EVALUATION OF HAPTIC VIRTUAL REALITY GUIDANCE IN PROSTATE TARGETED BIOPSY BASED ON MAGNETIC RESONANCE ELASTOGRAPHY

Author: Martina Berni

Advisor: Elena De Momì

UIC Advisor: Cristian Luciano
Prostate Cancer

Most common non-cutaneous cancer in US:

- 164,690 estimated new cases
- 29,430 estimated deaths

Need of
- EARLY DETECTION
- ACCURATE DIAGNOSIS
- EFFECTIVE TREATMENT
Gold Standard

Systematic blind biopsy:
Hollow needle → Takes n samples from different areas
Transrectal Ultrasound → Real-time guidance images

PROBLEMS:
- Non targeted
- Oversampling
Targeted Prostate Biopsy

Benefits over systematic biopsy:
• reduce false negative
• avoid oversampling

MRI-US Fusion Biopsy

**Pro**
- Optimal number of sample
- Reduced surgical time
- Improved accuracy

**Cons**
- Complexity of the system
- Pre-processing time
- Equipment cost
- TRUS
Elastography: “Remote Palpation” → 3D Maps of tissue stiffness

[DiRECT, Imperial College of London]

[Magnetic Resonance Elastography]

[SenseViewer, Li et al.]
Proposed Solution

Virtual Reality Navigation System

Haptic Magnetic Resonance Elastography Diagnosis

[Virtual Reality Navigation System for Prostate Biopsy, Rapetti]

[Visuo-haptic model of prostate cancer based on MRE, Tagliabue]
Haptic Surgical Guidance for Prostate Biopsy:

- Pre-operative planning tool
- Intra-operative guidance tool
- Tracking of the needle \[\rightarrow\] No TRUS
- 2D/3D virtual images \[\rightarrow\] Visual feedback
- MRE stiffness values \[\rightarrow\] Haptic feedback
- Target identification through MRE \[\rightarrow\] Haptic guidance
- Sensor on the patient pelvis \[\rightarrow\] Movements tracking
Previous Frameworks

Virtual Reality Navigation System

- Electromagnetic tracking system
- Registration of the patient respect the virtual environment

Haptic Magnetic Resonance Elastography Diagnosis

- Haptic feedback based on stiffness values
Setup

Computer with 3D Display
VIRTUAL ENVIRONMENT

Haptic Device & Biopsy Needle

PHYSICAL (REAL) ENVIRONMENT

Localization Sensor

Any Patient Movement

Martina Berni
Setup

3D Monitor

Phantom

Needle

Haptic Device
Target Definition and Guidance

- Center of the tumors individuation → k-means clustering
- Line effect from insertion point to one tumor at a time

Force = d * gain

Insertion Point

Target
Haptic Dynamic Prostate Simulator

MRE → Mesh → Stiffness matrix

Collision detection, mesh deformation and force feedback
For each vertex

\[ F = \frac{F_h}{1 + d^2} \]

\[ \text{Vel} = (F \Delta t - d k \Delta t)(1 - \xi \Delta t)S \]

\[ V_{\text{new}} = V_{\text{old}} + \text{Vel} \Delta t \]

**DEFORMED MESH**
20 SUBJECTS: 18 STUDENTS AND 2 UROLOGISTS

- Interact with the volumes using the haptic device
- Reach the identified lesions with/without haptic guidance

COVERED LENGTH AND TIME
Results ~ Guidance Haptic Feedback Evaluation

Covered lengths with and without haptic feedback

Average time to reach the target with and without haptic feedback

Kolmogorov-Smirnov test (p value < 0.05)
T-test (p value < 0.05)
Protocol ~ Hard Areas Detection

10 STUDENTS: BOTH WITH THE HAPTIC GUIDANCE FOR PROSTATE BIOPSY AND WITH THE HAPTIC DYNAMIC PROSTATE SIMULATOR

- Interact with the volumes using the haptic device
- Press a key when the cursor is inside an hard region
- Repeat the process to identify all hard spots

\[
\text{ACC\%} = \frac{N_{\text{hard}}}{N_{\text{tot}}}
\]
Results ~ Hard Areas Detection

Accuracy of the two systems

Kolmogorov-Smirnov test (p value < 0.05)
Haptic Surgical Guidance for Prostate Biopsy

Haptic Dynamic Prostate Simulator

• Targeted biopsy
• First prototype of deformation
• Target definition through MRE
• Haptic guidance towards the center of the tumors
• Real-time tracking of the needle
• Get/Set haptic device force
• No transrectal ultrasound
• Patient movements tracking
Future Developments

- Application development with Unity → more realistic deformation
- Testing of the system accuracy
- Application of MRE for *in-vivo* prostates
- Apply this technique to **other procedures**

Focal therapies

Brachytherapy
Thank you!

Questions?
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Image Registration

APPLICATION SCENARIO

Preoperative MRI
Preoperative MRE

VALIDATION ➔
LESIONS IDENTIFICATION

Histopathological images

APPLICATION SCENARIO

Preoperative MRI
Preoperative MRE

VALIDATION ➔
LESIONS IDENTIFICATION

Histopathological images
Image Registration

- DICOM
- VolView
- Volume
- Interpolated Volume
- BSpline Registration
- MRE
- 3DSlicer
Image Registration

Contour Matching

<table>
<thead>
<tr>
<th></th>
<th>MRE/Histo score</th>
<th>MRE/MRI score</th>
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</thead>
<tbody>
<tr>
<td>Prostate 1</td>
<td>83.32%</td>
<td>82.41%</td>
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<tr>
<td>Prostate 2</td>
<td>79.77%</td>
<td>78.29%</td>
</tr>
<tr>
<td>Prostate 3</td>
<td>82.82%</td>
<td>80.68%</td>
</tr>
</tbody>
</table>

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