PAIPR Prototyping: Some Thoughts on the Role of the Prototype in the 21\(^{st}\) Century

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Steven Pinker once said that his worst product interaction experiences were with a Bang & Olufsen television and phone. It should worry those with an interest in design that there should be a phone in production that an MIT professor cannot operate, let alone one from a company known as a ‘designer brand’. Yet the problems he found here arose because both the television and the phone are computer embedded products.

The computers in computer embedded products are constrained and controlled in such a way as to appropriately serve the design of the product they are embedded in. To paraphrase Bill Buxton, a PC is a computer you type into, a phone is a computer you put to your ear to and a digital camera is a computer you look into. Products that have computers embedded within them surround us. Increasingly, the product is actually the user interface while what we think of as the product largely just packaging it (think of the iPhone). Switches, dials, sliders, touchscreens etc. occupy a ‘middle ground’, behaving as a physical conduit to our virtual experience.

Some years ago the author had a conversation with an interactive appliance design expert who told him that, in their experience, industrial designers tend to address user interfaces, particularly Graphical User Interfaces (GUIs), with a 2-D mentality. Considering industrial design is focussed on three-dimensional output that is a damning criticism, but should it surprise us?

At the core of the issue is the fact that the computers within these machines enable so many possibilities that designing them to appropriately exploit that power is the problem. Consider just how much computing power we have at our disposal in the modern era: In the mid to late 1960s NASA developed a flight computer for the Apollo programme. Each Saturn V rocket carried two; one in the Command Module and one in the Lunar Lander. These computers had to handle radar, orbital rendezvous, navigation, engine firing and autopilot functions. They performed almost flawlessly throughout. Their specifications included 1MHz processing speed with 1KB onboard RAM and 12 KB of ROM. These early computers were very expensive and their functions were limited by their lack of computing power. Highly trained operators (astronauts backed up by a team of computer experts in Houston) learned to deal with their limitations. Our problem now is that computers are powerful, cheap and ubiquitous. The iPhone 4 for example has 800 times the processing speed of the Apollo computer, more than ½ a million times the RAM and the rough equivalent of more than 2½ million times the ROM. In order to succeed, these far more powerful machines need to be readily accessible to a non trained, disinterested user quickly, easily and without an instruction manual. Unfortunately they are frequently ill conceived, largely because the design process is flawed. Much of the problem is connected to the problems designers have with creating appropriate prototypes for computer embedded products.

When designers develop a design for a non computer embedded product, e.g. a chair or a light, prototypes of various kinds (soft models, rigs and facsimile models) play their part in a well ordered iterative system that ends with a well understood product. This reflects a core recognition in the design profession that designers need to be able to make ‘quick and dirty’ prototypes (employing what Schrage described as Serious Play [S1]) in order to evaluate the tangible interactions of their designs early in the design process. At the end of that process the client is able to review the design, and if necessary ask for adjustments to be made.
Now consider the design process for a computer embedded product. In this case the designer employs soft models to test ergonomics, but much of the users' interactions are computer interactions. For these, a screen based prototype is typically employed in place of the rig based prototype. This essentially occurs because designers do not have the skills to build very complex computer based prototypes. Unfortunately, screen based prototypes are not very good at simulating user interactions because our physical interaction with a product has a pronounced effect on our cognition. So, while screen based prototypes are good at simulating products where we poke largely unyielding buttons on a big, flat vertical interface with our index finger (e.g. like a microwave oven \[S2\]) they are poor at simulating products that we grasp in the hand. Hand held products might have controls that are not on the upper surface and which may be triggers or sliders or dials etc. Even in light of this however, one might argue that employing a screen based prototype is a pragmatic if less than optimal solution that enables a perfectly workable design process: Once the industrial designer has completed their work an electronics designer will build a fully working tangible prototype. The client is then able to review that before making an informed decision on the complete design proposal. One might argue all that happens in this case is that the electronic designer has made the prototype rather than the designer. Unfortunately the reality is quite different. Electronics designers have a lot to deal with. They need to design a reliable, workable product that can be produced to budget, at the right scale without drawing too much power and so on. They are not trained to tackle usability issues and even if they were, producing a full working prototype takes too long and is too complex to be part of a truly iterative process.

So while commentators have continually criticised the poor computer embedded product design process (see Buxton \[B1\], Cooper \[C1\] or Loudon \[L1\] for examples) and while that criticism is certainly justified, this author would argue that there is not yet enough serious, detailed and connected suggestions for industrial designer-oriented methodologies that might be employed to solve the issue. Part of the problem is that these products are so remarkably complex that they require a far more holistic methodology and this has certainly been recognised. As far back as the mid-nineties Thomas was already arguing for a systems approach \[T1\]. By 2000 Hollan had developed that concept further, arguing the case for distributed cognition \[H1\]. But how do we empower industrial designers to undertake these approaches? A number of companies (e.g. IDEO, DCA and PDD) have developed expertise in the development of computer embedded products and have multi disciplinary teams ‘in house’ who are able to deal with complex prototyping issues. Most designers don’t have access to the same facilities or expertise however, and recent research by Culverhouse \[C2\] has found that even when electronics expertise is available ‘in house’ it is not possible to utilise it quickly and iteratively in real world scenarios. A number of attempts have been made to tackle this issue, among them are:

- **Experience Prototyping** \[B2\], an ethnographic approach involving the use of low tech. props, role play and improvisation
- **Wizard of Oz** simulations \[M1\] which involve unseen human operators simulating sophisticated machine responses
- **Augmented Reality** \[N2\] which uses a combination of real and virtual simulations
- **Phidgets** \[G3\] and **Arduino** \[B3\] both of which provide electronic ‘building blocks’
- **Paper Prototyping** \[S3\] a well tested and entirely low tech. approach involving a facilitator observing user interactions and simulating machine responses by, for example, placing drawings of screens on a model of the appliance held by the user
- **DTools** \[H2\], a toolkit with bespoke hardware and software and the first attempt to produce an integrated solution to the hardware/software prototyping problem

All of these approaches represent real progress for the field and some can be used in conjunction with others (generally speaking, the ‘low tech.’ and ‘high tech.’ methods can be used together).
However those methods that use electronics tend to focus on solving technical problems whereas the intended users (designers) are, by and large non-technical.

The end result is that, in most cases the physical prototype is not able to play its part in the iterative design development process. This means that the full interaction experience of a computer embedded product design is not experienced until very late in the design process. Thus, while in theory the client can ask for the project to be restarted, in fact this doesn’t often happen because the time and cost of developing a design all the way to a working prototype is so significant. What happens then is that the product is either launched (flaws and all) or cancelled.

The author leads a research group called PAIPR¹, an industrial design research group with an interest in developing methods for designers involved in the development of computer embedded products. PAIPR concentrates on methods that are accessible to designers and which require as little as possible technological understanding. The group seeks to place the iterative prototype in its rightful place at the heart of the design process for computer embedded products, much as it has always been for more traditional products.

At the core of one of the group’s techniques is a product called an IE Unit, a low tech. product that works by facilitating the connection of a model embedded with switches to a P.C.-based GUI prototype [G1]. The system allows the P.C. to receive keyboard inputs (see Figure 1) so that when a user activates a switch in the model, the P.C. responds to perceived keyboard input and a keyboard triggered (usually Flash based) GUI is activated. The system has enabled hundreds of tangible prototypes to be produced over the years, most of them by undergraduate students learning about information ergonomics. As a result of their experiences PAIPR has become convinced of the value of tangible prototypes and physicality. In 2008 they published research with colleagues at Lancaster University that quantified the effects of physicality on user interactions, effectively proving the importance of an early, iterative physical prototype based design process [G2].

Figure 1: 4th generation IE Unit linking a prototype to a P.C.

One aspect of the IE System in this form is that the GUI is displayed on a remote P.C. screen. PAIPR wished to explore:

¹ The Programme for Advanced Interactive Prototype Research www.paipr.wordpress.com
1. whether a tangible prototype, even one with limitations, (e.g. a discrete screen) was more similar to a final product than the now traditional monitor based prototypes most commonly used by industry

2. how quick or how dirty can the prototyping process be and still provide valuable feedback early in the design process, i.e. the level of fidelity required to obtain an acceptable degree of tangible accuracy

A BT Equinox phone was ‘reverse engineered’ to mimic a very high fidelity tangible prototype. Genuine Equinox mouldings housed a second generation IE Unit and a representation of the screen’s output was displayed on a P.C. monitor via a Flash Graphic User Interface. The same Flash interface was used as the basis of a full on-screen prototype which would be interacted with through a touchscreen. This was referred to this as the software prototype.

![Figure 2: Equinox prototypes](image)

A test programme was designed to compare the performance of a real Equinox phone, the IE Unit prototype and the Software prototype (see Figure 2). Tasks were chosen to include common functions (ranging from simple to complex), unusual functions (such as the Equinox’s SMS button), and functions that involved more than straight forward transitions between the product’s states. 79 participants were divided into three independent groups (one for each manifestation of the interface, i.e. Equinox, IE Unit and Software) and given a series of tasks, each of which was timed and graded.
The data demonstrated that the Equinox and the physical prototype performed in a more similar fashion than the software alone. This was especially true of the time taken to complete each task (see Figure 3) but in performance the software was never better than the tangible prototype and sometimes markedly worse. In Norman’s theorizing [N1], the system image created by the physical prototype is a better fit of the user’s mental model of a phone device than a purely software simulation. This result is all the more significant for two major factors:

a) A phone is a ubiquitous computer embedded product so everyone in the test was able to draw on previous experience.

b) The Equinox has an all push button interface with controls mounted on the top surface. This allows the software prototype to compete on favourable terms. Had the selected appliance featured sliders, dials, triggers etc, or had the controls been mounted in a more three dimensional fashion around the product, then the software simulation may have matched the performance of the real product even less.

The data demonstrated that at high fidelity levels a relatively quickly built, low tech. prototype will out perform the standard screen-based industry method of simulation. What was so far unclear was how much effect the physical interaction was having on the user. In other words, could a very low fidelity physical prototype and interface give useful results in the same or less time than an entirely screen-based prototype? To find out, an ultra low fidelity physical prototype was constructed and married to a low fidelity GUI. The new prototype was constructed in blue modelling foam with the switches being topped with card cut-outs in the shape of the switches on the real phone. On top of these were glued the button graphics, and the screen was represented by a piece of coloured paper. The new Flash GUI was created using sketch work produced onscreen via the mouse. The GUI was driven via keystrokes in the same way as the higher fidelity prototype described above.

Further tests were now carried out using the low fidelity (Sketch) prototype using a similar procedure to the first experiment but without the SMS and Add tasks.
The low fidelity Sketch prototype had very similar results to the high fidelity IE Unit prototype in both time (see Figure 4) and performance, thus demonstrating the importance of the tangible prototype. The significance of the results lies in the fact that more accurate results were produced from a quicker, ‘dirtier’ tangible prototype produced in 80% less time than the high fidelity screen-based interface.

Looking Forward

The research described above, backed by studies of the challenges designers face [G4] and the work carried out with industry [G5] has given PAIPR the material to produce a set of guidelines to direct future research on prototyping methodologies. These include:

1. **Speed and fit**
   A successful computer embedded product prototyping system must provide a good fit for the way designers already work. To achieve this, toolkits need to enable fast, iterative, low fidelity prototyping in two hours or less without electronics or programming knowledge.

2. **Capability**
   Modern computer embedded products require a lot of input possibilities. Prototyping toolkits need to enable a wide range (25 - 50) of varied input types, including touch screen and analogue controls (dials, sliders etc.) as well as digital inputs (e.g. push buttons and rotary switches). For full flexibility, systems should ideally be capable of utilising off the shelf components.

3. **Physicality and scale**
   The proven importance of physicality in computer embedded product interactions directly implies an importance of scale. Thus, for example, a digital camera prototype at 1 ½ times the size of the intended product (to make prototyping easier) will have very different physicality from the finished product. It will therefore probably also have different user interactions. It follows that a successful prototyping method should enable 1:1 scaling.

4. **Screens**
   There are some applications where the inclusion of the screen is required. In general the rule of thumb is that ‘eyes down’ activities such as mobile phone texting require a screen on the prototype, whereas ‘eyes up’ activities such as navigating menus do not.
5. Education

If designers are to reclaim their role as prototype led innovators and user champions in the computer embedded product field then design courses need to train students accordingly.

Using these guidelines and others, PAIPR have been looking at improving their approach. A very brief description of some of that work is detailed below:

**Very Rapid Iterative Prototyping**

One of the guidelines above states that interactive, tangible low fidelity prototypes need to be producible in two hours or less. One of PAIPR’s members, Culverhouse has been working on ways to achieve this [C3]. He has proposed a system called StickIT that exploits the properties of passive RFID tags. The tags are broken by a switch so that they can only be detected when the switch is closed. A conductive substrate and coaxial pin system borrowed from Lancaster’s *VoodooIO ad hoc* networking system [V1] is used to allow the RFIDs to share a single aerial. A reader is mounted on a glove so that, in a hand held device it is always close enough to the RFID tag to power it up. Meanwhile, a Bluetooth transmitter on the glove sends a translated keyboard input to the P.C. which can be used to trigger changes in the GUI. The system allows the switches to be moved anywhere on the surface without any wiring or power issues. Switches can also be added or removed very easily.

*Figure 5: The StickIT prototyping method*

**Balancing physicality and fidelity**

The importance of tangible prototypes and the advantage they enjoy over virtual prototypes was discussed earlier in the chapter. One of the interesting aspects of that research that wasn’t mentioned in detail for space reasons was that when the fidelity of the prototype dropped below a certain level the performance of the tangible prototype decreased markedly. This led to an important question: “How low can the fidelity of a tangible prototype be taken before the data produced from user tests upon it become unrepresentative of the performance of the final product?”

Another PAIPR member, Hare led a study that set out to answer this question [H3]. Time was used to govern fidelity and so Hare was tasked with creating three prototypes. She was given 1 hour to make the first, 1 day to make the second and 1 week to make the third. User tests were carried out on the resulting prototypes. What was found was more evidence that physicality is important. What was
not found was a clear and present link between the level of fidelity and the accuracy of user experience and this is an area that PAIPR are consequently keen to examine in more depth.

New Paradigms

One of the current aims of PAIPR is to develop a tangible prototyping system so fast and flexible that it allows designers to develop new interaction paradigms for technologies that don’t yet exist. This is a work in progress. However one of the early bonuses of the programme was a technique to maintain physicality while gaining the advantage of mounting a screen on the prototype without the scale, power, speed and technological issues that accompany such an inclusion. The researcher, Zampelis, spotted the potential for the AR Toolkit to simulate an embedded screen. Zampelis moved the camera to the rear of the screen so that any object with the appropriate AR marker that was held behind it showed on the screen with the virtual display projected on its surface. The resulting system is called IRIS, and allows the user to both feel and see the device while the augmented reality aspect meant the screen appeared ‘on the device’. Zampelis modified the AR software so that IRIS works with keyboard triggered Flash files. Consequently, it works with both the IE System and StickIT.

![Figure 6: IRIS](image)

Conclusions

Industrial designers have always valued prototypes because they know that they enable better products that produce a satisfactory end user experience. Computer embedded products have been with us for some time but the problems of developing them using appropriate, designer friendly ‘quick and dirty’ tangible prototyping methods has not as yet been fully resolved. As well as a host of
techniques developed by researchers and practitioners across the world, a common solution has been to use multidisciplinary teams to design computer embedded products. Recent research by PAIPR has found a significant issue with this theoretically sound practice, namely that aligning the availabilities of the various skill sets in the context of more than a single project is somewhat problematic. Another common solution is to prototype ‘virtually’ by using touchscreen mock ups of product interfaces. This too is problematic:

PAIPR has empirically demonstrated what has long been qualitatively recognised: That a tangible prototype has a significant effect on the interactions of a user. Critically, the research has demonstrated that the physical prototype better mimics the interactions of a real product than the touchscreen alone. This continues to be the case even when the fidelity of both the tangible prototype and its interface are dropped significantly. This makes a lot of sense because it has been understood for many years that we do not experience the world through a series of separate channels as was once thought. In fact our senses all operate together and it is sometimes difficult for us to know which one is telling us what. The McGurk Effect [M2] is a good example of this. As far back as 1976, McGurk and McDonald proved that lip reading a person can actually change what we hear them say. Even when we know they are making one sound we can’t prevent ourselves hearing another if we watch them make the mouth movements of another sound. This is because the world we perceive is as much about what we do with information as the information itself. In that context it makes perfect sense that a tangible prototype is going to affect our interactions in a way that might not at first seem logical. It follows that in order to design effectively designers need to continue to use prototypes in the way they traditionally have and that computer embedded products need them no less than any other kind of product. In some ways, one could argue, computer embedded products need tangible prototyping methods more than most other products by dint of the sheer complexity of the user interactions they enable.

Since creating multidisciplinary teams doesn’t necessarily solve the problem of enabling tangible prototypes it follows that designers need to claim ownership of the process. While there remains much work to be done before the prototyping methods available to them allow the same level of flexibility and suitability as the techniques for traditional products, there are already enough tools, techniques and knowledge available to enable a more prototype centric approach than typically occurs.

Universities need to embrace and teach the techniques available and develop new ones. Only by stretching designers’ prototyping ‘technique toolbox’ will users start to experience a greater range of fully integrated and innovative computer embedded products.

References


[22]  [S3] Snyder, C. (2003), Paper Prototyping, Morgan Kaufmann, San Francisco, CA.
