Distortion-free Robotics Surface-drawing using Conformal Mapping

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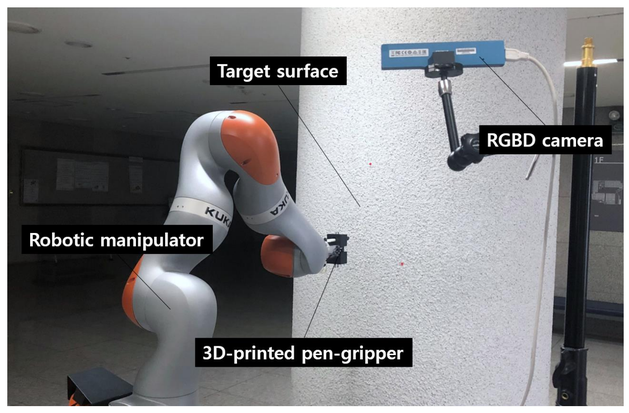
INTRODUCTION

We present a robotic pen-drawing system that is capable of faithfully reproducing pen art on an unknown surface. Our robotic system relies on an industrial, seven degree-of-freedom (7DoF) manipulator that can be both position- and impedance-controlled. In order to estimate a rough geometry of the target, continuous surface, we first generate a point cloud of the surface using an RGB-D camera, which is filtered to remove outliers and calibrated to the physical canvas surface. Then, our impedance-controlled drawing algorithm compensates for the uncertainty and incompleteness inherent to a point-cloud estimation of the drawing surface. Moreover, we rely on the least squares conformal mapping, reducing angle distortion during surface parameterization. As a result, our system can create distortion-free and complicated pen drawings on general surfaces with many unpredictable bumps robustly and faithfully.

SYSTEM SET UP

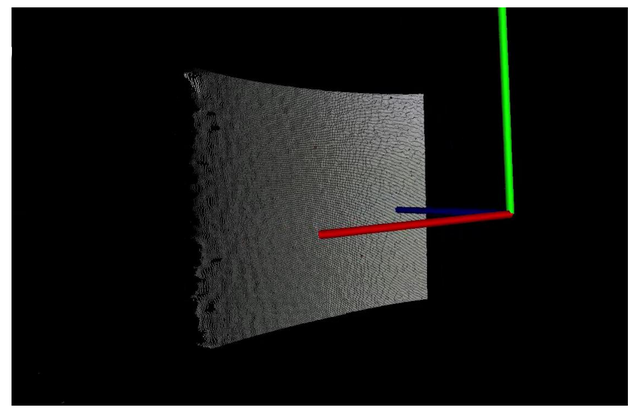
- KUKA LBR IIWA 7 R800 manipulator
- 3D-printed gripper to hold various types of pens
- Intel RealSense ZR300 RGB-D camera
- Java programming language under Windows for interfacing the IIWA



Robotic Drawing System Setup

SURFACE ESTIMATION

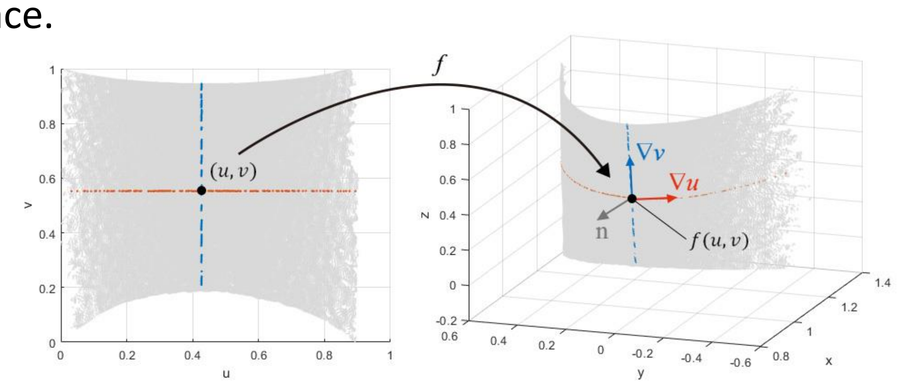
- We first acquire depth information of the target surface using RGBD camera.
- We calibrate a point cloud with the target surface by defining a local frame, attached to the target surface using three non-degenerated points on it.



Captured Point Cloud of the Target Surface

CONFORMAL MAPPING

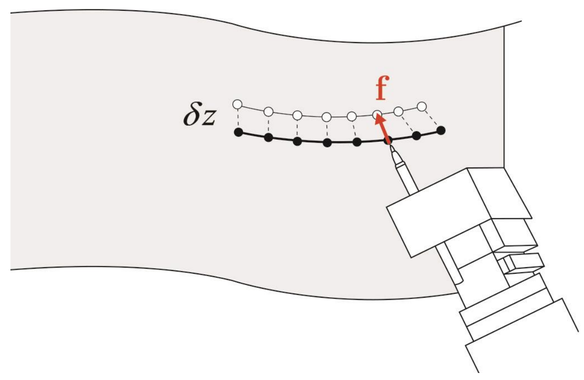
- Conformal mapping is one of the surface parameterization techniques that preserves both angles and shapes.
- We adopted the least squares conformal mapping (LSCM) to parameterize the target surface.
- Once we *unfold* the target surface into 2D parameter space, we search for proper parameter values of the 2D drawing data in the parameter space, and *refold* the surface into 3D space.



Conformal Mapping

IMPEDANCE-CONTROLLED PEN DRAWING

- With impedance control, we compensate for possible estimation or calibration error and generate continuous contact motions.
- The deviation δz between the target drawing position and the physical position of the pen tip results in a spring force.
- The controller is configured in such a way that the robot is compliant only in the normal direction of the surface.



Force (f) generated by the impedance-controlled manipulator

EXPERIMENTAL RESULTS

Pattern Drawing Results

Artistic Drawing Results

In pattern drawing results, it shows the robotic drawing results, the black lines using our method and the orange lines using projection mapping. Note that the orange lines are distorted compared to the black lines.