute to the research and development of hand designs. Small teams of R&D designers create and update each design and provide printing and assembly instructions; the rest of the community relies on these resources to create and assemble prosthetic hands. These R&D design teams use a heterogeneous set of software tools to support collaborative development:

- Various *computer-aided design (CAD) and 3D modelling* tools (e.g., Blender, Fusion 360) along with different CAD work styles (e.g., solid and surface modeling, parametric and non-parametric geometry)
- *Asynchronous communication platforms* to discuss designs as a community (e.g., Google+ posts, forums, Google Hangouts on Air) or within the team (e.g., email)
- *Online file sharing or file hosting services* to internally share design files or documentation (e.g., Fusion 360, email, Dropbox, Google Docs), or to publicly publish printer-ready 3D files, printing instructions and assembly instructions (e.g., Thingiverse, Github, Google Docs, Instructables).

These teams also validate that new designs are functional, robust, and can be printed on a range of 3D printers before designs are released to the broader community. They often ask the broader R&D group and hand recipients for help in physical functionality testing.

We are in the process of analyzing communications from this R&D community in e-NABLE to better understand the unique communication requirements of remote physical collaboration which are currently under addressed in HCI. Fortunately, e-NABLE values transparency within their

OSHW community; design ideas and design processes are shared publically online in forums, Google+ Community, and recorded video conferences. This offers access to design communication that would otherwise be difficult to obtain within companies due to intellectual property concerns. We are also guided by first-hand experience from one of our collaborators, who is a board member of the Enable Community Foundation and an active member in the research and design community within e-NABLE.

Remote Physical Task Collaboration

The HCI research community has developed technologies for remote collaboration around physical tasks such as remote gestures [6] and augmented reality (AR) drawing [5]. These systems and others focus on one-on-one, real-time remote collaboration on well-defined physical tasks (e.g., communicating with a partner to construct a set of Legos [6] or pointing out specific elements in a scene [5].

However, e-NABLE R&D happens in groups around open-ended physical tasks with unpredictable physical objects. Common tasks include: critique (e.g., identifying problematic features in a current design iteration); demonstration (e.g., demonstrating how a motion feels stiff); comparison (e.g., grasping of one hand versus previous iterations); ideation (e.g., using a prop to explain alternate design ideas). Some of these tasks may be supported through existing technologies and we can also create technologies tailored to capturing and communicating embodied interactions with physical objects.

We envision future work in HCI to explore these open-ended physical tasks by applying existing technologies such as AR drawing [5]. For instance we would like to run a user study where participants are asked to ideate (ie. brainstorm ideas) on possible attachments to the e-NABLE prosthetic hand under current video conferencing conditions or with AR drawing technology. By running studies such as these we will learn how well technologies from HCI research might support open-ended physical tasks. In addition to studying existing technology we believe there is room to create new tools or software to support these remote collaborative tasks.

Testing Physical Functionality

One way that OSHW development differs from OSS development is functional testing. Software development makes use of *Unit Testing* to determine the correct function of individual units of source code or modules. Software test engineers define inputs and expected outputs, which are re-used to ensure that parts of a program function properly when changes are made between versions. Meanwhile, professional product design teams create *Design Verification Test* prototypes, which are systematically tested and evaluated against design requirements and specifications by product test engineers.

In both OSS and OSHW communities, functionality testing occurs collaboratively and remotely, often without clear guidelines on how to evaluate prototypes, and often by people who are not experts at communicating design feedback or critique. Software developers can easily control inputs, measure outputs, and isolate problems to specific lines of code. Unfortunately, it is difficult to design and create controlled physical inputs and measure physical outputs at a distance. Moreover, multiple functions may be combined in the same physical feature – making it challenging to identify what can or should be changed to improve or fix a design.

In the absence of controlled physical measures, members of the OSHW community try to find ways to communicate their embodied interactions and experiences with the object to others. They resort to basic communication strategies –

Figure 1: A comparison of Cyborg Beast (left) to Talon 2.0 (right) posted to e-NABLE Google+ community. Photo: [4]

Figure 2: Mockup of common issues in dropdown box and an overlay of the 3D model for the Cyborg Beast to indicate where an issue exists in pink. Photo: [4]

such as object comparison – in order to provide feedback on physical prototypes. However, even communicating a simple comparison between two physical objects at a distance can be challenging.

For example, current prototype comparison is done through text, pictures or video conferencing. In one example Google+ Community posting, a hand recipient includes pictures (see Figure 1), as she tries to outline the differences between an early prosthetic hand design, and the recently-released Talon 2.0 design. She writes, "[user] had much difficulty trying to close the hand" [4]. Unfortunately, this description is too vague to be helpful as feedback for designers. How much force or effort was needed to operate the original design? Is the difficulty in closing the hand due to stiffness in the joints, rubbing between parts, surface finish from this particular print, misalignment in the assembly, overall sizing, improper print settings or something else entirely?

In cases like these the user of the final physical product is not a designer and thus may be unfamiliar with CAD models, design language or already commonly identified issues. We propose an image/video tagging tool to allow end-users to present feedback to designers by combining images, simple 3D models and standard terminology to help refer to common issues (see Figure 2). This solution focuses on non-designers being able to provide feedback about design issues and usage concerns in place of formal Design Verification Tests that would be used by professional designers.

Conclusion

By examining communications from the research and development teams within the e-NABLE community, we identified several common remote physical collaboration tasks which are not explored or supported by existing collaboration software or HCI research. These tasks are open-ended, ambiguous, and involve multi-party collaboration, and include communicating feedback and critique on physical prototypes. These physical tasks present unique challenges in communicating embodied experiences with physical objects that are not currently supported through general open source software tools. HCI research has the potential to create tools and processes that enhance communication around open-ended physical tasks, including communicating critique on fabricated designs.

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