M.Sketch: Prototyping Tool for Linkage-Based Mechanism Design

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ABSTRACT
We present M.Sketch, a prototyping tool to support non-experts in designing and building a linkage-based mechanism. It enables users to rapidly create the mechanism by blending bottom-up (drawing linkages) and top-down (optimizing movement path) approaches. The resulting movement can be reviewed on the fly in a 3D space. Functions for digital fabrication with laser cutting and modular kits allow users to easily and effectively transform the designed mechanism into a physical model. M.Sketch can be used for technical non-experts to prototype initial models of smart product, robots, toys, and kinetic sculptures.

Author Keywords
Mechanism design; linkage-based mechanism; prototyping tool; computational design; digital fabrication

ACM Classification Keywords
H.5.2. User Interfaces: Prototyping

INTRODUCTION
Linkage-based mechanisms are commonly used by makers to build interactive robots, toys, kinetic sculptures, and smart products. Although linkage-based mechanisms consist of simple connections of links by joints, it is challenging for non-experts without engineering knowledge and skill to generate a desired movement. Thus, it is important to provide easy and rapid design aid to sketch, simulate, and build mechanisms.

An iterative design and refinement with trials and errors are essential to reach a mechanism with a desired movement. This often requires the creation of a physical model after an initial conceptual design process. Although several fabrication systems [2, 7, 12] have been introduced, they have focused on building static models.

Engineering CAD tools can be used to design and simulate a mechanism. However, they are inefficient for early exploration of a desired movement, as sophisticated 3D modeling is

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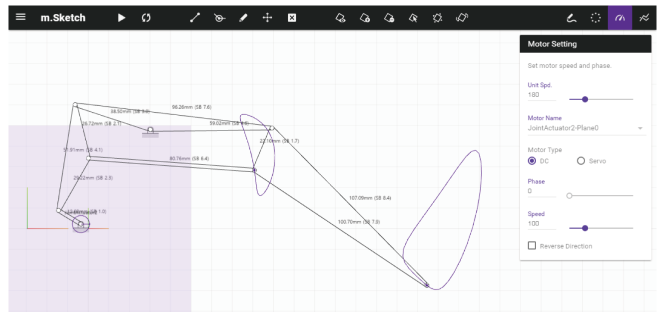

Figure 1. Snapshot of M.Sketch: illustrating mechanism drawing and movement path of a flapping wing.

needed. In addition, specialized tools such as *Linkage* [5] and *SAM* [9] exist for mechanism design. They focus on analyzing mechanical movement but do not support digital fabrication. Furthermore, several top-down design methods for generating mechanisms from certain motion input have been introduced [1, 3, 4, 6, 11]. These works are different from our tool, as they focus on algorithms and frameworks for mechanism generation instead of supporting practical prototyping. FoldMecha has demonstrated the automatic generation of a paper mechanism based on a parametric design approach for two specific examples [8]. Our work is distinct from the previous works because we aim to develop a readily usable tool for designing and building arbitrary types of linkage-based mechanism prototypes.

M.SKETCH
We present M.Sketch, a prototyping tool that supports non-experts to rapidly sketch, simulate a linkage-based mechanism, and transform it into a physical prototype (Figure 1). It provides intuitive interfaces for novice users without engineering knowledge and skills. M.Sketch has been developed as a Web-based computational design tool that is freely available on a public domain (http://cidr.kaist.ac.kr/msketch). It offers high device compatibility for PCs, tablets, and other mobile devices. Its key features include both movement simulation of the created mechanism and support for effective physical modeling.

Sketching A Moving Mechanism
M.Sketch supports the rapid design of linkage-based mechanisms. There are three ways to design mechanisms using M.Sketch. First, it applies sketching linkage geometries as a bottom-up approach. Novice users can easily design mechanisms by drawing and connecting geometries with

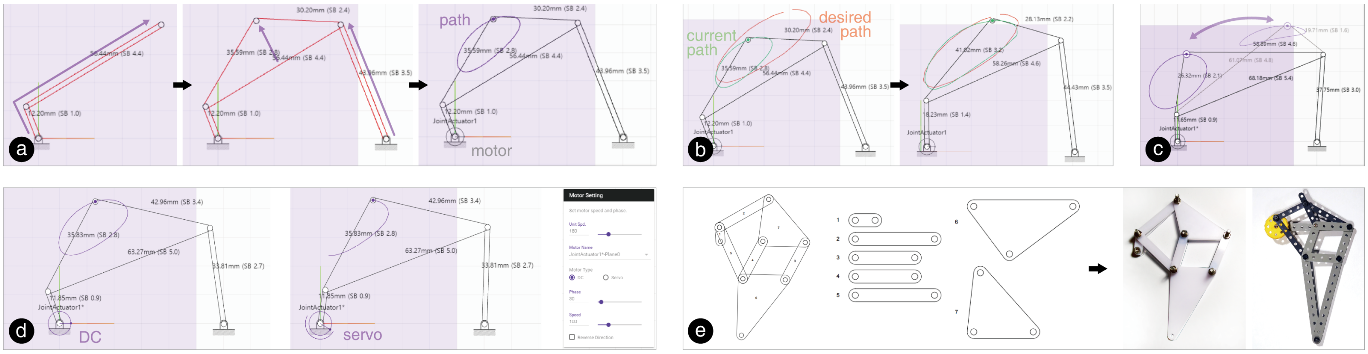

Figure 2. Sketching, simulating, and building a mechanism with M.Sketch: (a) sketching linkages and attaching motor to view a movement path, (b) optimizing the current path to a desired path, (c) checking the estimation of a path instantly, (d) setting the types and parameters of motors, and (e) building a physical model with laser-cut parts or Science Box.

dragging and snapping joints (Figure 2a). This method can generate arbitrary and complex mechanisms by drawing simple lines and connecting them. Second, the software enables the top-down adaptation of mechanisms to the desired path. When the user draws a desired path at a certain point, the system compares the desired and the current paths to derive the optimized positions of linkages using a gradient-descent algorithm (Figure 2b). Last, it provides various mechanism presets, such as 4-bar linkage, Jansen, Klann, and scissors mechanisms. Using the provided preset examples, a user can rapidly create similar linkage-based mechanisms.

Visualizing and Analyzing Movement

M.Sketch visualizes the expected motion paths of certain points of a mechanism when rotary motors are assigned to the joint of a linkage. When the user edits a linkage position, the expected paths are instantly changed (Figure 2c). The motion of a mechanism is influenced by different types of motors (DC or servo) as well as associated parameters, including speed, direction, and angle ranges (Figure 2d). Animated motion with assigned motors can be checked in a 3D view while using simulation. Multiple planar mechanisms can be located in 3D space to represent comprehensive movement. Additionally, M.Sketch provides a basic analysis of a path. When the user creates a walking mechanism such as a Jansen or Klann mechanism, it is possible to analyze the width and angle coefficient of the stride of the leg.

Supporting Fabrication

M.Sketch supports building a physical prototype after virtual mechanism design. The designed linkages can be exported as a vector drawing to be used for the cutting of paper, wood, or plastic. A physical model can be easily made by assembling linkages (Figure 2e). Another method of a creating physical model is to use *Science Box*, one of the most popular commercial modular kits in Korea [10]. *Science Box*'s rigid steel plates have holes to be assembled. M.Sketch provides snap and length-conversion functions for the length unit of *Science Box*. It is possible to build a hybrid physical prototype with paper or acrylic as well as parts from *Science Box*.

DEMO AND APPLICATIONS

Our demonstration allows participants to rapidly sketch and build a linkage-based moving mechanism. We plan to use several tablet PCs and laptops to demonstrate the M.Sketch interface. To show the rapid process of building a physical model, we plan to install a paper-cutting machine for building physical models on site. The paper prototypes can be used as souvenirs. We also plan to exhibit a few high-quality, interactive kinetic devices designed and built by M.Sketch to show the capacity and feasibility of the system (Figure 3).

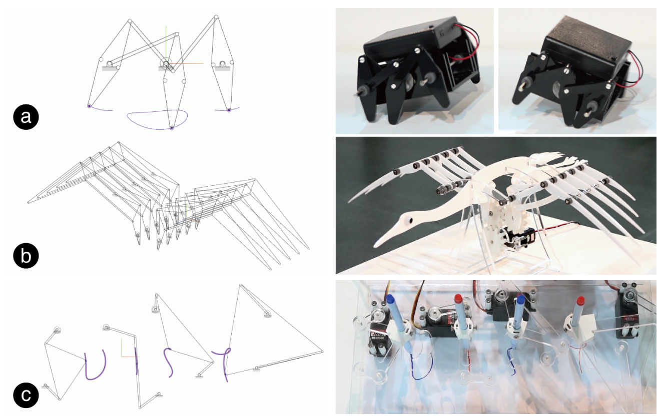

Figure 3. Example physical models designed by M.Sketch: (a) walking robot, (b) kinetic sculpture, and (c) drawing machine.

CONCLUSION AND FUTURE WORK

M.Sketch is a prototyping tool for non-experts to design and test linkage-based mechanisms. It can be used for early prototyping of smart products, robots, toys, and kinetic sculptures. For more comprehensive expression of mechanical movement, we plan to add more mechanical components beyond linkages, such as sliders, gears, cams, racks and pinions. We plan to further revise the top-down design approach using advanced optimization algorithms. As a result, it will be possible for non-experts to sketch more complex movement paths to generate associated mechanisms by M.Sketch. The planar mechanism will be extended to 3D. For the efficient assembly of physical linkages, support for 3D printing techniques with customized shape and joint structures will be adopted.

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