Repurposing mobile devices as electronic toolkit components for IoT and wearable prototyping

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Prototyping toolkits excel at creating proof-of-concept systems for novel hardware yet fall short for some elements of HCI research, such as IoT and wearable prototypes, which have specific form-factor or interface constraints. Single board computers are in high demand and are increasingly treated as components, while previous-generation mobile devices become e-waste. Our experiences of HCI research prototypes have persuaded us that there is an argument for allowing mobile devices to be repurposed as electronic toolkit components and that there is scope to extend prototyping toolkits to higher-level concerns, such as user interfaces.

CCS CONCEPTS • Human-centered computing → User interface toolkits

Additional Keywords and Phrases: electronics, prototyping, toolkits, physical computing

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1 ELECTRONICS PROTOTYPING FOR HCI RESEARCH

Our group has over 15 years of experience producing HCI research prototypes and systems, frequently with sensor-based ubicomp and wearable technologies. In addition, we have 9 years of experience running a post-graduate degree module on *Technologies for HCI*, attended by students from diverse subject backgrounds. This module includes a significant practical strand, and a group project component that relies on using prototyping technologies such as Raspberry Pi [11], BBC micro:bit [2], Arduino [1], GrovePi [6] and Phidgets [10]. Our experiences have allowed us to observe and reflect on how prototyping platforms and toolkits are used in HCI research, and the opportunities for how they might evolve.

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Electronic prototyping is used at various stages of novel hardware development, and prototyping platforms and kits might typically be used for proof-of-concept hardware. For research purposes, the goal is often not directly towards manufacture, but perhaps to demonstrate a novel idea, provoke a reflection on the design, or to collect data as part of a small-scale research deployment (e.g., [13]). In addition to novel hardware, prototyping technologies can be used to introduce specific elements, such as sensor or actuator components, as part of a larger prototype system.

From our experience – weighted towards pervasive and ubicomp systems such as mobile, wearable and IoT applications – two aspects become particularly important for human-computer interaction prototyping: the form factor, and any complex user interface requirements.

2 IOT AND WEARABLE PROTOTYPES

Where IoT, mobile and wearable designs extend beyond an initial proof of concept, such as for design reflection or as part of a research deployment, the fidelity of the form factor is often an important consideration. The requirements on the physical characteristics of the prototype can be at odds with what is achievable with standard prototyping kits. This becomes increasingly problematic when scaling the number of elements required, and some components, such as high-resolution displays or safely integrated rechargeable batteries, do not form part of typical prototyping kits.

Single-board computers (SBC), such as the Raspberry Pi, are popular in systems prototyping, and are often regarded as a component, despite being highly integrated systems. This is reflected in the availability of SBC modules, such as the Pi Compute Module [12], and the direction appears to be towards ever more integrated devices. Popular SBCs have recently seen supply issues (e.g., Raspberry Pi [14]), and readily available alternatives would be welcome.

2.1 Repurposing existing mobile devices

Mobile devices, such as tablets, phones, and smart watches, are already used to represent their own device types when prototyping systems, but they could become valuable prototyping toolkit components in their own right. This can be seen as an extension to increasingly capable SBC "components", and part of a solution to problems where a particular form factor is required.

Moreover, while SBCs have recently experienced supply issues, many mobile devices may be left unused while still functional (e.g., substituted for newer models). This e-waste could be reduced by extending the useful lifecycle of mobile devices by repurposing them. Such an option is readily available, cost-efficient and desirable – in general, and within research and design (e.g. [9] and [3]).

Mobile devices are very highly integrated and programmable systems, with a wealth of inputs and outputs that can be reused for prototyping [4], and typically include features such as:

- Compact form factor with environmental protection (dust, moisture, full waterproofing)
- High resolution display with multi-touch input
- Rechargeable battery
- Connectivity (wired, mobile network, Wi-Fi, Bluetooth, NFC)
- Inertial measurement unit (accelerometer, gyroscope, magnetometer)
- Camera and microphone
- Speaker and vibration motor
- GNSS such as GPS
- Large storage capacity
- Significant RAM and processing capabilities

The host of features allow mobile devices to be powerful stand-ins for an array of inputs and outputs, and the compact form factor enables them to be embedded in a device or environment or to represent wearable devices (e.g., by prototyping an appropriate enclosure).

Existing mobile devices are not typically extendable by direct connection to other components, yet connectivity with other toolkit components may be achieved over a wired USB connection (such as CDC/Serial), Wi-Fi, Bluetooth, or NFC – either directly, or via a prototyping server acting as a bridge, so that sensor data and commands can flow in either direction. Networked and addressed data has seen successful use in prototyping using technologies such as OSC [8], and is the mechanism that allows prototyping over a wired bus in the Jacdac prototyping platform [5].

2.2 Prototyping complex user interfaces

Prototyping IoT and wearable systems for HCI research can have requirements beyond basic hardware inputs and outputs and may require a more complex screen-based interface. Prototyping kits are often focused on the electronics and are typically used "headless" or with low-density I/O, and do not concern themselves with higher-level software issues, and so do not typically include high resolution displays or the means to create complex display-based interfaces.

The multi-touch display and processing capabilities of mobile devices allows them to be directly used to prototype more complex interfaces. Non-trivial native UIs can become complex tasks. Simple prototyping techniques include "slideshow" placeholders, or wireframe interface prototyping software. From our experiences, we have noticed a pattern of prototyping such systems using web interfaces with the browser-based front-end on tablets, smart phones, and SBCs – and this approach can apply to mobile devices as components in prototyping toolkits. In addition, WebAPIs [13] are closing the gap between the browser-based and native platform capabilities.

Although web interfaces are inherently cross-platform, for very thin clients that cannot host a web browser, we have also had good experience "streaming" the entire prototype interface: using a more capable device to receive all inputs and sensor values from the client and rendering the interface and sending it to the client to be displayed.

Both web-based and streaming UI prototyping methods allow for the interface to be carefully controlled in the prototype platform, and are compatible, for example, with a "Wizard of Oz" configuration.

3 DIRECTIONS FOR PROTOTYPING TOOLKITS

We believe there is significant value in encouraging prototyping toolkits to allow mobile devices to be easily repurposed as affordable elements. These devices represent highly integrated set of sensors and I/O functionality and are in a form factor that is desirable for certain situations, yet would be difficult to achieve using traditional simple prototyping methods.

Such repurposing could be largely accomplished in software – for example, by allowing prototyping software to additionally provide a server for web-based mobile device clients: the server could provide a page that streams in any required sensor data inputs and streams out any required outputs (including any user interface).

While mobile devices are somewhat homogenous within an ecosystem (e.g., iOS or Android), there is a wide variation in exact specifications of each model: physical dimensions vary between models; Android and WearOS typically have wider variation in hardware and software as there are many manufacturers; iOS and watchOS are typically more restrictive in what is allowed; older or unsupported devices become more difficult to work with and may be less secure.

Existing prototyping toolkits do not readily assist with complex UI prototyping but, in treating ever more integrated systems as "components", the future may include such higher-level concerns.

3.1 Browser Bridge

We are in the early stages of developing a *MakeCode* extension [7] for the BBC micro:bit called *Browser Bridge* (see Figure 1), which allows simple, block-level interfaces to access inputs and outputs from a mobile device running a client. The client is a web page that works on any device that runs a browser supporting the Web Bluetooth API or Web Serial API, it will work offline if the page has previously been accessed, and can be started directly from the device's home screen launcher. Inputs include device sensors, text entry, and examples requiring higher-level processing (such as barcode scanning and face tracking), outputs include web content (such as text, images, sound and video), in addition to arbitrary "fetch" web requests (within constraints such as CORS). The client can connect to the micro:bit host over a Bluetooth LE connection, or a wired USB serial connection.

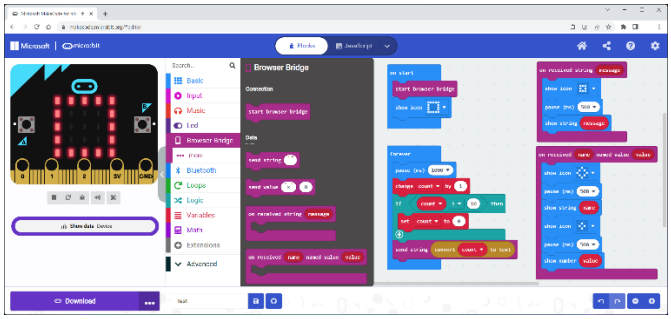

Figure 1: Early prototype of *Browser Bridge* software, providing easy linking to a mobile browser.

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