MARCut: Marker-based Laser Cutting for Personal Fabrication on Existing Objects

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TEI '16, February 14-17, 2016, Eindhoven, Netherlands

DOI: http://dx.doi.org/10.1145/2839462.2856549

Abstract
Typical personal fabrication using a laser cutter allows objects to be created from raw material and the engraving of existing objects. Current methods to precisely align an object with the laser is a difficult process due to indirect manipulations. In this paper, we propose a marker-based system as a novel paradigm for direct interactive laser cutting on existing objects. Our system, MARCut, performs the laser cutting based on tangible markers that are applied directly onto the object to express the design. Two types of markers are available; hand constructed Shape Markers that represent the desired geometry, and Command Markers that indicate the operational parameters such as cut, engrave or material.

Author Keywords
Personal Fabrication; Laser Cutting; Marker-based

ACM Classification Keywords
H.5.m. Information interfaces and presentation

Introduction
In this paper we present MARCut, a marker based approach for interactive fabrication, allowing both novice and expert users to operate a laser cutter. Our method leverages the tangible nature of physical markers allowing users to specify operations directly

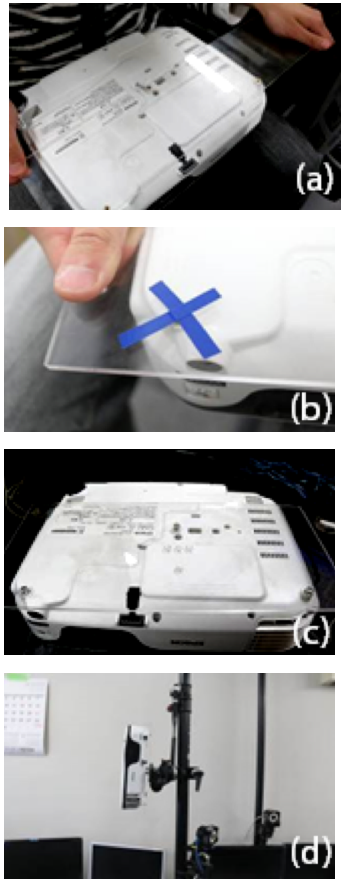

Figure 1: Creating a projector support with screw holes on an acrylic board.
(a) Placing a material over the object. (b) Create markers in line with screw. (c) Fabricate with MARCut and attach screw.
(d) Completed Projector Mount.

physical objects and material to be manufactured. The method allows the design specification and material alignment to be expressed intuitively.

An example of employing MARCut is the creation of a projector mounting bracket made from clear acrylic sheeting. Our system allows the specification of cutting operations to be determined in relation to existing physical objects. The operation in this example is the cutting of holes at the location of the mounting bolt holes on the bottom of the projector. The clear acrylic board is placed over the bottom of the projector, and the screw holes locations are indicated by the center of blue cross retro-reflective markers placed by hand on the clear acrylic sheet overtop of the mounting bolts. Figure 1 depicts the work flow of creating screw holes to attach support onto the projector. The clear material with the Shape Markers work effectively to specify the positions of the holes. To perform the same operation with traditional laser cutting techniques, the user would have to measure the relative positions of the mounting bolts. These positions would be translated into an electronic drawing. The cutting operation would then be performed. Errors in measurement and translation may occur, and the process would have to be repeated until a satisfactory solution is found.

Personal fabrication using a laser cutter employs two methods to create objects: from raw materials or modifying the appearance of an existing object such as engraving on an iPad. Our process explores a new approach that changes both the way designs are specified and how the transfer of the operations onto the physical objects is achieved. The new process employs a physical marker process for interactive fabrication. MARCut combines tangible design process focused on the existing object to be modified and the advantages of traditional CAD based designing process.

MARCut reduces the complexity of the laser-cutting process by using markers placed directly onto the object and recognizing them. This alignment process increases the usability, which leads to the reduction of operation time and improves the users understanding when specifying and aligning their design.

The MARCut system enables not only cutting and engraving an existing object but also supports the following operations: adjustment of laser power and speed appropriate for the material of the object, copy the shape and paste to another plane, setting the order of the operation, and the alignment of CAD model. These operations are carried out by attaching additional markers that correspond to each operation. The main contributions of our work are as follows:
1) Proposing a marker-based technique that allows users to have tangible interactions to operate the fabrication process with a laser cutter.
2) Defining markers to instruct the laser cutter with multiple parameters to perform cutting and engraving operations, e.g. specifying the design, setting the laser power and speed for the material.
3) Implementing a vision based system that allows the user to instruct shapes and the positions with simple markers on existing objects. It enables precise alignment on arbitrary position and instant creation.

RELATED WORK

CopyCAD [1] is designed to allow users to interactively create and modify 2D geometric shapes with a 3-axis milling machine. Operations such as copying a physical object and changing details are supported. Visual

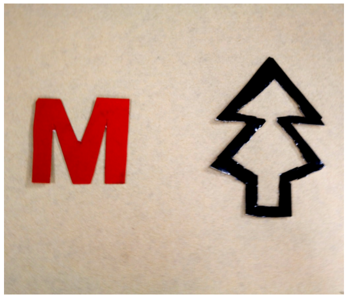
Figure 2: Shape Markers

Figure 3: Command Markers

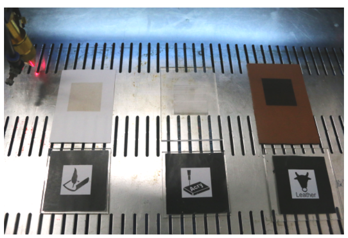
Figure 4: Material Markers

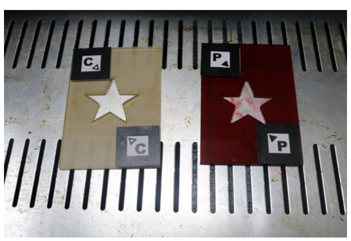
Figure 5: Copy and Paste Markers

feedback is provided through an overhead projector. CopyCAD only focuses on the geometry of the object and does not support operations such as material selection, engraving, or other machining settings.

Sketch It, Make It (SIMI) [2] is a pen-based modeling tool that enables novice user to create 2D drawings for fabrication with laser cutters. SIMI employs a constraints engine to convert freehand input into structured vector drawing. VAL [6] employs spatial augmented reality to provide the user with visual support the users' processing model reducing alignment time and increasing accuracy.

The constructable [3] system allows the user to control the laser cutter with gestures from a hand-held laser pointer. This system cuts where the laser pointer points, which eliminates the need of manual alignment. The operations are all based on freehand gestures of the initial placement and size of objects. Many of the operations provide constraints to ensure regular features, such as straight lines or regular circles.

Roland GX24 [4] detects markers on a sticker to specify the place to cut a sticker. In this system, the marker position is already determined and the user places the design between the markers on the computer. The markers are effectively used to specify locations.

MARCUT – TANGIBLE PERSONAL FABRICATION

This section describes our new MARCut system. First we describe the standard laser cutting process with an existing object that has four main steps: measurement, creating digital model, alignment, and cutting.

A standard method to capture the geometry of existing objects is to *measure* the objects in detail and *create* a digital model that enables the user to place the laser cutting operations relative to existing features. In addition, the standard method requires precise manual alignment by the user using the laser pointer mounted on the laser cutter, which is a time consuming and error prone task. For the alignment, the object is first placed on the laser cutter bed. Secondly, the common challenge with manual alignment is when the offset position of the part is not at zero. The user sets a zero position on the material for the laser cutter's head. The laser cutter is sent a drawing that is defined as a piece of paper with a size and origin (zero position). This process requires the user to understand the offset from the zero position and the rotation of the object in the drawing. To perform the *cutting* operations, information is encoded into a 2D drawing sent to the laser cutter to adjust the laser's speed, power and frequency. The drawing also informs the cutter whether to cut or engrave an object. The setting of these parameters has to be well understood by the user.

Design Process of MARCut

MARCut alters the standard laser cutting process into an intuitive interactive personal fabrication process using markers. Users first create a design using Shape Markers (see Figure 2) to define shape of how they want to modify the object. The users then place the marker at the position where they want the operation to be performed. The alignment of the laser operation and the object is done simultaneously. A set of Command Markers (see Figure 3) may be used to provide more detailed commands (such as the objects material to determine the intensity of the laser cutter). MARCut is a vision-based system and employs an

Figure 6: Engraving a logo on to an object is used in many situations to show the belonging. Our system allows the user to engrave onto the specific position of an object by using the Shape marker.

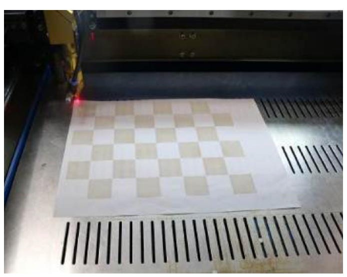

Figure 7: Calibration process

overhead switchable IR and visible light camera to capture the marker design.

Object Oriented Marking

The principle concept of MARCut is to attach the information directly onto the existing object with tangible operation (Figure 6). As this method focuses on the object that is to be modified, specifying the place to cut and adding details of operation that is suitable to the object are important factors of this system. Both factors can be easily set by attaching specific Shape or Command Markers.

Focusing on the object brings effective usage of the object and provides visual feedback. For example, user can use specific part of the materials that have patterns that differs one by one such as wood and cloth. Tangibility of the marker allows the user to design objects according to other existing objects, for example the clear projector mount.

Shape Marker

The Shape Marker is created from colored retro-reflective material to support the definition of the geometry and choice of cutting and engraving laser cutter operations. The user can create a design combining primitive Shape Markers that are cut freehand or laser. Color is used as an element to differentiate the cutting operations as shown in Figure 2. Line fitting operations are performed on the center lines of the of the Shape Marker outlines. The tree outline Shape Marker would have a single line down the center of the black outline. The extract all outline would apply the operation on the entire area of the Shape Marker. Yellow markers have the engraving over the entire yellow region of the marker, and the red markers have the cutting applied to the interior and exterior of the shape. The intersection point operation assumes two overlapping approximately linear blue shapes, and the system determines a center point to apply a hole to be centered and cut there. The diameter of the hole is defined by the size of the overlapping area. We envisage a large set of generic pre-defined shapes could be made available to users. For more complicated geometries, the user can still create designs using CAD. The user may use the Pre-defined Shape Marker to use CAD model for the operation.

Command Marker

We designed the Command Markers with fiducal markers for materials, copy/paste, and order of operation (Figure 3). After recognizing the retro-reflective marker, a color image is taken without the IR light to determine the color of the Shape Marker, and at the same time the Command Markers are recognized from this color image.

Material Marker

The power and speed of the laser is set based on the material type and thickness to be cut or engraved, Figure 4. In the standard operation of the laser cutter, the user is required to set the speed and the power for every operation. In our system, users can specify the material of the object with the use of one of the Material Markers. We have defined four Material Markers to support different materials of different thicknesses: paper, wood, acrylic and leather.

Copy and Paste Markers

Although personal fabrication is not suitable for mass production, there are cases where users may wish to repeat the same design. We created Copy and Paste

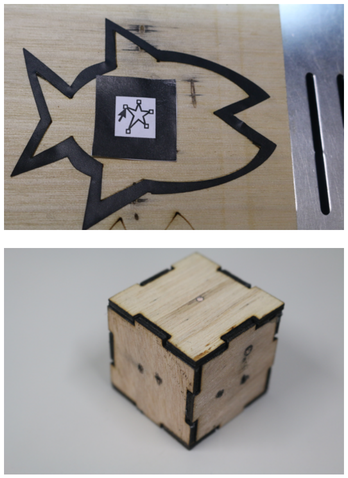

Figure 8: Creating an Object Using the Pattern of the Material. Materials, such as wood, have unique characteristics that differ from piece to piece. There are cases where users want to use these characteristics in their design. One advantage of the MARCut method is it allows the user to specify the position by hand, using a Predefined Shape Marker, and create unique one off designs. The use of a fish shaped marker where the fish's eye and the dots of the dice is created by selecting an appropriate knot in the timber.

Markers, which copies a shape of a Shape Marker and enables the design to be replicated. An alternative to this method is creating multiple copies of the same marker using the same Shape Marker multiple times in a serial fashion.

Figure 5 depicts the copy and paste operation. Two Copy Markers are placed to define an enclosing rectangular region around the Shape Marker to be replicated. One or more pairs of Paste Markers are placed where the replicated shape operations are to be applied. The area between the two Copy Markers is copied and it can be pasted with scaling by two Paste Markers. Numerous other editing operations could be supported in the future, such as alignment and grid replication.

Order of Operation Marker

The order of laser cutting operations of the shape is one of the key parameters in laser cutting operation. For example engraving operations are normally performed before cutting operations. When designing with a CAD system, the order can be set by the path and is defined in the drawing file. However, in vision-based systems the order is determined by order of which the shape is found by the raster scan of the camera. We created a marker that enables the user to specify the order of operations. By placing a Command Marker with a number next to the Shape Marker, the operations are performed in the order defined by the numbers (see the marker on the far right of Figure 3).

Predefined Shape Marker

CAD packages allow users to create precise and complex designs. However, in the standard laser cutting process the alignment of the designs is done by the user's intuition based on their experience which is not a precise operation. Our system allows the users to assign predefined shapes developed with CAD software to a Command Marker. The marker is used as an alignment tool. Instead of controlling the laser to align, user can place a marker to indicate the position to cut the CAD design, see the fish cut in Figure 8.

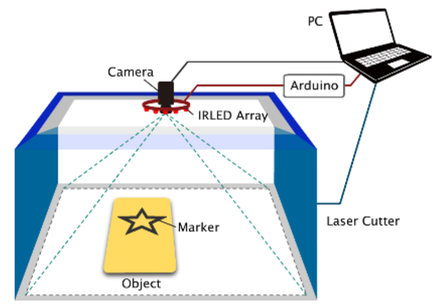

Figure 9: System Configuration

IMPLEMENTATION

We employ an overhead camera to view the top clear casing of the laser cutter, see Figure 9. We designed a camera device that has an IR LED array in front of the camera. This is a visible light webcam (iBuFFALO BSW20KM11BK) modified to capture both visible and IR light. The IR light array is created from 36 IR LEDs. The IR array may be turned on and off controlled by an Arduino Mini Pro. The system was written in C++ and with the OpenCV library. We control the laser cutter (LaserWorks) with the LaserWorks v6 software.

The process starts with a one off calibration process. In the calibration process, the camera coordinates and the laser coordinates are made to correspond. First step is for the checker pattern to be made from the laser

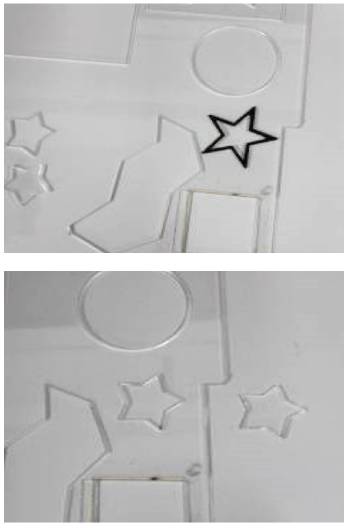

Figure 10: Packing Objects within Used Material. Creating objects from raw material does not require precise alignment. However, when creating objects from raw material which is used more than once and has many holes, alignment becomes an important task. Determining the place to cut is an essential task when creating from used material, thus reducing the material waste [5]. Markers visualize the output and our system enables the users to place objects in small areas.

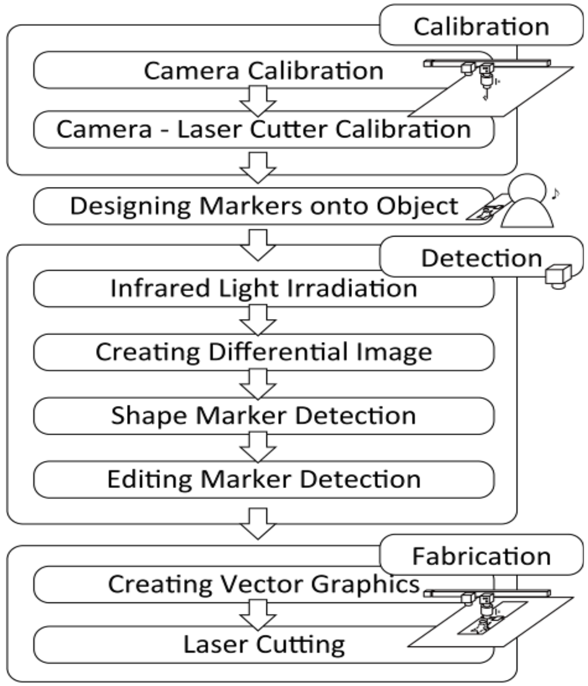

Figure 11: Process Flow

cutter itself, as in Figure 7. Next the user places markers directly onto the object to indicate how and where the laser cutting operation will be performed.

To detect retro-reflective marker, the marker is illuminated with infrared light and a binary image is extracted. A pixel point in the camera image is mapped to a point in the world coordinate on the laser cutter table using a projective transformation. The color marker is then detected in a visible light mode and a vector graphic EPS file is created defining the cutting operations and converted to an AI file as an output. The AI file is then sent to the laser cutter. The details of the process, i.e. laser power, speed are encoded into the color of the shapes in the file.

CONCLUSION

In this paper, we present our new marker-based laser cutting system (MARCut) as a novel method for laser cutting on existing objects. Our method allows a user to fabricate objects interactively by creating markers with simple hand crafting methods instead of using CAD based design tools. Our main contribution is to define a novel set of interactive fabrication techniques that reduce processing complexity for users. We present our implementation of MARCut, a vision based system that recognizes the marker to communicate laser cutter operations. We demonstrated examples using MARCut and highlighted the extendibility of our method.

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