Sketching and Prototyping Personalised Objects: From Teapot Lids to Furniture to Jewellery

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ABSTRACT
The products that we use every day are typically designed and produced for mass consumption. An emerging alternative approach is personal fabrication: the end-user participates in the entire process of creating a customised product, from the initial concept stage of sketching and designing a 3D shape to the testing and manufacturing of the final product. We have developed various sketch-based tools that take this approach. Our 2D sketching tool allows the user to sketch on top of a single photo to create a new personalised object that fits well with the existing objects and environment in the photo. Our 3D augmented reality based system allows the user to draw and visualise customised furniture and other household products directly in the real-world. We are currently in the process of developing an interactive system for creating personalised jewellery. Our system is different from existing software such as JewelCAD in that our interface will be much simpler. We envision that users will be able to create complex 3D shapes of bracelets and rings with a minimal number of user-drawn lines and strokes.

KEYWORDS: 3D Modeling, Sketching Interfaces, Personal Fabrication

1. INTRODUCTION

The idea of “design tools for everyone” [1, 2] is to give novices the ability to design and fabricate personalised physical objects. Although there exists many 3D/CAD modelling tools (e.g. Autodesk 3ds Max, Autodesk Maya, Blender, Google SketchUp), they are typically difficult and time-consuming for a beginner to both learn and use. Some of these software tools even have authorised training centres all over the world where users can take training courses and receive certification for their ability to use the software. Moreover, the process of modelling a 3D shape can be tedious. It can take in the order of days for even an expert to create a single 3D model from scratch. Hence the 3D modelling or shape creation process is still a bottleneck that must be resolved to realise the concept of personal fabrication.

The goal of our work is to create interfaces that are easy for users to design their own 3D models/shapes, such that the virtual shapes can then be fabricated into real-world personalised products. We use the word “design” to refer to the ability to explore various 3D models/shapes in the modelling process. Our focus is on creating tools that are easy-to-use. This means that the tool can be used immediately by most users with a minimal amount of instruction (such that we do not need manuals or courses).
To achieve this goal, we have built several systems and are in the process of building a new one for creating personalised products.

First, we have built a 2D sketching tool that allows the user to sketch on top of a single photo to create a new personalised object that fits well with the existing objects and environment in the photo [3]. We call this idea Modeling-in-Context, as the new objects are complementary to the existing ones in the original photo. We provide an interface for the user to sketch the new shapes using the photo as a reference. The newly created virtual 3D models can then be fabricated into physical objects with a 3D printer or a laser cutter. We have used our system to design a variety of real-world objects, including teapot lids, bookshelves, and storage boxes.

Second, we have developed a 3D augmented reality based system that allows the user to draw and visualise virtual 3D shapes directly in the real-world environment [4]. We call this concept Situated Modeling, and it is similar to the idea of Modeling-in-Context, except that the modelling is directly performed in 3D space instead of the 2D screen space. The idea of using the existing objects and environment as a guideline while creating the new shapes is common among both systems. We provide a shape-stamping interface where the user manipulates a set of tangible tools corresponding to primitive geometric shapes directly in the real world. We have used our system to design a variety of customised furniture and other household products.

Third, we are currently in the process of developing sketch-based tools for everyday users to easily create their own jewellery. The goal is to build an easy-to-use system that is different from existing software such as JewelCAD. We expect that our interface will be much simpler. We envision that users will be able to create complex 3D shapes of bracelets and rings with a minimal number of user-drawn lines and strokes. It is hoped that individual users with little or no experience in 3D modelling can use for our system to create jewellery that they will use themselves.

We describe each of these systems in the following three sections of the paper, and conclude with a discussion of our overall work.

2. SKETCHING TEAPOT LIDS AND OTHER COMPLEMENTARY OBJECTS WITH A 2D PHOTO-BASED INTERFACE

This section describes our Modeling-in-Context [3] system for designing complementary objects with a single photo. The significant concepts that we introduce are: (i) The end-user participates in the entire process from the initial concept stage to the final production of the new complementary real-world object; (ii) We advocate the use of a single photo as a reference for the user (instead of the algorithm) to sketch a new customised object that does not exist. The photo provides references about the perspective and relative dimensions of the new object; and (iii) We introduce a Modified Lipson method to create precise 3D shapes interactively.

2.1 Related work
The PhotoModeler software [5] is closely related to our system. Their method is vision-based and requires an initial camera calibration step that takes user-marked lines or points from a realistic photo as input. In particular, their method cannot take any user 2D drawing as input. Furthermore, for the case of a single photo, many photos cannot be used with their software. In general, PhotoModeler and other vision-based methods ask the user to trace over existing objects in photos to recover their 3D shapes. On the other hand, our system is user-based and we advocate the use of a single photo for providing some “context” for sketching a new customised object that does not exist. Since the new object does not exist in the photo (or in the real-world), we cannot apply vision-based techniques. As an example, a possible photo may include a desk with some books and stationery on it to provide the context for drawing a new and personalised desktop organiser. The new object is complementary to the other existing objects and should fit well with them. The photo acts as a reference for the user and is not used in our algorithm, again in contrast to vision-based methods. The advantages of having the photo are that it provide hints about the perspective for drawing the 2D outlines, and the relative dimensions of the new object can be easily assessed by the user.

2.2 User interface

Given the photo, the user sketches the 2D outline of the new object and certain annotations about the geometric properties of its 3D structure (Figure 1). Since the 2D sketch is user-drawn and may be inaccurate, the annotations are important and necessary for producing the 3D shape. To make it easy for novices, our input interface is entirely in 2D. This is in contrast to common CAD modeling programs which require manipulations in 3D that are known to be difficult for beginning users [6]. In addition, although Lipson’s method [7] tries to automatically recognise certain annotations from the user input, it is not necessarily robust as it depends on the camera perspective and complexity of the shape. We thereby leverage human ability to annotate the 2D sketch.

Figure 1: A screenshot of our system. On the left, the user sketches the 2D outline and annotations of the new object on top of the photo. On the right, we use a Modified Lipson optimisation method to create the virtual 3D model.
2.3 Implementation

We take the user input, extract a 2D graph along with the corresponding annotations, and “expand” this 2D input into a 3D structure. We found that a direct application of Lipson’s approach [7] for performing this expansion does not robustly produce precise 3D shapes and does not provide interactive results. Hence we introduce a Modified Lipson method that improves upon Lipson’s algorithm in two main ways. First, we use a two-step optimisation process, in contrast to Lipson’s method which takes a complete 2D sketch as input and performs one optimisation step. Our initial optimisation finds a depth value for each vertex while trying to satisfy the annotated geometric constraints. It provides an estimate of the solution. The full optimisation then finds a 3D position for each vertex, while trying to satisfy the geometric and projection constraints. Second, we optimise in a reduced dimensional space, as many CAD models have a regular structure and we need not optimise with three dimensions for every vertex. Our algorithm does not perform camera calibration with the information in the photo, but the projection constraint also finds a set of camera parameters such that the projection of the 3D vertices onto the 2D screen matches with the original 2D sketch as much as possible. We convert the 3D shape to either a polygonal mesh for 3D printing or a set of coplanar profiles for laser cutting.

2.4 Results

We show a variety of new real-world objects made with our system. We can sketch each of these objects in between two and ten minutes. Our results demonstrate the concept of modeling-in-context with new objects that fit well with existing ones. Our system supports the creation of user-customisable objects, as shown by the different types of desktop organizers that we made.

Figure 2: Each row shows the original photo, the photo with 2D sketch, the resulting 3D virtual model (middle two), and the new real-world object (right two) fitting well or exactly with the existing objects. The objects are (from top to bottom): bookshelf (plywood), desktop organiser (acrylic), and teapot lid (ABS plastic from 3D printer).
3. MODELLING FURNITURE AND OTHER HOUSEHOLD PRODUCTS WITH A 3D AUGMENTED-REALITY-BASED INTERFACE

This section describes our Situated Modelling [4] system for modelling household products with a head-mounted display (HMD) augmented reality (AR) system. The significant concepts that we introduce are: (i) Stamping interaction techniques with tangible 3D primitive shapes; (ii) Situated modelling approach where tangible shapes use real-world environment and other existing objects as a physical guide; and (iii) Two-handed stamping of shapes to provide tactile feedback.

3.1 Motivation and related work

Traditional modelling methods usually lack references to the real world, making it difficult to design a model that fits well with the target environment. We present a tool for users to create real-sized 3D models directly in 3D space to address this problem. While a single photo [3] can provide a 2D background reference for modeling-in-context, modelling directly in real 3D space provides the ultimate reference. The 1:1 size ratio of the new object relative to the existing ones allows the user to better perceive, model and visualise the result. Fiorentino et al.’s system [8] combines augmented reality and 3D modelling methods for sketching curves and surfaces, but they do not use the real-world as a reference. Yee et al.’s system [9] is closely related to our work. Their system can be used to sketch new objects in 3D space. However, it does not allow for physical interactions between the modelling tool and the existing physical objects and environment, except that it uses the real-world as a general background reference.

3.2 Shape-stamping, situated modelling, and two-handed interaction

We introduce shape-stamping methods where a user models with tangible primitive 3D shapes such as a cube or cylinder (Figure 3). We can stamp a virtual shape in 3D space that corresponds to the physical shape. We can further stamp a shape multiple times in one smooth sweeping action to extend the basic shape (sweep-stamping). These primitives represent smaller parts of larger materials such as wooden bars or plates available at local stores. They naturally support the creation of do-it-yourself household products by everyday users. In our implementation, the user wears a HMD and identifies the shapes with a set of markers.

Figure 3: Left image shows tangible primitive shapes. Middle image shows HMD. Right image shows examples of sweep-stamping.
Another significant aspect of the tangible shapes is that they naturally allow for Situated Modeling (Figure 4). The shapes can directly touch and interact with the real-world environment and existing objects. Hence we can use the real-world as a direct reference and to provide physical feedback when modelling in empty 3D space. For example, as we create a new table that follows the shape of the wall, we can use the real wall and ground as references. The new virtual table is life-sized and can be displayed immediately in the space where it will be used as the modelling process takes place. While one can measure the sizes of the existing objects and/or space, make a new object separately with respect to these sizes, and then place the new object with the existing ones to visualise them together, our approach can perform all these steps at the same time.

![Figure 4: Left images show examples of Situated Modeling. Right images show examples of two-handed stamping.](image)

Furthermore, as the new virtual model is being created, it is often necessary to add additional parts or shapes to the overall model. However, this is difficult as this involves stamping a physical shape in empty 3D space. We leverage previous research in two-handed manipulation that finds that the non-dominant hand is used as the frame of reference [10]. We introduce a two-handed stamping technique for providing tactile feedback during stamping (Figure 4).

### 3.3 Results

We demonstrate our approach by creating a variety of do-it-yourself furniture and household products (Figure 5). Situated Modeling is demonstrated by the resulting virtual models: they already have the correct dimensions for fitting in the real-world, and can be immediately visualised together with the actual objects and environments that they may be used in.

![Figure 5: Virtual models and physical objects created by our system.](image)
4. SKETCHING JEWELLERY

We are currently in the process of developing a sketch-based system for everyday users to easily create their own jewellery. The focus is on building a tool that is easy-to-use for most people. Users will be able to draw simple sketches, explore different designs, visualise the autonomously generated virtual 3D shapes of jewellery, and fabricate real pieces of jewellery that are personalised to each individual and that the creator can wear himself/herself. The term jewellery includes a range of products that have great demand for the buyer’s point of view. From the seller’s point of view, it is relatively easy to 3D print, package, and ship them. Hence it is a type of product that is interesting from the prototyping and manufacturing viewpoints.

The existing systems for modelling 3D shapes of different types of jewellery tend to have a typical CAD-like interface, with many buttons or icons representing features of the software. JewelCAD is one such existing system for designing jewellery. It seems to be popular among jewellery suppliers and experts. However, since it has a typical CAD-like interface, it requires users to have 3D modelling experience. Thus, it is not accessible to the average person. We aim towards creating a system that is different from existing tools such as JewelCAD in that our interface should be much simpler.

We will explore different methods for creating a simple interface. At the moment, we are focusing on an interface where the user draws a few simple lines and curves on the 2D screen with a mouse. Our system then converts these lines and curves into complicated 3D shapes representing bracelets and/or rings. The bracelets are to be worn on the wrist, and the rings are to be worn on the fingers. It may be useful to have a set of template shapes that the user can start with, as most bracelets and rings have a circular shape. The user-drawn strokes may then add details to the generated 3D shapes.

Figure 6 shows some examples of the types of real rings and bracelets that we intend to create with our system. We will use 3D printers to fabricate physical prototypes with plastic material and wearable pieces with metallic.

![Figure 6: Examples of rings and bracelets [various sources from Google Image Search] that we intend to create with our system.](image-url)
5. DISCUSSION

We have described three systems (two existing and one work-in-progress) for sketching and prototyping personalised products. These systems all represent progress towards the area of personalised design and fabrication. This is an emerging area and many new businesses based on the concept of fabricating personalised products by the end-user have recently started. This promising area has the potential to become the “new or third industrial revolution” [11,12]. Hence we believe that our interactive tools and the direction that our overall research work is following have the potential to radically change the ways many products are currently designed, manufactured, stored, transported, and consumed.

ACKNOWLEDGEMENTS

The author thanks the Lancaster University Early Career Small Grants Scheme for their support.

REFERENCES