Artistic Pen Drawing on an Arbitrary Surface using an Impedance-controlled Robot

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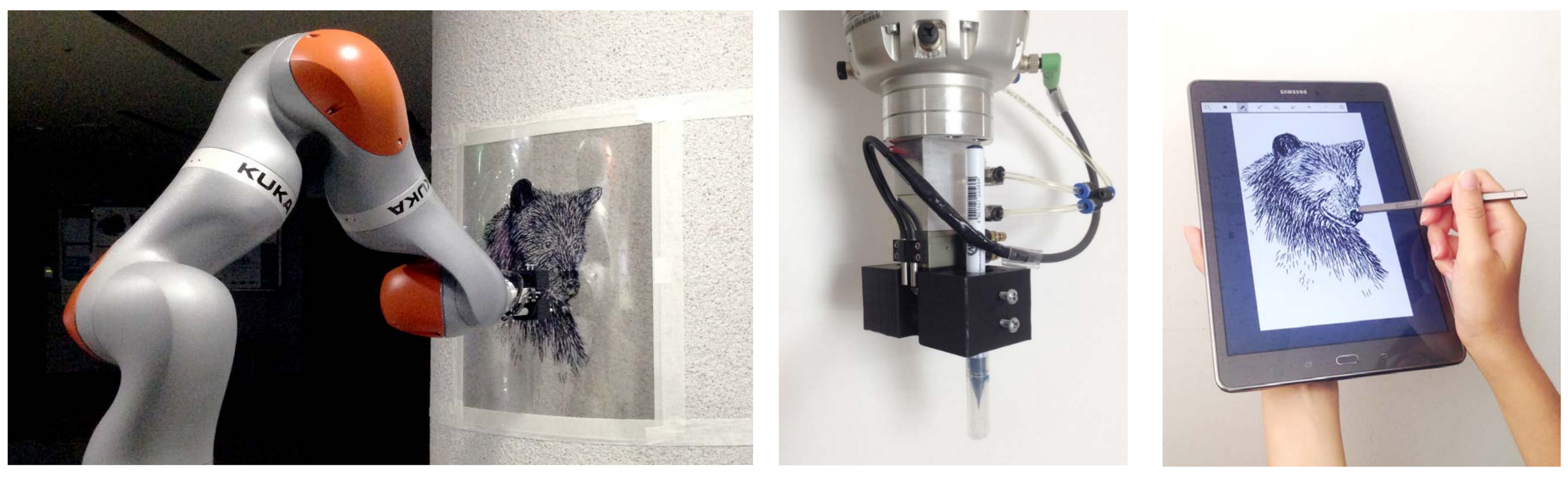
INTRODUCTION

We present a semi-autonomous robotic pen-drawing system that is capable of creating pen art on an arbitrary surface, but without reconstructing the surface explicitly. Our robotic system relies on an industrial, seven-degree-of-freedom (7DoF) manipulator that can be both position- and impedance-controlled. We use a vector-graphics engine to take an artist's pen drawing as input and generate Bézier spline curves. In order to estimate geometric details of the target, unknown surface, during drawing, we rely on incremental and adaptive sampling on the surface using a combination of position and impedance control. Then, our control algorithm physically replicates this drawing on any arbitrary, continuous surface by impedance-controlling the manipulator. We demonstrate that our system can create visually-pleasing and complicated artistic pen drawings on general surfaces without explicit surface-reconstruction nor visual feedback.

SYSTEM SET UP

We use KUKA LBR IIWA 7 R800 manipulator, which has 7DoFs and can be position- and force-controlled. A 3D-printed gripper is attached to the end-effector to hold various types of pens. We use a Samsung Galaxy Tablet PC for running vector graphics under Android operating system. We also use Java programming language along with Sunrise OS for interfacing the IIWA.



Robotic Drawing System Setup

VECTOR GRAPHICS ENGINE

- Vector graphics generates a sequence of continuous vectors that can be well mapped to manipulators' continuous motion.
- Our algorithm generates quadratic Bézier spline curves from a set of input points, each curve using three control points in $\mathbb{R}^2$ with associated pen pressures in the following steps:
  1) Calculate the mid-points of all successive input points.
  2) Choose an input point as well as its two adjacent mid-points, to constitute the three control points to define a single Bézier curve.
  3) To render a curve with varying thickness, classify each curve into six cases of bounding polygon of the offset curve and triangulate them.
  4) We use resolution independent curve rendering to render the offset curves from the triangulation.

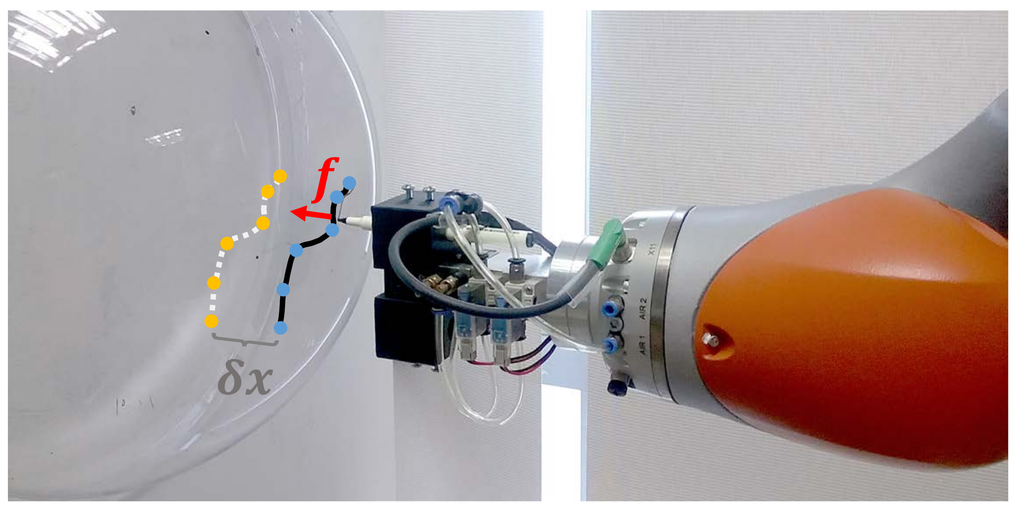
ROBOTIC CURVE RENDERING

SUFACE ESTIMATION

- Instead of explicitly reconstructing the target surface, we estimate the geometry of the target surface by incrementally sampling the surface before and during the drawing.
- The resulting sampling points constitute a 2.5D height field and are represented as a quad tree data structure.
- The positions of the control points are roughly estimated using bilinear interpolation.

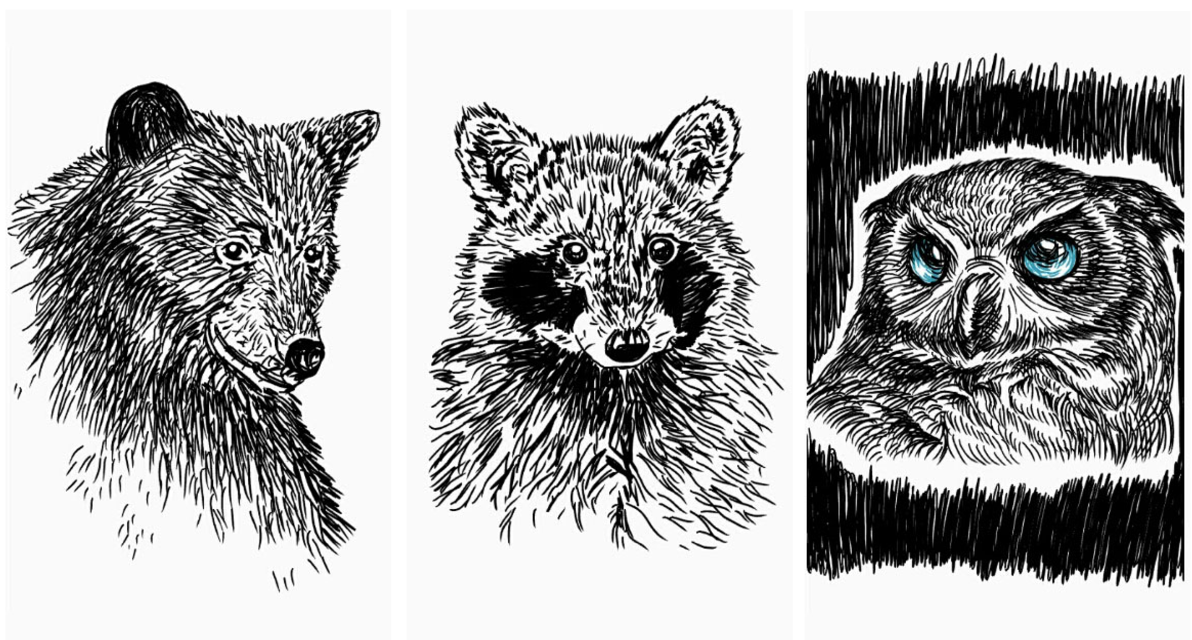
IMPEDANCE-CONTROLLED DRAWING

- The deviation δxbetween the target drawing position, and the physical position of the pen tip results in a compliant force in Cartesian space.
- The controller is configured in such a way that the robot is compliant only in the normal direction of the surface.
- The impedance control, in absence of interaction, guarantees that the end-effector frame asymptotically follows the desired frame. In the presence of contact with the environment, a compliant dynamic behavior is imposed on the end-effector according to the impedance.



Force (f) generated by the impedance-controlled manipulator

EXPERIMENTAL RESULTS



Digital Vector Graphics

Drawings on a Circular Column Wall

Drawings on Arbitrary Surfaces

The figures show examples of pen drawings on curved surfaces, such as a circular column wall, an acrylic half sphere, and a water tank, compared to the digital drawings created from the vector graphics engine. The robotic execution time to reproduce 252 x 491 (mm) size drawing on a circular column wall took about 221 minutes, 186 minutes, and 337 minutes each.

FUTURE WORK

We are currently working on having a vision support, where the point cloud data can be used as a minimal support in surface-sampling.

Also to be presented in IEEE ICRA 2018

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