Universität Stuttgart

THE UNIVERSITY OF AUCKLAND
Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND

DFG IRTG GRK2198/1

Soft Tissue Robotics

Simulation-based control of Soft Materials with an Industrial Robot

06 July 2018

C. Hinze, F. Jaensch,
J. Köhler, B. Maier,
S. Shavanez, D. Tomzik,
M. Wnuk

Contents

Motivation

- Say why our task is important
- ...

Figure: Robotic teleoperation in an everyday scenario. Picture taken from the SitCom "The Big Bang Theory"

Goal

- Define goal set for the demonstrator week here
- ...

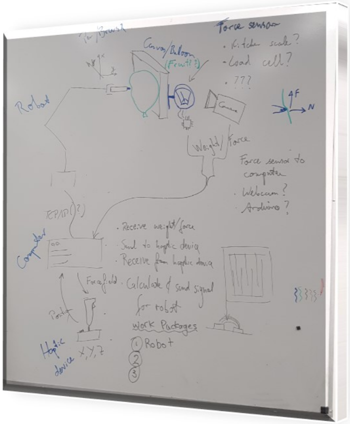


Figure: Early concept for the 2019 summer school demonstrator

Problem formulation

Universität Stuttgart | THE UNIVERSITY OF AUCKLAND Te Whare Wānanga o Tāmaki Makaurau NEW ZEALAND

- Here goes the description of the involved problems
- Force feedback from soft tissue
- control for the system
- sensor
- communication and interfaces
- ...

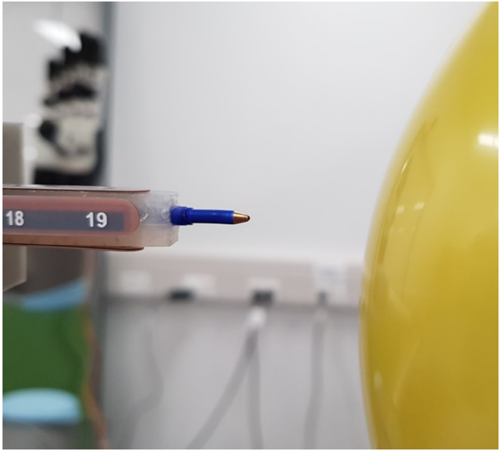
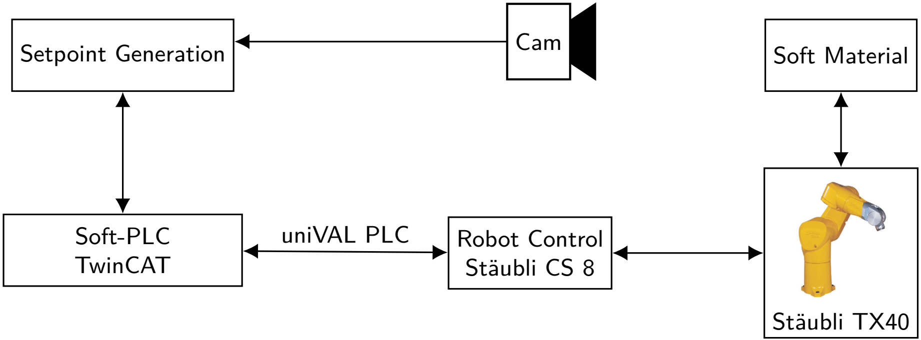
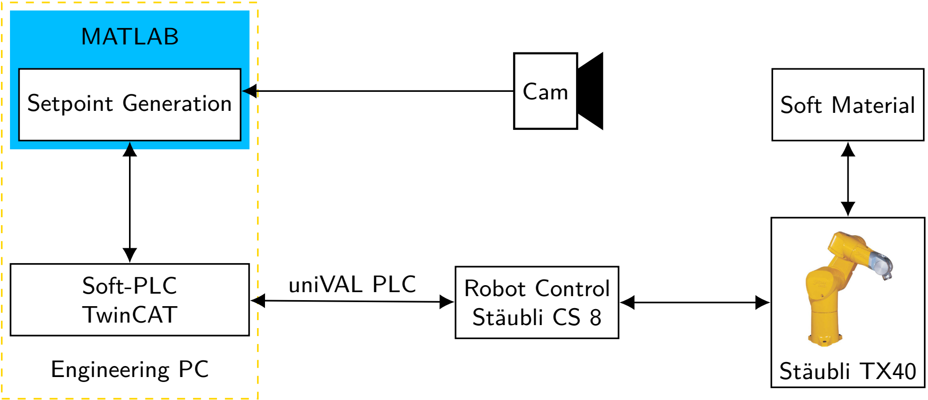


Figure: Early concept for the 2019 summer school demonstrator

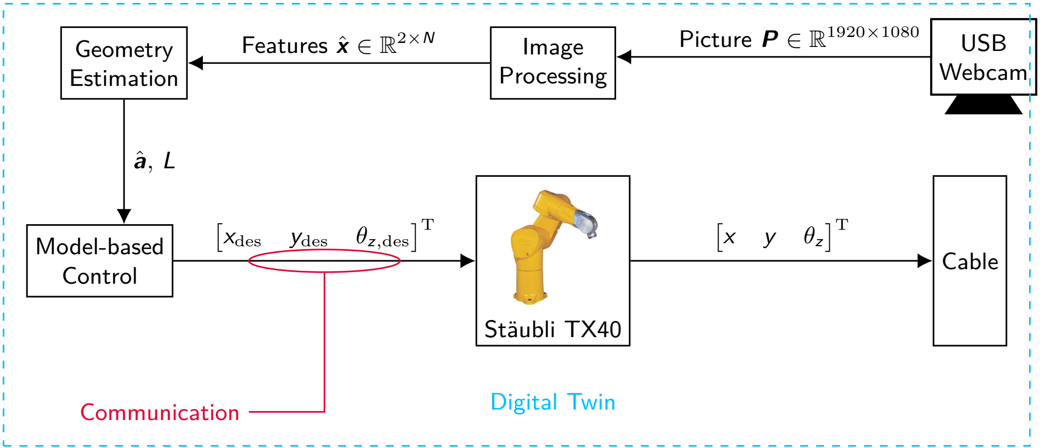
Setup for external control of a Stäubli TX 40




MATLAB
Setpoint Generation
Cam
Soft Material
Soft-PLC
TwinCAT
uniVAL PLC
Robot Control
Stäubli CS 8
Stäubli TX40
Engineering PC

Contents

The General Architecture



The General Architecture

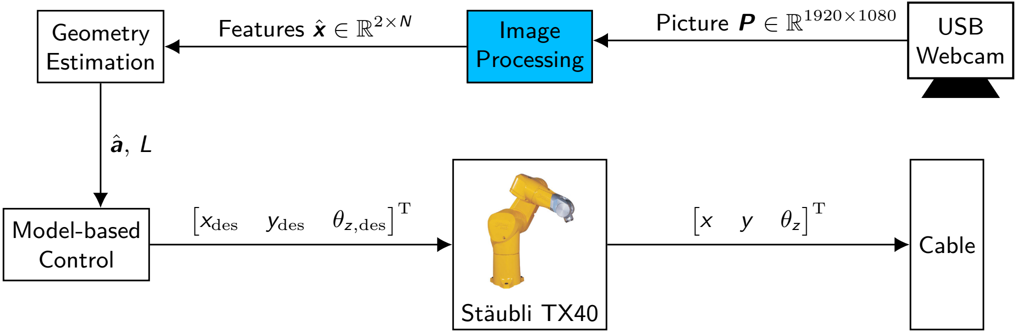
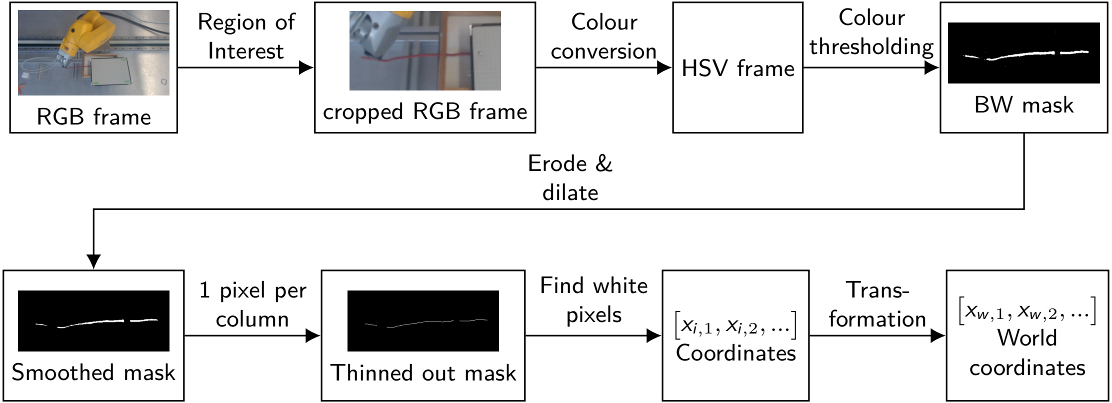
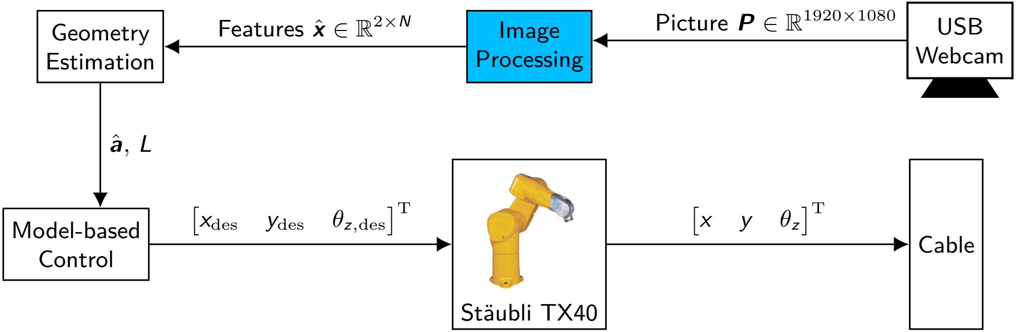


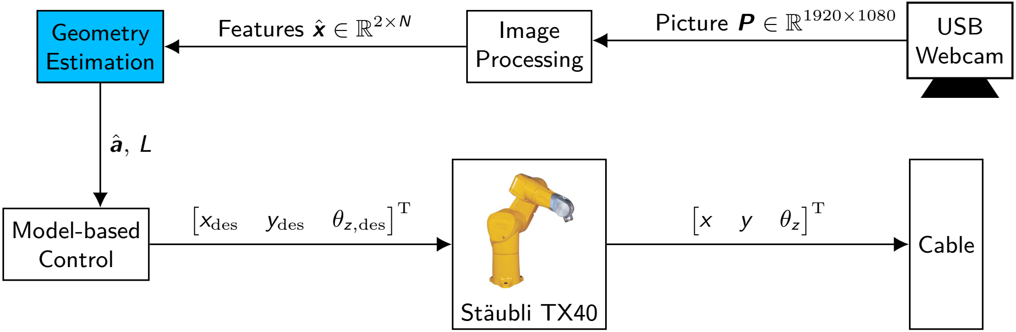
Image Processing: Pipeline



Architecture Overview



Architecture Overview



- Description by curvature angle θ:

$$\mathbf{x}(s,t) = \mathbf{x}(0,t) + \int_0^s \begin{bmatrix} \cos(\theta(u)) \\ \sin(\theta(u)) \end{bmatrix} \mathrm{d}u$$

- Formulate a optimization problem

$$\begin{aligned} F(\hat{\mathbf{a}}, L, \hat{\mathbf{s}}) = \quad & \sum_{j=1}^{N} \|\mathbf{x}(\bar{s}_i) - \hat{\mathbf{x}}_j\|_2^2 && \text{... fit to data} \\ & + \alpha_1 \sum_{i=2}^{n} a_i^2 && \text{... regularization} \\ & + \alpha_2 \left(L - L_{\text{expected}}\right)^2 && \text{... avoid overfitting} \\ & + \alpha_3 \|\mathbf{x}(L) - \mathbf{x}_{\text{end}}\|_2^2 && \text{... ensure end point} \end{aligned}$$

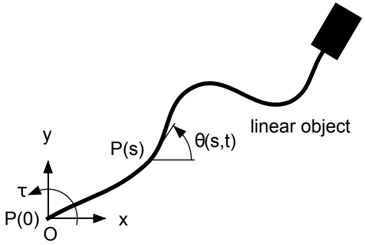
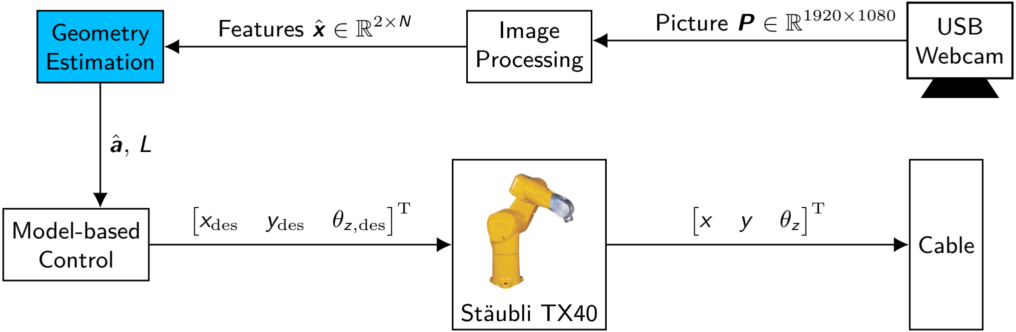


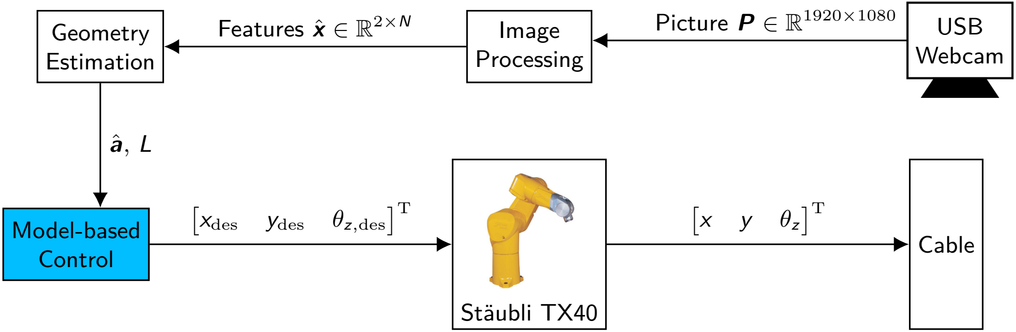
Fig. 1. Dynamic 2D deformation of inextensible linear object

Source: [?]

Architecture Overview



Architecture Overview



Two options

- **Linear quadratic regulator** (LQR)
  objective functional: $\min_u \int_0^\infty \|x\|_Q^2 + \|u\|_R^2 d\tau$
  experienced some technical/numerical issues

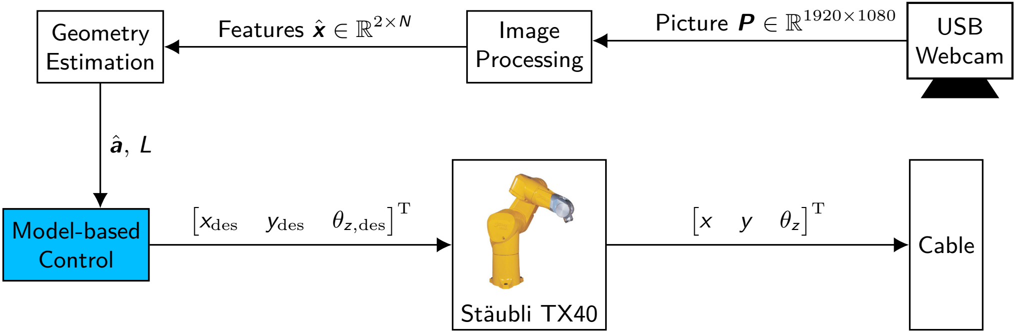
- **Predictive (functional) control**

1. Transform model: acceleration $u \overset{a_{\max}, v_{\max}, T_s}{\Leftrightarrow}$ relative position command to robot
2. Formulate objective function:

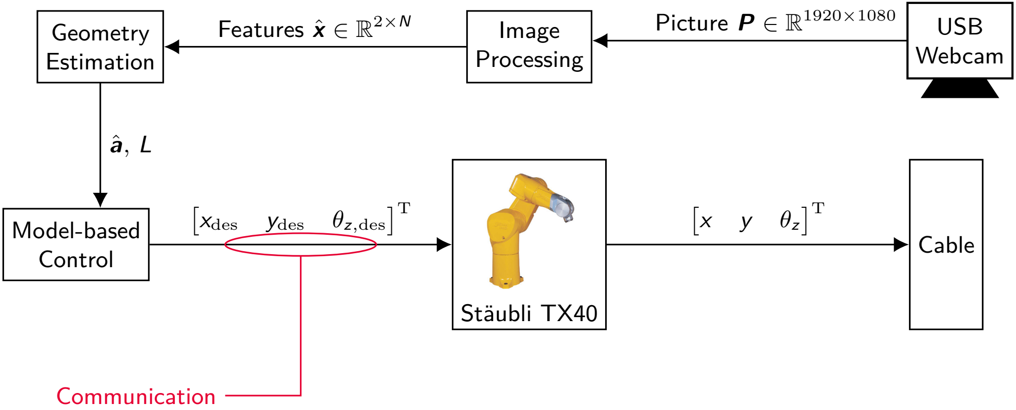
$$\min_{u \in \mathbb{U}} \|y(L) - y_{ref}\|^2 + \|u\|^2$$

$$\text{s.t. } \Delta a = B_d u, \quad \theta(s) = \sum_i a_i e_i(s) \quad y(L) = \int_0^L \cos(\theta(s)) ds,$$

3. use CasADi to solve optimization problem online (for a given configuration a)
4. Give position command with maximal velocity/acceleration to robot control

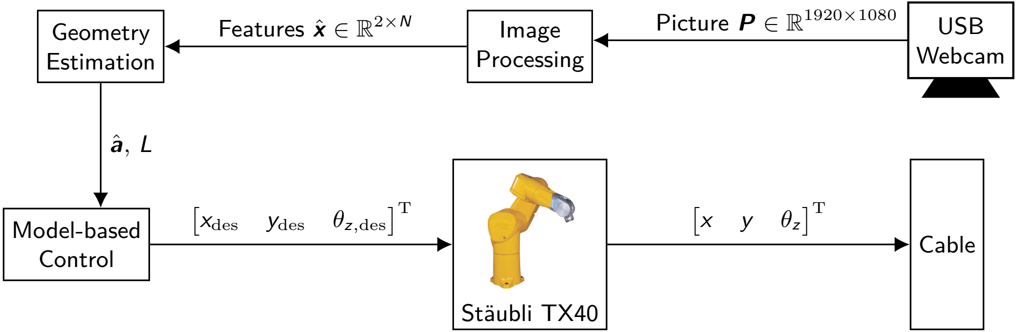

Geometry Estimation
Features $\hat{\boldsymbol{x}} \in \mathbb{R}^{2\times N}$
Image Processing
Picture $\boldsymbol{P} \in \mathbb{R}^{1920\times 1080}$
USB Webcam
$\hat{\boldsymbol{a}},\ L$
Model-based Control
$\begin{bmatrix} x_{\mathrm{des}} & y_{\mathrm{des}} & \theta_{z,\mathrm{des}} \end{bmatrix}^{\mathrm{T}}$
Stäubli TX40
$\begin{bmatrix} x & y & \theta_z \end{bmatrix}^{\mathrm{T}}$
Cable

Architecture Overview

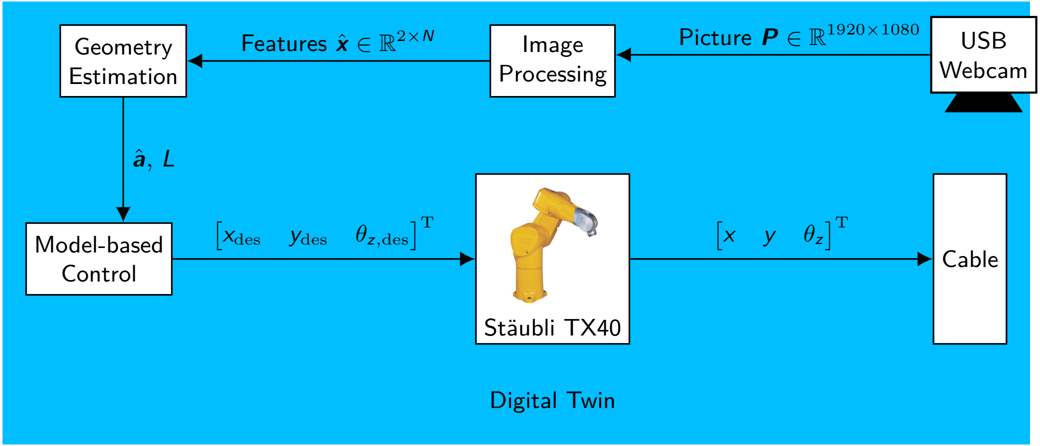


Communication – Sequence and Protocol

- Communication between MATLAB and Stäubli RC over Matlab $\leftrightarrow$ TwinCAT $\leftrightarrow$ Stäubli RC
- No real-time communication
- Only open loop control of setpoints


Geometry Estimation
Features $\hat{\boldsymbol{x}} \in \mathbb{R}^{2\times N}$
Image Processing
Picture $\boldsymbol{P} \in \mathbb{R}^{1920\times 1080}$
USB Webcam
$\hat{\boldsymbol{a}},\ L$
Model-based Control
$\begin{bmatrix} x_{\mathrm{des}} & y_{\mathrm{des}} & \theta_{z,\mathrm{des}} \end{bmatrix}^{\mathrm{T}}$
Stäubli TX40
$\begin{bmatrix} x & y & \theta_z \end{bmatrix}^{\mathrm{T}}$
Cable

Architecture Overview



Robot simulation:

- Realtime simulation Tool ISG-virtuos
- Kinematic model of the ABB IRB 1600

Cable simulation:

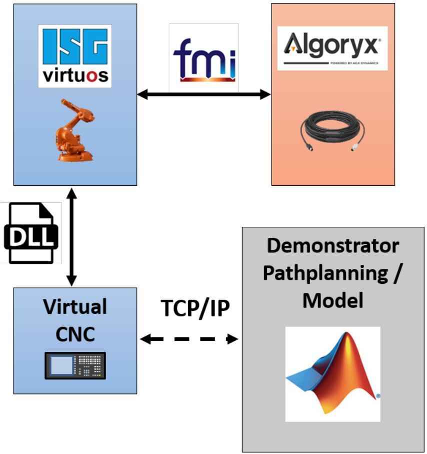
- Physics engine AGX-Algoryx
- Multi-(Rigid)-body model
- Integration into ISG-virtuos as an FMU (FMI-Interface Standard)

Virtual Robot Control:

- CNC Kernel with inverse kinematics
- Integrated into Robot simulation environment

Virtual Camera (not realized):

- Direct feature output out of the cable model



Contents

Digital Twin

Real Scenario

Conclusion & next steps

Universität Stuttgart THE UNIVERSITY OF AUCKLAND Te Whare Wānanga o Tāmaki Makaurau NEW ZEALAND

Proof of concept

- Based on visual data acquisition and processing
- Model based position control
- Toolchain for position control over TCP/IP

Possible extensions

- Identified and experienced problems of the overall toolchain
- Recognizing the complexity of the problem and challenges to overcome

Literature