Beyond prototyping boards: Easing tensions in hardware R&D

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The proliferation of "low-barrier to entry" prototyping platforms in the last decade has enabled a wide range of individuals to unlock creative ideas and turn them into interactive devices which sense, actuate and communicate in surprisingly novel ways. However, the potential of these ideas and devices are often limited by practical barriers resulting in creative projects stalling or being abandoned altogether.

This paper argues that these trends are not necessarily the result of a lack "novel" development boards but caused by practical issues stemming from the inherent tensions in hardware R&D and the hidden barriers of PCB design & manufacture. As such this paper presents 'MEMA': an expandable technology stack which takes the lessons learned from experiences of hardware prototyping and attempts to ease some of the tensions inherent in hardware R&D.

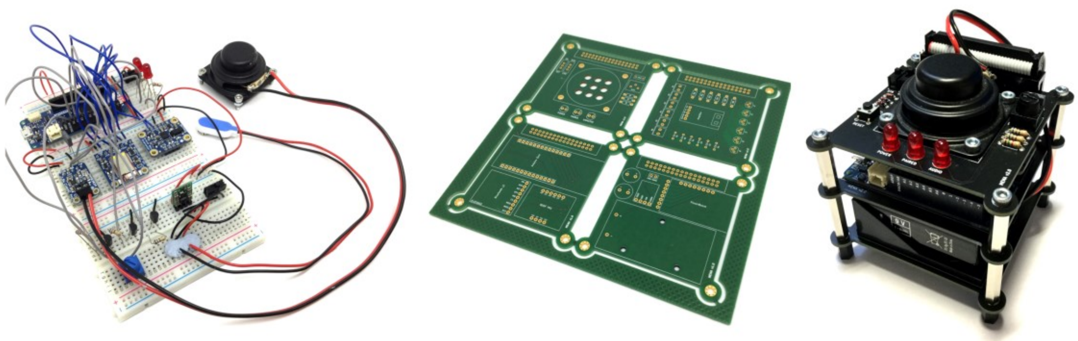

Figure 1: MEMA is an expandable technology stack for combining sensors, I/O modules and actuators into an embedded form. It is based on modular PCBs, a common IDE bus interface and controlled via a web application framework utilizing BLE protocols. The picture shows its development from breadboard to prototype PCB, to modular build.

1 INTRODUCTION

The call to arms of this workshop rightly highlights the barrier reducing tools permeating maker, academic and engineering communities. As such new ecosystems have developed aiming to empower creative individuals - democratizing engineering processes which, until recently, have been limited to experienced hobbyists or engineering professionals. Online platforms such as Hackaday.io[1], Tindie[2] and maker events such as Arduino Day[3] and EMF[4] are testament to these ideals - showcasing the potentials of imagination and electronics. However, whilst these platforms offer individual empowerment they also come with limitations.

For example, whilst Hackaday.io enables electronic projects to be showcased and collectively developed many are abandoned in the long term. Tindie, a marketplace for makers, cannot enforce the rigorous requirements of compliance testing, raising questions about the platforming of non-compliant products. And Arduino based platforms are not always a substitute for industry standard systems, which require bespoke development. Therefore, the future of electronic prototyping needs to focus on expanding possibilities for consumers of these platforms. As such, this paper highlights three areas for collective action:

- A renewed understanding of prototyping tensions between ideation and engineering - pitting perils of "one size fits all" vs bespoke solutions.
- An awareness of the limitations for PCB prototyping: cost, knowledge and time.
- An appreciation for the importance of compliance testing and the implications for prototyping.

To begin addressing these issues we introduce a new prototyping toolkit: MEMA. MEMA is an expandable technology stack for combining sensors, I/O modules and actuators into an embedded form. It is based on modular PCBs, a common IDE bus interface and controlled via a web application framework utilizing BLE protocols. Whilst currently being developed for academic research projects, this toolkit was initially designed from lessons learned across a range of hardware projects spanning over a decade.

2 TENSIONS IN HARDWARE R&D

We believe that the future of electronic prototyping can be shaped not by introducing the "next gen" of microprocessor boards but by addressing insurmountable barriers which appear during the prototyping process: time limitations, cost factors, conflicting requirements, component availability and testing limitations (to name a few) can all co-conspire at every stage. However, whilst a full treatment of these barriers is well beyond the scope of this paper, we believe three key issues can be highlighted for further debate by seeking:

- A renewed understanding of prototyping tensions between ideation and engineering - pitting perils of "one size fits all" against the necessity for bespoke solutions.
- An awareness of the limitations for PCB prototyping: cost, knowledge and time.
- An appreciation for the importance of compliance testing and the implications for prototyping.

2.1 One Size Does Not Fit All

In hardware development a tension arises between flexibility and bespokeness. An "off the shelf" solution may bring immediate flexibility but is often less robust in the long term. A bespoke system may bring more robust solutions in the long term but at the cost of short-term gain or system flexibility. This tension is most apparent at the prototyping stage. For example, breadboarding enables quick and flexible opportunities for circuit design but is unsuitable for low noise circuits (e.g. audio applications) or robustness to mechanical shock (e.g. wearable applications). Prototyping with bespoke PCBs may bring additional benefits such as ground planes[5] to reduce audio noise or material flexibility[6] to avert mechanical stresses inherent in wearable technology. However, PCBs require knowledge of CAD and Gerber standards, are expensive and timely to manufacture in one-off quantities and can require additional assembly skills or tools.

As such, a key question arises about how to bridge these two mediums? Can designers utilize better methods? Can we adopt hybrid approaches? Can we interface or modularize at better levels of abstraction?

2.2 Perils of PCB Design

The design of PCBs can be non-trivial, acting as a prototyping barrier when knowledge, funding or timing is limited. Whilst some entry-level platforms exist to reduce these barriers[7] they lack complexity to solve non-trivial design problems. Furthermore, manufacturing guidelines need to be understood and adhered to before a design can be realized. However, the biggest barrier for PCB manufacture is potentially cost, with small one-off prototypes easily costing over €100. Whilst these costs can be reduced by sourcing PCBs worldwide the quality of manufacture and technical support can vary dramatically. An alternative to the reliance on 3rd party manufacture is to utilise maker-level milling machines to create custom PCBs[8]. These solutions enable individuals to mill and drill two layer FR-4 PCBs cheaply and quickly. However, they are not suitable for more complex designs which require through-hole plating, silkscreening or multi-layer implementations.

To develop prototypes a radical rethink of PCB manufacture is required to reduce reliance on low-fi engineering methods such as breadboarding. This debate needs to cover the software (CAD) and hardware issues, encompassing the practicalities of getting the right materials into hands quickly and cheaply.

2.3 No One Likes Compliance Testing

The next issue for prototyping is less immediate but no less important: compliance testing. Depending on where an electronic product is being sold, CE[9], UKCA[10] or FCC[11] compliance is required. The path to compliance, however, should not be an afterthought and should start as part of any serious electronic prototyping methodology. For example, radiated emissions and immunity testing[12] can be an expensive process requiring access to specialist equipment and expertise. To reduce the risk of product failure early-stage prototypes can be developed with compliance in mind: adequate ground planes, checks to remove floating inputs, digital and analog track spacing / separation and enclosure shielding are just a few simple considerations which can save time and money in the long term.

Compliance testing is often an afterthought when developing hardware and is a hidden barrier when taking an idea from prototype to market. Whilst this may not be an issue for non-commercial projects a wider dialog on the issues could potentially accelerate ideas through commercial innovation pipelines.

3 THE MEMA TOOLKIT

In this paper we present the MEMA toolkit: an expandable technology stack for combining sensors, I/O modules and actuators into an embedded form to create interactive devices. The hardware consists of a controller board (comprising a microcontroller, BLE[13] module and 9DOF accelerometer) and stackable auxiliary boards for driving actuators, expanding sensory input and powering the unit. Each board is connected using a common IDE bus interface which manages power, protocols such as I2C & SPI and I/O lines. Furthermore, hybrid PCB prototyping boards can be utilized with the toolkit to rapidly prototype new features. Hardware can be controlled via software updates (over serial) and by expanding the BLE protocol which interfaces with the controller board through web based applications.

The MEMA toolkit has been designed from engineering "lessons learned" to enable the rapid and robust development of interactive devices, combining both "off the shelf" components and a bespoke modular PCB design to create a hybrid, non-proprietary and reusable platform. This has multiple benefits, for example:

- Utilizing a common bus interface enables hardware modularization and agnosticism - a developer can build plug and play components without being tied to a particular development board.
- Using a hybrid style “protoboard” enables new modules to be rapidly and flexibly prototyped without the need for breadboarding.
- PCB modules are of a standard form factor, enabling new modules to be created using the same layout, mount points and footprints. Furthermore, they can be designed with compliance in mind - utilising ground planes and track layout techniques.
- MEMA devices can be controlled via BLE, enabling wireless applications which utilize custom or standard protocols eg. BLE UART. This additional level of abstraction enables MEMA devices to be controlled through an array of languages: C, Python, Javascript etc.

Whilst this toolkit is in an early stage of development it is hoped that these ideas and methods can be evaluated in a range of contexts, providing empirical opportunities to improve the prototyping process.

4 DISCUSSION: THE FUTURE OF PROTOTYPING

We have highlighted outstanding issues inherent in electronic prototyping and presented an early-stage development toolkit for addressing some of the issues raised. We believe, however, that a more holistic approach needs to be adopted by practitioners to ignite new opportunities “beyond prototyping boards”.

Moving from a focus on “novel” microprocessor boards towards modularization could aid this development. This would not take the form of new “breakouts” but a cultural shift towards abstracting hardware development at the prototyping stage. Leveraging hardware reuse through common interfaces, modular design and plug ‘n play components could help balance the tensions between “off the shelf” and bespoke approaches to design. An opportunity also exists through opening sourcing these designs. A library of common and interoperable “protoboards” could unlock new ecosystems - creating new forms, packages and enclosures to reduce PCB design costs. Industry lead engagement with these forms could also bring manufacturing closer to the pockets of makers, hobbyists, wholesalers and resellers. Finally, earlier engagement with compliance testing experts could help fast track development lifecycles, mitigating issues which delay commercial development. Or, furthermore, developing desktop compliance tools which enable early flagging of these issues could move self-certification from a laborious task to a simple workflow component, requiring only the press of a button.

In this paper we highlight inherent issues in developing creative and innovative solutions to engineering problems. Rather than emphasizing the need for more sophisticated microcontroller boards to empower creative practices, we advocate a debate surrounding these core issues. In short, the future of electronic prototyping is a search for solutions not through better technology, but through a better collective understanding of the issues at play.

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