GRAphics and INtelligent Systems group

Ph.D. XXIX Cycle
Federico Manuri

Thesis Dissertation

Supervisor: prof. Andrea Sanna

GRAINS
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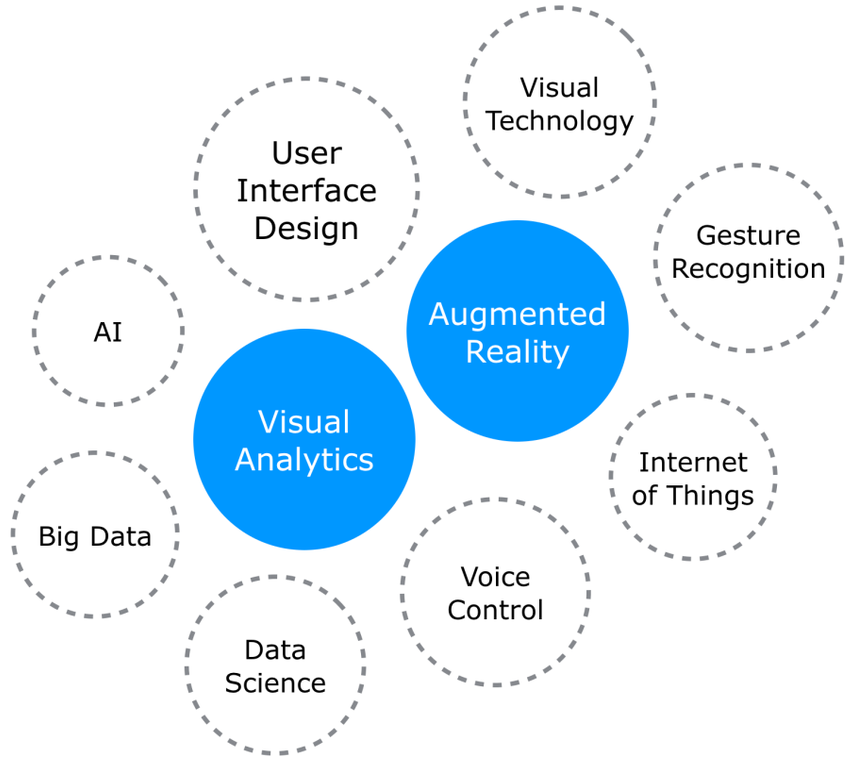
Visualization & Human-Machine Interaction

Augmented Reality for Maintenance

- Reconfigurable procedures
- Robust and intuitive interfaces

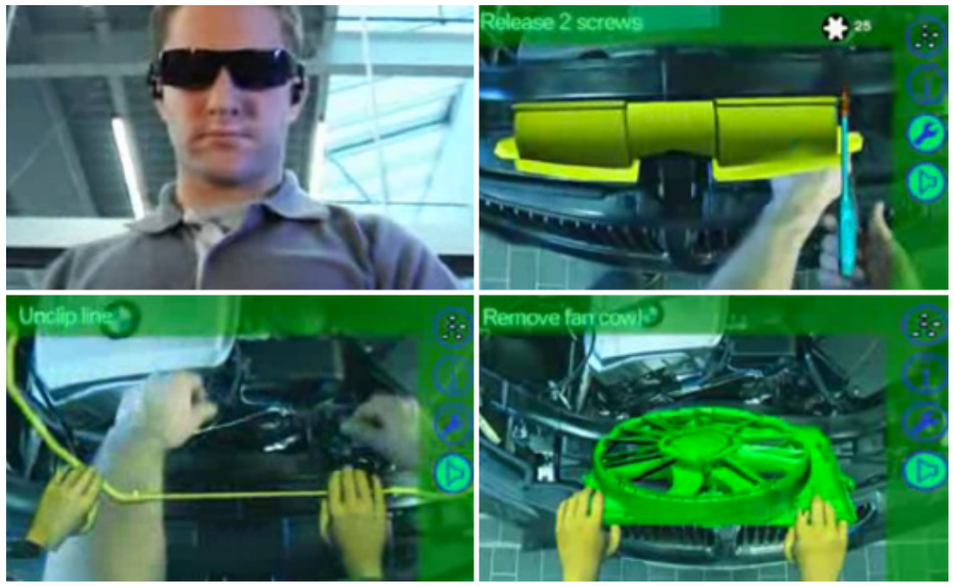
Visual Analytics

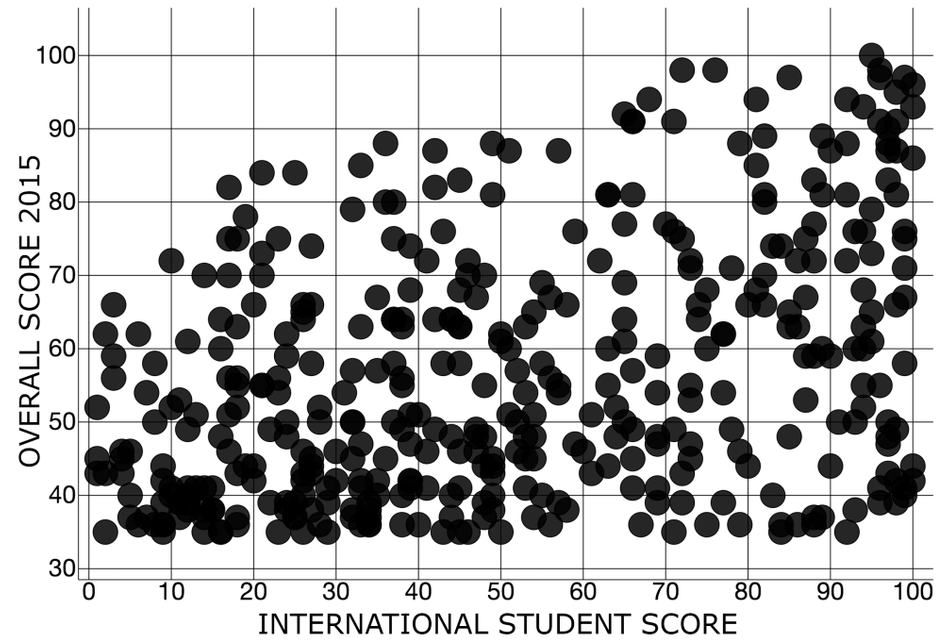
- Multivariate Data Visualization



OUTLINE

- Augmented Reality for Maintenance
  - Context & Motivation
  - Methodology
  - Problems & Solutions
  - Results & Analysis
- Multivariate Data Visualization
  - Context & Motivation
  - Methodology
  - Problems & Solutions
  - Results & Analysis
- Conclusions & Future Works





AR DEFINITION

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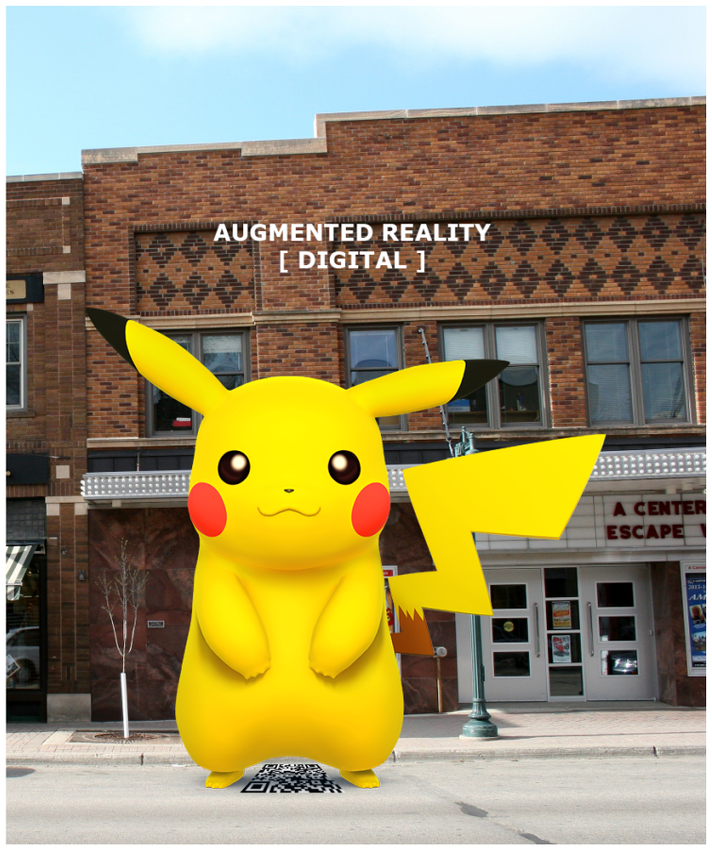
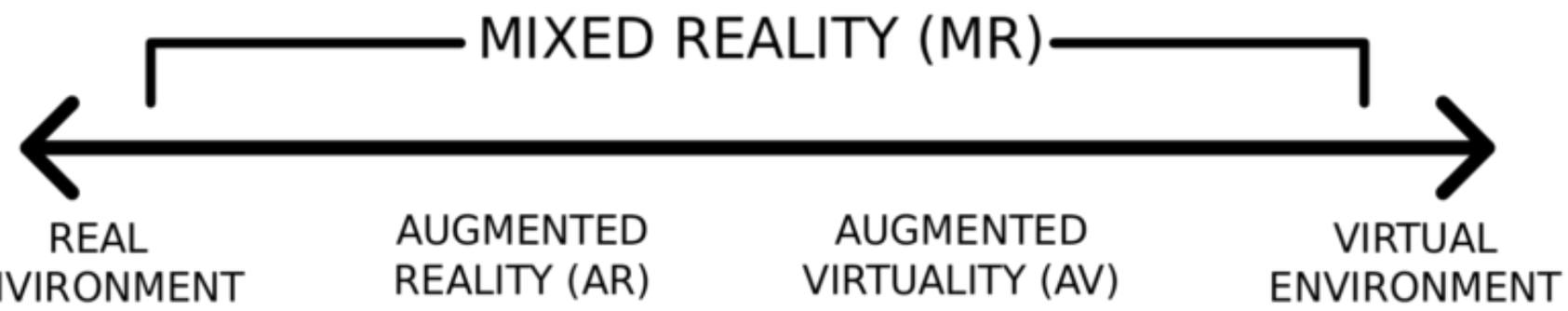
The term Augmented Reality refers to a set of devices and technologies that grant the user the ability to see both the real world and the virtual space at the same time, thus enhancing the user perception of reality.





Paul Milgram and Fumio Kishino. A taxonomy of mixed reality visual displays. IEICE TRANSACTIONS on Information and Systems, 77(12):1321–1329, 1994.

AR SYSTEM ARCHITECTURE

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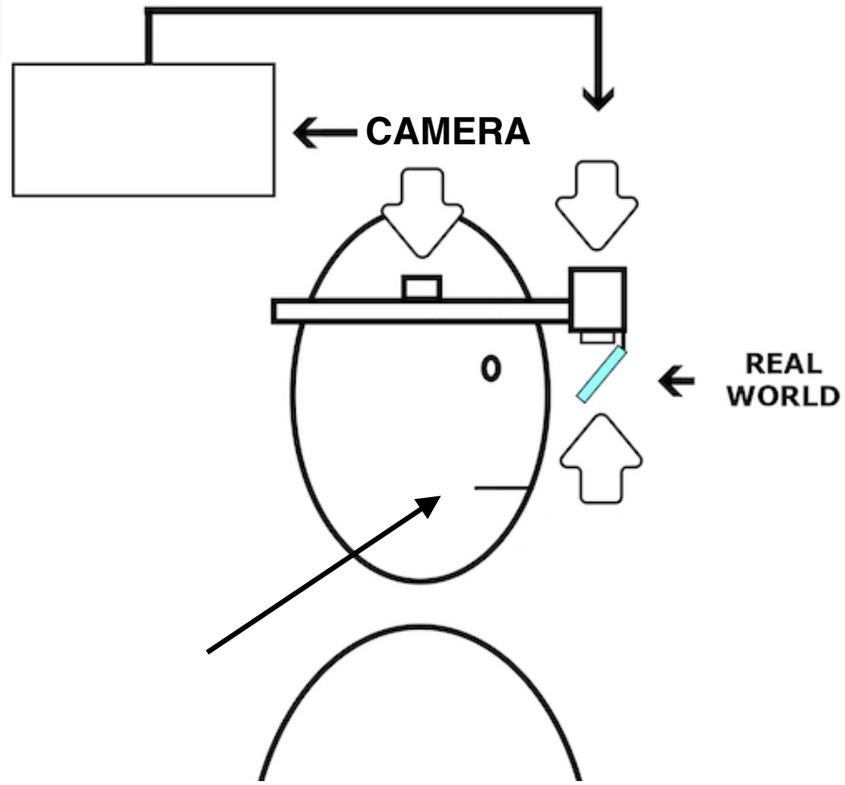
Hardware

Tracking System

Software

Tracking Algorithm



AR SYSTEM ARCHITECTURE

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Hardware

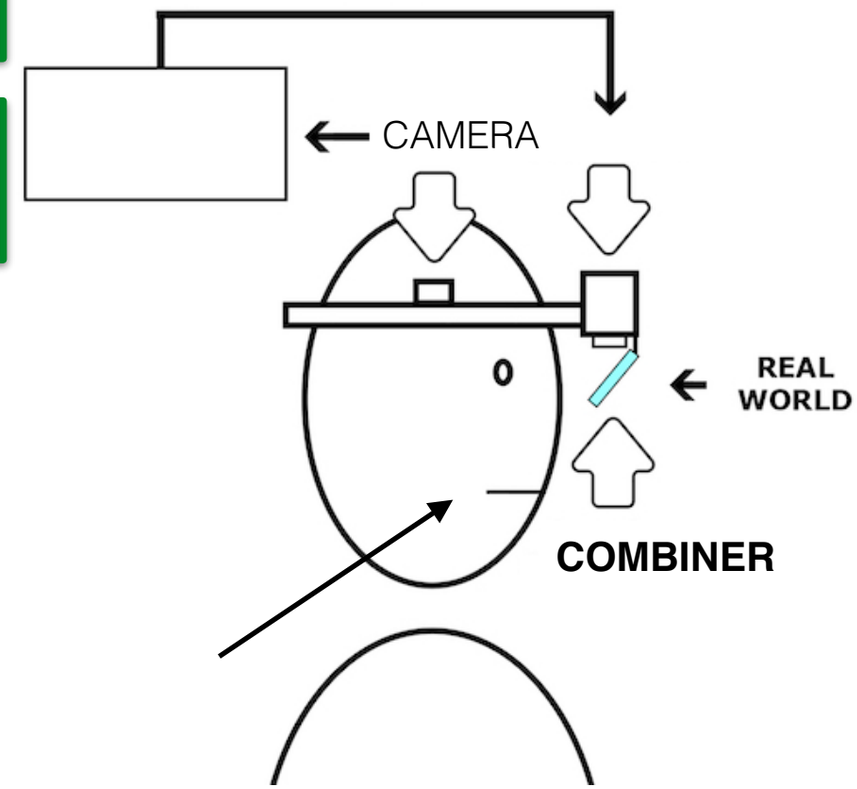
Tracking System

Combiner

Software

Tracking Algorithm

Combiner



AR SYSTEM ARCHITECTURE

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Hardware

Tracking System

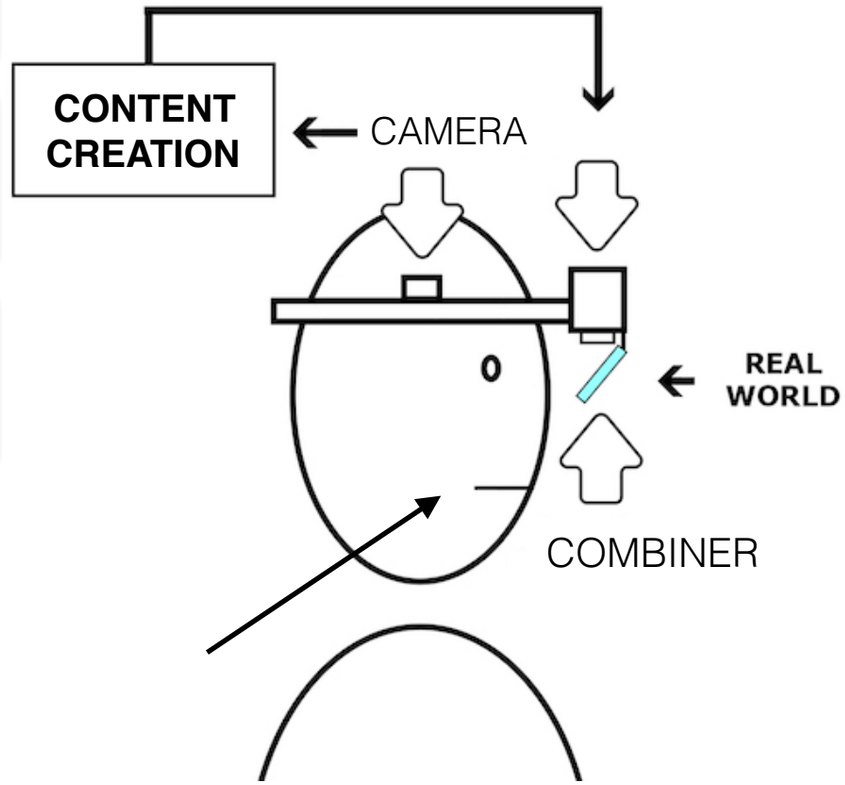
Combiner

Software

Tracking Algorithm

Combiner

Contents Creation



AR SYSTEM ARCHITECTURE

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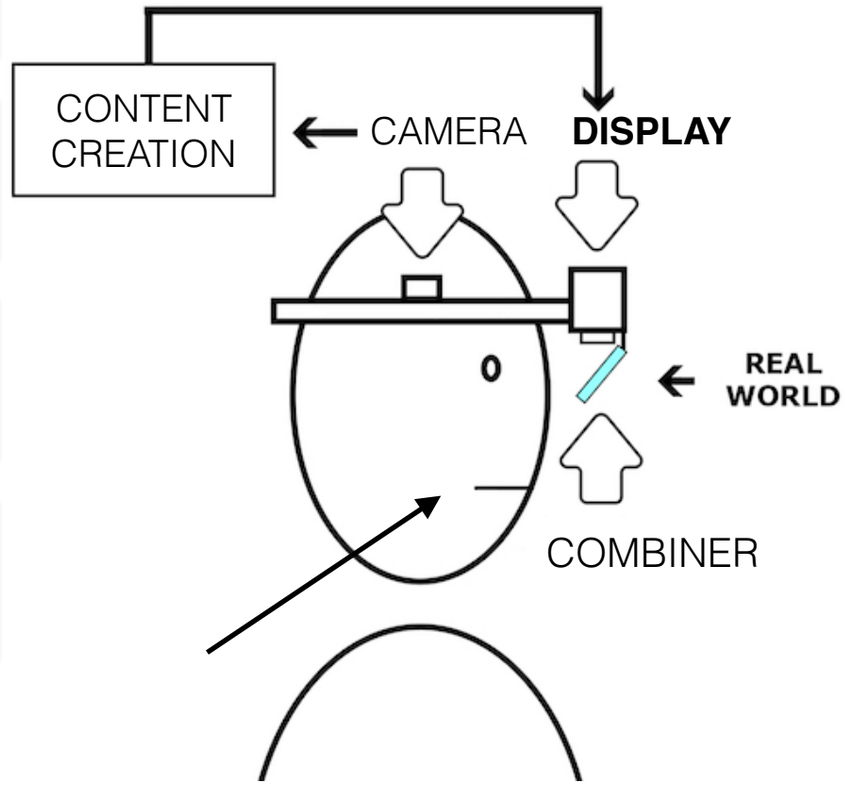
Hardware

- Tracking System
- Combiner
- Display

Software

- Tracking Algorithm
- Combiner
- Contents Creation
- Graphic Interface



AR SYSTEM ARCHITECTURE

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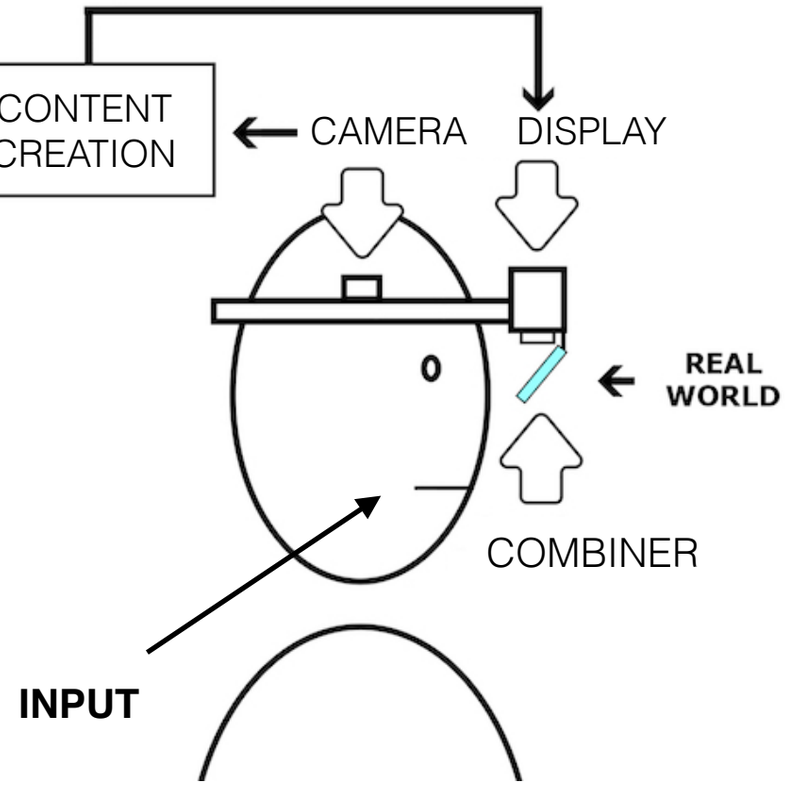
Hardware

- Tracking System
- Combiner
- Display
- Input Interface

Software

- Tracking Algorithm
- Combiner
- Contents Creation
- Graphic Interface
- Input Libraries



AR TECHNOLOGIES

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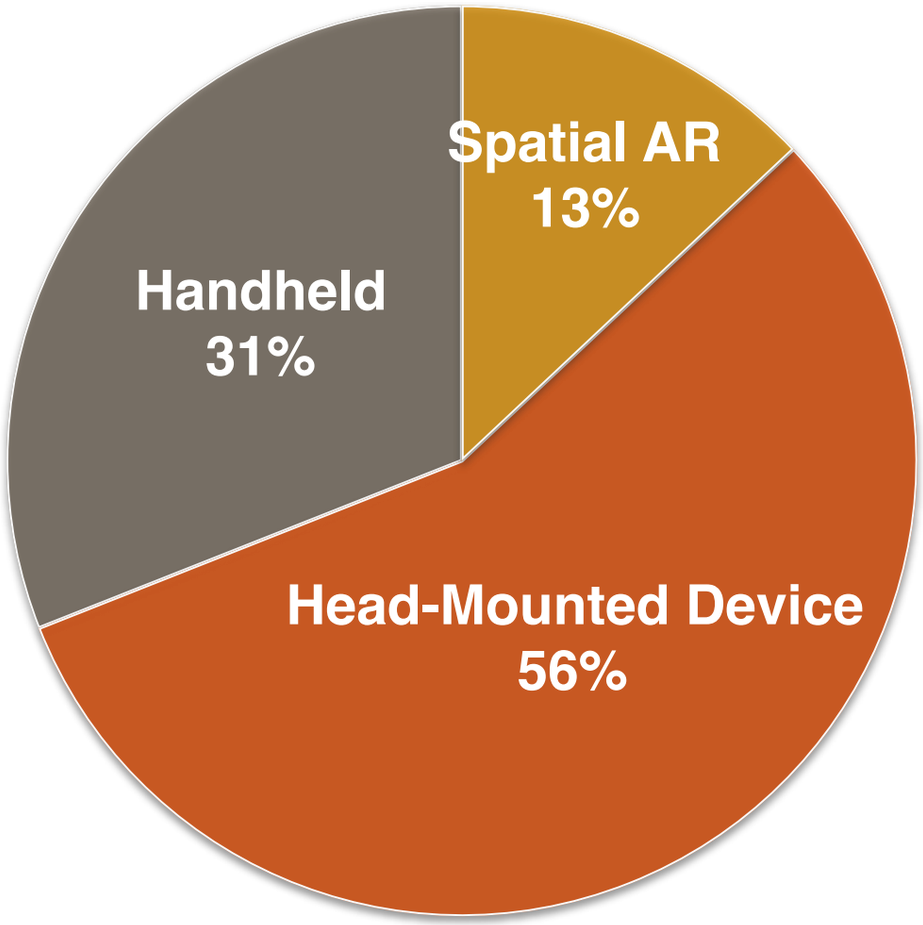
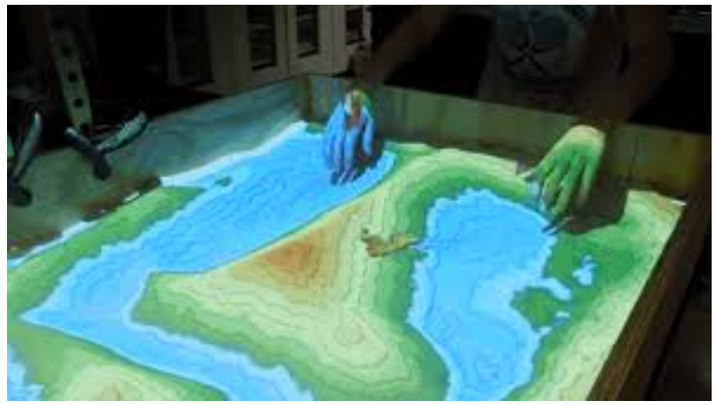
Handheld Device





Spatial AR

Head-Mounted Device

Applications per types of AR devices (includes tests and implementations)

MAIN APPLICATIONS

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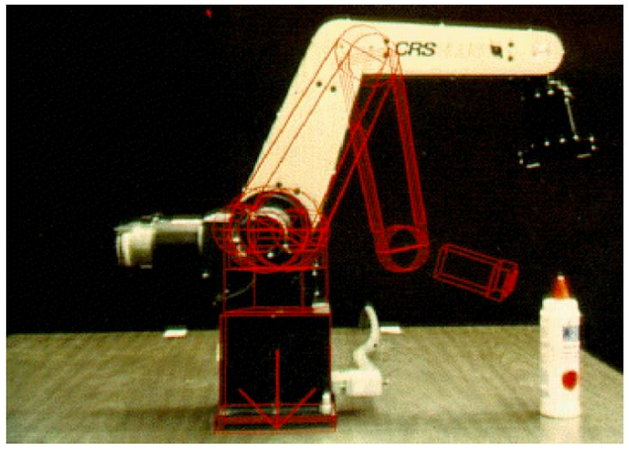
Manufactoring

Medicine

Robot path planning



Annotation & Visualization

Entertainment

Military

Historical Domain

Maintenance is one of the first field of application identified by Azuma [1]

[1] Ronald T Azuma. A survey of augmented reality. *Presence: Teleoperators and virtual environments*, 6(4):355–385, 1997.

DOMAIN: AR 4 MAINTENANCE

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Historical Domain

Maintenance is one of the first field of application identified by Azuma [1]

Financial Impact

$1.2 billion revenue in 2016 , expected $83 billion revenue by 2021 [2]

[1] Ronald T Azuma. A survey of augmented reality. *Presence: Teleoperators and virtual environments*, 6(4):355–385, 1997.

[2] Digi-Capital, *After mixed year, mobile AR to drive $108 billion VR/AR market by 2021*, January 2017

DOMAIN: AR 4 MAINTENANCE

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Open Problems

Maintenance offers all the most common and important challenges that AR can arise.

[1] Ronald T Azuma. A survey of augmented reality. *Presence: Teleoperators and virtual environments*, 6(4):355–385, 1997.

[2] Digi-Capital, *After mixed year, mobile AR to drive $108 billion VR/AR market by 2021*, January 2017

OPEN PROBLEMS

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AR ARCHITECTURE

Hardware

- Tracking System
- Combiner
- Display
- Input Interface

Software

- Tracking Algorithm
- Combiner
- Contents Creation
- Graphic Interface
- Input Libraries

MAIN PROBLEMS

- Pose Tracking
- Reconfigurability
- Interface Design
- Robustness of the interface
- Training Systems
- Technology Acceptance

STATE OF THE ART

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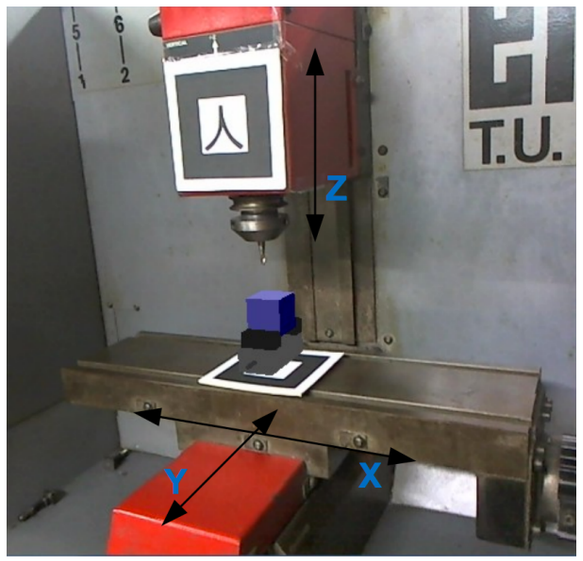
The MARS (Mobile Augmented Reality System), the first outdoor mobile AR system[1]



AR was used to simulate and validate the programs of Computer Numerical Control (CNC) machines [2]

Speech enabled AR interface [3]

[1] Tobias Höllerer, Steven Feiner, Tachio Terauchi, Gus Rashid, and Drexel Hallaway. Exploring mars: developing indoor and outdoor user interfaces to a mobile augmented reality system. *Computers & Graphics*, 23(6):779–785, 1999.

[2] Gandjar Kiswanto and Dedy Ariansyah. Development of augmented reality (ar) for machining simulation of 3-axis cnc milling. In Advanced Computer Science and Information Systems (ICACSIS), 2013 International Conference on, pages 143–148. IEEE, 2013.

[3] Stuart Goose, Sandra Sudarsky, Xiang Zhang, and Nassir Navab. Speechenabled augmented reality supporting mobile industrial maintenance. IEEE Pervasive Computing, 2(1):65–70, 2003.

METHODOLOGY

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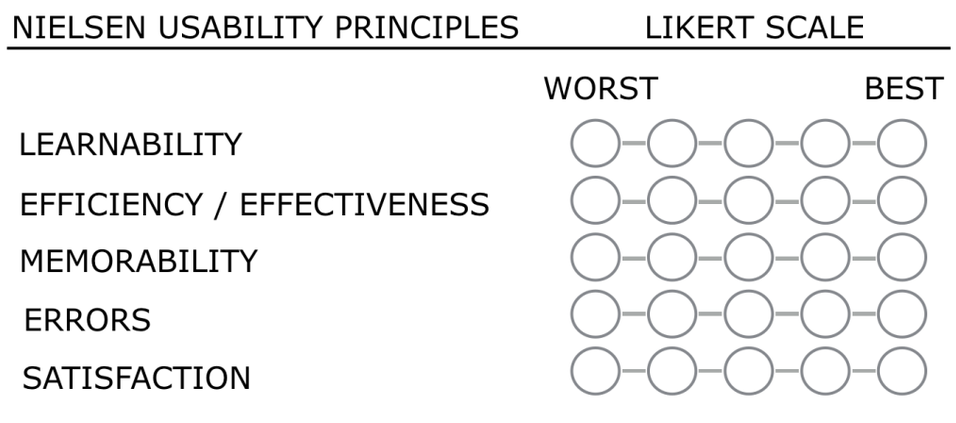
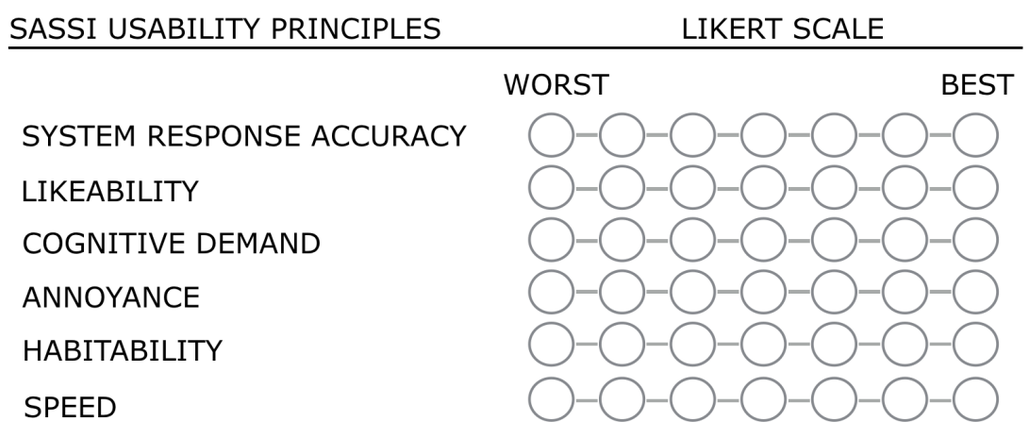
- Collecting user requirements
- Designing and developing a prototype to assess the given problems
- Testing the prototype with a small group of users to get feedbacks
- Fixing the prototype and repeating the tests with another small group of users
- Testing the final version with a larger group of testers, assessing results and feedbacks with questionnaires based on SASSI[1] and Nielsen[2] usability principles





[1] Kate S Hone and Robert Graham. Towards a tool for the subjective assessment of speech system interfaces (sassi). 2000.

[2] Jakob Nielsen. Usability metrics: Tracking interface improvements. Ieee Software, 13(6):12, 1996.

USE CASES

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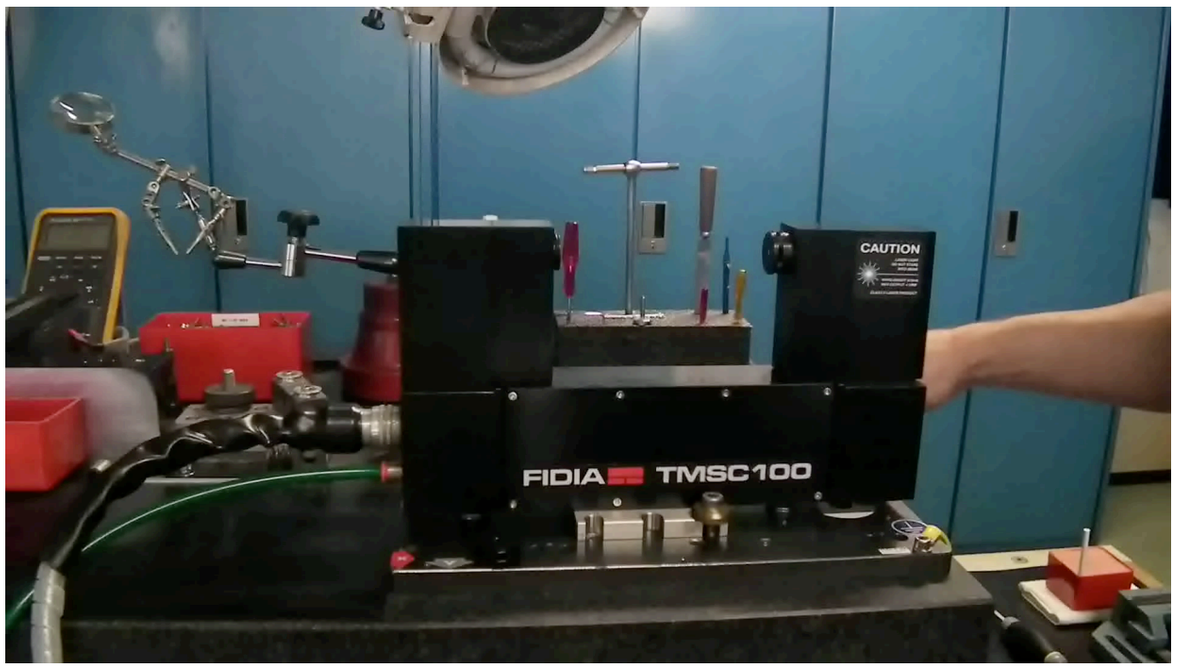
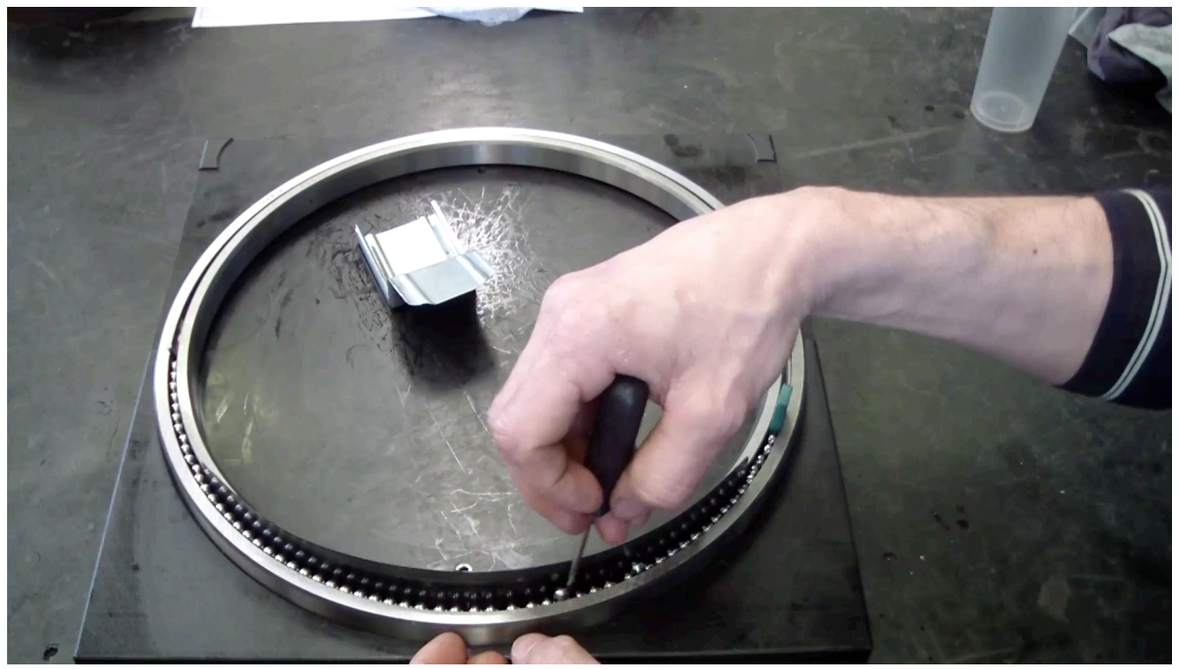
EASE-R³

FIDIA

WIRES engineering





REQUIREMENTS & CHALLENGES

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ARCHITECTURE

Hardware	Software	OPEN PROBLEMS
Tracking System	Tracking Algorithm	Pose Tracking
Combiner	Combiner	
	Contents Creation	Reconfigurability
Display	Graphic Interface	Interface Design
Input Interface	Input Libraries	Robustness of the interface
		Training Systems
		Technology Acceptance

MAIN REQUIREMENTS [1] MUST & SHOULD

Hardware

- Use of glasses for augmented reality built into helmet
- Hands-free
- Physical interaction (touch)
- Offline usage
- Good Connectivity

Software

- The application recognize the machine in the environment
- Allows the user to move through various stages of the procedure
- Real-time support
- Menu with a list of available procedures
- Not real-time support is dynamic (virtual)
- Multiple languages
- Don't stop maintenance to obtain information
- Video Capabilities
- View support while performing the procedure (having hands free)
- Textual & Visual assets

[1] MoSCoW method, International Institute of Business Analysis. A Guide to the Business Analysis Body of Knowledge (BABOK Guide), Version 2.0. International Institute of Business Analysis, 2009.

PROPOSED SOLUTIONS: adopted technologies

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ARCHITECTURE		OPEN PROBLEMS	ADOPTED TECHNOLOGIES
Hardware	**Software**		
Tracking System	Tracking Algorithm	Pose Tracking	metaio
Combiner	Combiner		
	Contents Creation	Reconfigurability	to be designed and developed
Display	Graphic Interface	Interface Design	 
Input Interface	Input Libraries	Robustness of the interface	Microsoft Speech API
		Training Systems	to be designed and developed
		Technology Acceptance	

PROPOSED SOLUTIONS: operation workflow

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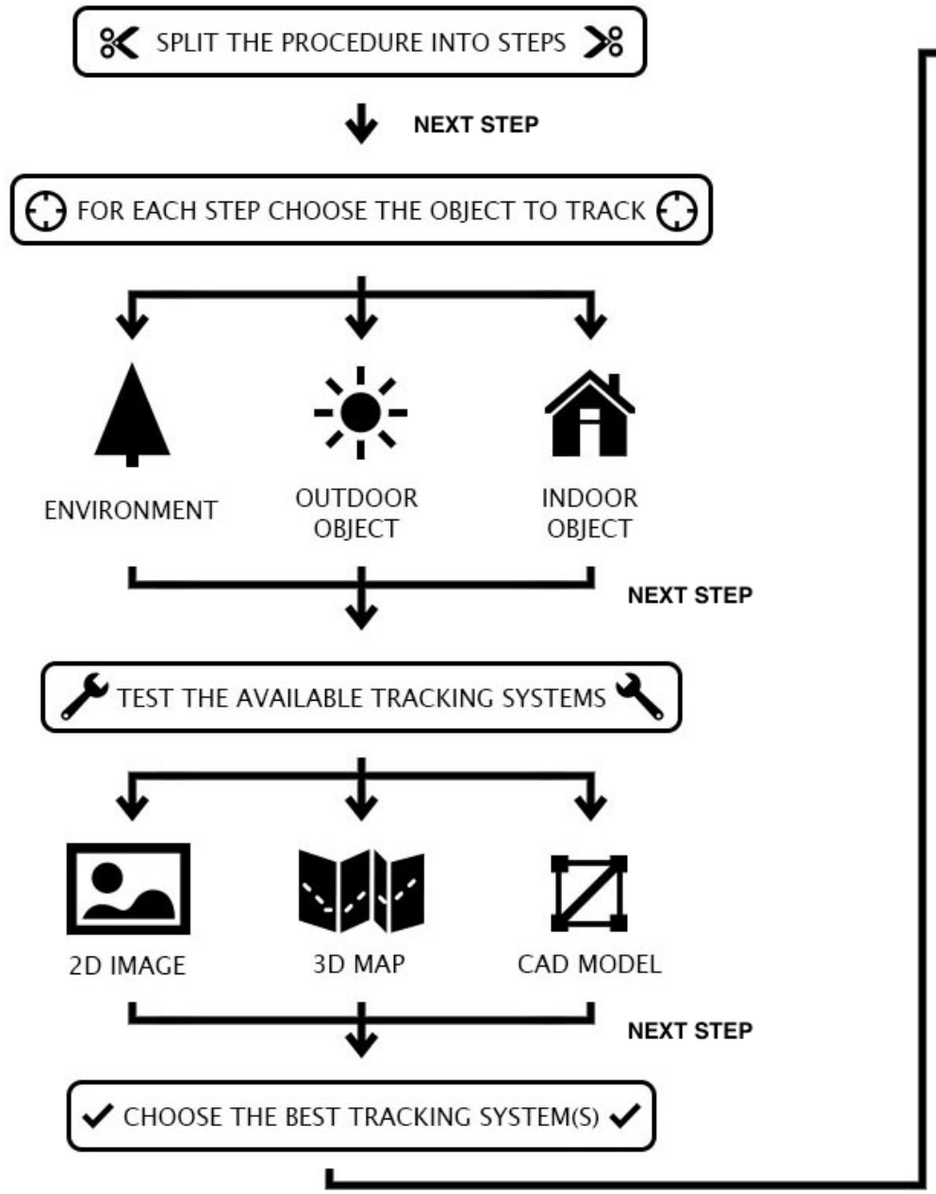

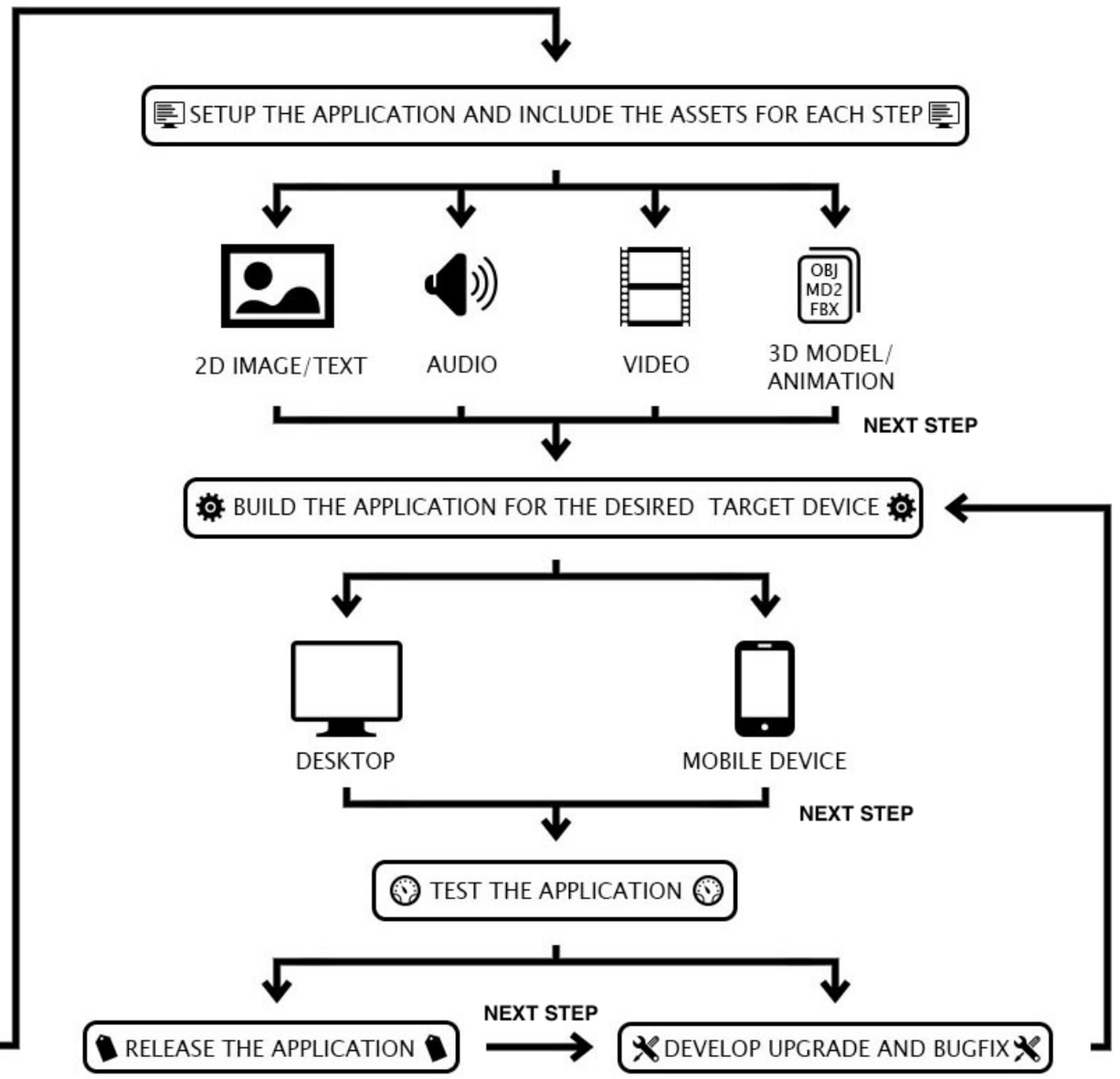

PROPOSED SOLUTIONS: framework architecture

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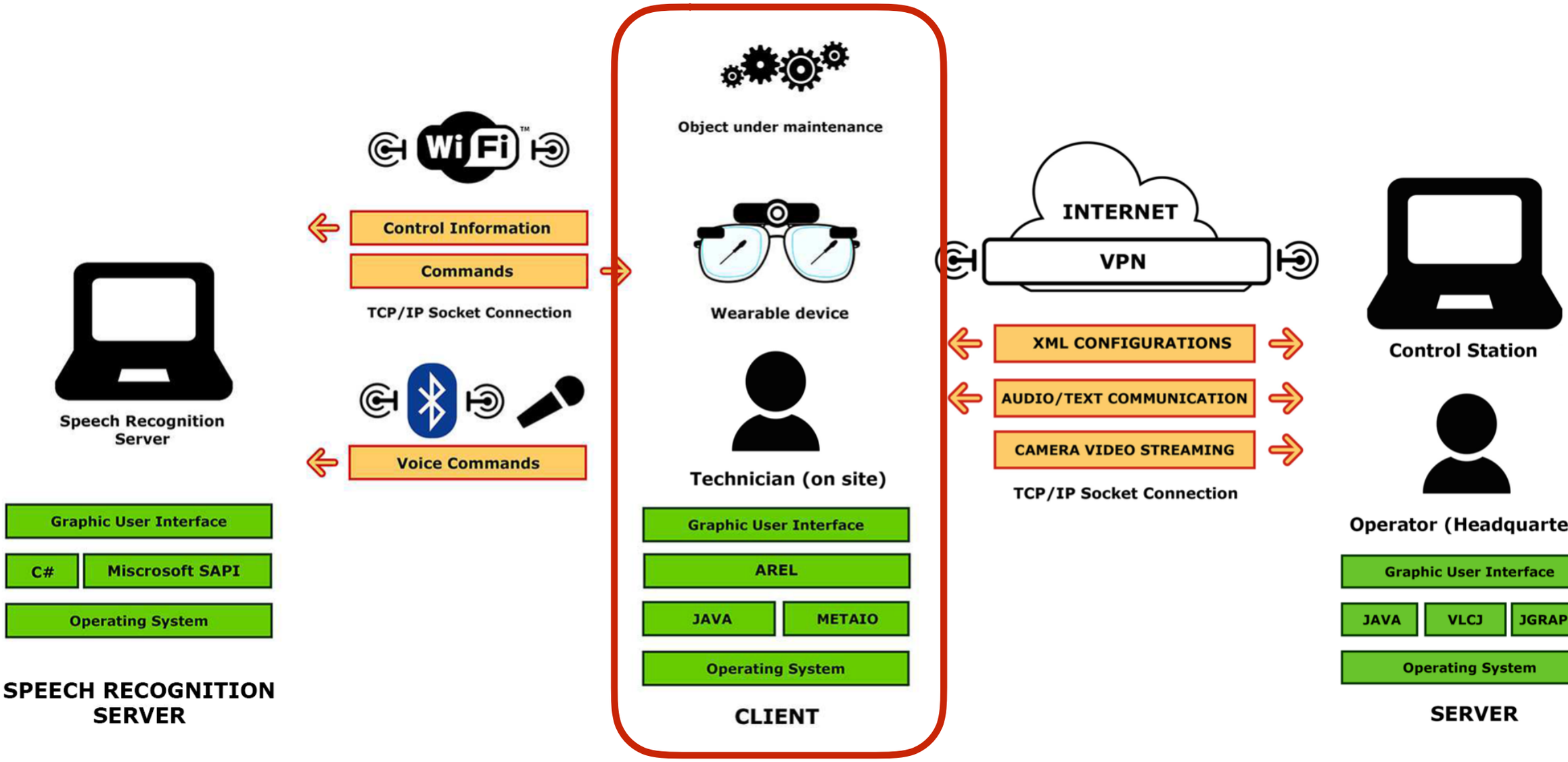
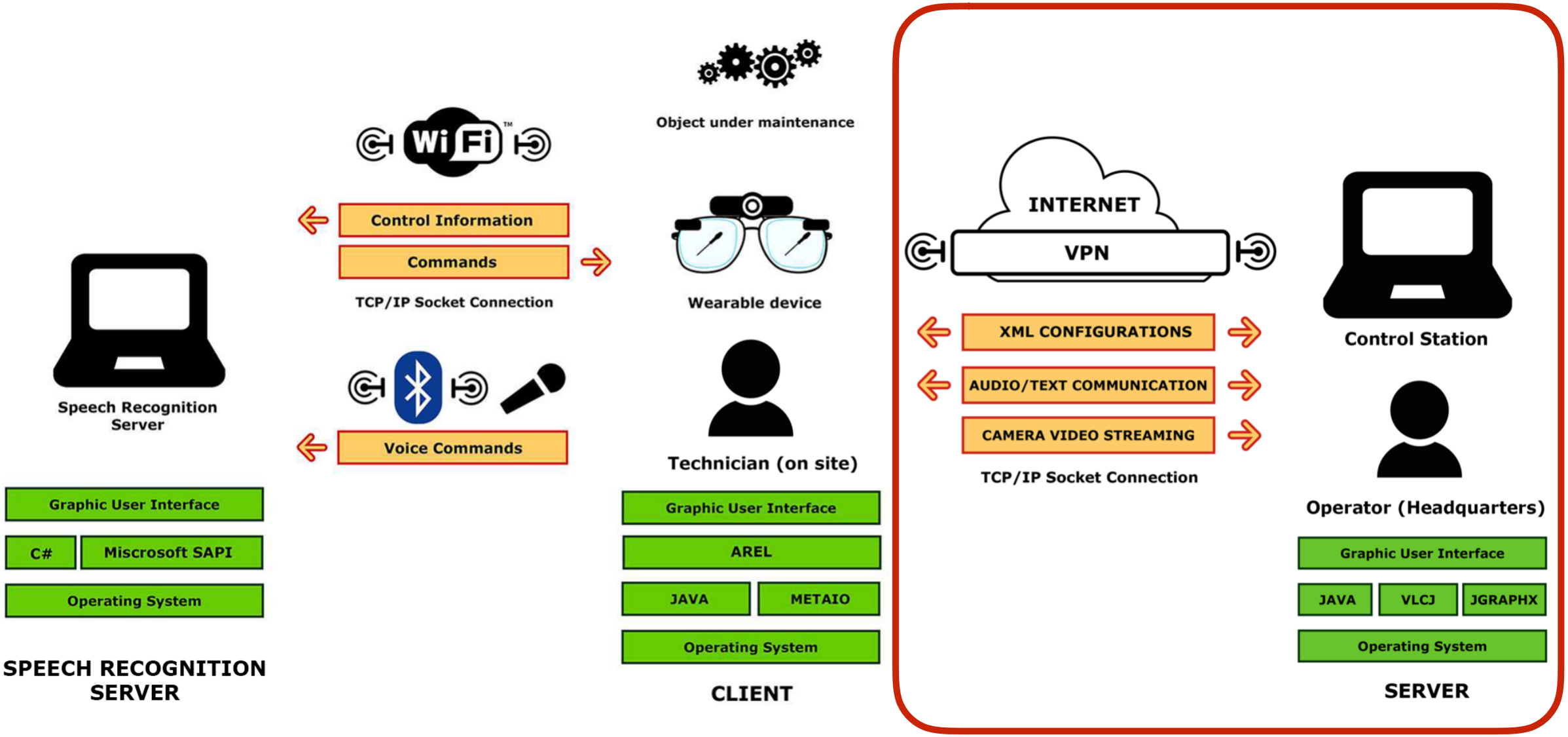


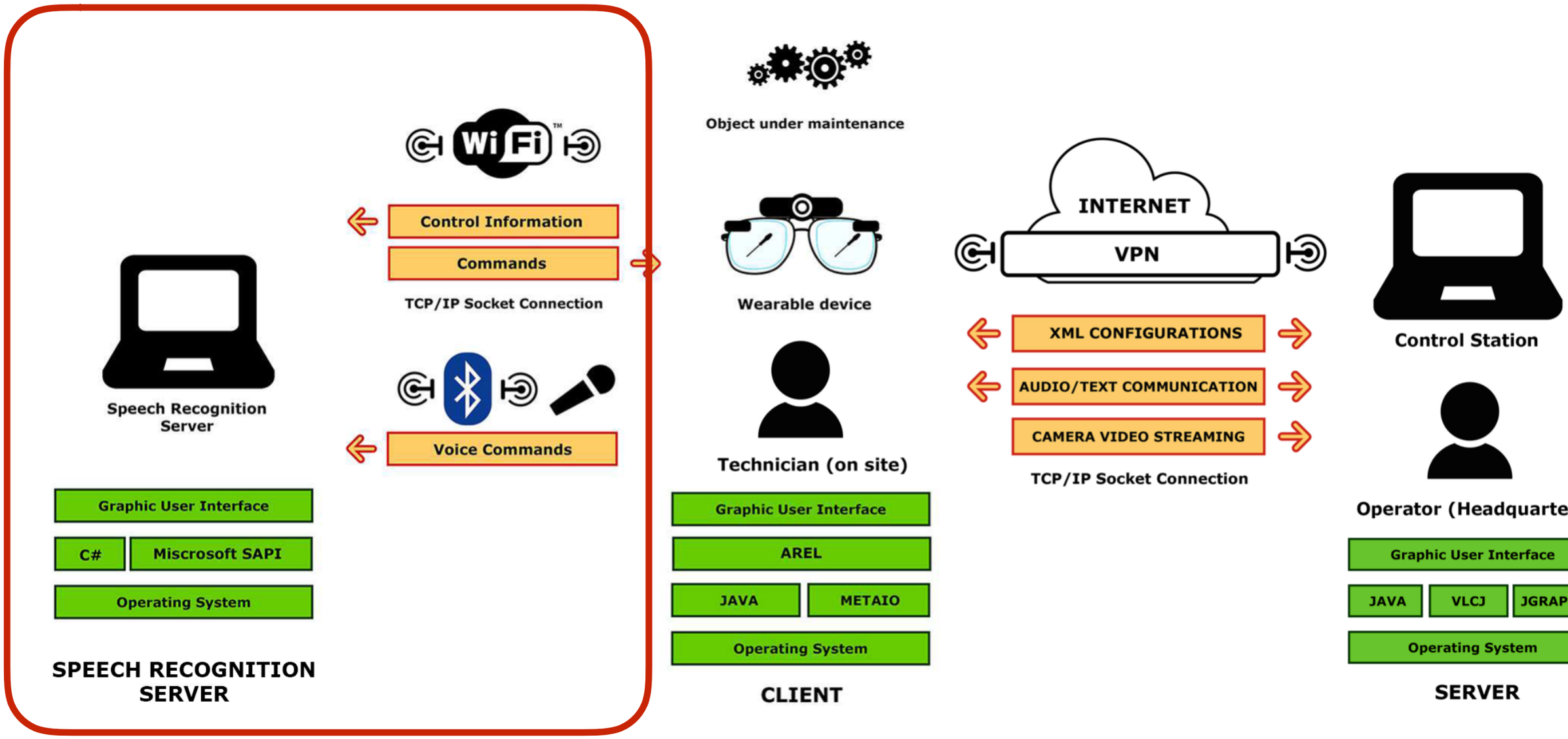
PROPOSED SOLUTIONS: framework architecture

GRAphics and INtelligent Systems group



PROPOSED SOLUTIONS: framework architecture

GRAphics and INtelligent Systems group



PROPOSED SOLUTIONS: server interface

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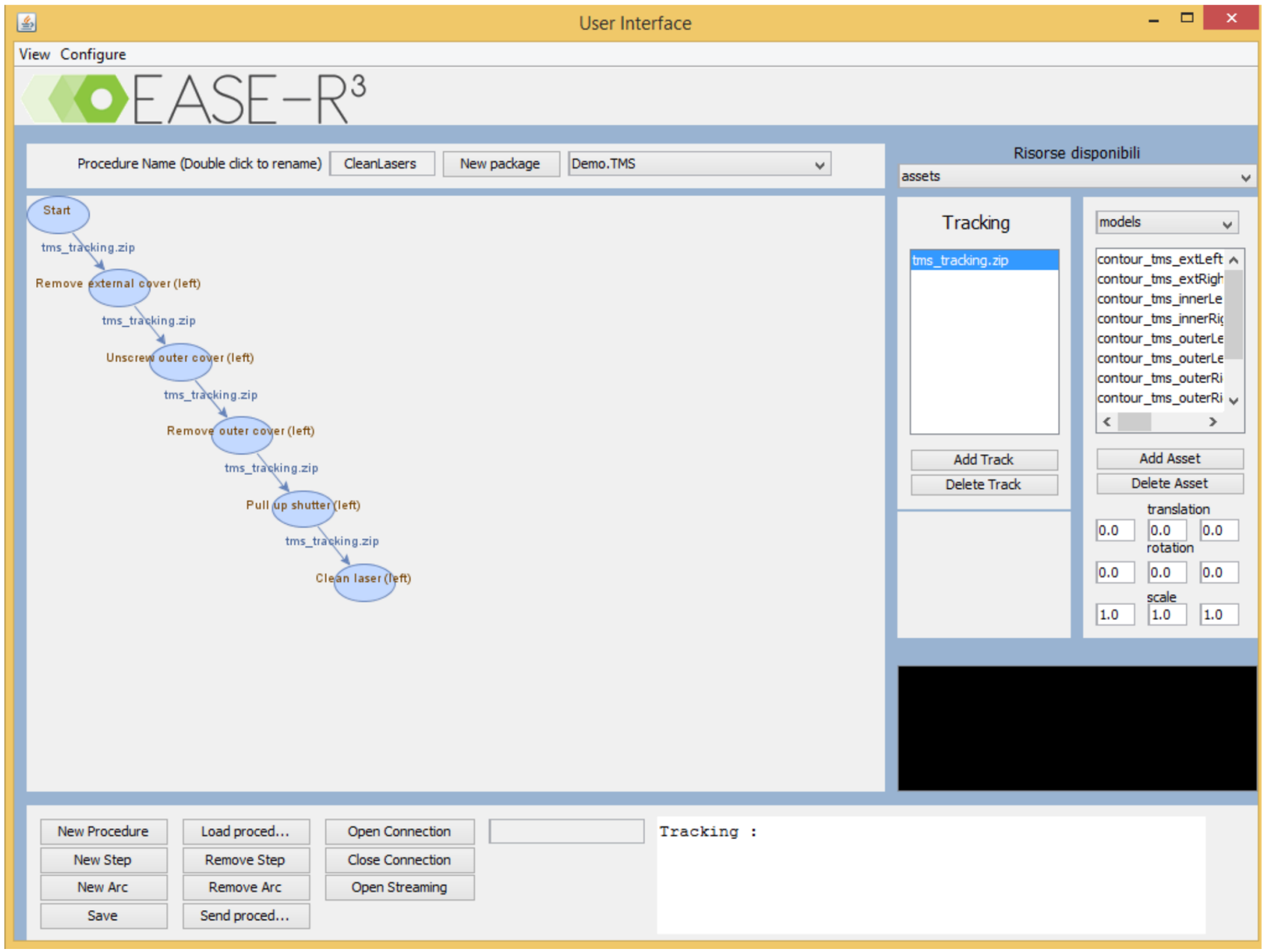
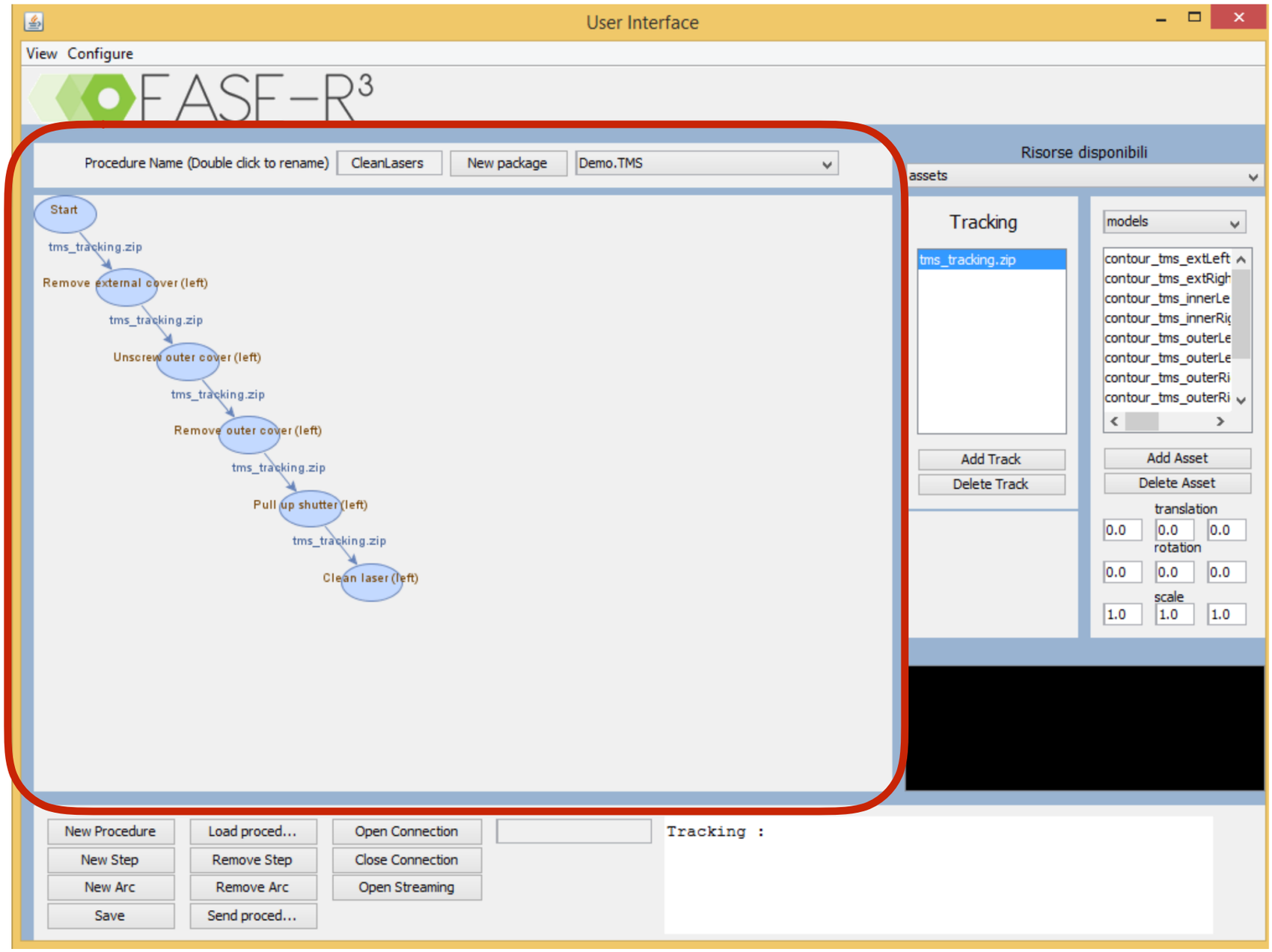


PROPOSED SOLUTIONS: server interface

GRAphics and INtelligent Systems group



State-machine representation

PROPOSED SOLUTIONS: server interface

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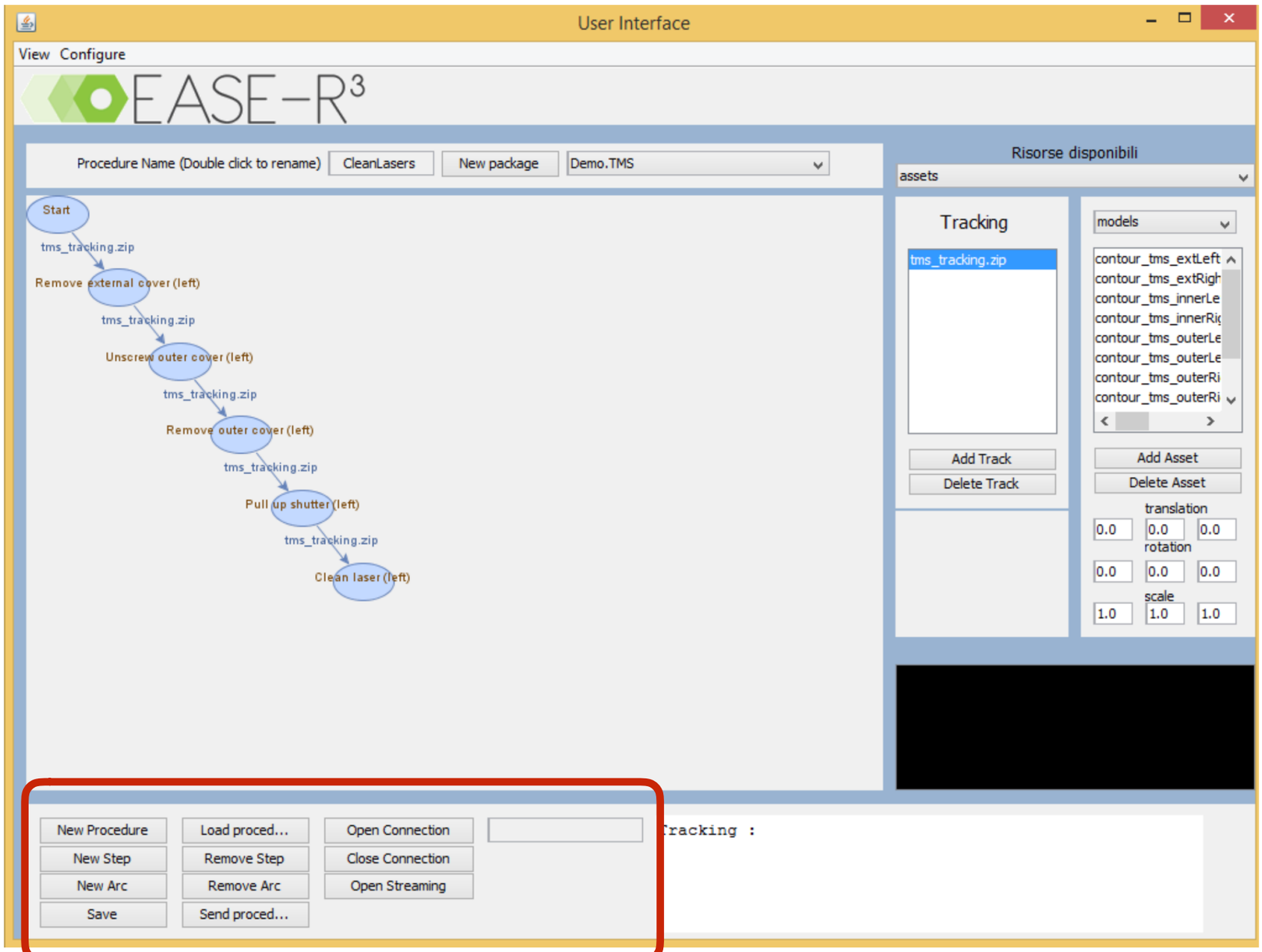

Main Panel

PROPOSED SOLUTIONS: server interface

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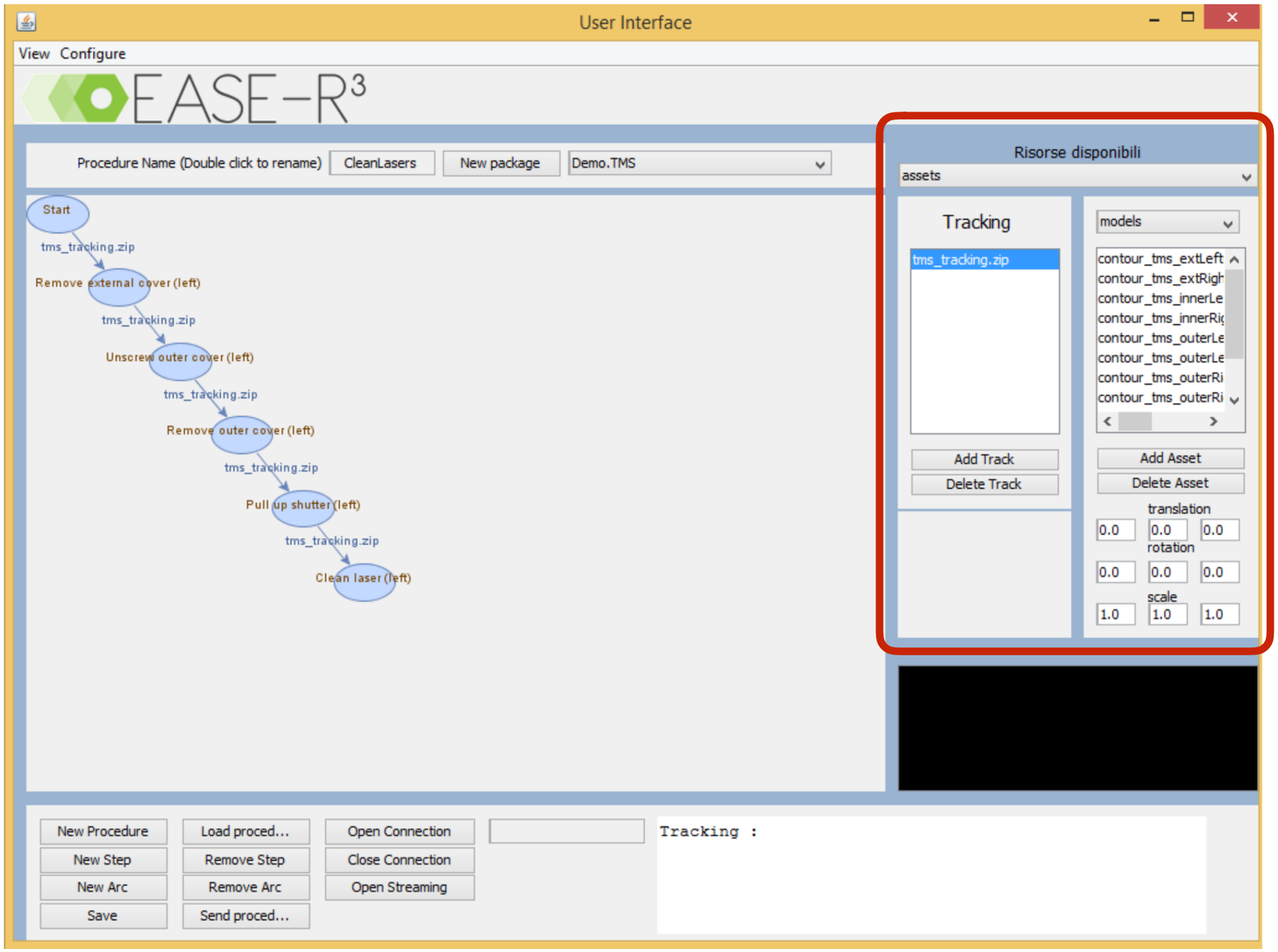

Content Manager

PROPOSED SOLUTIONS: server interface

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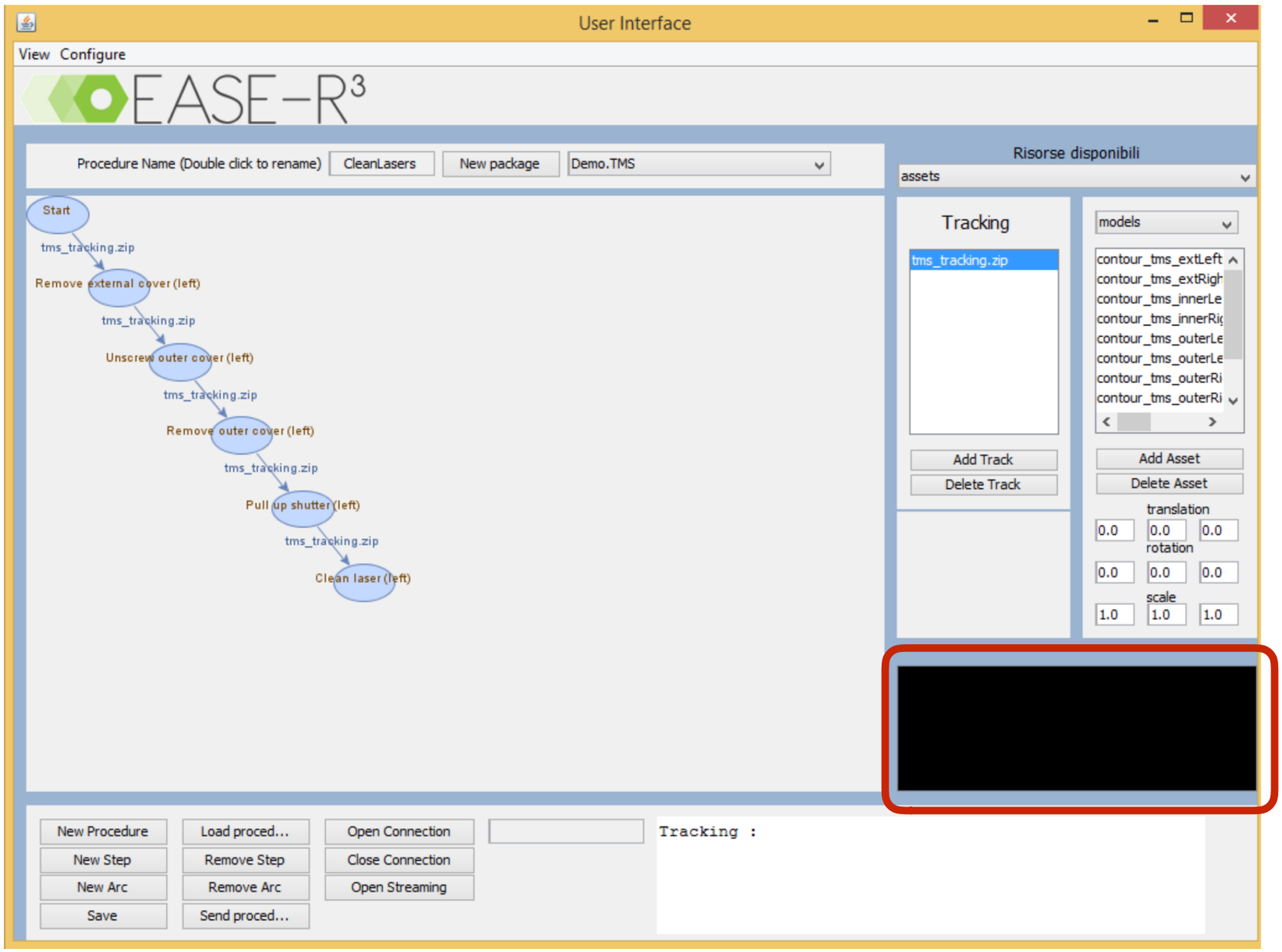

Remote Connection Console

PROPOSED SOLUTIONS: server interface

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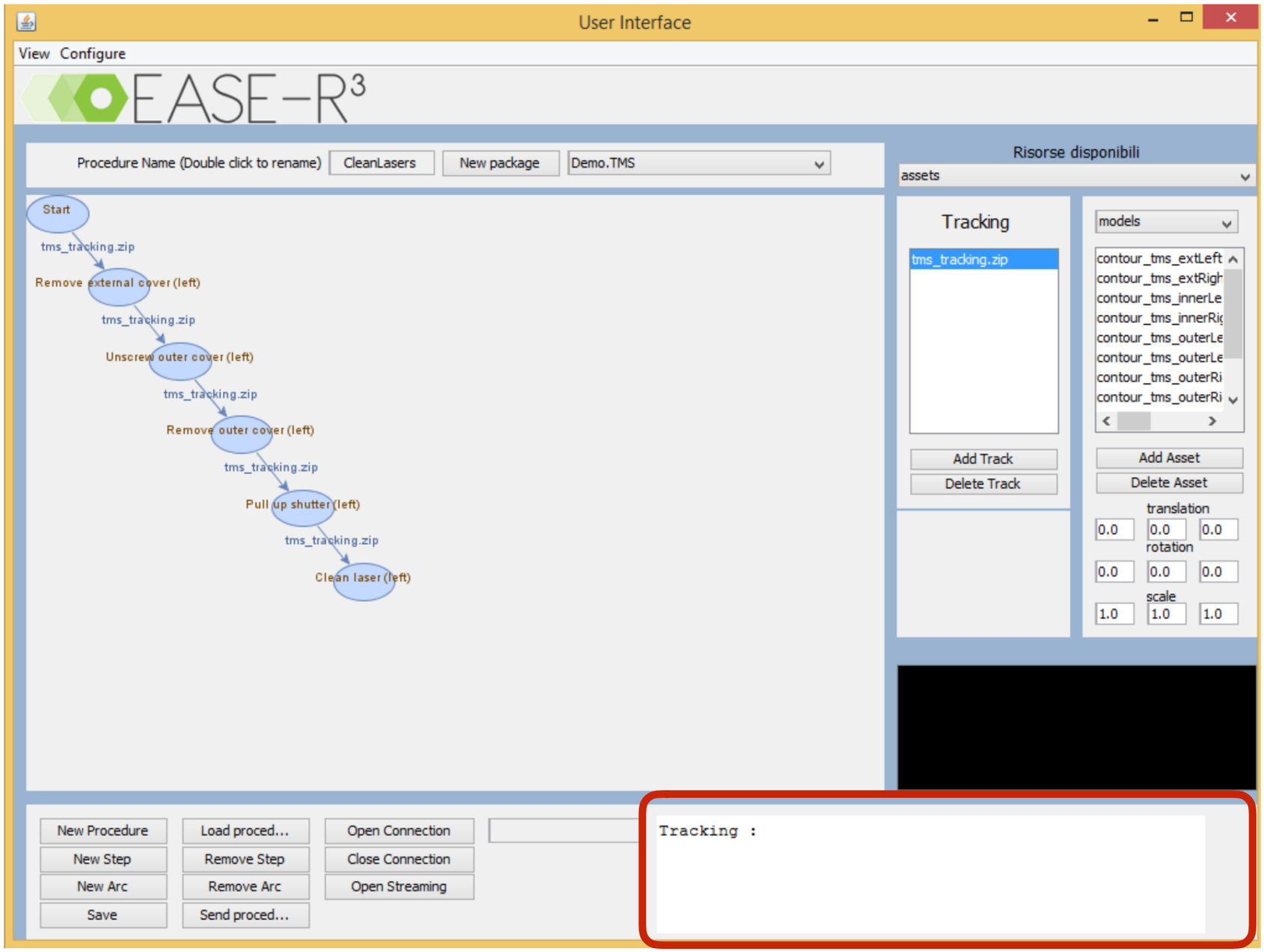

Log Console

PROPOSED SOLUTIONS: an example

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RESULTS & ANALYSIS

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REQUIREMENTS	TABLET	AR GLASSES
MUST		
Allows the user to move through various stages of the procedure.	✓	✓
Real-time support.	✓	✓
Hands-free.		✓
Off-line usage.	✓	✓
Multiple languages.	✓	✓
Menu with a list of available procedures.	✓	✓
SHOULD		
Use of glasses for augmented reality built into helmet.		✓
Don’t stop maintenance to obtain information.		✓
The application recognize the environment machine.		
View support while performing the procedure (having hands free).		✓
Video Capabilities (recording different formats).		
Physical interaction (touch).	✓	
Good Connectivity.	✓	✓
Textual assets.	✓	✓
Visual assets.	✓	✓
Not real-time support is dynamic (virtual).	✓	✓

RESULTS & ANALYSIS (2)

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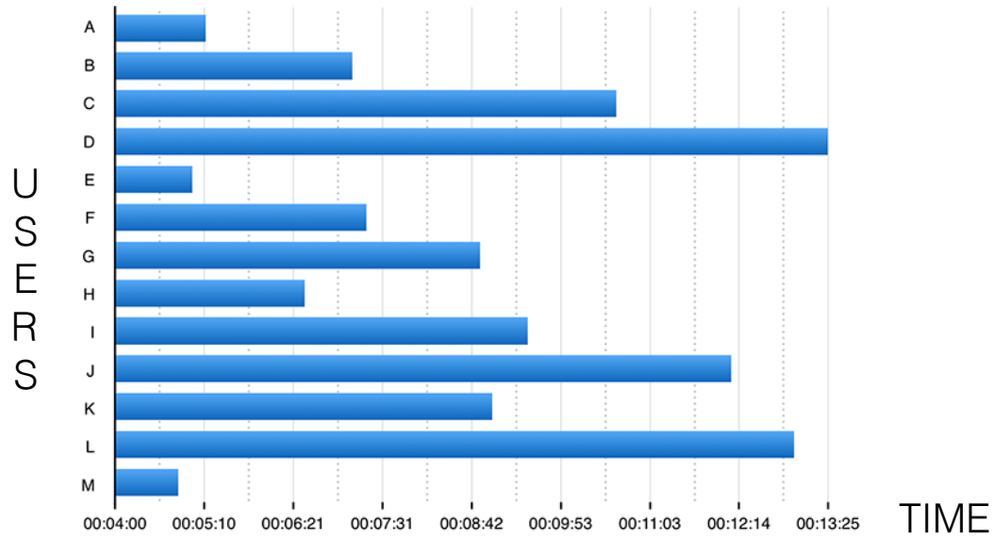
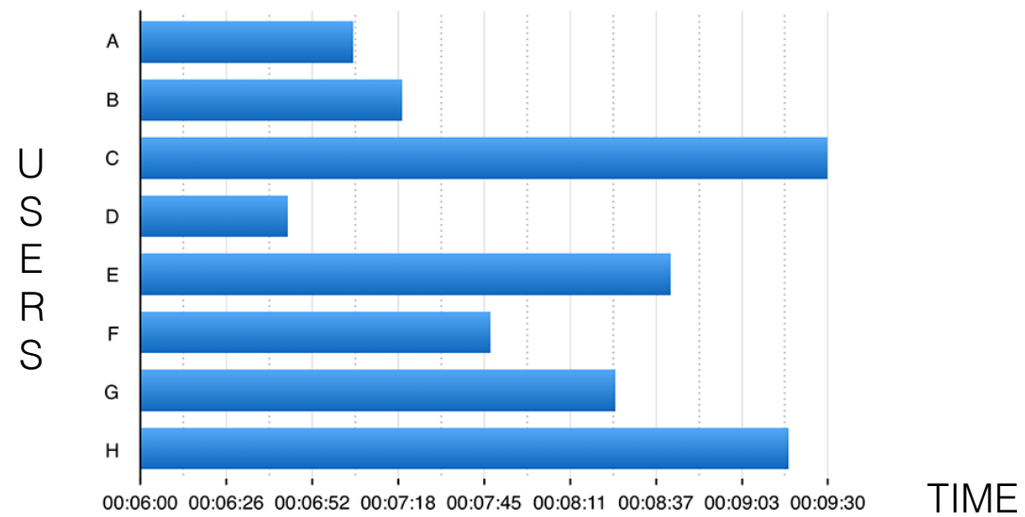
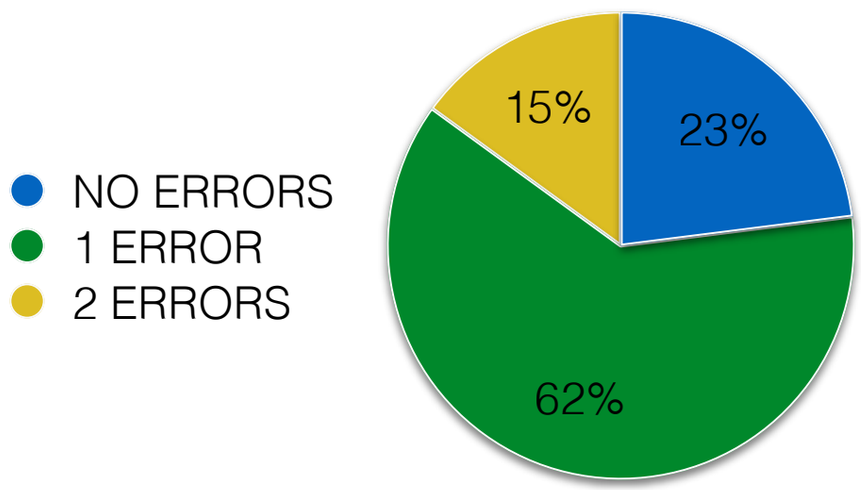
COMPLETION TIME



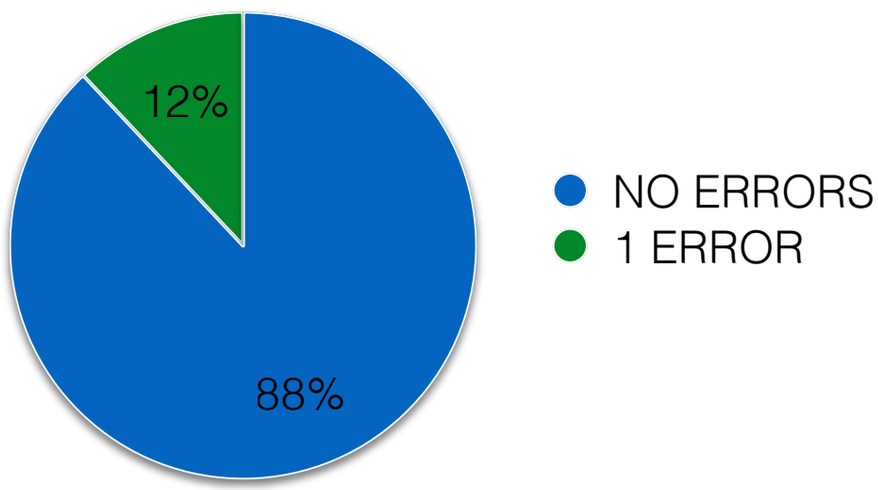


STUDENTS



ERRORS

TECHNICIANS



SEMANTIC VOICE COMMAND BAR

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Problem: reducing cognitive load

Proposed Solution: defining a set of icons that easily evokes the corresponding voice commands

- Questionnaire to associate actions to icons
- Extraction of synonyms and antonyms
- Computation of similarity index
- Mapping between icons and functionalities

PROPOSED SOLUTIONS: an example

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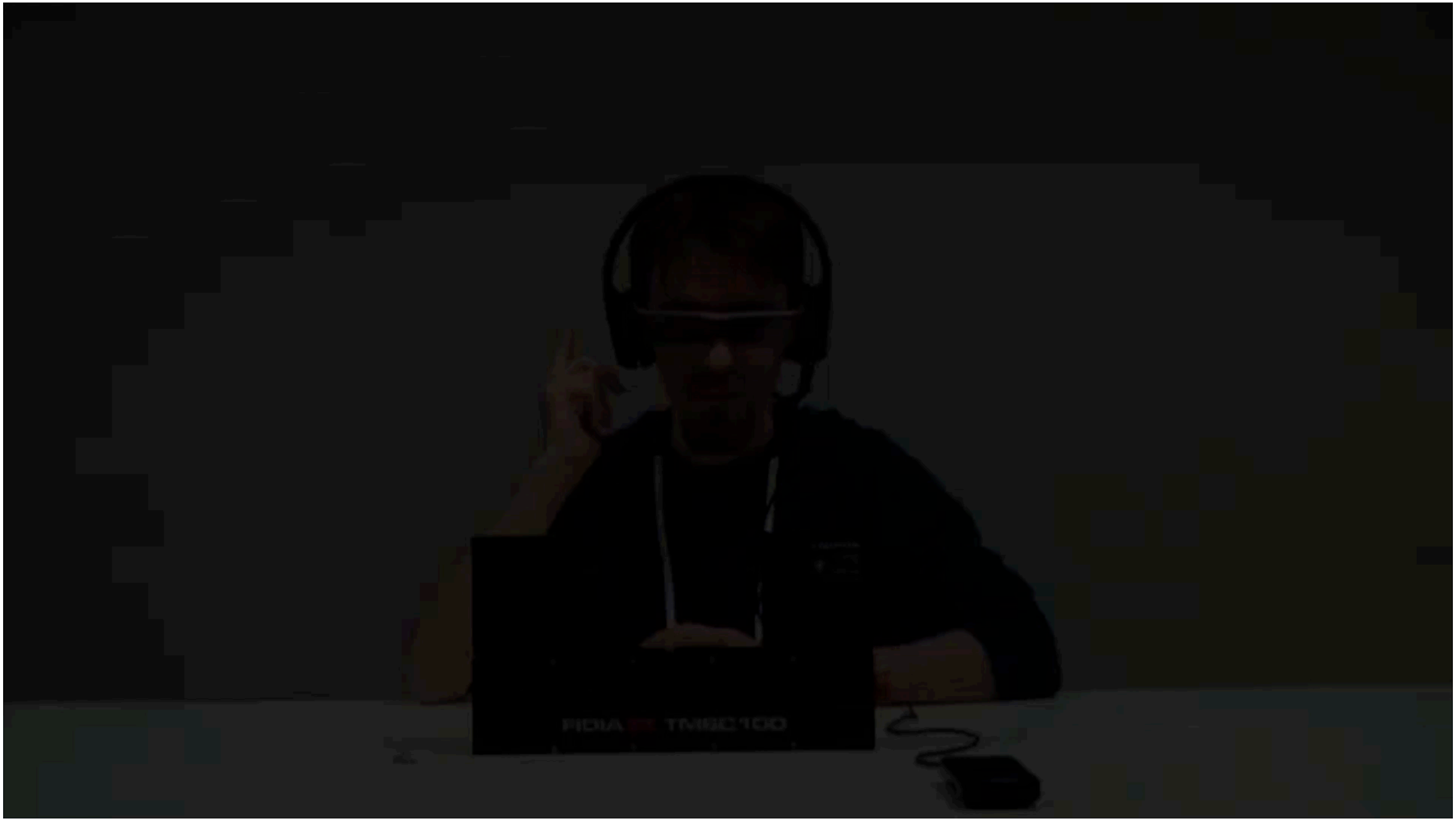

RESULTS & ANALYSIS

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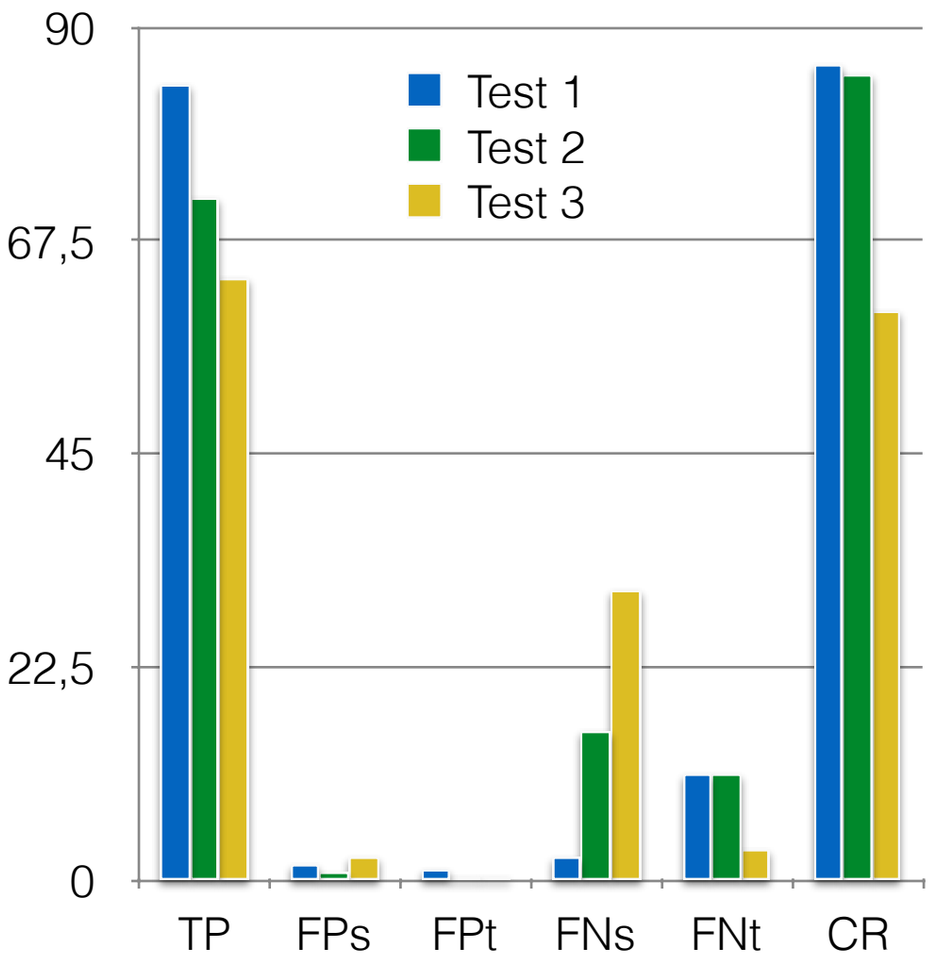
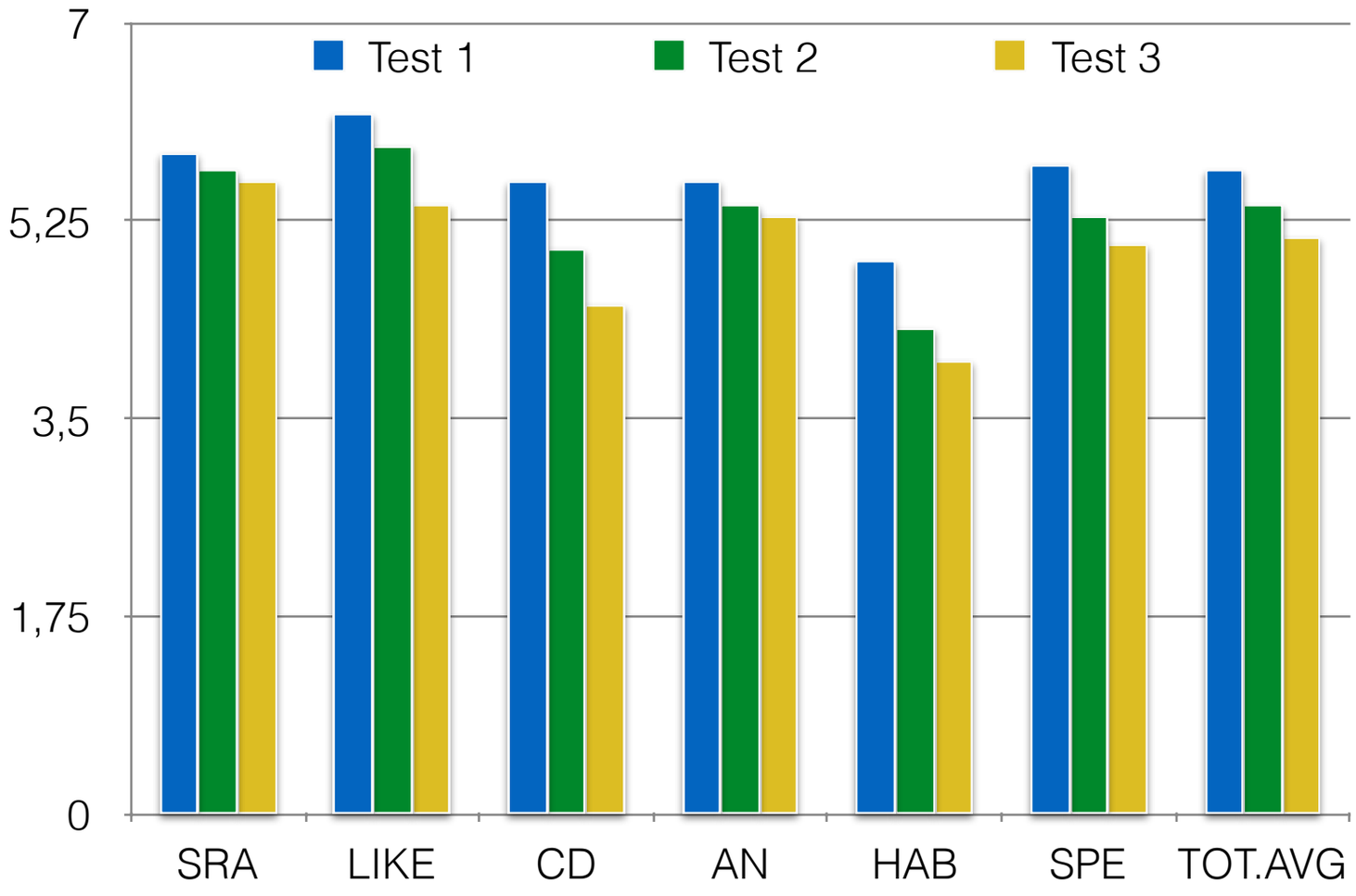


The number of true positives (TP), semantic and technological false positives (Vps and FP_t) and false negatives (FN_s and FN_t), plus the average completion rate (CR) for the given task.



Testers evaluation through SASSI usability principles: System Response Accuracy (SRA), Likeability (LIKE), Cognition Demand (CD), Annoyance (AN), Habitability (HAB), Speed (SPE) and Total Average (TOT.AVG).

ROBUST VOCAL INTERFACE

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- Problem: robustness in noisy environments
- Proposed Solution: designing an developing a vocal version of a one switch interface

AVOS

IVOS

BVOS

OBJECTIVE RESULTS

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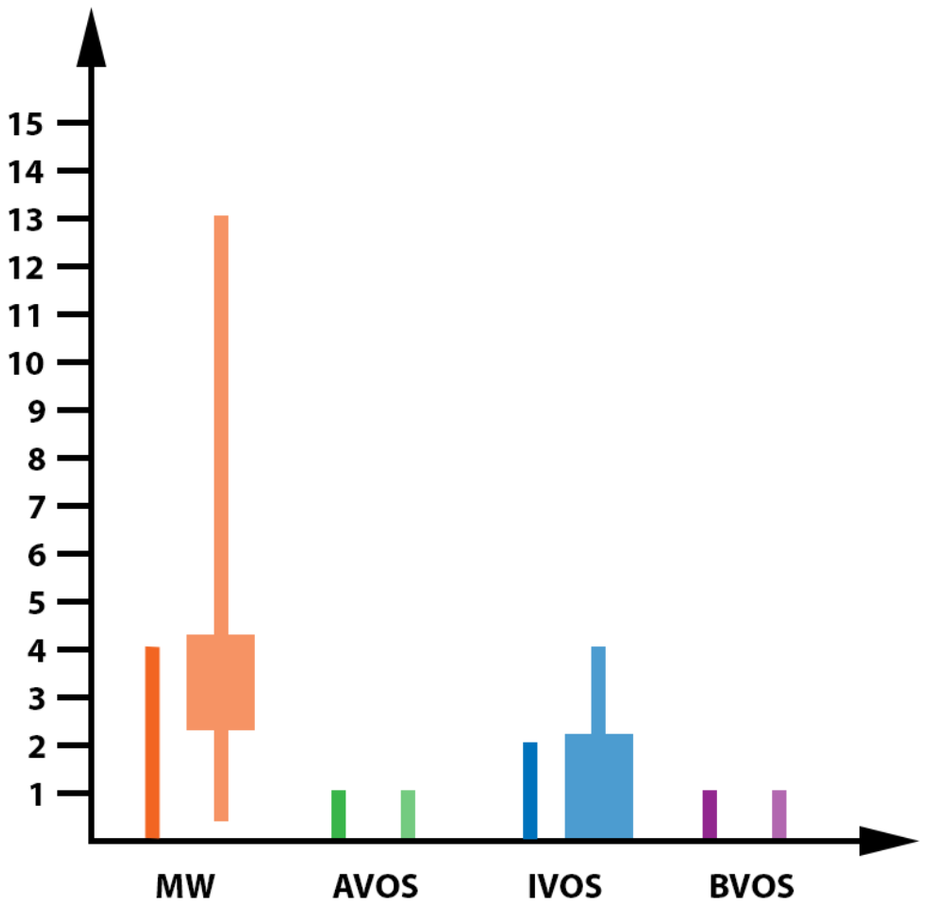
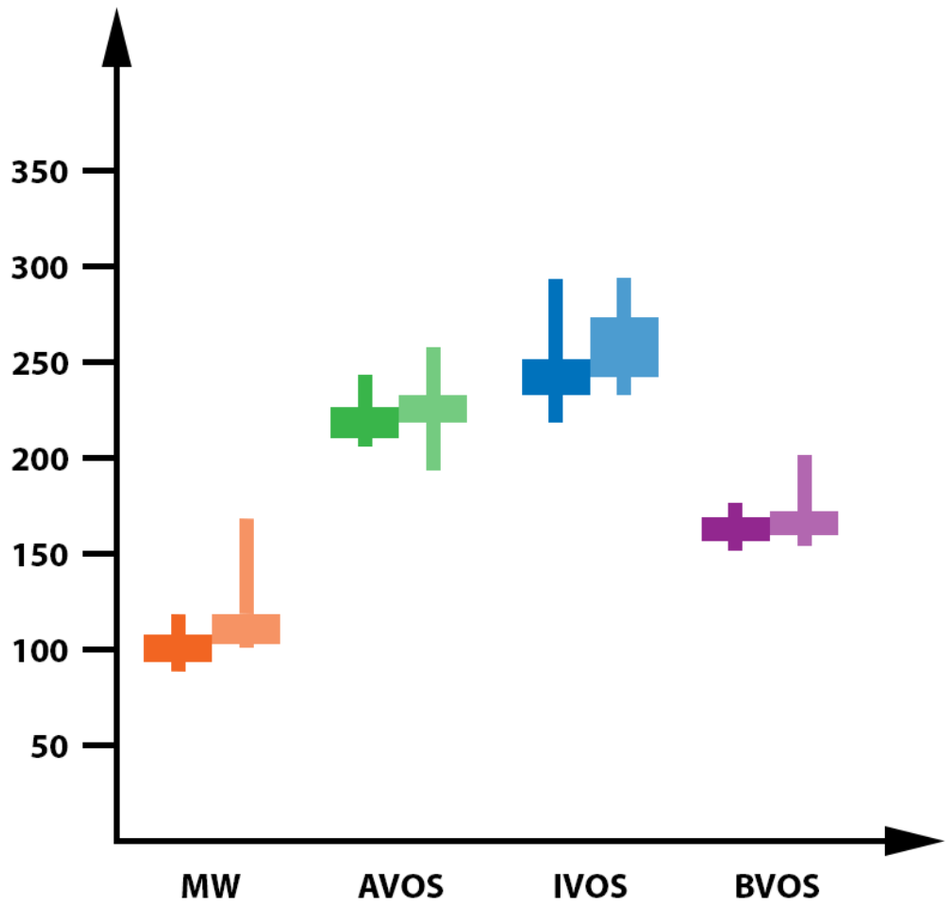
NUMBER OF ERRORS



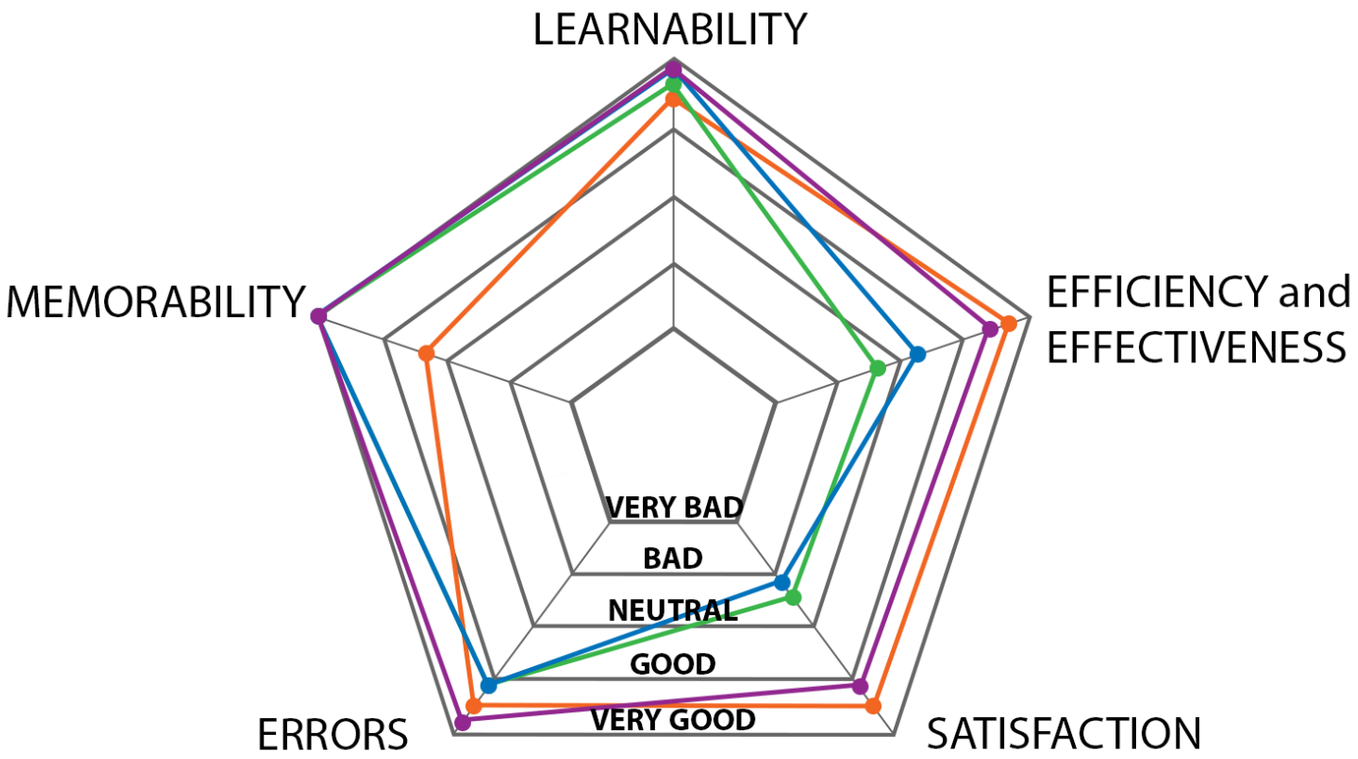
COMPLETION TIME IN SECONDS



WITHOUT NOISE

WITH NOISE

SUBJECTIVE RESULTS



NIELSEN USABILITY PRINCIPLES

SUBJECTIVE RESULTS

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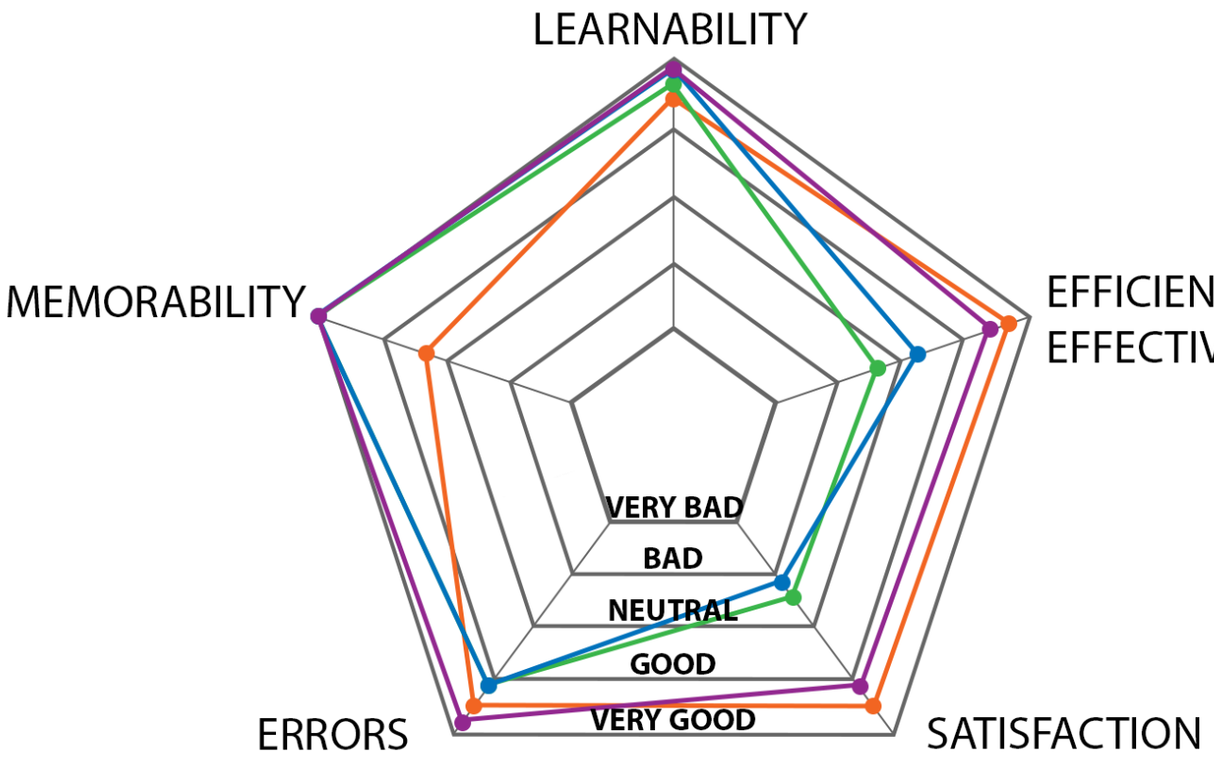
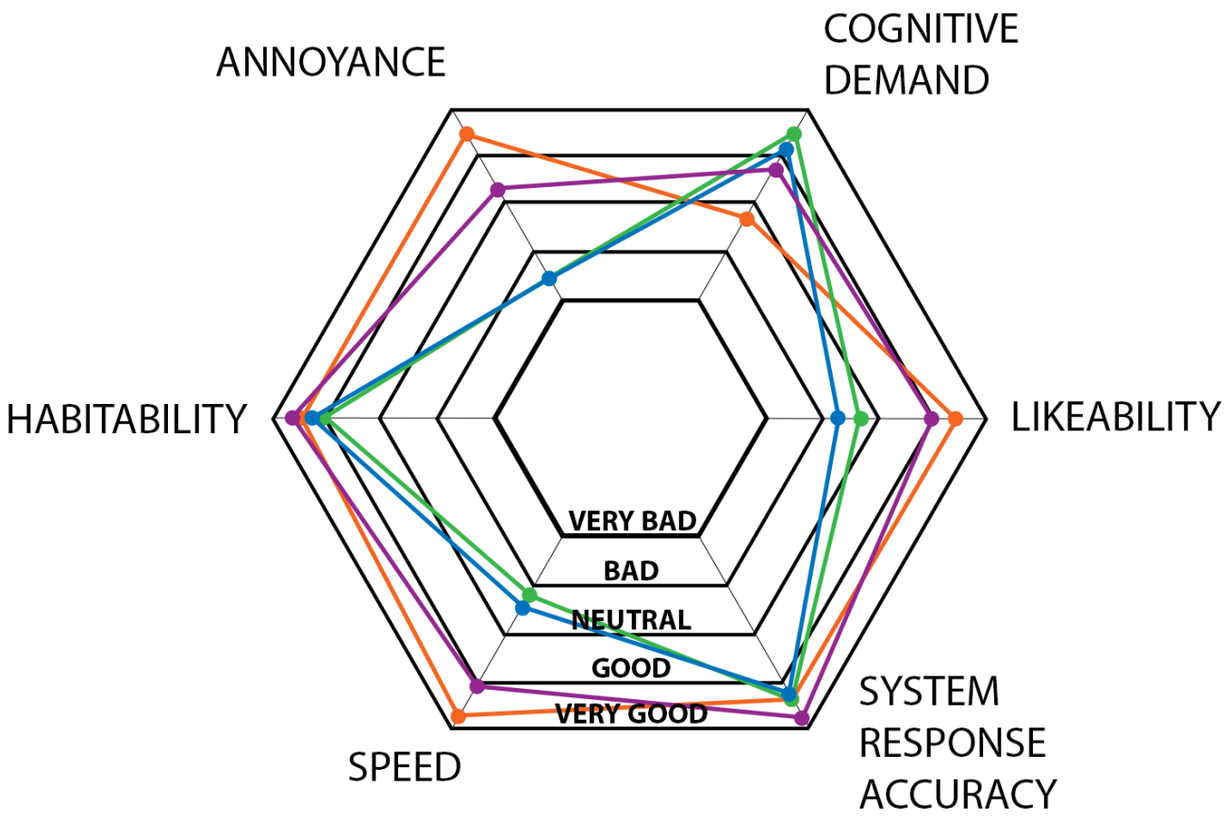


NIELSEN USABILITY PRINCIPLES

SASSI USABILITY PRINCIPLES



CONCLUSIONS & FUTURE WORKS

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CHALLENGES	COMPLETION	OPEN PROBLEMS	FUTURE WORKS
Pose Tracking		CAD TRACKING OF SIMPLE OBJECTS	FURTHER INVESTIGATION OF TRACKING ALGORITHMS
		RECOGNITION OF CURRENT STEP COMPLETION	
Content Creation			
Reconfigurability		MULTIPLE CHOICES FROM A GIVEN NODE	RELATED TO TRACKING CAPABILITY
Interface Design		COGNITIVE DEMAND COULD BE REDUCED	FURTHER INVESTIGATION OF SPEECH RECOGNITION SOLUTIONS AND ONE SWITCH SOLUTIONS
Robustness of the interface		RECOGNITION ERRORS COULD BE REDUCED	
		PERCEIVED ANNOYANCE COULD BE REDUCED	
Training Systems		VIDEO RECORDING CAPABILITY	RELATED TO TECHNOLOGY
Technology Acceptance		IMPROVING USABILITY	FURTHER INVESTIGATION OF HARDWARE INTERFACES

VIS - CONTEXT & MOTIVATIONS

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"Big Data is high volume, high velocity, and/or high variety information assets that require new forms of processing to enable enhanced decision making, insight discovery and process optimization"

- Many possibilities in terms of enhancing existing instruments or creating new ones.
- Multivariate Data Visualization is relevant in many different domains such as finance, environment, automotive
- Analyzing and researching existing visualization tools to improve their usability

APPLICATION DOMAINS

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Digital Marketing Optimization

Data Exploration and Discovery

Fraud Detection and Prevention

Machine-Generated Data Analytics

Social Network and Relationship Analysis

STATE OF THE ART

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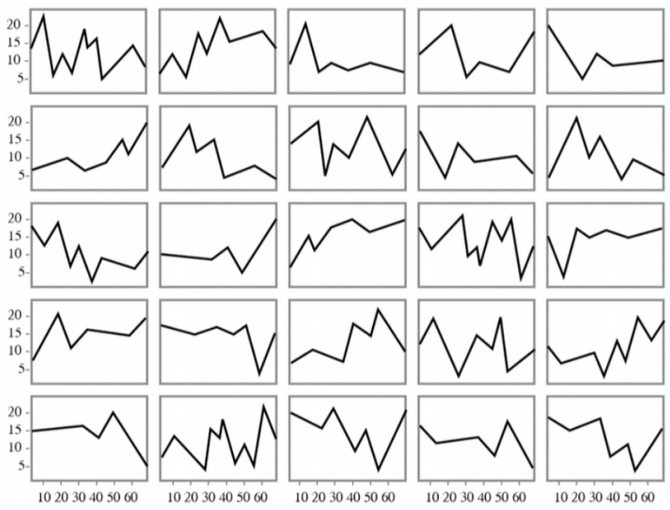
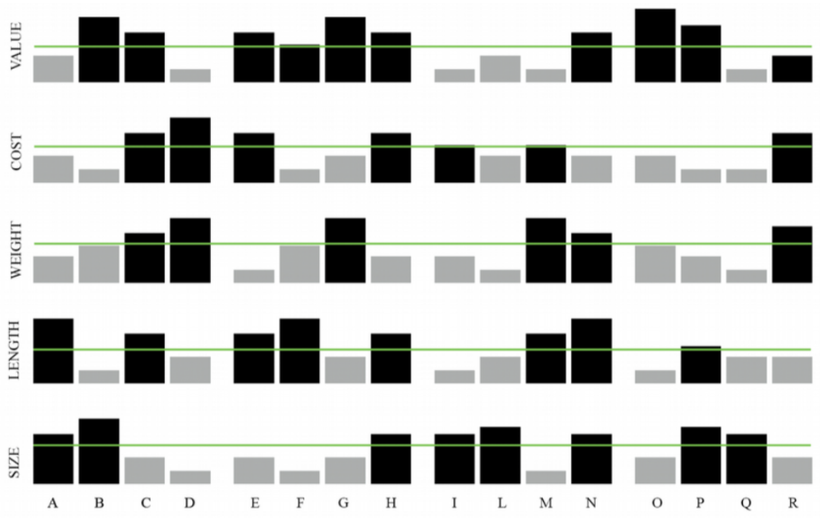
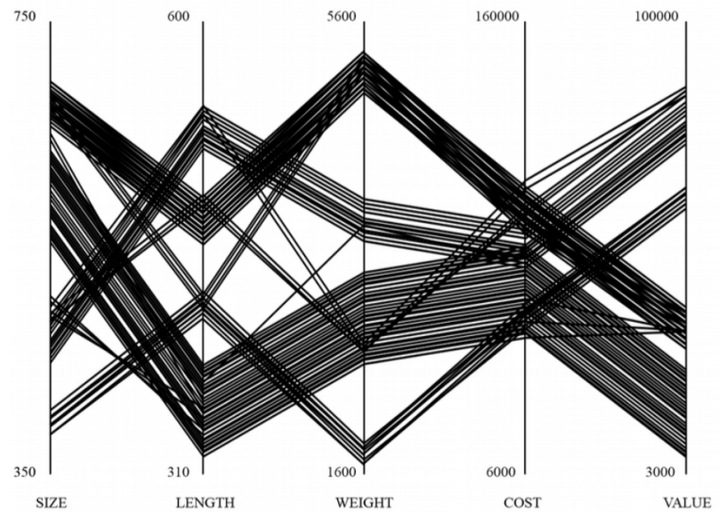
Small Multiplies

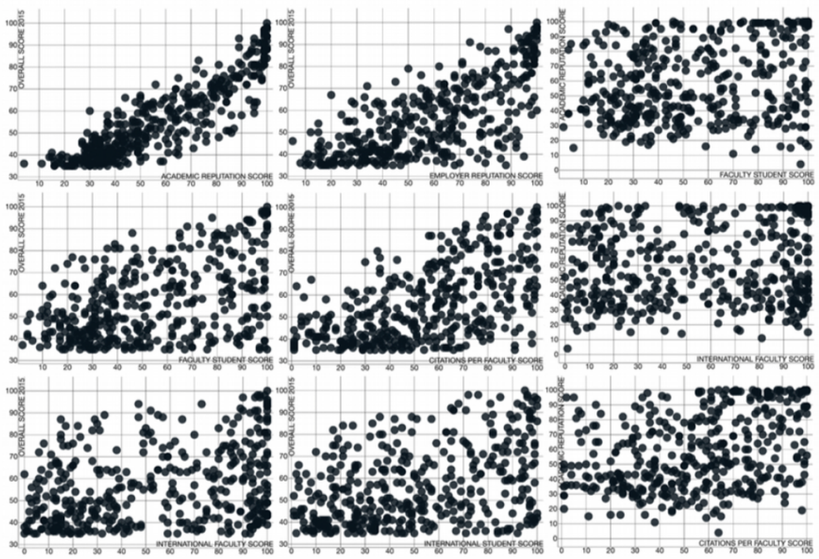


Permutation Matrix

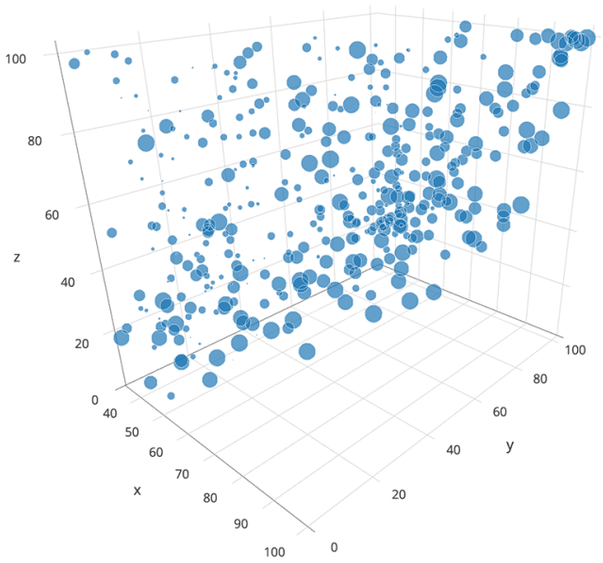


Parallel Coordinates

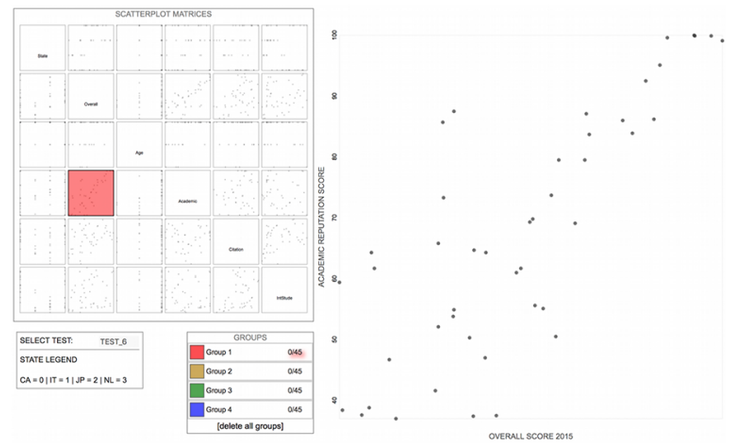




Scatterplot Matrix



3D Scatterplot



ScatterDice

PROBLEMS

- It could be difficult to correctly understand all the pertinent information for a specific domain/task at a given time
- Time-related task could lead to errors and misunderstanding of the data
- Depending on the variables, some graphic effects are more pertinent and understandable than other for different kind of variables
- Some kind of variables are traditionally displayed with specific graphic effects and changing this practice may lead the user to misunderstanding

METHODOLOGY

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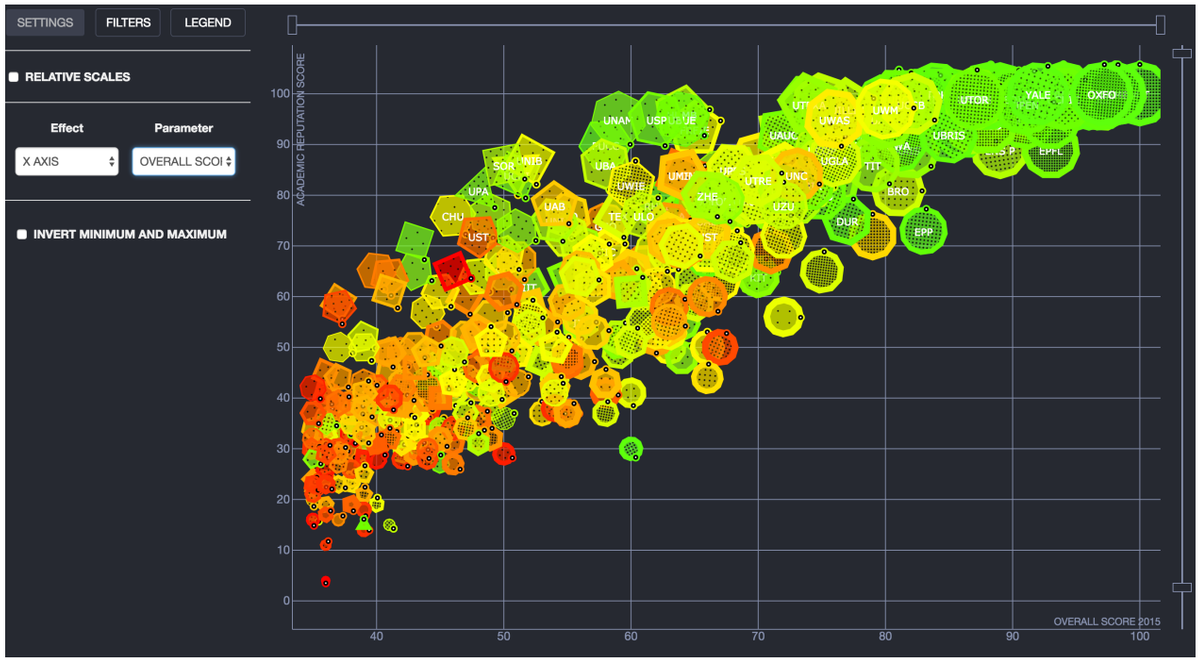
- Understanding and classifying all the variables pertinent to a specific domain/task and identifying the most important ones
- Analyzing the state of the art to point out which graphic effects could be more significant for each variables, in order to add them to an existing visualization tools
- Designing and developing a prototype to asses the given problem
- Testing the prototype with a group of users pertinent to the specific domain/task to get feedback

PROPOSED SOLUTION

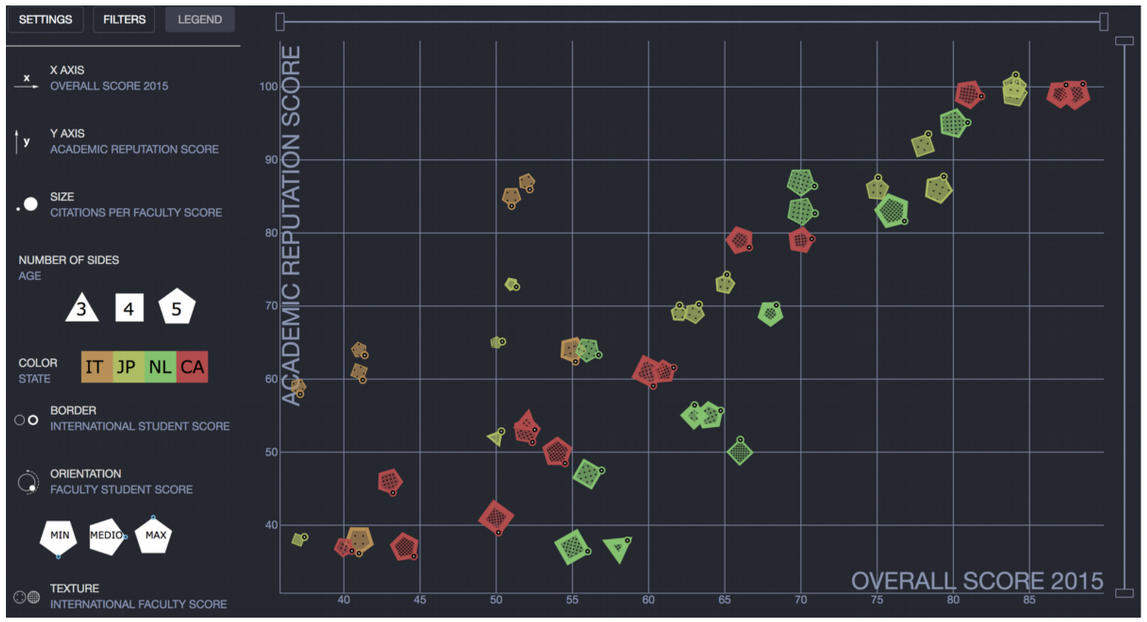
- Improve the scatterplot visualization tool adding graphical effects

- The tool is customizable depending on the domain and user preferences

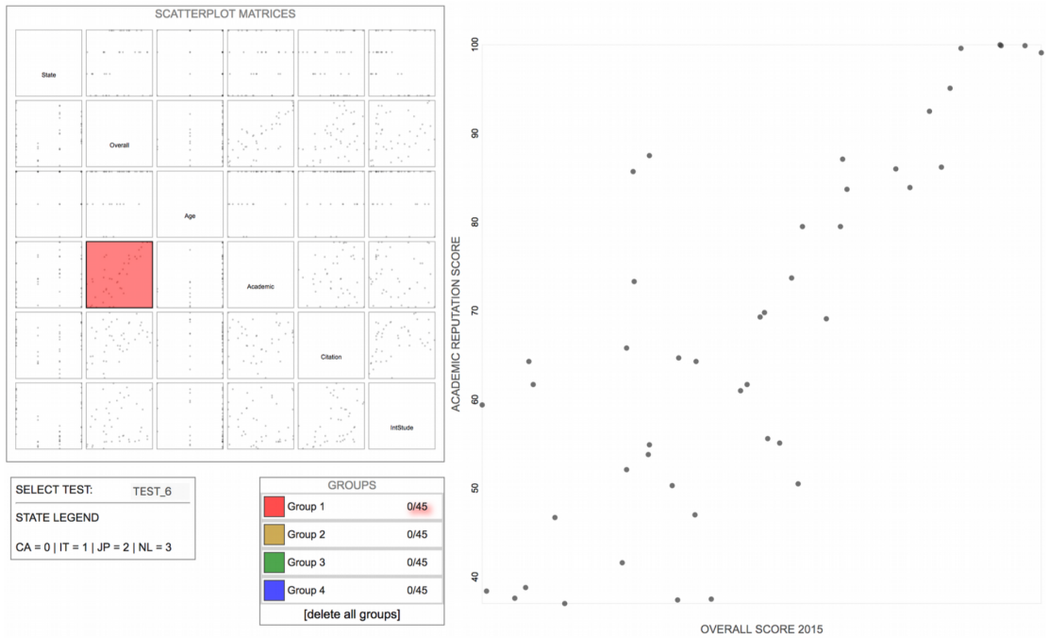


- Instead of multiple visualizations with less variable, one visualization that contains all the relevant information

TESTS



VS



QS World University Ranking Dataset

QS world university ranking. http://www.iu.qs.com/university-rankings/world-university-rankings/

RESULTS & ANALYSIS

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- Almost everyone was able to correctly complete the given task
- Everyone completed the most difficult task with both tools

Question	SD	MS
1. Is it easy to use the tool the first time?	2.6	3.5
2. Is it easy to use the tool after practicing it?	3.6	3.9
3. Was it easy to carry out the given task with the proposed tool?	3.0	3.5
4. How much difficult was the proposed task?		
task number one	2.3	1.8
task number two	2.4	2.1
task number three	2.5	2.3
5. Is the tool quick to use/examine?	2.7	3.7
6. Does the tool require a high cognitive demand to be used?	2.7	2.2
7. Give an overall score to the tool	3.8	4.5

ScatterDice (SD) and Multidimensional Scatterplot (MS) subjective evaluation

CONCLUSIONS & FUTURE WORKS

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Multivariate Data Visualization

- A set of best practices to support the design and development has been defined
- Evaluating the efficacy of different visualization techniques to increase the dimensions displayable through the multidimensional scatterplot
- The comparison should be reinforced considering different datasets and use cases
- Analyzing and researching animated graphic effects to enhance data comprehension of real time visualizations

THANKS FOR YOUR ATTENTION

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Questions & Answers