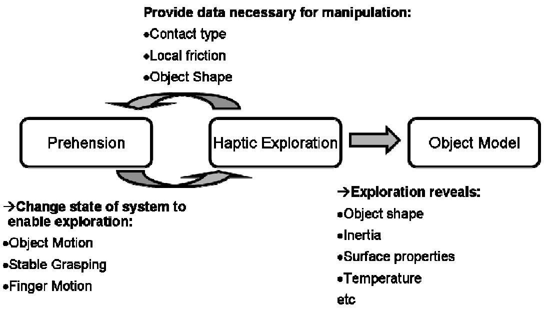
Representation of softness characteristics for active robotic in-hand exploration of objects

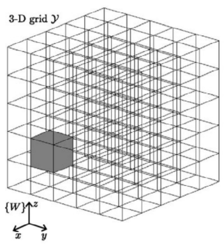
Objectives:



- Implementation of a volumetric representation (spatial discrimination of heterogenous objects) of the softness characteristics of objects;
- The elementary spatial representation of perceived softness is described as a probabilistic combination of softness description of reference sample materials;
- The perceived softness is represented based on previous experience and knowledge, to incorporate uncertain and to be progressively updated;

Object softness volumetric representation:

→*Volumetric representation framework*



- Volumetric discrete grid;
- The grid divides the workspace into equally sized voxels;
- Edges are aligned with the world reference frame *{ W };*

- The knowledge about the softness of a voxel, m_l, after n batches of measurements is modeled trough a probability distribution function:

$p(m_l|\mathbf{D}^l_n)$: m_l ε {Material$_1$, Material$_2$, …, Material$_M$}

- Each of the *M* softness categories is specified by a sample of a representing reference material

→*Softness categories representation*

- Characteristic signature of each of the reference materials, *m* , is modeled by:

$$C^m_P(C_D) = a^m_1 C_D^{\frac{3}{2}} + a^m_2 \qquad C^m_P(C_A) = a^m_3 C_A^{\frac{3}{2}} + a^m_4$$

- The curve parameters *(* a_1, a_2, a_3, a_4*)* for each reference material, *m* , can be learnt by performing several human demonstrations of unaxial palpation of the test materials.

- Assuming that the data samples $C_P{}^m$ are statistically independent and the statistical distribution of each sample $C_P{}^m$ follows a Gaussian distribution.

$$p(C^m_{P,i}|(a^m_1,a^m_2)) = \frac{1}{2\pi\sqrt{\sigma}}e^{-\frac{(C^m_{P,k}-(a^m_1 C^{\frac{3}{2}}_{D,i}+a^m_2))^2}{2\sigma^2}} \qquad p(C^m_{P,i}|(a^m_3,a^m_4)) = \frac{1}{2\pi\sqrt{\sigma}}e^{-\frac{(C^m_{P,k}-(a^m_3 C^{\frac{3}{2}}_{A,i}+a^m_4))^2}{2\sigma^2}}$$

- The parameters (a_1, a_2, a_3, a_4) for each reference material, *m*, are estimated by least square estimate

→*Volumetric representation update*

-For each voxel *l* , the set D^l_{n-1} contains the *n-1* measurements influencing that voxel

$$p(m_l|\mathbf{D}^l_n) = \beta_1\beta_2\prod_{j=1}^{n} p(m_l|\mathbf{D}^l_j) = \beta_1\beta_2 p(m_l|\mathbf{M}^l_i)p(m_l|\mathbf{D}^l_{n-1})$$

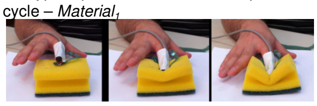
- $p(m_l|\mathbf{M}^l_i)$ converts the measurements $\mathbf{M}_k$ = (C_P,C_A,C_D) in estimation of softness values m_l of voxel *l*.
- $p(m_l|\mathbf{M}^l_i)$ is determined by $p(m_l|\mathbf{M}^l_i) = \frac{P(\mathbf{M}^l_i, m_l)}{p(\mathbf{M}_i)} = \frac{p(\mathbf{M}^l_i|m_l)p(m_l)}{\sum_m p(\mathbf{M}^l_i|m)p(m)}$

Object softness volumetric representation:

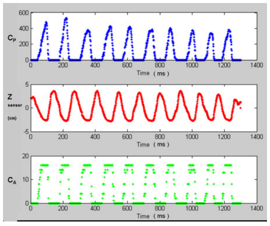
→*Training - softness reference categories*

- Set of three reference materials *Material$_1$* , *Material$_2$* and *Material$_3$*
- Each of the reference materials has different softness properties

- Example of the typical protocol involved in the press and release cycle – *Material$_1$*



- C_P(t), C_D(t) and C_A(t) for 10 press and release cycles of *Material$_1$*



- Representation of the dynamic signatures (C_P,C_D,C_A) for each of the reference materials

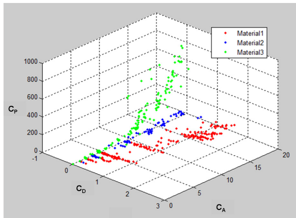
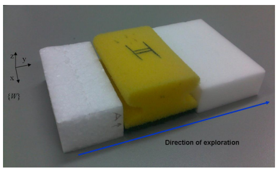
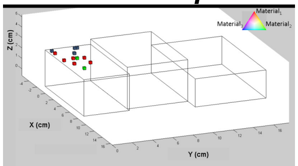


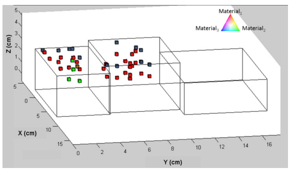
TABLE I: Model parameters estimation for each reference material

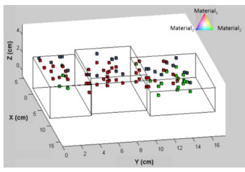
Reference Material	a_1	a_2	a_3	a_4
$Material_1$	68.1	19.73	3.30	16.05
$Material_2$	365.6	16.01	2.77	7.64
$Material_3$	1832.00	7.57×10^{-6}	9.309	5.92×10^{-6}

→*Object softness representation – volumetric representation and update*









- The representation of the profiles (C_P,C_D,C_A) has used to demonstrated that the softness characteristics of the three different reference materials is distinct.
- The volumetric probabilistic representation framework has allowed the characterization of the global shape of an heterogeneous object .

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