Interactive Robogami: Data-Driven Design for 3D Print and Fold Robots with Ground Locomotion

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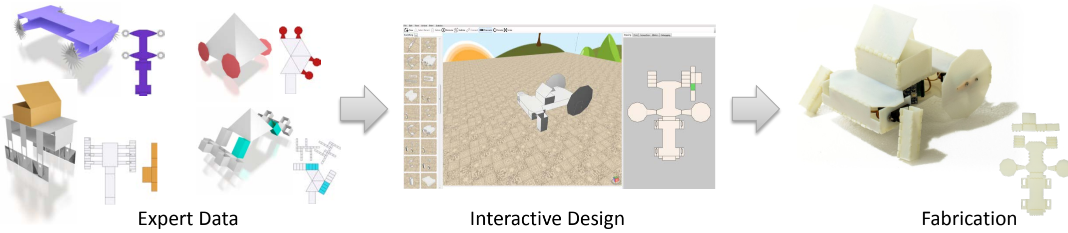

Figure 1: *From the left to right: expert data is extracted from a collection of robot designs created by roboticists. This data is used in a composition tool that allows casual users to easily create new designs following the assembly-based modeling paradigm. The designs can be fabricated using a 3D print and fold method.*

1 Introduction

The process of designing and programming a new robot requires expert knowledge and design skills that are often acquired over the course of many years. This makes design of new robots difficult for non-experienced users. In addition to design, physical realization of a robot is also time and labor intensive. We propose a new fabrication process for mechanical robots, called *3D print and fold*, which combines 3D printing with origami fabrication methods. In our technique, robots are 3D printed as flat faces connected at joints and are then folded into their final shape. To help casual users design ground robots using our 3D print and fold technique, we present our Interactive Robogami system. The system leverages a database of examples created by expert roboticists. A composition tool allows users to create new designs by composing parts from the robots in this database. The system automatically ensures that the assembled robot is fabricable and that it can locomote forward while still giving creative freedom to users.

2 Overview

Figure 1 illustrates the design workflow. Using the components in the database, users can explore adding and attaching different physical parts to the robot. Our tool provides interactive assistance by suggesting the connection and movement between parts and by ensuring that the design that the user is creating is fabricable. Designs can be simulated in order to verify that they move in an expected fashion, and interactive feedback is provided. Once the user is done, the system generates a model that can be 3D printed.

Database Using the ideas described in [Mehta and Rus 2014], we have created a database of robots that can be fabricated with our 3D print and fold technique. This novel fabrication method exploits the versatility of 3D printers while producing lightweight structures that are fast to print and use little support material. Each design in the database contains a 3D representation and a corresponding 2D unfolding, which are jointly represented as parametric shapes. This allows for structure-preserving manipulations such as scaling, rotation, and translation of the entire design or subcomponents. Furthermore, each design follows a hierarchical representation that includes information on connectivity between parts and on the motion of each part, so that the system can simulate the behavior and we can physically actuate the models post-fabrication.

Interactive Design Using our composition tool, users can pick and drag parts from different designs and connect them together to create a new composed design. Similarly to [Schulz et al. 2014], the system guides the user through composition by automatically handling parameter manipulation, part placement, and connections between parts. Parameter manipulation simultaneously updates the 3D mesh and the 2D unfolding, allowing users to create models that differ from those in the original database The system automatically suggests part placement using information from the database and the user specified positioning. The user can continue to manipulate the object until satisfied with the configuration. After the part is placed, the user invokes a connecting operation, which automatically creates joints and relative motions between the connected parts, and adds constraints for parameter manipulations. Our system can also analyze designs and simulate their motion in order to guide users through choosing parameters in real-time. If the design fails to achieve a desired goal property, for example stability during forward locomotion, the tool proposes parameter changes by drawing arrows on the UI. Our system also includes a global stabilization method that automatically searches for a stable configuration while optimizing for average speed or geometry error.

3D Print and Fold Fabrication The robots can be fabricated using a two step process. First, following the design phase, the system automatically converts the robot's 2D design with connection information into articulable STLs that can be sent directly to a 3D printer. We have designed new printable, snappable joints that give users greater design flexibility than traditional print and fold fabrication. The resulting models take approximately one hour to print. Second, we assemble the robot by attaching actuators and circuitry to the print and folding the body into its final shape.

3 Results

We provide end-to-end demonstrations which start with geometric models composed from parts in our database and undergo several rounds of user transformations and stability checks. We have used our system to create physical functional prototypes for a biped, three multi-legged crawlers, and a wheeled robot.

References

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