Head-mounted display visualization system for surgical operations

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Co-supervisors: Dr. Hang Su, Dr. Salih Ertug Ovur

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Academic year 2019-2020
Minimally Invasive Surgery – Robot Assisted Surgery

Introduction

Minimally Invasive Surgery

Robot-Assisted Surgery

Operative Side

Patient Side

Video Stream

Endoscope

Surgical Instruments

Console

Manipulators

Operator Side

Hand’s Movement

Video Stream

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POLITECNICO DI MILANO
### Minimally Invasive Surgery

- Camera held by assistant
- 2D visualization on an external monitor

Limited field of view
Lack of depth perception
Hard eye-hand coordination

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### Robot - Assisted Surgery

- 3D visualization on the console
- 2D external monitor for first assistant

Limited field of view
Hard eye-hand coordination
Uncomfortable head movements

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[G. Chen et al., 2009]

[C.D. Van’t Hullenaar et al., 2017]
State of the art

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HIDDEN STRUCTURE RECOGNITION
PRE – INTRA OPERATIVE FUSION
AR DEVICE – ROBOT INTEGRATION

Move towards more versatile and intuitive solutions

• Case – Dependent Systems
• Hard eye-hand coordination
• Uncomfortable head movements

[S. Drouin et al., 2015]
[I.M. Sauer et al., 2017]
[L. Qian et al., 2018]
Aim of the work

Implementation of a novel human-machine interface for AR visualization system and teleoperation using an AR device

- User-friendly interface
- More ergonomic system
- Coordination improvement
- Accuracy improvement
System architecture

**PATIENT SIDE**
- Endoscope
- Manipulator

**OPERATOR SIDE**
- Head-Mounted Display
- joystick

**TELEOPERATION**
- Video stream
- Manipulators’ position
- Surgeon’s movement

**COMMUNICATION CHANNEL**

**AUGMENTED SCENARIO**

**GRAPHIC INTERFACE**
- Linux
- ubuntu®
- ROS
- Windows 10
- unity
- STEAM®VR

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Graphic Interface Setup

- **Methods**
  - Video stream
  - Video split
  - Left image compressed
  - Right image compressed
  - Unity compressed

- **Unity Environment Implementation**

- **ROS**

- **Results**

- **Conclusions**
Methods

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Graphic Interface Setup

Introduction | State of the art | Aim | Methods | Results | Conclusions

-[P. Zhao et al., 2010]

PHYSIOLOGICAL BINOCULAR VISION BASED

[ unity ]

POLITECNICO DI MILANO
Graphical Interface Setup

**Methods**

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**UNITY ENVIRONMENT IMPLEMENTATION**

**VIDEO STREAM**

**PHYSIOLOGICAL BINOCULAR VISION BASED**

[6.P. Zhao et al., 2010]
AR Device – dVRK Integration

Methods

WORLD – Laboratory Reference System
ECM – Endoscope Control Manipulator
HMD – Head-Mounted Display
PSM – Patient Side Manipulator
AR Device - dVRK Integration

PATIENT SIDE

OPERATOR SIDE

ECM – Endoscope Control Manipulator
HMD – Head-Mounted Display
PSM – Patient Side Manipulator
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AR Device - dVRK Integration

Methods

\[ T_{HMD}^{ECM} = \text{inv}(T_{ECM}^{world}) \cdot T_{HMD}^{world} \]

WORLD – Laboratory Reference System
ECM – Endoscope Control Manipulator
HMD – Head-Mounted Display
PSM – Patient Side Manipulator
Methods

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AR Device - dVRK Integration

WORLD – Laboratory Reference System
ECM – Endoscope Control Manipulator
HMD – Head-Mounted Display
PSM – Patient Side Manipulator
VIRTUAL – Unity Reference System
Methods

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AR Device - dVRK Integration

Introduction | State of the art | Aim | Methods | Results | Conclusions

HMD’s POSITION

CONOTROLLERS’ POSITION

JOYSTICK BUTTON STATE

ENABLE/DISABLE

TRACKPAD

TRIGGER

GRIP

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POLITECNICO DI MILANO
Augmented Reality Development

Methods

AR DEVICE – DA VINCI RESEARCH KIT (dVRK) INTEGRATION

VIRTUAL INFORMATION

REAL SCENARIO

AR VISION SYSTEM SETUP

AUGMENTED REALITY DEVELOPMENT

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POLITECNICO DI MILANO
Augmented Reality Development

Methods

- **INSTRUMENTS LOCALIZATOR**
  - Support for orientation

- **TARGET HIGHLIGHTER**
  - Better target localization

- **TARGET LOCALIZATOR**
  - Support for navigation
Methods

Test and Evaluation

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- **Task Design**
- **Experimental Protocol**

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Task Design – Pick and Place

Methods

- **TASK 1 – CHESSBOARD**
- **TASK 2 – HEIGHT POSITIONING**
- **TASK 3 – RING INSERTION**

**STANDARD CONFIGURATION**

**AR CONFIGURATION**

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The document details an experimental protocol involving 10 non-medical participants. The protocol includes the following tasks:

**Standard Configuration**
- Task 1: Chessboard
- Task 2: Height positioning
- Task 3: Ring insertion

**Augmented Reality (AR) Configuration**
- Task 1: Chessboard
- Task 2: Height positioning
- Task 3: Ring insertion

**Performance Metrics**
- **Successful Score** ($S_{u,k}$): The total number of successful attempts ($S$) with specific user ($u$) for specific task repetition ($k$). Minimum: 0, Maximum: 3.

**Completion Time** ($T_{u,k}$): Time taken to complete a specific task repetition ($k$) for specific user ($u$).

**Performance Index** ($P_{u,k}$): $P_{u,k} = \frac{T_{u,k}}{S_{u,k}}$
- $T$: Completion time
- $S$: Successful score
- $u$: Specific user
- $k$: Specific task repetition

**References**
- Mnyusiwalla et al., 2020
- Campo et al., 2010
Results

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**Successful Score**

<table>
<thead>
<tr>
<th>TASK 1</th>
<th>TASK 2</th>
<th>TASK 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4</td>
<td>1.5</td>
<td>1.3</td>
</tr>
<tr>
<td>2.17</td>
<td>2.03</td>
<td>2.17</td>
</tr>
</tbody>
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**AVERAGE SUCCESSFUL SCORE**

- **STANDARD**: 0.00390
- **AR**: 0.00402

**STATISTICAL ANALYSIS**

- **Wilcoxon signed-rank test** shown significative statistical differences ($\alpha = 0.05$)

**p - values**

- **TASK 1**: < 0.05
- **TASK 2**: 
- **TASK 3**: < 0.05

*Wilcoxon signed-rank test shown significative statistical differences ($\alpha = 0.05$)*
**Results**

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**Completion Time**

**STATISTICAL ANALYSIS**

- **STD** = Standard configuration

<table>
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<th>TASK 1</th>
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<td>&lt; 0.05</td>
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*Wilcoxon signed-rank test shown significative statistical differences (α = 0.05)*

- **Wilcoxon signed-rank test**

**p - values**

- TASK 1: < 0.05
- TASK 2: < 0.05
- TASK 3: < 0.05

STD = Standard configuration
Performance Index

**Results**

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**STATISTICAL ANALYSIS**

Wilcoxon signed-rank test shown significative statistical differences ($\alpha = 0.05$)

STD = Standard configuration

*Wilcoxon signed-rank test shown significative statistical differences ($\alpha = 0.05$)*

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</tr>
<tr>
<td>TASK 3</td>
<td>&lt; 0.05</td>
</tr>
</tbody>
</table>
Results achieved suggest that the system developed provides:

- User-friendly interface
- Orientation improvement
- Efficiency improvement

Training is needed.
Future works

Conclusions

ANATOMICAL 3D MODELS REGISTRATION

VISUAL FEEDBACK

MORE COMPLEX SURGICAL TASKS
Thank you for your attention!

< debora.bonvino@mail.polimi.it >
Bridge the Windows system and Linux one:
Results

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Latency

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**HAND MOTION**

- Video Stream: 30 Hz
- Delay: 15 ms

**PSM MOTION**

- 90 Hz
- Delay: 45 ms

**HEAD MOTION**

- ECM MOTION
**HTC VIVE PRO**

**Methods**

**HARDWARE AND ACCESSORIES**

- Head-Mounted display
- Joysticks
- Base stations
- Vive Tracker
- Wireless adapter

**DEVICE CONFIGURATION**

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Qualitative analysis

SUBJECTS FEATURES:

AGE: 26.5 ± 1.3601

GENDER: 60% Female
40% Male

DOMINANT HAND

What is your level of experience with virtual reality system?

- None
- Limited - I have tried once or twice
- Good - I have used a similar system sometimes
- High - I have some experience with VR systems

How much do you rate your level of experience with video games?

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**QUESTIONNAIRE:**

I think I would need support from a technician to use this interface

- **STANDARD**
  - 1: 0 (0%)
  - 2: 2 (20%)
  - 3: 2 (20%)
  - 4: 6 (60%)
  - 5: 0 (0%)

- **AR**
  - 1: 0 (0%)
  - 2: 1 (10%)
  - 3: 3 (30%)
  - 4: 5 (50%)
  - 5: 1 (10%)
I still had/needed to learn a lot before becoming familiar with this interface.
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Qualitative analysis

I felt comfortable using this interface

QUESTIONNAIRE:
Reference Systems

Methods

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HMD – JOYSTICK TRANSFORMATION

Methods

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HMD

ECM

\[ T_{ECM}^{HMD} = \text{inv}(T_{ECM}^{world}) \times T_{HMD}^{world} \]

Controllers’ position

PSM

\[ T_{PSM}^{Joystick} = \text{inv}(T_{PSM}^{world}) \times T_{Joystick}^{world} \]
Methods

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PSM TRANSFORMATION

\( T^{Unity}_{PSM} = T^{Unity}_{ECM} \cdot T^{ECM}_{PSM} \)

PSMs’ position

Unity

PSM

ECM

PSM

ECM

HMD

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