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Surface Sensing of 3D Objects Using Vibrissa-like Intelligent Tactile Sensors

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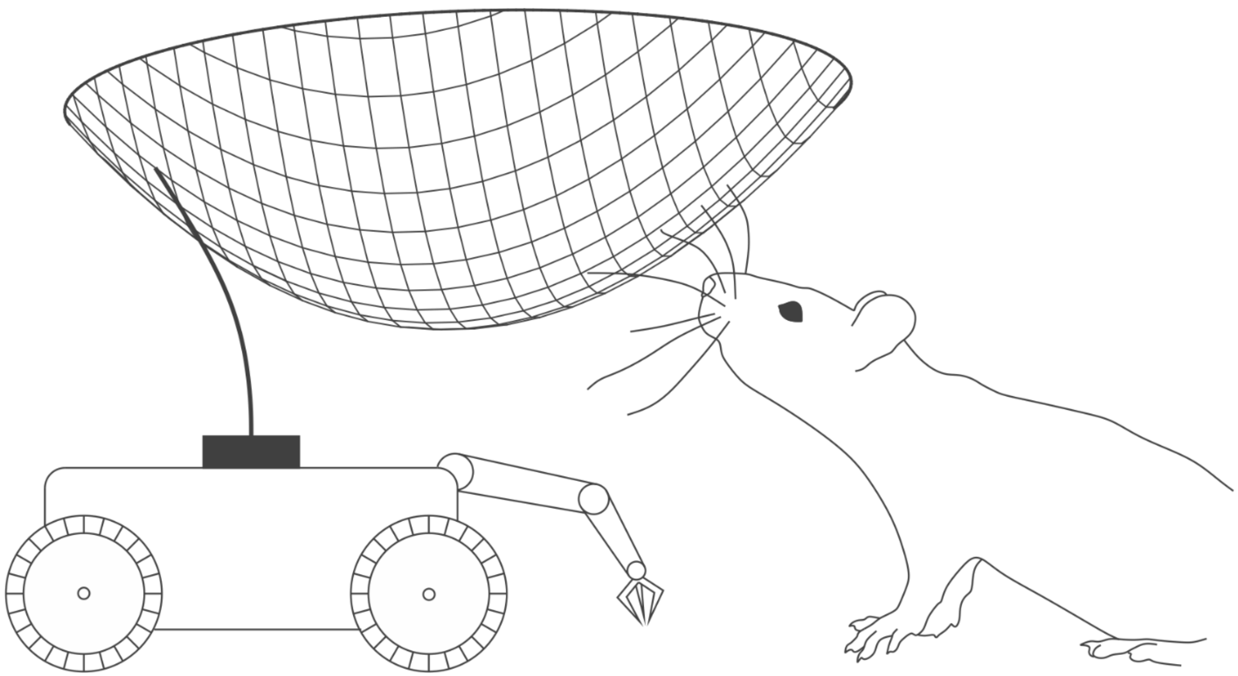

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Short Resume of the Presenter

Lukas Merker received the B.Sc. degree (2015) and the M.Sc. degree (2017) in Mechanical Engineering from Technische Universität Ilmenau. Since 2017, he has been working as a Ph.D student at the Department of Mechanical Engineering at Technische Universität Ilmenau. His research interests include the development of biologically inspired tactile sensors for object shape recognition .

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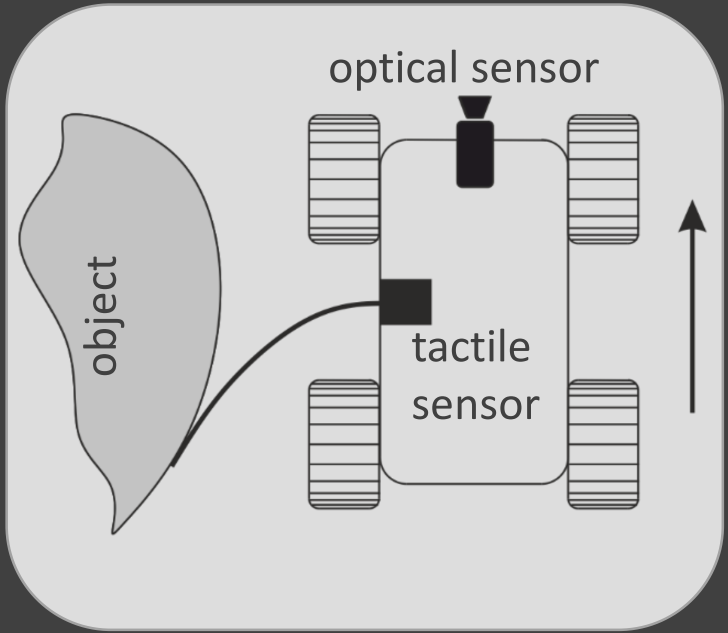
1. Introduction – Future Goal

biological paragon

- vibrissae enable animals to determine different object features: size, orientation, shape, surface texture
- sensing information only in follicle/support of each vibrissa

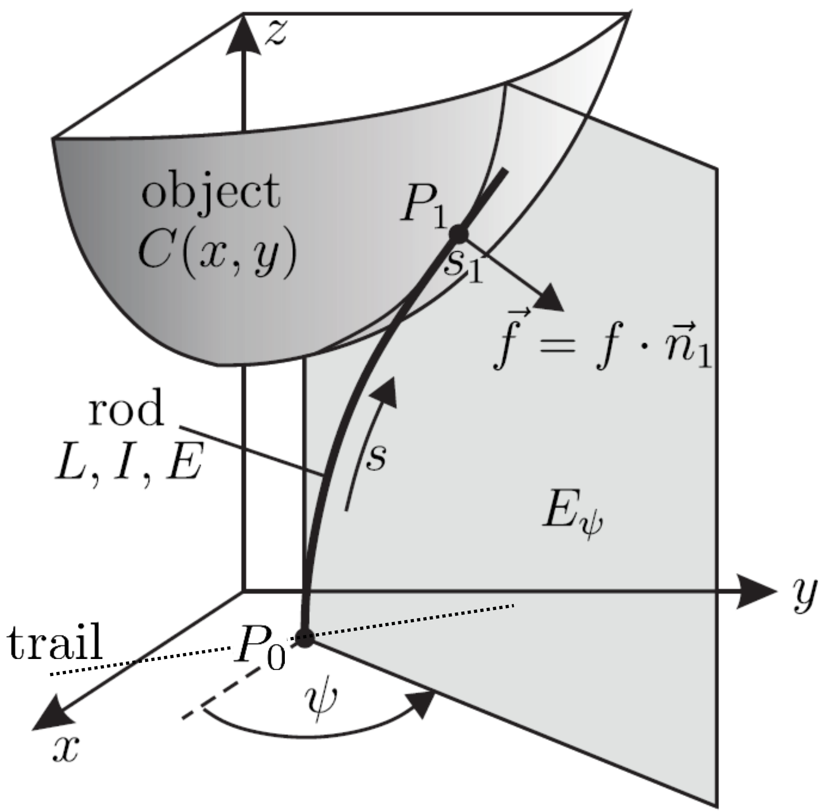
technical application example



highly flexible tactile sensors (complementing optical sensors)

- for object shape scanning and reconstruction
- path planning for rovers

2. Mechanical Model



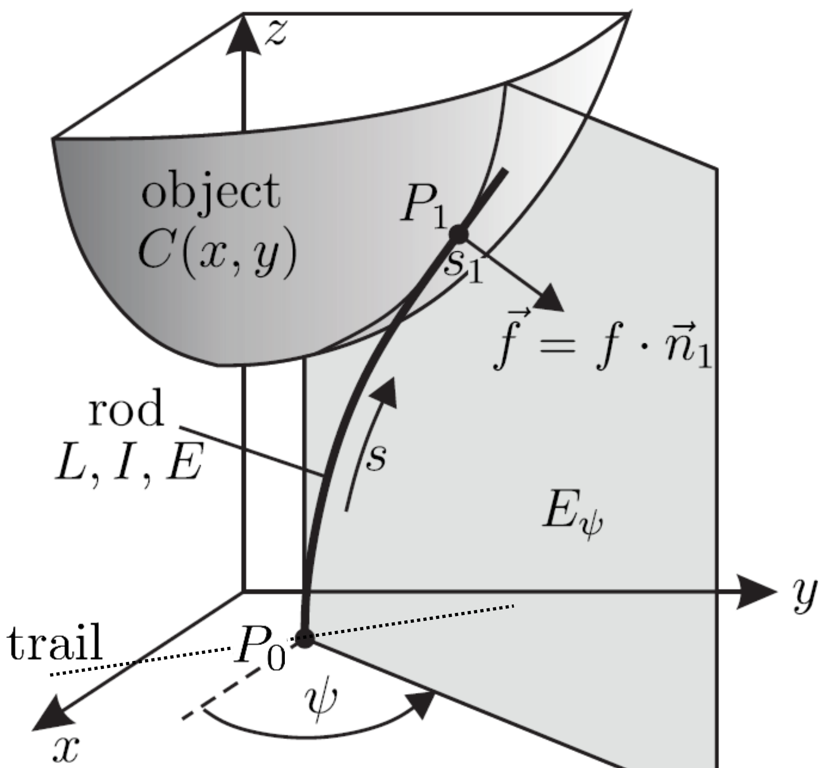
technical vibrissa (transducer)

- nonlinear Euler-Bernoulli bending rod, one-sided clamped
- straight, circular cylindrical shape
- isotropic, homogeneous Hooke's material
- length L, constant Young's modulus E and second moment of area I

nondimensionalization

- introducing the following units of measure:
  - $[length] := L,$
  - $[force] := \frac{EI}{L^2},$
  - $[moment] := \frac{EI}{L}$

2. Mechanical Model



object – surface

- rigid body
- strict convex, smooth surface $C(x, y)$

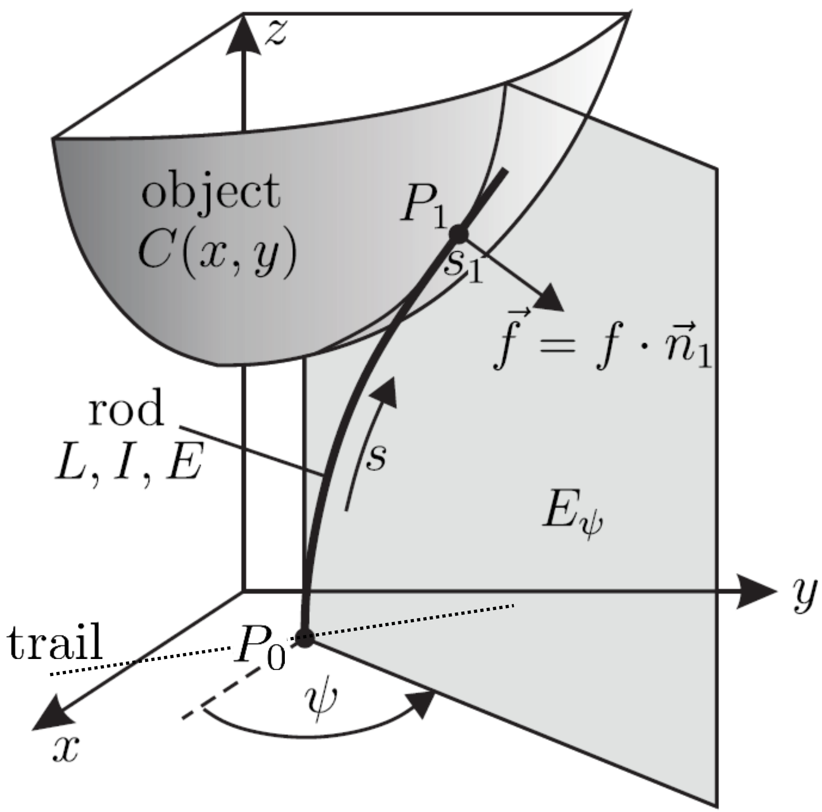
process – object scanning

- quasi-static translational displacement of clamping P_0 on straight scanning trail in x-y-plane

contact

- ideal one-point contact, no frictional effects

2. Mechanical Model

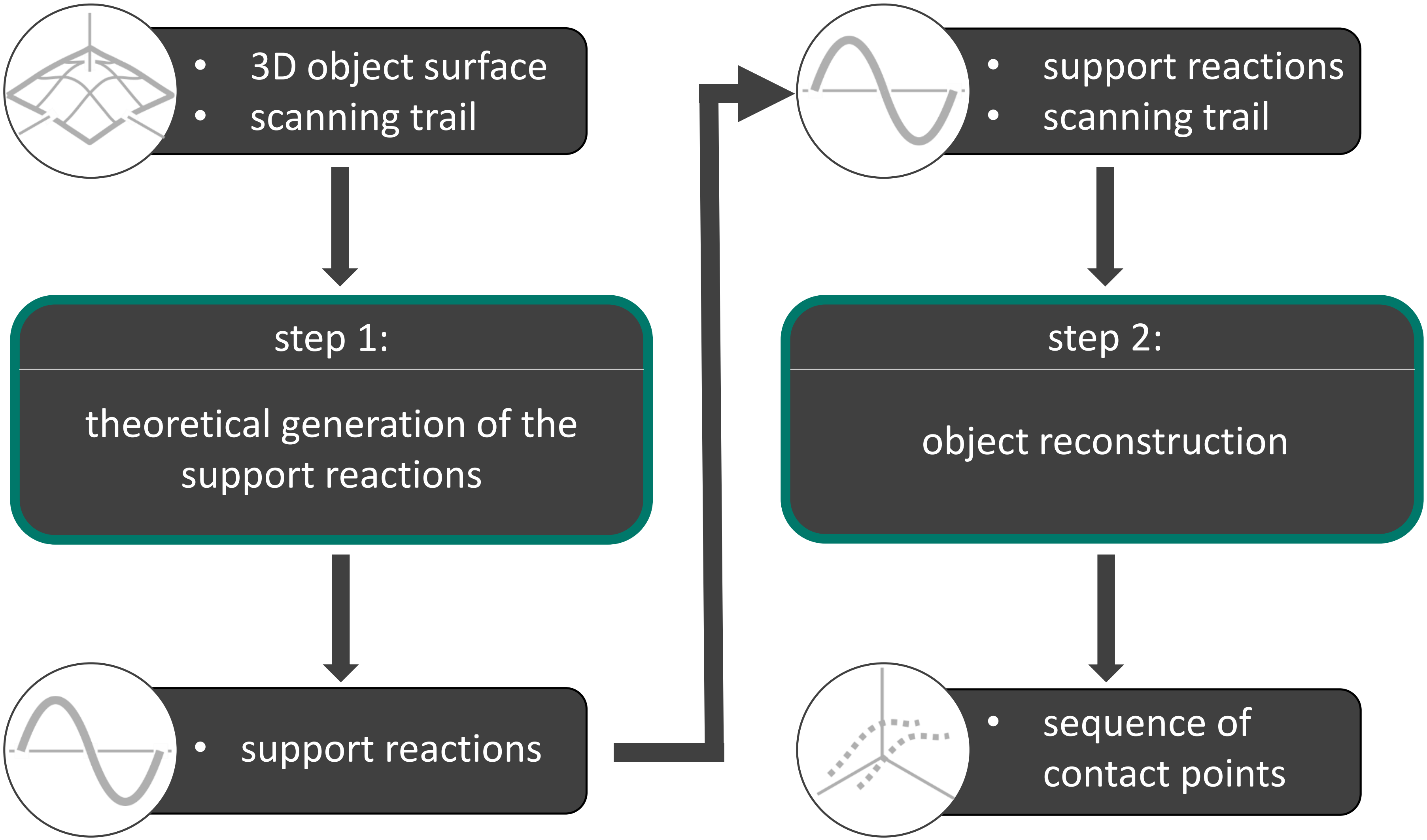


- homogenity and isotropy of rod and support
- convexity of object ⇒ single contact point (single contact force)

the elastic line of the rod shrinks from 3D to 2D in the plane E_ψ (with unknown orientation ψ)

$$\left.\begin{array}{l} \vec{q}(s) \left\{ \begin{array}{l} x'(s) = \cos\big(\varphi(s)\big)\cos(\psi) \\ y'(s) = \cos\big(\varphi(s)\big)\sin(\psi) \\ z'(s) = \sin\big(\varphi(s)\big) \end{array} \right. \\ \qquad\quad \varphi'(s) = \kappa(s) \\ \qquad\quad \kappa'(s) = f \cdot \det(\vec{q}(s), \vec{n}_1, \vec{e}_\psi) \end{array}\right\} \quad (1)$$

2. Mechanical Model – Process steps



2. Mechanical Model – Process steps

step 1:

theoretical generation of the support reactions

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boundary-value problem

boundary conditions for system (1)

clamping	tip contact	tangential contact
$x(0) = x_0$	$x(1) = \xi$	$x(s_1) = \xi$
$y(0) = y_0$	$y(1) = \eta$	$y(s_1) = \eta$
$z(0) = 0$	$z(1) = \theta$	$z(s_1) = \theta$
$\varphi(0) = x_0$	/	$\vec{q}(s_1) \cdot \vec{n}_1 = 0$
/	$\kappa(1) = 0$	$\kappa(s_1) = 0$

step 2:

object reconstruction

⬇

initial-value problem

initial conditions and parameters for system (1)

clamping
$x(0) = x_0$
$y(0) = y_0$
$z(0) = 0$
$\varphi(0) = x_0$
$\kappa(0) = -\vec{m}_0 \cdot \vec{e}_\psi$

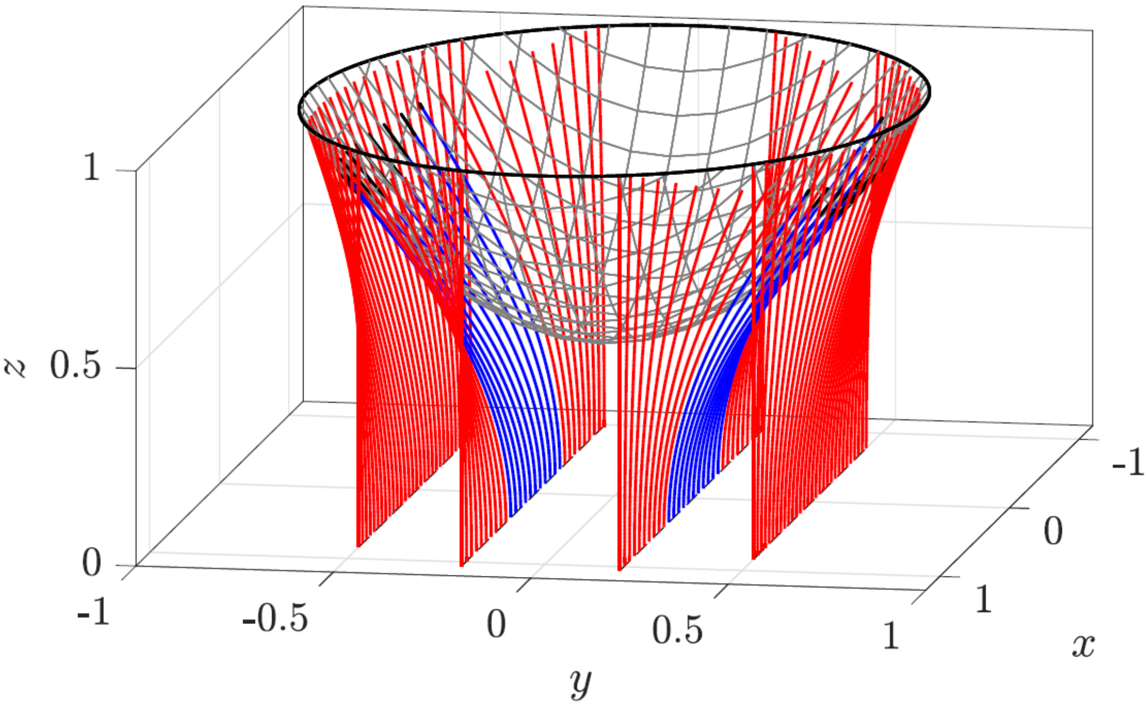
$$f = \left\| \vec{f}_0 \right\|_2, \qquad \vec{n}_1 = -\frac{\vec{f}_0}{f},$$

$$\psi = \operatorname{atan2}(m_{0x}, -m_{0y})$$

termination condition:

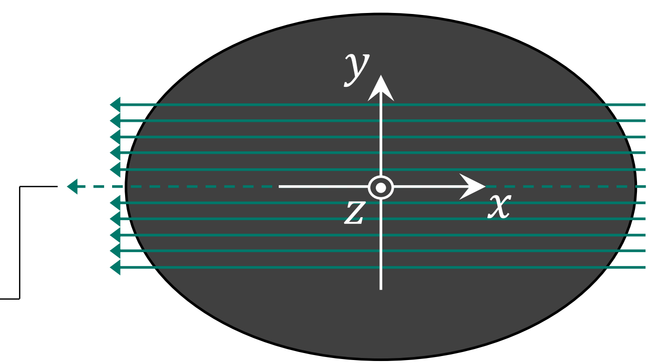
$$\kappa(s_1) = 0 \Rightarrow s_1$$

3. Simulations & Results



- exemplary object surface: $C(x, y) = 0.5x^2 + y^2 + h$
- object distance $h = 0.4$
- tangential (blue) and tip contacts (red)
- rod bends around the object (lateral slip)

- eleven scanning trails with $y_0 \equiv -0.5{:}\, 0.1{:}\, 0.5$ (only four sweeps are shown in the Figure above)
- scanning displacement in negative x-direction
- plane special case $y_0 \equiv 0$ yields tremendously increased signals [2], omitted here



3. Simulations & Results – Step 1

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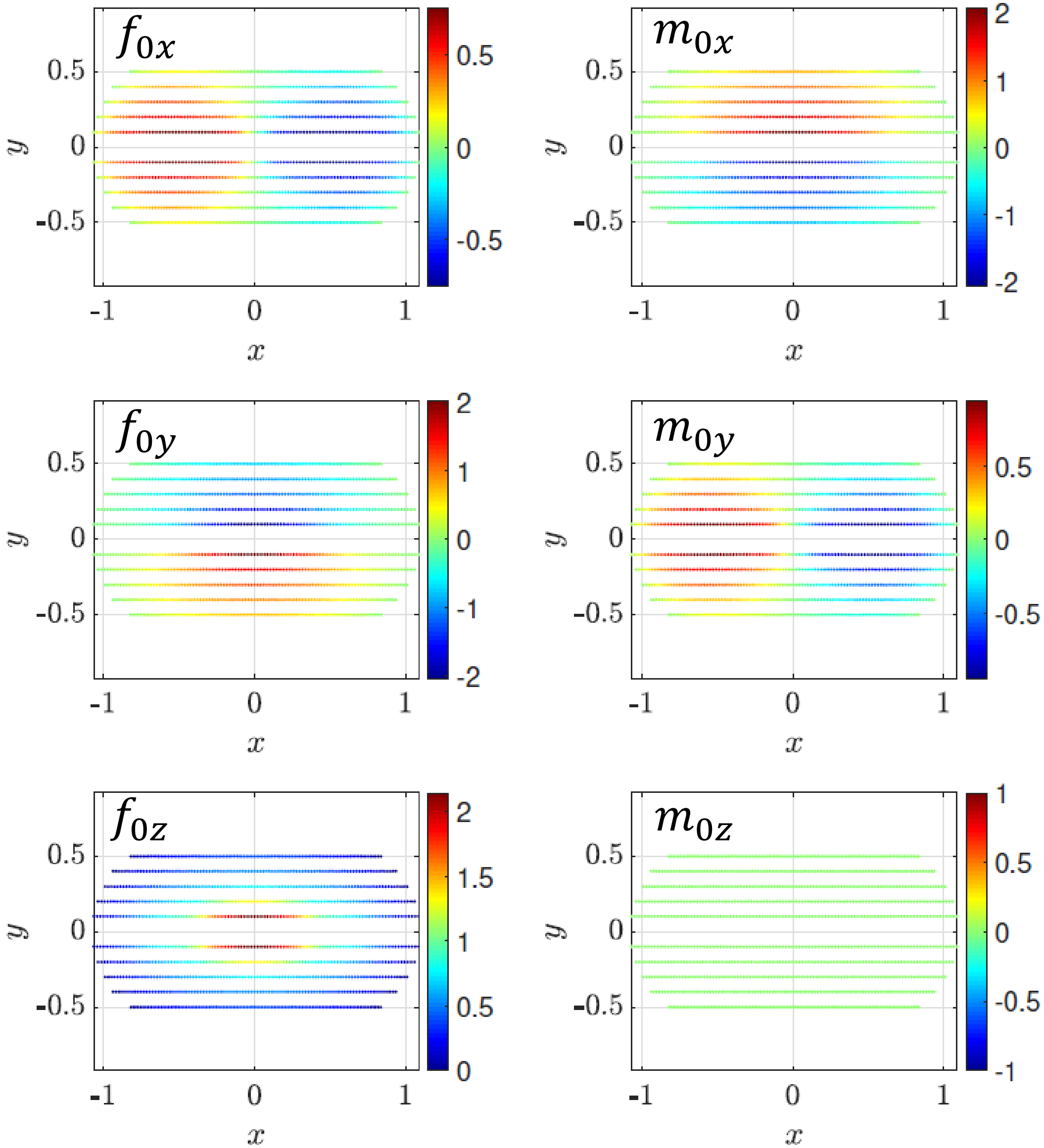
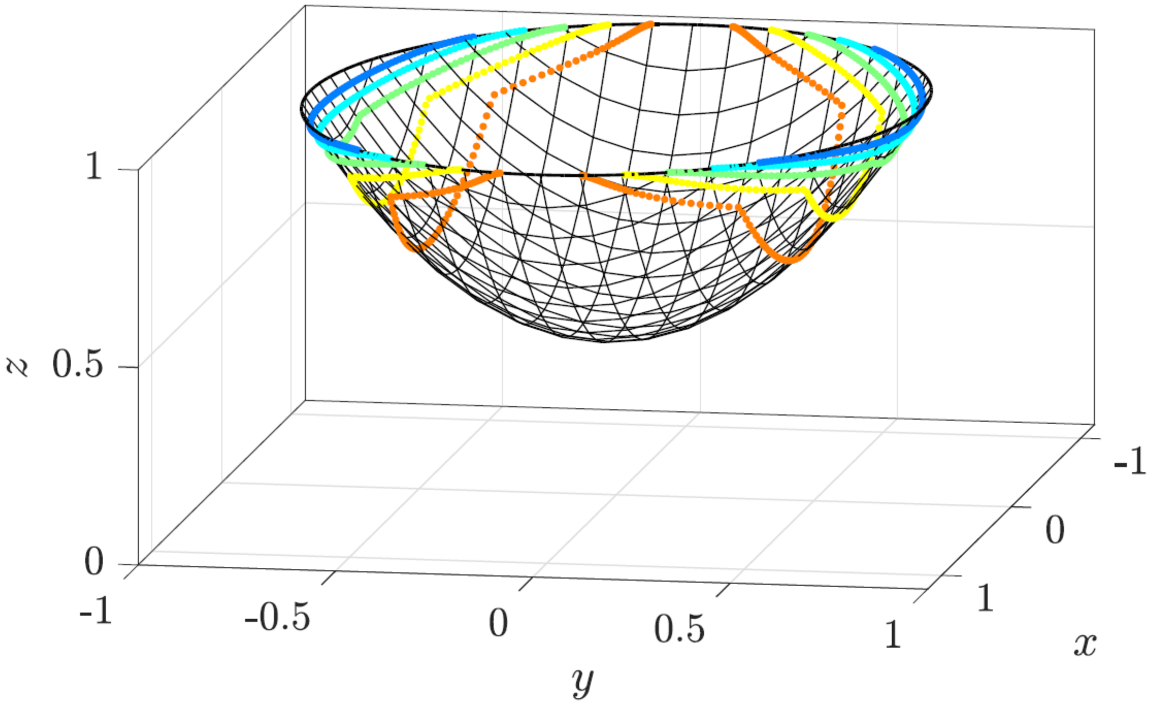


- signal strengths of support reactions

$$\vec{f}_0 = \begin{pmatrix} f_{0x} \\ f_{0y} \\ f_{0z} \end{pmatrix} \quad \text{and} \quad \vec{m}_0 = \begin{pmatrix} m_{0x} \\ m_{0y} \\ m_{0z} \end{pmatrix}$$

- object symmetry and symmetry of trails reappear in the signals
- f_{0z} seems to approximate the shape
- m_{0z} is always zero ⇒ no twist
- support reactions do not directly allow conclusions about the object

3. Simulations & Results – Step 2



- reconstructed contact points
- error within numerical boundaries
- reconstruction gap below the center of the object (cannot be reached by the rod)

- scanning using different orientations/ object distances ⇒ avoid reconstruction gaps
  - both aspects are observed in animals‘ whisking
- measuring principle
  - provides object points and corresponding normal vectors
  - is highly suitable to compliment optical sensors

4. Summary and Outlook

Summary

- model for scanning and reconstructing 3D surfaces
  - step 1: generating theoretical support reactions
    - provides important basis for parameter studies and optimization
  - step 2: reconstruction using theoretical support reactions
    - provides proof of concept and shows potential for improvement
- presented measuring principe
  - is suitable for passive dragging
  - might complement optical sensors

Outlook

- further investigations connecting the observables with the measurand
- using normal vectors for better reconstruction results
- reducing reconstruction gaps
  - varying scanning orientations and distances
  - using various rod shapes (e.g., tapered and/or pre-curved shape)
- experimental implementation
  - influence of friction and dynamical effects
  - influence of disturbance factors (e.g., temperature variations or wind flows [3])

5. References

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