ConTac: Continuum-Emulated Soft Skinned Arm with Vision-based Shape Sensing and Contact-aware Manipulation

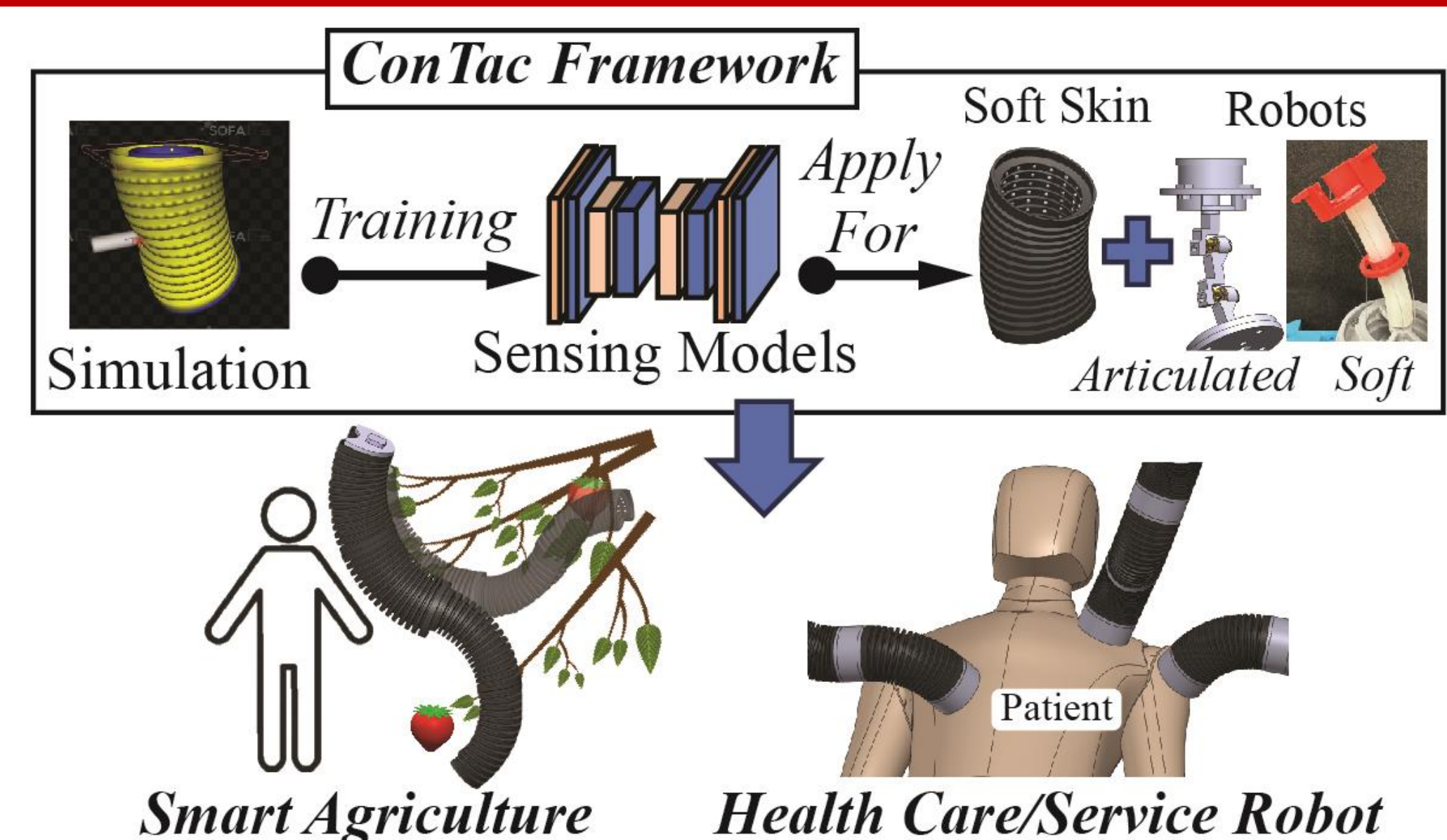Tuan Tai Nguyen[1], Quan Khanh Luu[1], Dinh Quang Nguyen[2], and Van Anh Ho[1]

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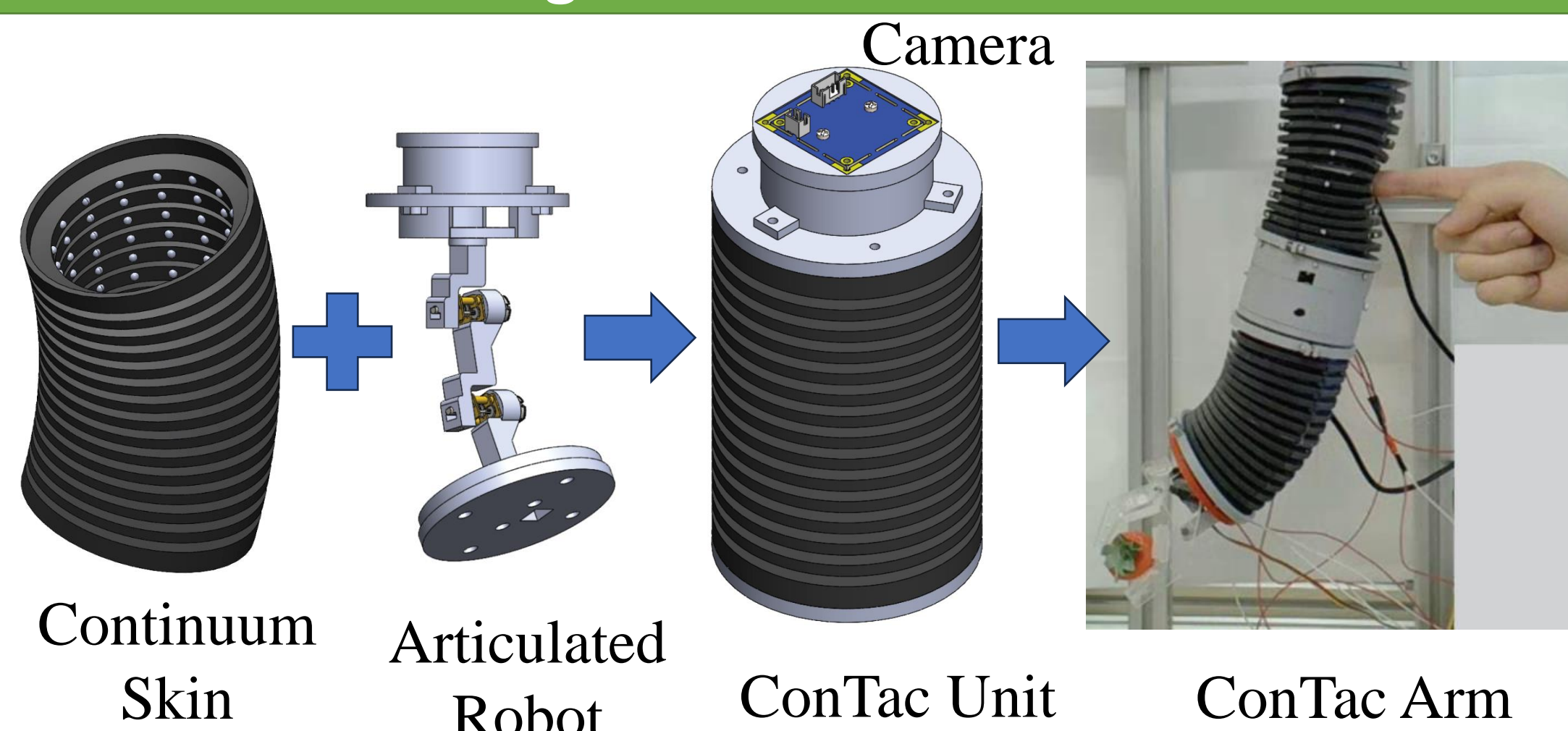
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Introduction

Hyper-redundant and continuum robots provide great advantages in flexibility, dexterity, and the capability to handle unexpected situations. However, providing them with perception solutions remains a challenge. In this work, we present the *ConTac framework* that can **estimate the shape and contact** of a *continuum-emulated robot with soft skin*.
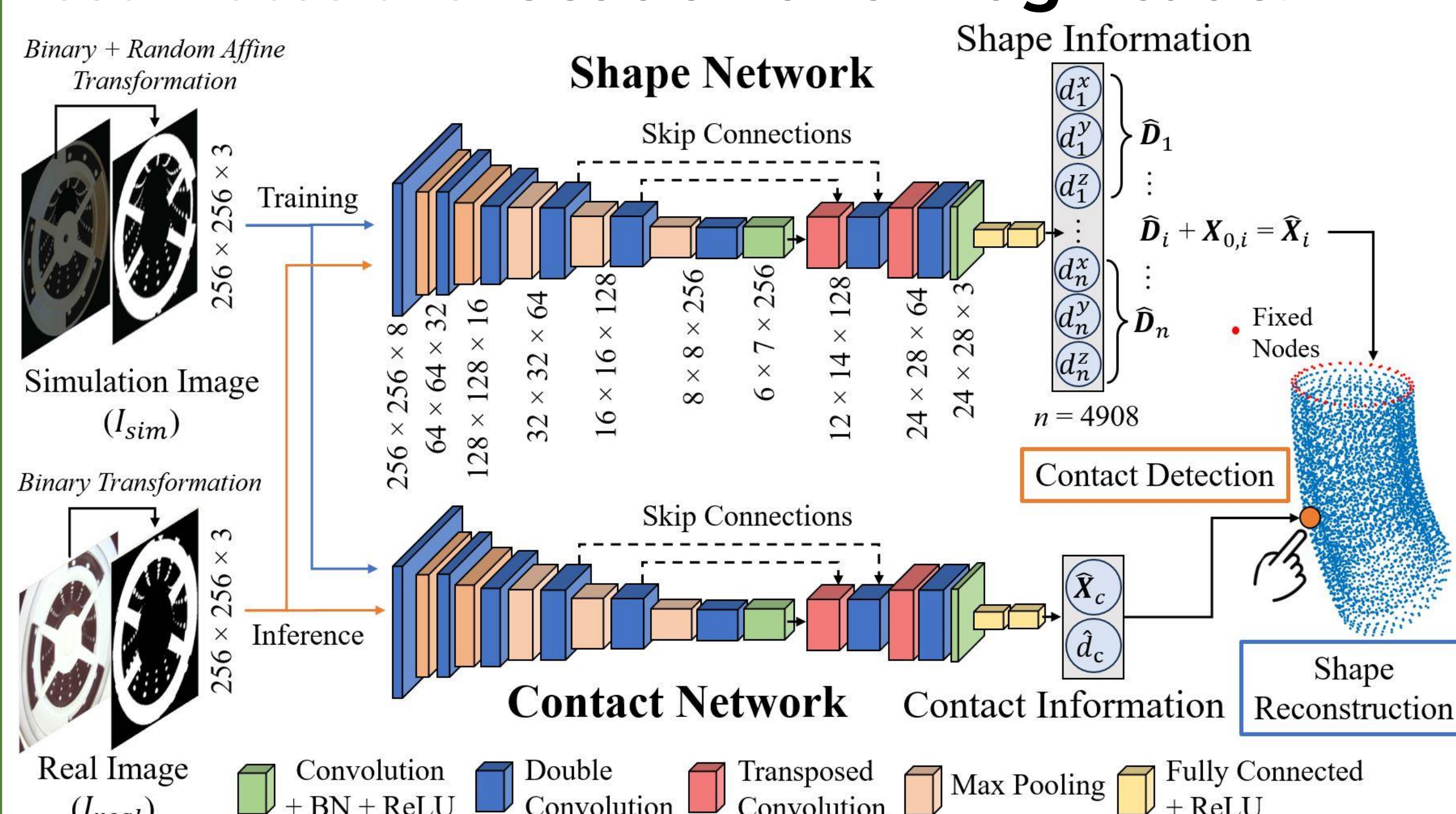

ConTac Framework: Simulation → Training → Sensing Models → Apply For → Soft Skin + Robots (Articulated, Soft)

Smart Agriculture   Health Care/Service Robot

Project's website

Methods

Design of robotic module

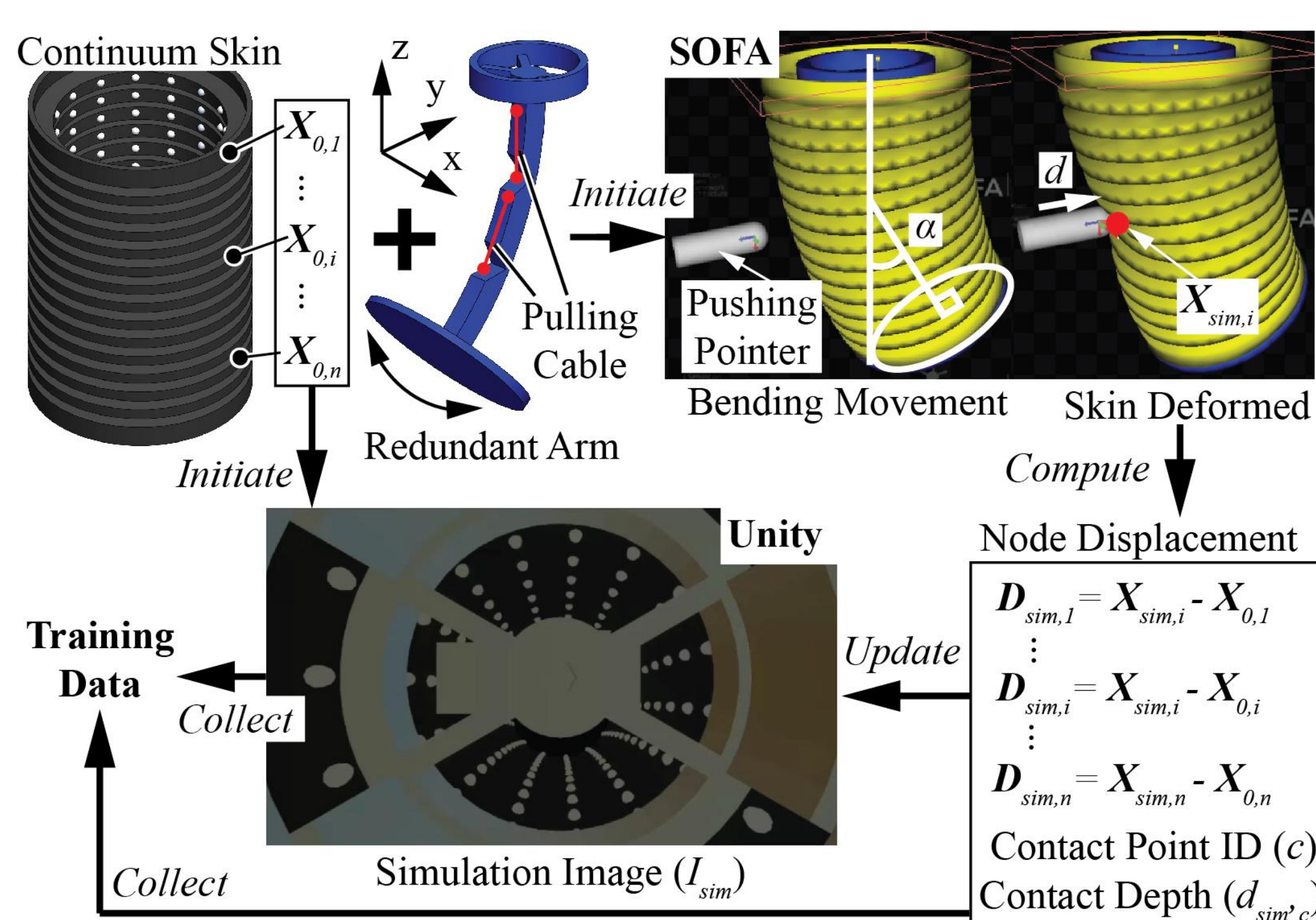Continuum Skin + Articulated Robot → ConTac Unit → ConTac Arm (Camera)

Sensing principle

From a tactile image, the *Shape Network* predicts the **displacement of the skin**, while the **of the contact**. *Contact Network* estimates the **location and magnitude**.
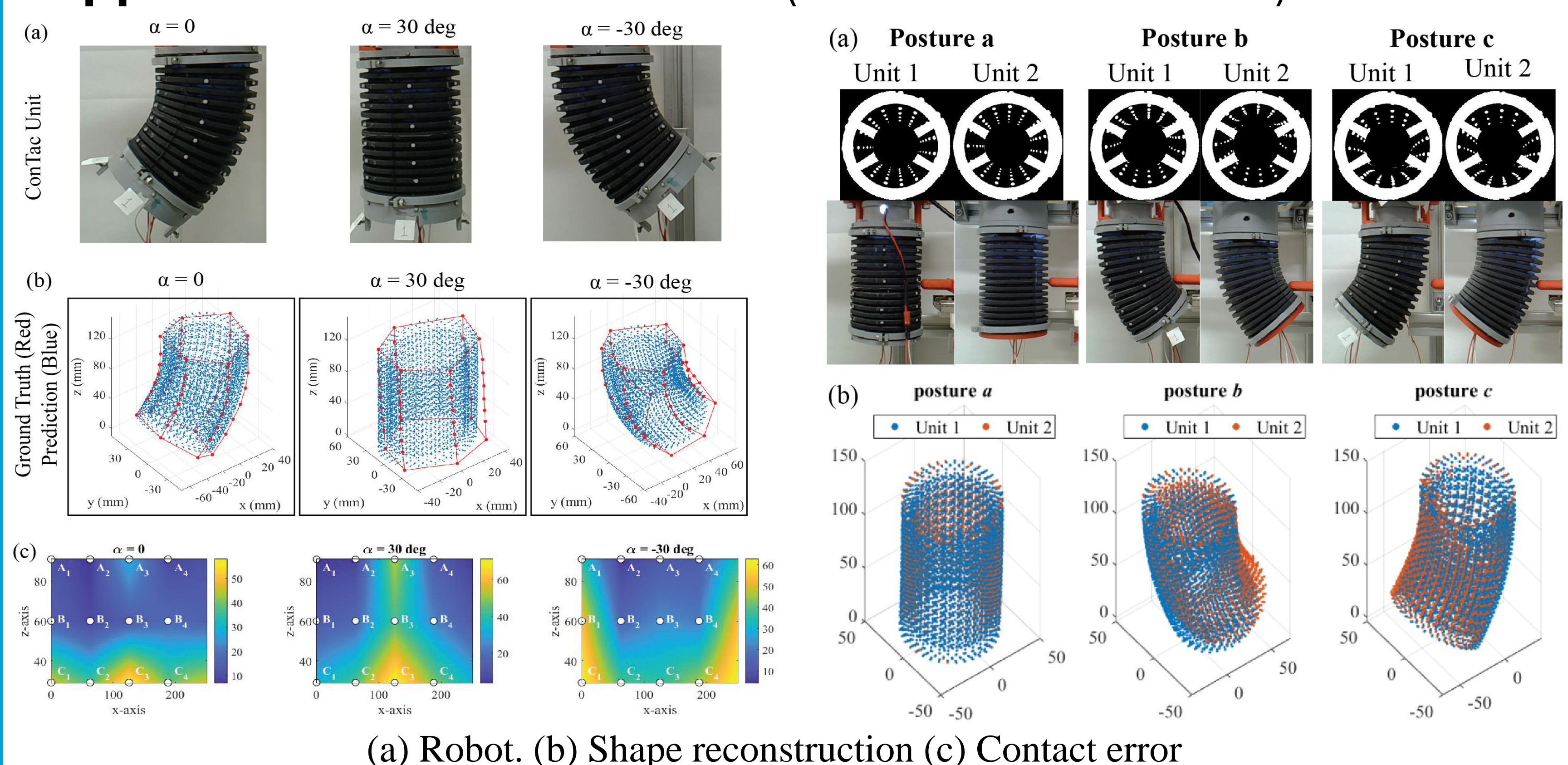

Binary + Random Affine Transformation

Shape Network
Skip Connections
Simulation Image (I_{sim})
$256 \times 256 \times 3$
Shape Information
$\bar{D}_i + X_{0,i} = \bar{X}_i$
$n = 4908$
Contact Detection

Binary Transformation
$256 \times 256 \times 3$
Real Image (I_{real})
Contact Network
Skip Connections
Contact Information
$\hat{x}_c$, $\hat{d}_c$
Shape Reconstruction

Convolution + BN + ReLU | Double Convolution | Transposed Convolution | Max Pooling | Fully Connected + ReLU

Data acquisition

We use *SOFA* to acquire **physical deformations** and *Unity* to collect **simulation images**.

Continuum Skin: $X_{0,1}$, $X_{0,i}$, $X_{0,n}$

SOFA: Initiate → Bending Movement, Skin Deformed
Pushing Pointer, Pulling Cable, Redundant Arm

Unity → Simulation Image (I_{sim})

Compute Node Displacement
$D_{sim,1} = X_{sim,1} - X_{0,1}$
$D_{sim,i} = X_{sim,i} - X_{0,i}$
$D_{sim,n} = X_{sim,n} - X_{0,n}$
Contact Point ID (c)
Contact Depth ($d_{sim,c}$)

Training Data: Collect, Update, Collect

Results

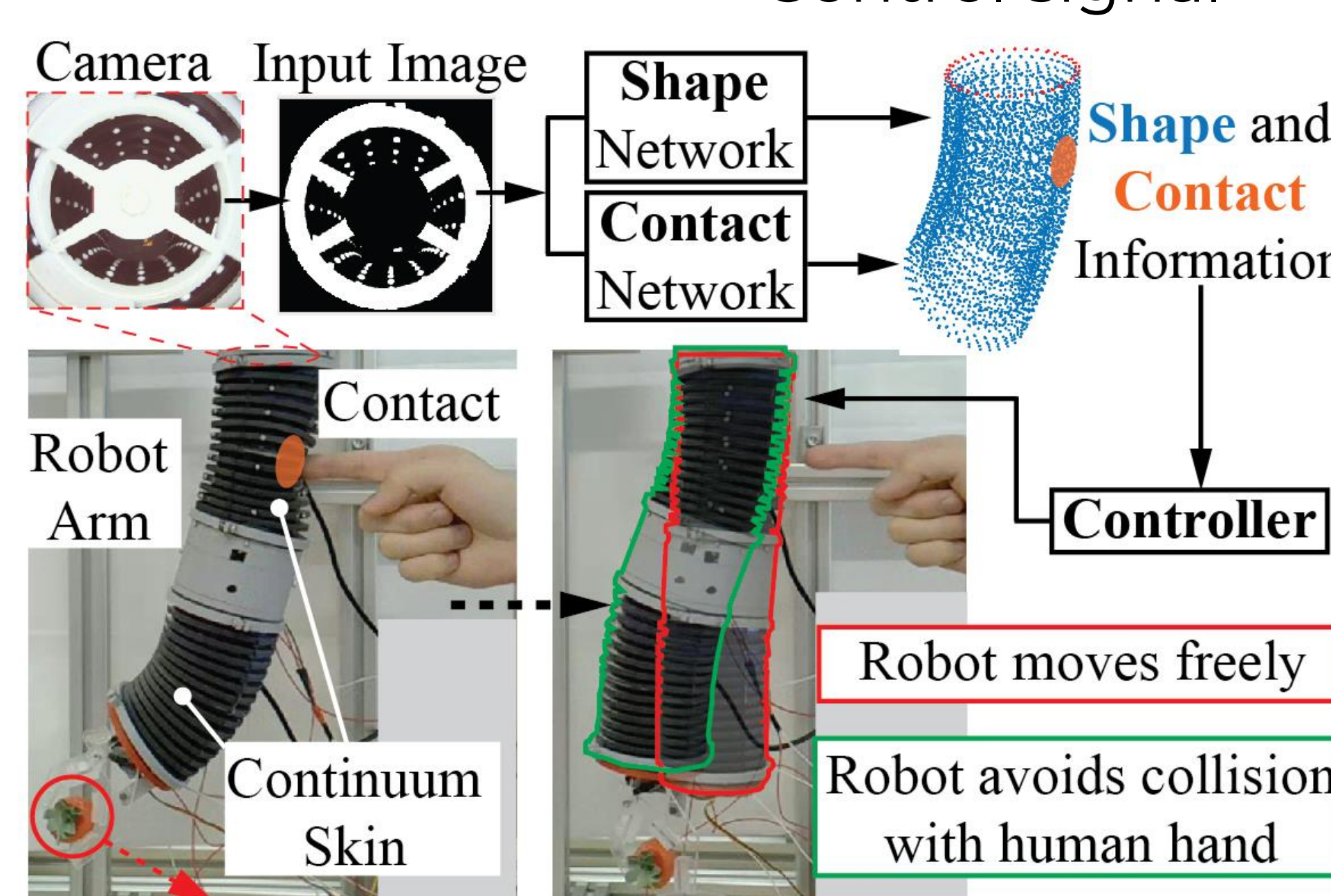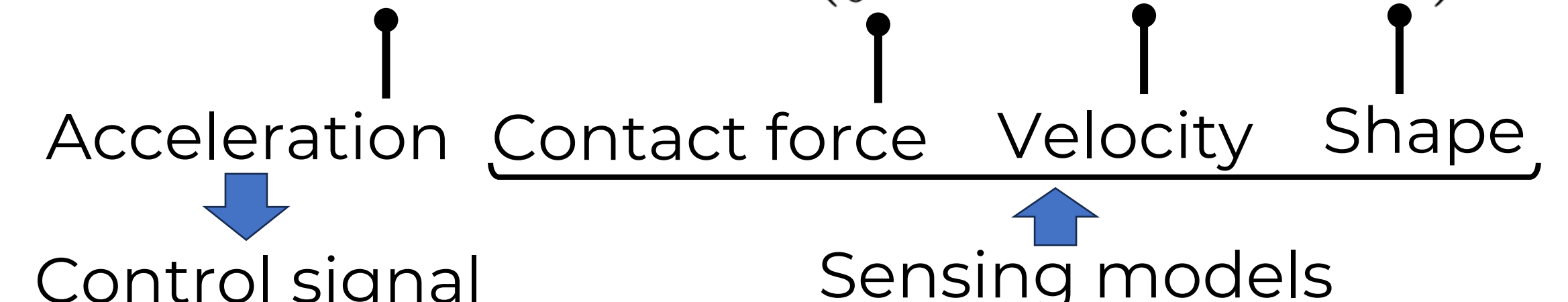### Sensing capabilities

The sensing models **trained with simulation data** can be **applied to two ConTac Units** (No extra calibration).

(a) $\alpha = 0$, $\alpha = 30$ deg, $\alpha = -30$ deg — ConTac Unit
(b) Ground Truth (Red) Prediction (Blue)
(c)

Posture a, Posture b, Posture c — Unit 1, Unit 2
(a) Robot. (b) Shape reconstruction (c) Contact error

Applications

Admittance-based control: $\ddot{\alpha}_d = m^{-1}\left(f_c - c\dot{\alpha} - k\alpha\right)$

Acceleration | Contact force | Velocity | Shape
Control signal ← | Sensing models

Camera | Input Image → Shape Network, Contact Network → Shape and Contact Information → Controller
Robot Arm, Contact, Continuum Skin
Robot moves freely
Robot avoids collision with human hand

Robot can:
• detect, avoid collision,
• adjust its trajectory.

Shape sensing for soft robot:
The ConTac system can be immediately used to estimate the bending of a soft robot (No extra calibration).

Future work: ConTac for true continuum robots.

Soft Backbone, Tendon, Camera
$t = 0$, $t = 4$ s
Bending Angle (Degree) vs Time (s)
Ground Truth, Prediction