UNIVERSITÀ
DEGLI STUDI
DI BERGAMO

Dipartimento
di Ingegneria Gestionale,
dell'Informazione e della Produzione

XR for Rehabilitation

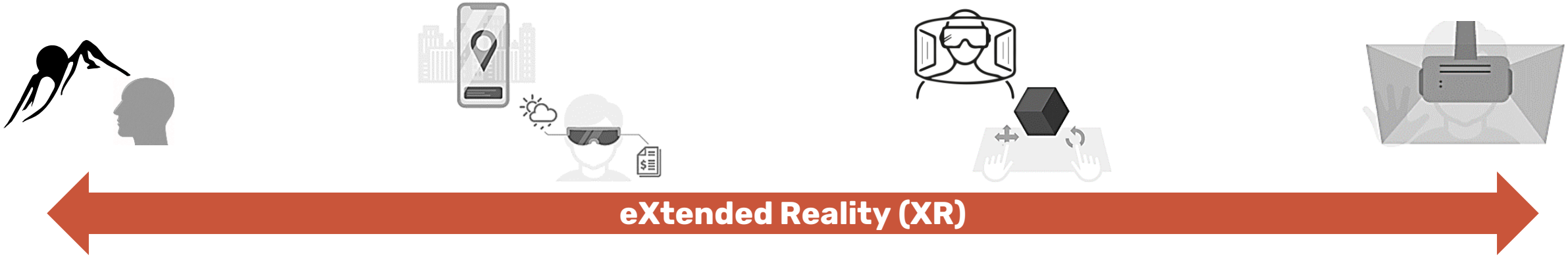
Prof. CATERINA RIZZI
Prof. DANIELE REGAZZONI
Prof. ANDREA VITALI

UNIVERSITY OF BERGAMO

Outline

- EXtended Reality (XR)
- Types of VR Systems
- VR and emulation of 5 Senses
- VR Devices
  - VR Cave
  - Head Mounted Display
  - Hand Tracking Devices
  - Haptic Devices
  - VR devices for Smell
- Design of Natural User Interfaces (NUIs) for VR
- Development Environments for VR
- Method to design VR Serious Games for Rehabilitation
- Cases Study
  - Medical assessment test of extrapersonal neglect using virtual reality
  - Virtual reality platforms for the medical rehabilitation of severe memory loss after brain stroke

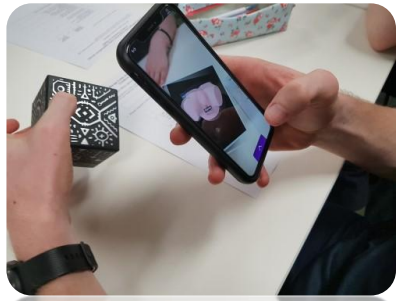
XR: VIRTUAL AND REAL WORLDS TOGETHER



- **WHAT IS THE EXTENDED REALITY - XR?**
  - A TERM REFERRING TO ALL REAL-AND-VIRTUAL COMBINED ENVIRONMENTS AND HUMAN-MACHINE INTERACTIONS GENERATED BY COMPUTER TECHNOLOGY AND WEARABLES [1].

[1] Fast-Berglund, Å., Gong, L., & Li, D. (2018). Testing and validating Extended Reality (xR) technologies in manufacturing. Procedia Manufacturing, 25, 31-38.

XR: VIRTUAL AND REAL WORLDS TOGETHER



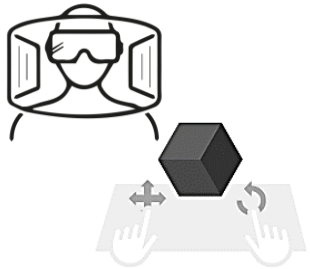
eXtended Reality (XR)

Augmented Reality (AR)

- **AUGMENTED REALITY - AR**
  - USERS SEE BOTH REAL SCENES AND VIRTUAL OBJECTS THAT DO NOT EXIST IN THE REAL-WORLD AT THE SAME TIME [2]
  - VISUALIZATION BY MEANS OF **SMARTPHONES** OR **SMART GLASSES**
  - **INTERACTION LIMITED TO THE INTERFACE OF THE AR DEVICE**

[2] He, Z., Sui, X., Jin, G., & Cao, L. (2019). Progress in virtual reality and augmented reality based on holographic display. Applied Optics, 58(5), A74-A81.

XR: VIRTUAL AND REAL WORLDS TOGETHER



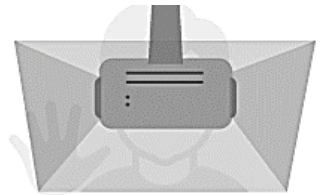
eXtended Reality (XR)

Mixed Reality (MR)

- **MIXED REALITY - MR**
  - USERS SEE BOTH REAL SCENES AND VIRTUAL OBJECTS THAT DO NOT EXIST IN THE REAL-WORLD AT THE SAME TIME [2]
  - VISUALIZATION BY MEANS OF **HEAD MOUNTED DISPLAYS**
  - **INTERACTION USING HAND GESTURES**

[1] Fast-Berglund, Å., Gong, L., & Li, D. (2018). Testing and validating Extended Reality (xR) technologies in manufacturing. Procedia Manufacturing, 25, 31-38.

XR: VIRTUAL AND REAL WORLDS TOGETHER



eXtended Reality (XR)

Virtual Reality

- **VIRTUAL REALITY - VR**
  - USERS ARE **COMPLETELY IMMERSED IN A VIRTUAL WORLD** AND CANNOT SEE THE REAL WORLD AROUND THEM [1].
  - USE OF A **HEAD MOUNTED DISPLAY** OR **VR CAVE**
  - INTERACTION WITH **CONTROLLERS, HAND-TRACKING DEVICES** AND **HAPTIC GLOVES**

[1] Fast-Berglund, Å., Gong, L., & Li, D. (2018). Testing and validating Extended Reality (xR) technologies in manufacturing. Procedia Manufacturing, 25, 31-38.

VR and emulation of 5 Senses

- **Simulation of the 5 senses using interactive devices, which send and receive information**

- Eyesight
  - Stereoscopic eyewear
  - Head Mounted Displays
- Touch
  - Hand tracking devices
  - Haptic devices
- Hearing
  - Headphones
- Smell
  - Ad-Hoc developed devices
- Taste
  - Prototypes

Used for Rehabilitation

Fields of Use

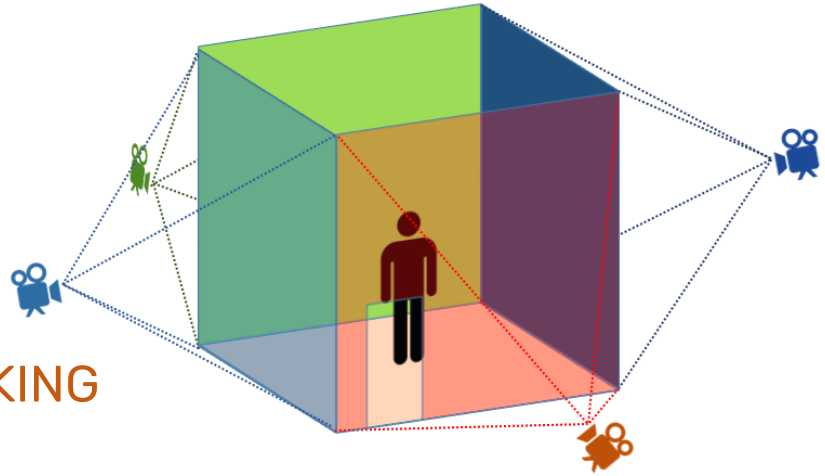
- **Military**
  - Training
  - Flight simulations
  - …
- **Automotive Industry**
  - Design and engineering reviews
- ***Healthcare***
  - *Design of medical devices*
  - *(Tele-) Rehabilitation*
  - Occupational Medicine
  - Training & Surgical Planning
- **Retail**
- **Tourism**
- **Sport**
- **Real estate**
- **Architecture**
- **Entertainment**
- **Art and design**
- **Social Networks**
- **…**

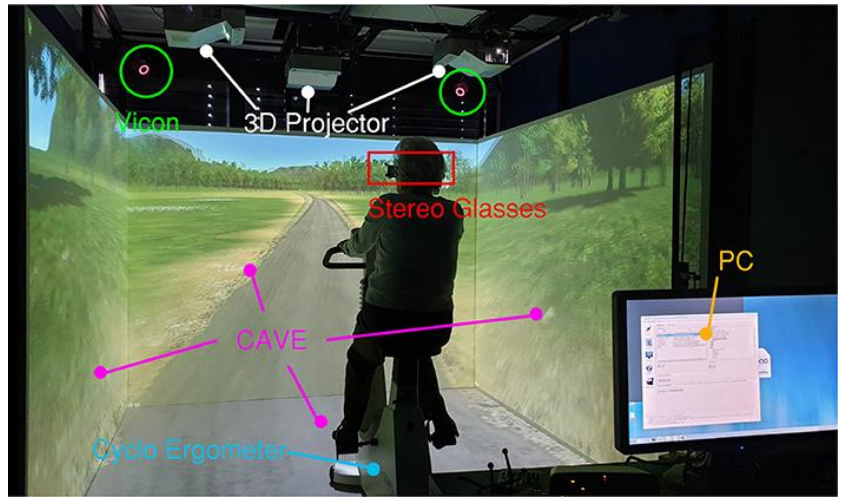
Types of VR systems

- **Non-Immersive VR systems**
  - A regular computer display (CAD systems and Gaming)
  - Interaction using only mouse and keyboard
- **Semi-Immersive VR systems**
  - Large, concave screen, projection system and monitor
  - Hard simulators (Cockpit) that partially replicate design and functionality of a real-world mechanism
- **Full-Immersive VR systems**
  - **VR Cave**
  - **Head Mounted Display**
  - Interaction based on controllers, hand-tracking devices, haptic devices and headphones

VR CAVE: CAVE AUTOMATIC VIRTUAL ENVIRONMENT

- **USE OF 3D PROJECTION SCREENS TO CREATE A HIGHLY IMMERSIVE VIRTUAL ENVIRONMENT**
  - DEPTH SENSE USING STEREOSCOPIC EYEWEAR
  - INTERACTION WITH WANDS, JOYSTICKS, HAND-TRACKING AND HAPTIC DEVICES
  - DEDICATED ROOM IN THE SHAPE OF A CUBE
- **USER'S MOVEMENTS TRACKED BY A MARKER-BASED MOCAP SYSTEM**
  - **HIGH COMPUTING PERFORMANCE** TO SYNCHRONIZE THE INDIVIDUAL USER'S PERSPECTIVE WITH HER/HIS POSITION IN THE CAVE





Pedroli, Elisa, et al. "An immersive motor protocol for frailty rehabilitation." Frontiers in neurology 10 (2019): 107.

VR CAVE: APPLICATION AND COST

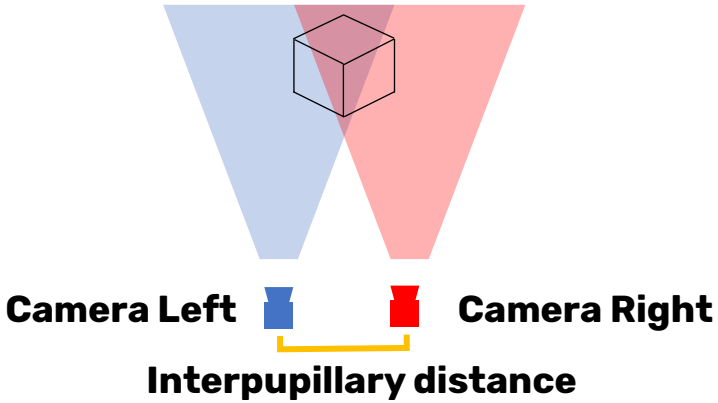
- **APPLICATIONS**
  - ARCHITECTURE, ENGINEERING, CONSTRUCTION
  - AUTOMOTIVE INDUSTRY
  - UNIVERSITIES AND EDUCATION
  - …
  - **MEDICINE AND HEALTHCARE**
    - Training
    - Monitoring and pre-empting diseases
    - Planning complex operations
    - Rehabilitation
- ***EXPENSIVE SOLUTION***
  - AVERAGE COST: **500K €**

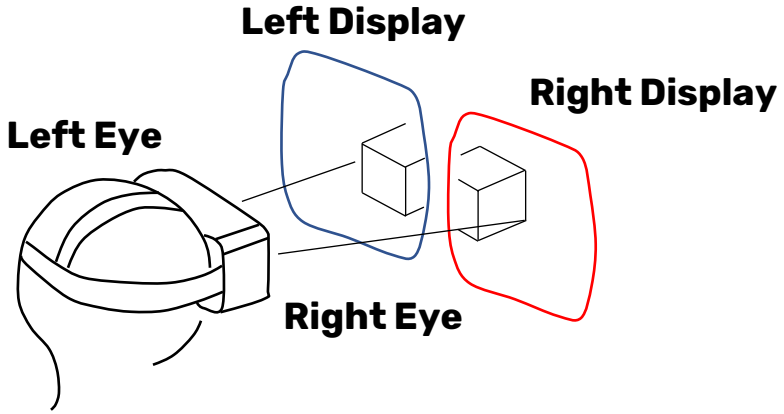
VR HMD: Head Mounted Display for Virtual Reality

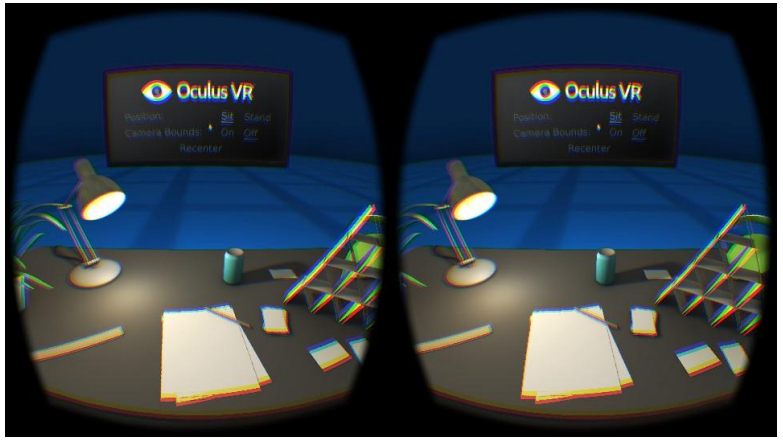
- **A VR HMD is the main device to guarantee immersion in the virtual world using *consumer technology***
  - VR Immersion using dedicated UHD displays or a smartphone
  - Connected to a laptop or all-in-one
  - Interaction with Controllers, Hand-tracking and haptic devices
- **Applications**
  - Engineering
  - Automotive industry
  - Universities and education
  - **Medicine and healthcare**
    - Training
    - **Rehabilitation**
    - **Tele-rehabilitation: based on Web Technologies**

VR HMD: MAIN FEATURES

- **MAIN FEATURES OF A VR HMD:**
  - DEPTH SENSE BY MEANS OF STEREOSCOPIC 3D EFFECT

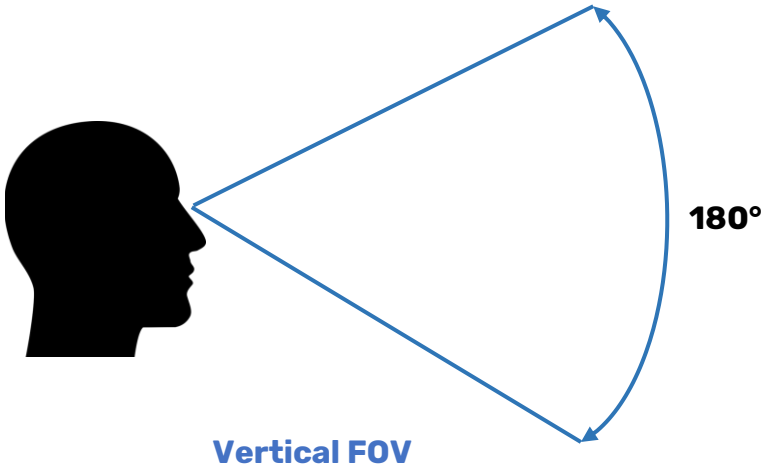


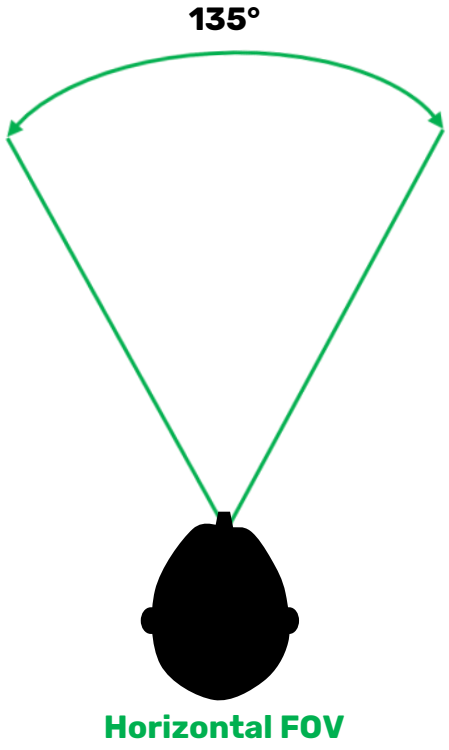




VR HMD: MAIN FEATURES

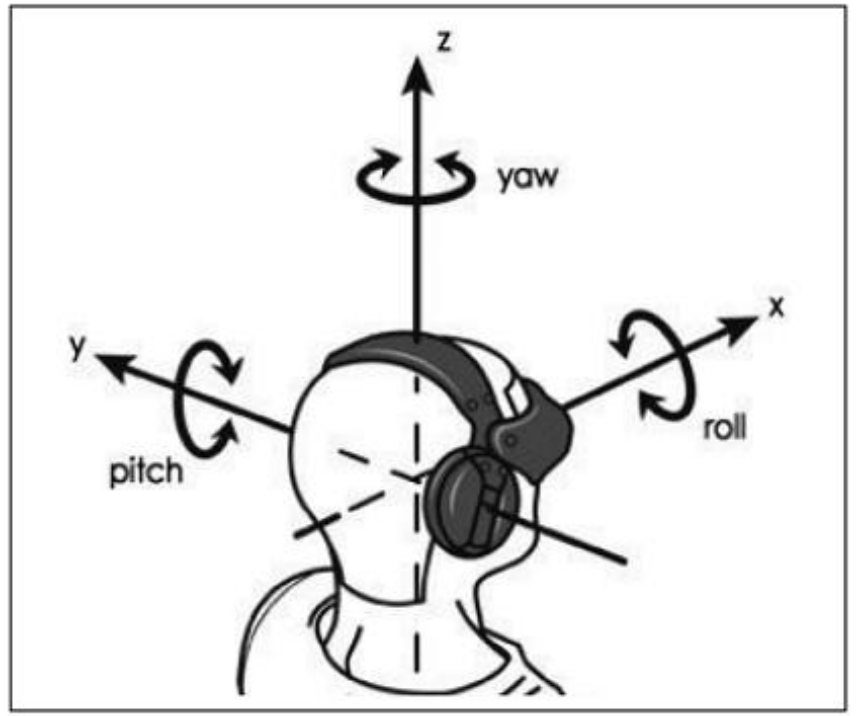
- **MAIN FEATURES OF A VR HMD:**
  - DEPTH SENSE BY MEANS OF STEREOSCOPIC 3D EFFECT
  - LARGE FIELD OF VIEW (FOV)
    - HMD should cover as much of the vision range as possible
    - Horizontal FOV: 135°
    - Vertical FOV: 180°





VR HMD: MAIN FEATURES

- **MAIN FEATURES OF A VR HMD:**
  - DEPTH SENSE BY MEANS OF STEREOSCOPIC 3D EFFECT
  - LARGE FIELD OF VIEW (FOV)
  - ROTATIONAL TRACKING
    - Tracking orientation of the head
    - Embedded gyroscope, accelerometer and magnetometer



VR HMD: MAIN FEATURES

- **MAIN FEATURES OF A VR HMD:**
  - DEPTH SENSE BY MEANS OF STEREOSCOPIC 3D EFFECT
  - LARGE FIELD OF VIEW (FOV)
  - ROTATIONAL TRACKING
  - POSITIONAL TRACKING
    - Performed with motion capture systems
    - Sensors and cameras external to the HMD
    - Tracking of the position of the user's head, body and hands anywhere within the volume of motion acquisition
    - Rotations and translations

VR HMD: MAIN FEATURES

- **MAIN FEATURES OF A VR HMD:**
  - DEPTH SENSE BY MEANS OF STEREOSCOPIC 3D EFFECT
  - LARGE FIELD OF VIEW (FOV)
  - ROTATIONAL TRACKING
  - POSITIONAL TRACKING
  - EYE TRACKING
    - Embedded sensors to track the movements of pupils
    - Measuring how long the user is staring at a particular area in the FOV

VR HMD: MAIN FEATURES

- **MAIN FEATURES OF A VR HMD:**
  - DEPTH SENSE BY MEANS OF STEREOSCOPIC 3D EFFECT
  - LARGE FIELD OF VIEW (FOV)
  - ROTATIONAL TRACKING
  - POSITIONAL TRACKING
  - EYE TRACKING
- **THESE FEATURES DEFINE THE COST OF EACH SPECIFIC HMD**

Commercial Head Mounted Displays

- **Low-Cost HMDs (10 € - 150 €)**



- **Entrainment HMDs (350 € - 2000 €)**



- **Professional HMDs (Higher than 2000 €)**



Hand Tracking Devices

- **Devices ad-hoc designed for tracking hands, part of them and thin objects held in hand**
  - Optical Marker-less systems
    - Microsoft Kinect Azure device
    - Ultraleap Leap Motion device
    - Embedded in HMD

  - Gloves with Inertial Sensors
    - Manus VR
    - Senso Gloves

- **Used for Hand Motor Skills Rehabilitation**

Hand Tracking Devices

- **Tracked Data: Positions, Orientations, Linear and Angular Velocities, Accelerations**
- **Main parameters to choose the right hand-tracking device**
  - Cost and Ease of use
  - Sensitivity to track small movements of hands/fingers
  - Ease of software development (SDKs, Documentation, software interfaces with other platforms)

Haptic Devices

- **Emulation of tactile sense during the interaction with virtual objects**
  - Force-Feedback
  - Temperature
  - Softness
- **Haptic Gloves**
  - Weart
  - Sense Glove
- **Used for Hand Motor Skills Rehabilitation**

Haptic Devices

- **Main parameters to choose the right Haptic Gloves**
  - Integration with the HMD
  - Ease of software development (SDKs, Documentation, software interfaces with other platforms)

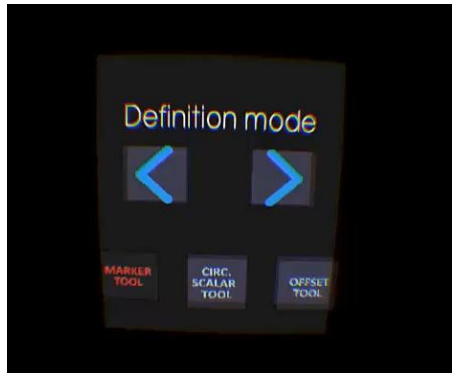
- **The last generation of VR gloves embeds both hand-tracking and haptic feedback**

VR DEVICES FOR SMELL

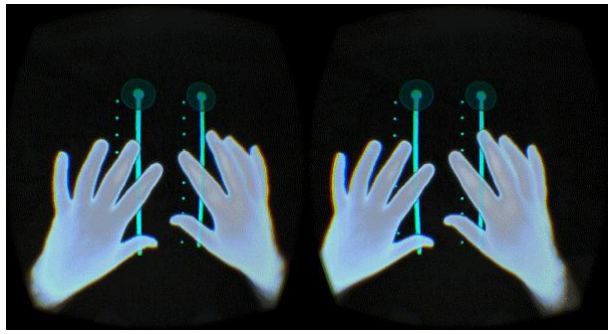
- **A SET OF PHIALS THAT CONTAIN DIFFERENT SCENTS**
  - A MICROCHIP OPENS A PHIAL AND ALLOWS THE INHALATION OF A SCENT ACCORDING THE INTERACTION WITH THE VR ENVIRONMENT
  - NEED OF PREDEFINED SET OF PHIALS
    - Tropical beach
    - Pine Forest
    - Wildflower fields
    - …
  - COMMERCIAL DEVICES READY TO BE MOUNTED WITH VR HMDS
  - COST: APPROXIMATIVELY 250 €
    - OVR Technology OX1
    - Feelreal Sensory Mask
- **USED FOR NEUROLOGICAL REHABILITATION**

Design of Natural User Interfaces (NUIs) for VR

- **What is a NUI?**
  - A NUI is a user interface designed with the aim to achieve **a direct and consistent interaction** through a natural human behavior, which enables **the user to reach his/her final purpose**.



- **Good NUI for VR follows 3 fundamentals:**
  - Immediate understanding
  - Progressive learning
  - Direct interaction
- **Define the Vocabulary of Gestures to Define the Interaction Style of the new VR Applications**
  - **Increase the adherence of the therapy for rehabilitation**
    - Definition of tutorials for a correct interaction
    - Auditory Feedbacks and Textual Helps



Development Environments for VR

- **Software Development Tools oriented for the design of virtual environment and their integration with VR devices**
- **Main features to choose the right development tool:**
  - No need of high skills in computer graphic development
  - Accessible documentation (tutorials, examples)
  - Useful plug-ins for interfacing HMDs, hand-tracking devices and Haptic Gloves

Method to design VR Serious Games for Rehabilitation

- **Main challenges to introduce VR Serious games in Traditional Rehabilitation**

  - Physical Therapy Adherence
    - BOTH **FOR MEDIUM-TERM REHABILITATION** PROGRAMS AND FOR LIFE-LONG PRESCRIPTIONS FOR **CHRONIC PATIENTS**
    - DIFFICULTIES TO **SCHEDULE PHYSIOTHERAPY**
    - **LACK OF MOTIVATION** OR TRUST
    - **ECOLOGICAL VALIDITY**: THE ABILITY OF A RECOVERY PROCESS TO REHABILITATE PATIENTS TO REAL LIFE
  - User Experience with VR technologies
    - DESIGN OF VR SERIOUS GAMES ACCORDING TO PHYSIOTHERAPISTS' RECOMMENDATIONS
    - **CUSTOMIZABLE FOR ANY PATIENT**
    - BASED ON DAILY LIFE TECHNOLOGIES (LOW-COST PHILOSOPHY)
    - FOR BOTH REHABILITATION CENTER AND AT HOME (**TELE-REHABILITATION**)

THE MAIN STEPS OF THE METHOD

1 - MEDICAL REQUIREMENTS ANALYSIS

- Meeting with physicians and physiotherapists
- Formalization of domain rules and evaluation guidelines
- Extrapolation of specific functionalities
- Evaluation of the technological feasibility

PubMed

Scopus

Google Scholar

2 - IDENTIFICATION OF ICT TOOLS

- VR devices: HMD and Hand-Tracking devices
- SDKs of VR devices
- 3D acquisition technologies for realistic 3D environments
- Free/Open Source software development tools

unity

node

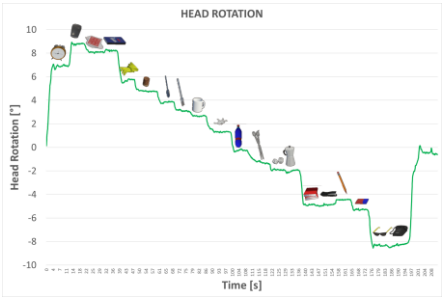
blender

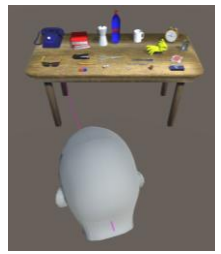
LoopBack.io
Node.js API Framework

mongoDB

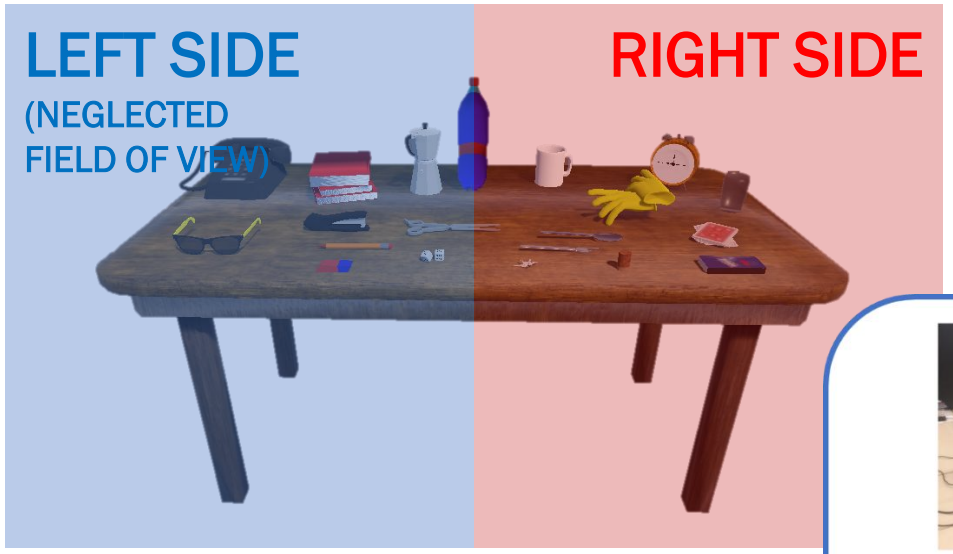
3 - MEDICAL DATA MANAGEMENT

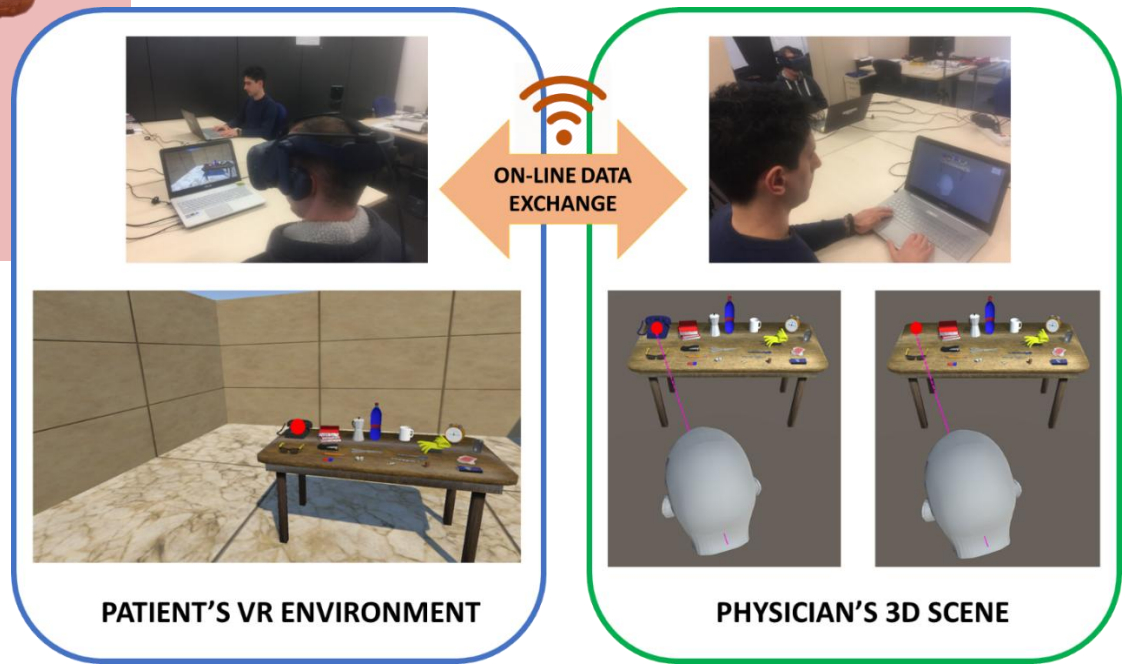
- Data storage techniques
- User interface for medical personnel
- Automatic elaboration of data to obtain medical information
- Generation of medical reports





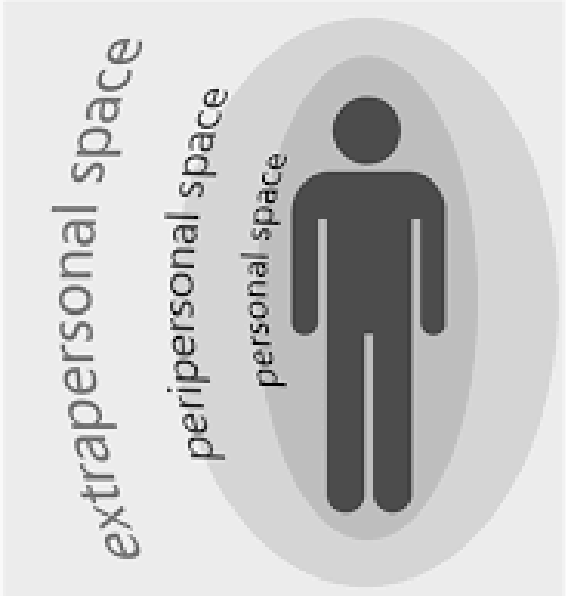
MEDICAL ASSESSMENT TEST OF EXTRAPERSONAL NEGLECT USING VIRTUAL REALITY





Medical Context

- **Unilateral spatial neglect** also known as neglect disorder.
- Neglect is caused by **a lesion** of the right/left hemisphere **of the brain**
- The patient's **incapability to** both **perceive and keep attention** at objects, people and representations positioned in the visual hemi-field that is contralateral to the brain lesion
- There exist **several test for the evaluation of Neglect syndrome** to identify the **level of deficit** according to the specific space
- There is the lack of **an objective and detailed test** (i.e., a gold standard) for the **extrapersonal neglect**



AIM

- THE EXTRAPERSONAL NEGLECT IS ASSESSED BY **USING REAL OBJECTS** POSITIONED IN THE SPACE **AROUND THE PATIENT**, WITH A **POOR CAPABILITY OF REPETITION AND DATA GATHERING**

- THE **AIM** OF THIS RESEARCH WORK IS THE INTRODUCTION OF A **VR SOLUTION** BASED ON **CONSUMER TECHNOLOGY** FOR **THE MEDICAL ASSESSMENT**

- DESIGNED **IN COLLABORATION WITH PHYSICIANS AND PHYSIOTHERAPISTS**

MEDICAL FUNCTIONALITIES

Patient has strong difficulty to consider the existence of objects placed in the part of field of view relative to the controlesional side

- **The goal** of the serious-game is to **identify and say aloud** everything the patient sees on a table
- Consumer IT with **high usability**
- **Remote monitoring** of the extrapersonal neglect test by medical personnel
- Monitoring of **patients' head movements**
- **No direct patient's interaction** with the virtual world
- **Automatic generation of data report** useful for medical assessment

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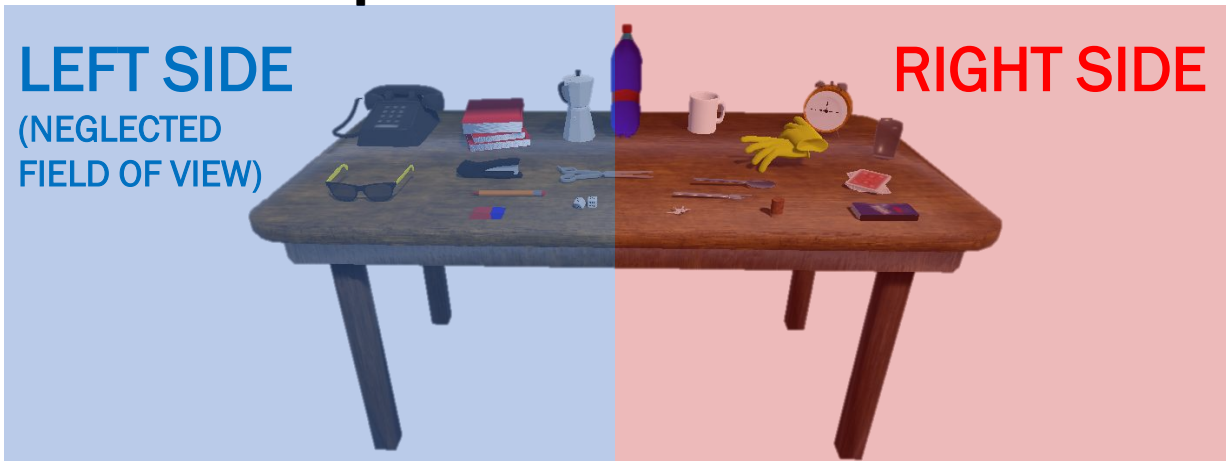


Development Tools

The whole VR platform has bee developed using low-cost and free development tools

SOFTWARE: Unity e Blender

HARDWARE: HTC Vive Pro

Software Architecture

EXTRAPERSONAL NEGLECT VR TEST

Motion data recording for medical assessment
Voice recognition for object selection

UNITY

Universal Windows Platform for voice recognition

Networking between patient and physician for real-time valuation

Data exporting

Visualization of recorded sessions

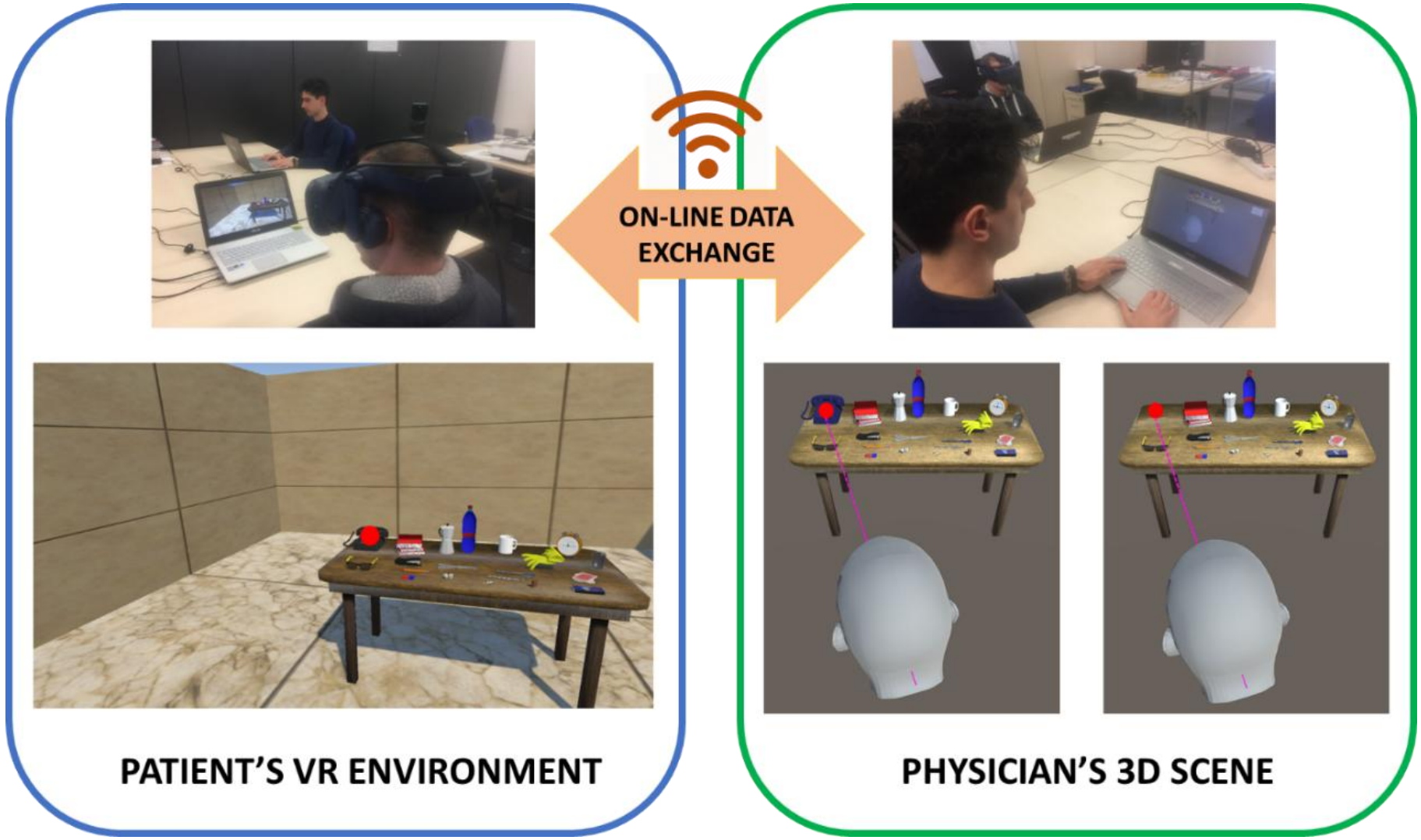
HMD HTC Vive Pro

Head Tracking for motion data recording

Microphone for voice recognition

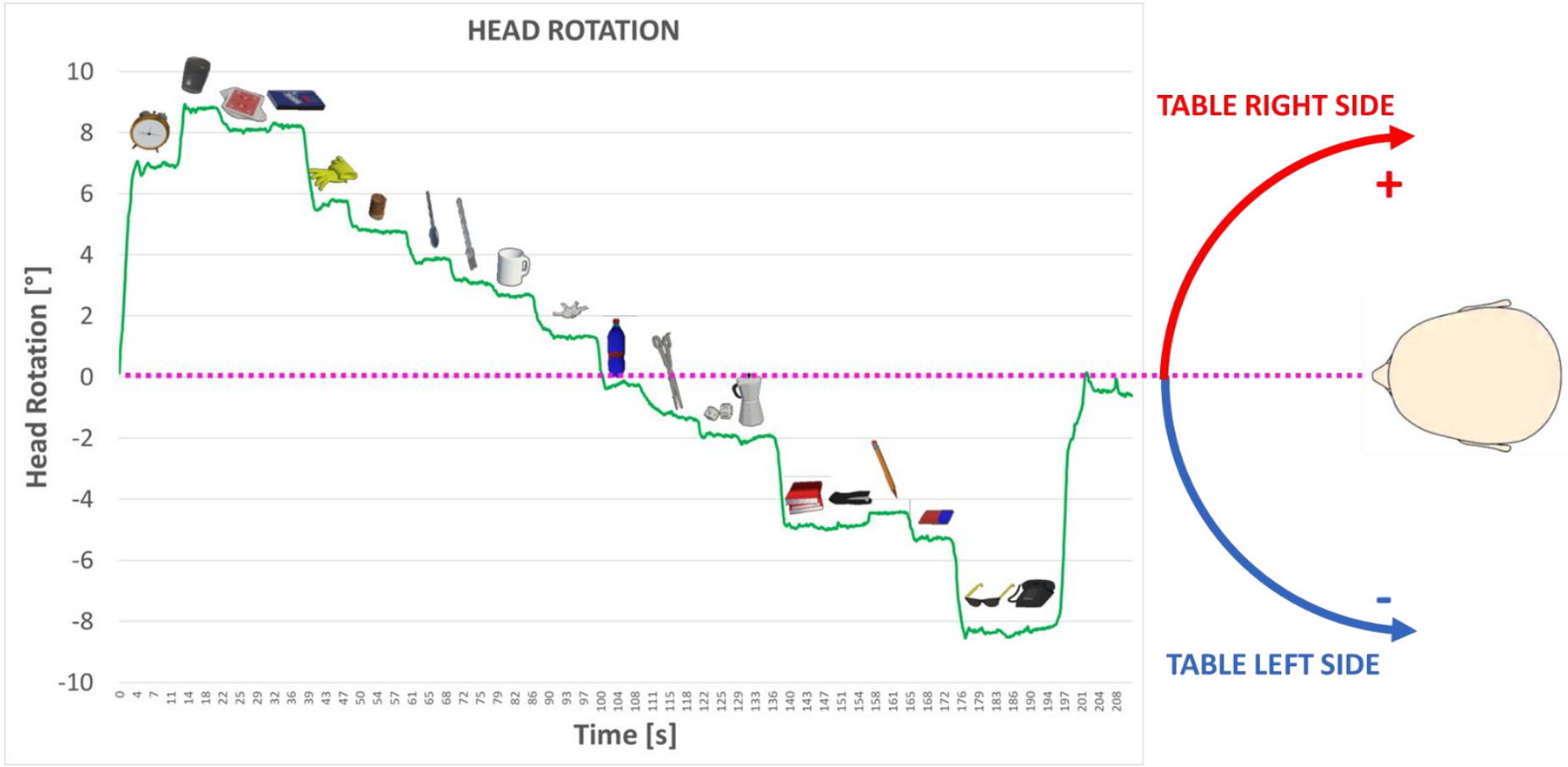
Rendering of 3D scene

How the VR Platform works



MEDICAL REPORT

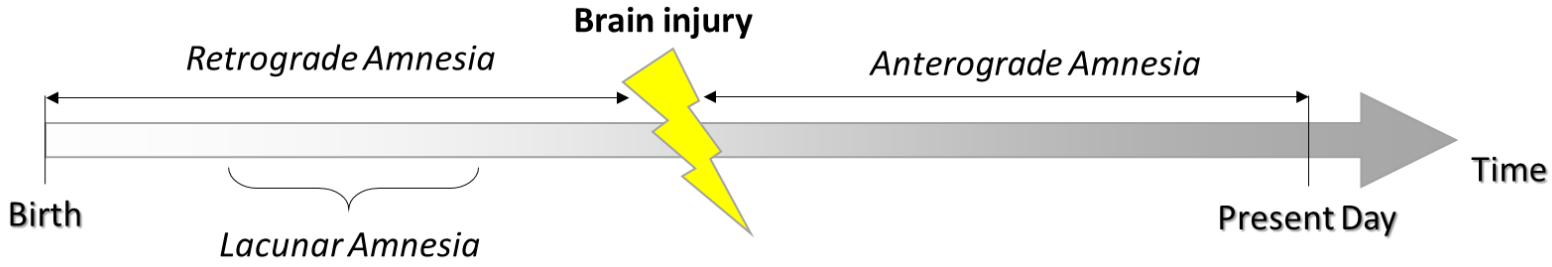
- **HEAD ROTATIONS** AND **TIME** TO RECOGNIZE EACH 3D OBJECT



VIRTUAL REALITY PLATFORMS FOR THE MEDICAL REHABILITATION OF SEVERE MEMORY LOSS AFTER BRAIN STROKE

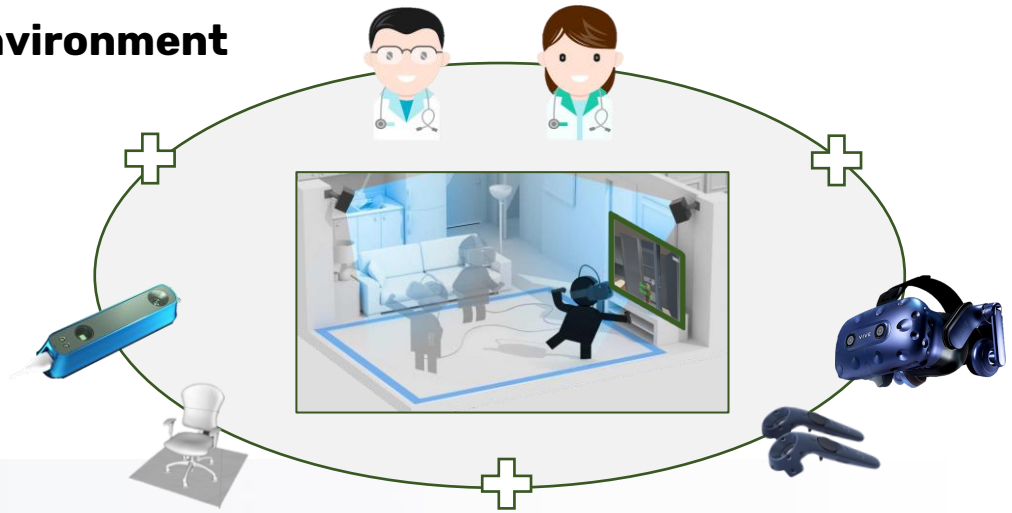
Medical Context

- Severe memory loss, in particular **retrograde amnesia**
- Amnesia is usually caused by **brain stroke**
- The patients **cannot remember events or information** acquired before a brain stroke
- Given the low probability of spontaneous recovery of memory, it is necessary to establish a **specific rehabilitation plan for each patient**
- The traditional procedure consists in **showing pictures** of the familiar places both to stimulate residual memories and to assess what they can recall
- There exist several **VR Serious Games** which show **potentialities** compared to the traditional test



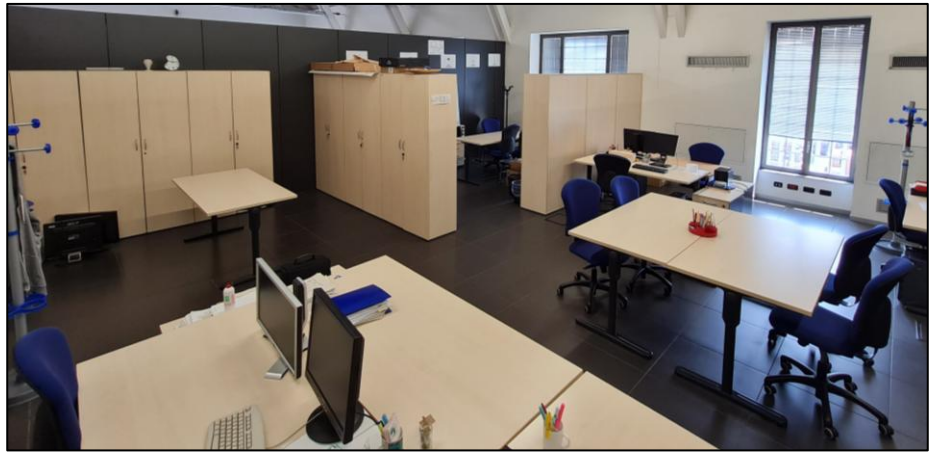
AIM

- IMPROVE NEURO-REHABILITATION EFFECTIVENESS **FOR RECOVERING THE LOST MEMORY** BY MEANS OF **VR**
  - INCREASE **ECOLOGICAL VALIDITY**
    - **Reproducibility** of real environments
    - Customized for each patient
  - **3D SCANNING PROCEDURE TO REPLICATE FAMILIAR ENVIRONMENTS**
    - **Feasible** with **low-cost 3D scanners**
    - **High realistic**
  - VR SERIOUS GAMES TO INTERACT WITH THE FAMILIAR ENVIRONMENT
    - **Search a series of objects positioned around the environment**
    - **Memorize** the familiar environments
    - **Specific task** for recovering memory



MAIN FEATURES

- **REMOTE MONITORING** OF THE MEMORY TEST BY MEDICAL PERSONNEL
- MONITORING **PATIENTS' MOVEMENTS AND THE OBJECTS FOUND**
- **AUTOMATIC GENERATION OF DATA REPORT** FOR MEDICAL ASSESSMENT
- **RECORDED DATA:**
  - KINEMATIC DATA RELATED TO THE MOVEMENT OF HEAD AND HANDS IN 3D SPACE
  - TIME REQUIRED TO FIND ALL THE OBJECTS
  - THE LIST OF FOUND OBJECTS



Real environment

Virtual environment

DEVELOPMENT TOOLS

SOFTWARE: Unity, Blender and Skanect

Serious Game Development

3D Modeling

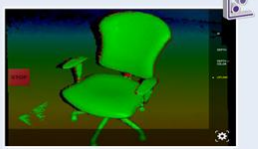
3D Scanning

HARDWARE: HTC Vive Pro and Structure Sensor (supported by an i-Pad)

SOFTWARE ARCHITECTURE

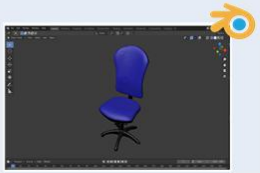
1. ACQUISITION & MODELLING

Structure sensor and **Skanect** for the 3D acquisition of the familiar environment/objects



Add texture, **clean** and **export** the acquisition in '*.obj*' file format

Modelling the acquisition with **Blender** and **export** in '*.obj*' file format



3. DATA RECORDING AND MEDICAL MONITORING

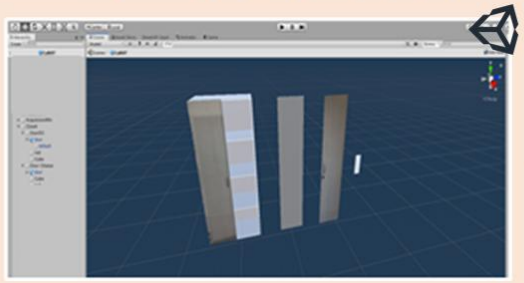
Recorded data: the physician can see the **replay** of each performance

Patient doing test and physician can see in **real time a virtual faithful replica**

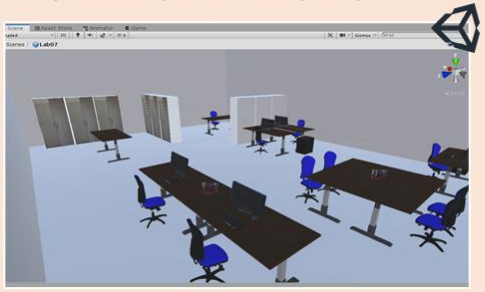
The physicians choose the **familiar environment** and the **objects to be found** and then, starts the test

2. ASSOCIATION BETWEEN ENVIRONMENT AND GAME LOGIC

Create the 3D virtual room in **Unity** starting by **the interactive closets or dressers**



Exporting of the Unity package: **patient-specific Unity Project**



Interface with the VR HTC VIVE Pro for the patient's interaction

DEVELOPMENT OF THE SERIOUS GAME

- DESIGN OF AN INTERACTIVE 3D ENVIRONMENT
  - DEVELOPED WITH UNITY
  - SEGMENTED ROOM RESPONSIVE TO THE USER INTERACTION
    - Traditional interaction style
    - Virtual and Augmented Reality
- GAME LOGIC ACCORDING TO MEDICAL SUGGESTIONS
  - UNITY SCRIPTS EASILY REUSABLE ONLY CHANGING THE 3D SEGMENTED MODEL OF THE HOME ENVIRONMENT
  - 3 LEVELS OF ENTERTAINMENT
    - “Explore”
    - “Object by Object”
    - “Treasure Hunt”

Objects to be found

How the serious game works

MEDICAL REPORT

- **CALCULATION OF AVERAGE DELAY FOR EACH PAIR OF OBJECTS**

Starting position	Final position	Path time (P_t) [s]	Reference time (R_t) [s]	Deviation time (D_t) [s] $D_t = P_t - R_t$
Initial	Headphones	27	19	8
Headphones	Cereals	37	22	15
Cereals	Vacuum	23	19	4
Vacuum cleaner	Clothes	27	23	4
Clothes	Dishes	34	17	17
Dishes	Cheese	13	5	8
			Average delay [s] = $\frac{\sum D_t}{n}$	9