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MIXED REALITY FOR SMART HEALTH

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Abstract—The goal of this white paper is to give a brief overview of the current trends and possible applications in the field of Mixed Reality (MR) for smart healthcare applications in rehabilitative medicine. One of the main challenges is the development of innovative clinical models supported by MR services for the treatment of disability and an increase of autonomy in an aging society. This results in the need to identify proper sensing technologies able to empower the therapist clinical evaluation embeddable in the same framework. In this context, the technologies developed in the context of Industry 4.0 are playing an important role and analysis is necessary regarding the impact of these technologies on the existing clinical protocols of rehabilitative medicine.

Keywords—mixed reality, augmented virtuality, augmented reality, healthcare.

I. INTRODUCTION

Nowadays, in rehabilitation medicine and occupational ther- apy (OT), the assessment tool is essentially the human eye observing the person performing activities of daily living to evaluate his/her level of independence, efficacy, effort, and safety, to design treatment programs. On the contrary, in other clinical settings, diagnostics have very sophisticated technological tools such as Computed Axial Tomography, 3D ultrasound, Functional Magnetic Resonance Imaging, Positron Emission Tomography, and many others. Recently, it is possible to fill this gap in rehabilitation using new MR enabling technologies through which it will be possible to provide the rehabilitator, in addition to the evidence provided by the human eye, also a large amount of data describing the person's motion in 3D, the interaction with the environment (e.g. forces, contact pressure maps, and motion parameters related to the manipulation of objects), and the "internal" parameters (e.g. heart rate, blood pressure, respiratory rate, and sweating). This amount of information can be fed back to the clinician in an animation that represents the reality augmented with all the above parameters using methodologies of Augmented Virtuality (AV) offline or Augmented Reality (AR) in real time.

The main benefit of this new interaction methodology is two-fold: the observed scenarios depicted in animations contain all the relevant parameters simultaneously and the related data are well defined and contextualized. This new methodology is a revolution in rehabilitative evaluation meth- ods that allow on one hand to increase the objectivity and effectiveness of clinical observation, and on the other hand to re-define more reliable assessment scales and more effective rehabilitation programs.

II. REALITY-VIRTUALITY CONTINUUM

The last decade was characterized by the so-called Aug- mented and Virtual Reality revolution [1]. The birth of these new technologies enabled the mix-up of reality with virtual worlds (Fig. 1) to create new environments where, if the virtual is superimposed to the current reality we speak of Augmented Reality (AR), if real data are imported and shown in the virtual context we speak of Augmented Virtuality (AV). For AR, actually, not only virtual contents but also real data can be fed to the current user viewpoint.

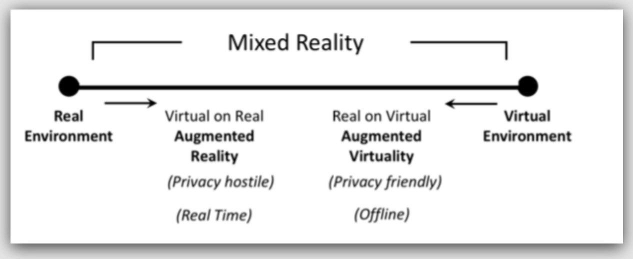


Fig. 1: The Reality-Virtuality continuum.

In AR, virtual cues and real data are superimposed to the real view of the scene using different technologies such as smartphones, tablets, glasses, and projectors. In AV, real cues are superimposed to the virtual world via similar technologies to AR, but in a more immersive way. For example, AR glasses allow us to see through, AV glasses are usually blind: they show only the virtual environment.

Considering clinical applications, privacy can be an im- portant requisite. In AR it is more difficult to keep private information while in AV real (sensible) data can be easily anonymized. AR must be played in real-time. So, information coming from real data acquired via distributed sensor networks shall be quickly elaborated and shown with low latency to the user. AV can be played offline. So, information coming from real data acquired via distributed sensor networks can be elaborated with complex algorithms then presented at a different time to the user.

III. MIXED REALITY TO ENHANCE HUMAN CAPABILITIES

Human enhancement can be defined as "any attempt to temporarily or perma- nently overcome the current limita- tions of the human capabilities (physical and cognitive) through natural and/or artificial mean" [2].

TABLE I: Pattern of neuropsychological functions.

Macro function	Specific function	Specification	Environmental correlations	For example
Orientation	Spatial Orientation Temporal Orientation	Ability to organize the self-perception in space and time.	Orient oneself of "where and when" in specific situations.	What time is it? Where are you?
Attention	Vigilance/ Alertness	Activation (level of arousal).	Physiological quickness in stimulus responses.	Athlete that waits the race start.
	Selective attention Sustained attention	Selection of one attention target and inhibition of distractions. Preserve attention in a long time.	Ability to take the interested stimulus out of context and ignore distractions, in a span of time.	Try to listen to a conversation while other conversations are in progress.
	Divided attention	Division of attentive resources between many simultaneous stimulus/tasks.	Pay attention to more information or more tasks.	Speak on the telephone while you are cooking.
Memory	Short Term Memory (MBT) and Working memory (WM)	Temporary retention system, elaboration and selection of visual-spatial information, verbal and write, finalized to make a cognitive task.	MBT: memory and recall of just presented information. WM: ability of keep in memory the information for the all-time necessary to finalize the task.	Ability to repeat the last expression that you have hear. Mental calculus of complex algebraic operations.
	Long Term Memory (MLT)	Permanent or part time retention system, in the memory stock.	Capacity to organize events, situation, learnings, to render available this information if necessary.	Serf-memory, memory of events, learning knowledges.
Executive functions	Planning Attention Control – Inhibit inappropriate responses Set Shifting – Cognitive flexibility Abstraction Motivation	Capacities to plan action's strategies and inhibit automated behaviors. Plan strategies for problem solving. Abstraction and classification of stimulus and events. Willingness to begin many actions.	Capability to organize own actions and behaviors, in relation of the environmental requests, social relations, even in non-ordinary situations.	Write the shopping list to plan what you want to buy. Find the motivation to leave the house. Go in the supermarket, according to necessity, but having the flexibility to put down in the shopping trolley one economic product, for example. Go in checkout counter having patience, standing in line and having the willingness to pay.
Language	Verbal production Oral comprehension	Ability to produce understandable verbal messages. Ability to understand verbal messages.	Ability to interact and communicate.	Participation in a conversation between 2 or more persons
Visual perception	Object Space	Ability to recognize objects through the visual channel. Ability to elaborate the surrounding space.	Recognize objects. Recognize places and environments.	Distinguish between a pen and a pencil. Distance between me and an object.
Motion	Executive Strategical	Patterns of finalized motor behavior.	Programming of motor actions, in relation of the space into which the action takes place and in relation with the surrounding subjects.	Climb a mountain.

In general humans interact with the outer world via perception-action loops. Perception can be dramatically in- creased via MR as far as data acquired with sensor networks of very different sensory kind can be simultaneously fed to a user in real time (Fig. 2). Elaboration of these large amount of data can, via Artificial Intelligence, parallel the human brain and show in AR the results with low latency. Furthermore, almost all cognitive functions can be highly empowered via AR technologies as detailed in the following (see Tab. I for a schematic explanation of cognitive functions).

Action planning/scheduling can be enhanced via, for ex- ample, real time animations superimposed to the scene while proprioception of the user motion can be augmented via wearable or 3D vision. In collaborative robotic applications, where human action capabilities are enhanced via the robotic agent, MR can be used to align the human with the machine environment.

The Pattern of neuropsychological functions comprises memory, attention, orientation, executive functions, language, visual perception and motion.
Working memory can be released as far as the user can be led step by step via textual information or visual cues that embed animations (that can be contextualized temporally and spatially) to the environment. To contextualize spatial information Simultaneous Location And Mapping (SLAM) can be exploited taking into account the user field of view in real time. Also long term memory can be improved having the possibility to recall whichever information stored in modern databases.

Attention can be improved in all aspects. Vigilance/Alert- ness can be enhanced by increasing the level of arousal by visual or sound cues to shorten the response time. Selective attention can be improved by recognizing and/or highlighting possible stimuli out of the context and/or simultaneously suppressing distractions. Sustained attention can be improved by recognizing and suppressing distractions. Managing different sources of information dynamically and as a function of its relevance in real-time can be an enabling factor for divided attention. Moreover, attentive functions can be supported by alert and/or alarm fed back according to distributed sensing and ubiquitous computation systems.

Spatial Orientation can be improved by an external localiza- tion system that interacts with the user via MR. Examples are the use of MR to study how persons with dementia interact with their environment [3]. Visual and audio cues can be fed considering the spatial context. 3D sound technology can be very useful for this purpose: by using binaural sound systems to capture, process and playback audio waves, it is possible to provide the listener with an audio experience that mimics real- life sounds associated with the exact sensation of the sound source spatial position. Temporal Orientation can be easily achieved using an embedded digital timer.

Regarding executive functions, attention control can be scheduled by visual cues (color, transparency, motion) to trigger the workflow of proper actions and at the same time inhibit inappropriate behaviors. Moreover, many assistive tech- nologies can interact with a human being via MR. Examples are personalized scheduled tasks in nursing, AR technologies to guide mild cognitive impaired peoples to execute various daily tasks, and serious games.

Language, both in verbal production and oral comprehen- sion, can benefit from the current technologies of “text to speech with natural sounding voices” and “automatic speech recognition & translation online”. Both can be integrated naturally in MR and can be useful to overcome language barriers in clinical activities.

Visual perception, i.e. the ability to recognize objects and to elaborate the surrounding space, can be significantly enhanced thanks to the combination of the powerful Deep Neural Networks (DNN) capability to classify objects and SLAM with MR. Such info can be easily shown and manipulated also in a hierarchical manner. Examples of applications could be during surgical procedures, such as 3-D anatomical reconstruction and computer-based procedures planning [4] or surgical instrument tracking [5]. Motion planning and execution can be enhanced through real-time animations superimposed to the scene and through wearable or 3D vision sensing able to reconstruct human kinematics and dynamics that, with the help of MR, can be fed back to the same user or the operator that is helping him/her in a specific context.

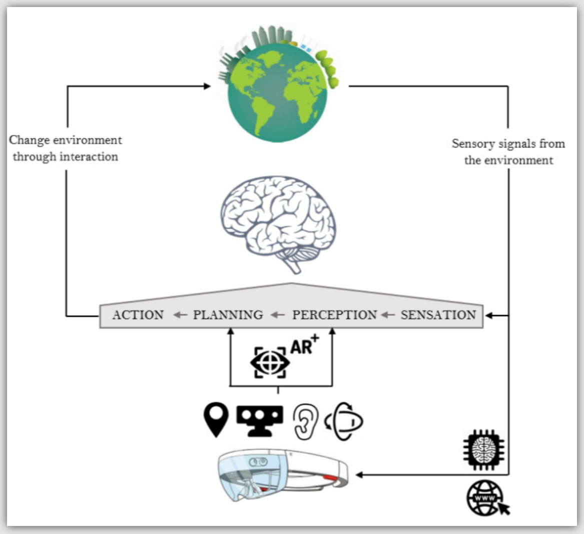


Fig. 2: The "perception-action loop".

IV. MIXED REALITY IN HEALTH-CARE SYSTEMS

Mixed Reality (MR) has many applications that span from gaming, military, space, marketing, journalism, tourism, edu- cation and training, location-based services for mobile devices, to the service of industrial maintenance for parts analysis, simulation and/or staff support.

VR, which completely immerses the person in a simulated environment [6], has also a long use in the field of mental health, psychotherapy [7], to treat acrophobia [8] and the fear of flying [9], [10]. In rehabilitation it has been applied during the assessment of upper extremities mobility [11] and cognitive deficits [12], [13]. In addition, VR has been used in cognitive and physical rehabilitation using video games [14–18] and for gait training [19–21], as well as during the retraining of activities of daily living [22]. Furthermore, it has been used in combination with robotics [23], treadmill training [24], during driving assessments for people with head injuries [25], and to optimize driving interfaces and learning, for example with individuals who use wheelchairs [26].

The impact of MR on healthcare affect different areas such as surgery, doctors, physicians and nurses training, patient education and treatment, and diagnostic tools. For example, AR is already applied in executing surgical operations. In the operative phase, surgeons can see radio- graphic superimposed to the surgical site with the overlaid simulated route [27]. AV can instead empower surgeons in pre-visualizing anatomy and thus plan the route of intervention.

A better understanding of registration and ergonomics will help the widespread of MR in this field. As an example, one of the difficulties in using head-mounted displays (HMDs) is the requirement for a common optical focal plane for both the real world scene and the computer-generated image. In order to increase the clinical acceptance, they have adapted for AR a miniature, cost-effective, head-mounted binocular [28].

Innovations in VR and AR have also the potential to signif- icantly enhance the training-education stage of surgery [29]. Other applications involve pathology residents performing an autopsy wearing HoloLens while remotely instructing them with real-time diagrams, annotations, and voice instructions. Telepathology allowed users to remotely access a pathologist for guidance and to annotate areas of interest on specimens in real-time [30].

V. MIXED REALITY FOR AUGMENTED PHYSICIANS IN SMART LIVING SCENARIOS – THE AUSILIA PROJECT

An example in which MR technology is used for health- care scenarios can be found in the AUSILIA project [31].

AUSILIA consists of a domotic apartment, a gym with recon- figurable spaces for testing activities of daily life (ADL) and an interdisciplinary laboratory for analysis and preliminary design project. The apartment and the gym are both equipped with sensors for quantitative and qualitative evaluation, embedded systems for data acquisition and pre-processing, networks for data collection.

As just outlined, MR in rehabilitation settings is mainly used by patients, not physicians. In rehabilitation and OT, the main assessment 'instruments' are the clinician's eyes, and the use of standardized clinical tools and procedures. Actually their observational skills can be highly incremented with MR, thus facilitating a more comprehensive and objective assessment.

In order to cover this gap, the engineering team of the University of Trento in the context of the AUSILIA developed two scenarios:
1) An augmented domotics environment which acquires individual's motion/actions, his/her interactions with the environment (e.g. forces, contact pressure maps, and motion parameters related to the manipulation of objects), and internal status via physiological parameters (e.g. heart rate, blood pressure, respiratory rate, and sweating) while performing self-chosen activities of daily living, and provides it offline via immersive AV to the clinician;
2) A gym with completely reconfigurable living spaces where the same measured parameters are acquired and fed to the clinician via AR in real time thus enabling a more effective evaluation via an emphatic approach. The physi- ological parameters enable in fact a change of perspective by the physician that is now able to feel the stress perceived by the subject.

Both AV and AR in AUSILIA enable the clinicians with a clearer picture regarding the performance of the individual under observation and an additional quantitative mean for assessment and classification with an emphatic approach. In MR, a fundamental role is played by sensing technology. In order to design the proper distributed sensor networks and methods to retrieve them in MR were considered the main target observations related to main activities in relevant ADL scenarios.

Tab. II lists the main observation scenarios (bathroom, kitchen, bedroom, house management and safety) for the domotics apartment with the associated daily activities relevant with respect to individual's autonomy.

In order to augment the clinical eye in the listed ADL activities, it was designed a sensor network that is able to cover the user behaviour, his interaction with the environment and his internal status. The resulting network comprises three categories of sensors:

1) 3D Time of Flight (ToF) technology to acquire user motion/actions that allow to navigate in the video sequence both temporally and spatially, i.e. to freeze the subject posture and observe it from infinite points of view;
2) Interaction force and pressure maps, objects manipulation variables, etc. to sense the interaction user/environment;
3) Physiological parameters such as heart rate, blood pressure, breath frequency, and skin conductance to sense the user internal status.

A. Comparison between traditional vs MR immersive interfaces

With respect to traditional means to feedback clinical stored data, i.e. 2D graph and charts, immersive MR offers different advantages:

• In 3D, it is possible not only to navigate in time with slow motion, time slider etc, but it is possible to assume the best viewpoint in all the three dimensions to observe the patient actions in the optimal way;

TABLE II: Overall clinical observation requirements.

Observation Scenario	Relevant daily activities
1. Bathroom	1.1 I want to use the toilet for bodily needs;
	1.2 I want to wash my hands, face, teeth, head, upper arms/arts underarms, shave with a razor blade and foam;
	1.3 I want to wash up: shave with an electric razor, comb my hair, get dressed, put on makeup;
	1.4 I want to wash my whole body (bath, shower ...).
2. Kitchen	2.1 I want to eat;
	2.2 I want to drink;
	2.3 I want to prepare meal;
	2.4 I want to fix/tidy up the kitchen.
3. Bedroom	3.1 I want to go to/get up from bed;
	3.2 I want to manage the activities in bed;
	3.3 I want to get dressed / undress;
	3.4 I want to make the bed.
4. House management, safety	4.1 I want to do the laundry;
	4.2 I want to clean the rooms;
	4.3 monitor the house environment;
	4.4 security of the house environment;
	4.5 patient safety.

• Data are all aggregated in the actual context and not divided through different plot or scales (see Fig. 4). As an example, in the virtual environment it is possible to link measured data with the corresponding object. It is possible to explore the mixed environment, find a specific object, select it and then display different kind on information directly linked to the specific object;
• Data from 3D cameras can be easily embedded in vir- tual environments. These data, in the form of point clouds, are much more privacy friendly. Similar oper- ations (anonymisation) on standard vision technologies causes higher losses of information;
• In VR, it is possible to exploit modern animation frame-works to animate virtual and real objects as a function of the distributed augmentative measurements. This enables to create proper links between cause and effect that best suits the human brain representation of the specific con- text, thus improving the feedback to the user in terms of readability. Fig. 5) shows an example in which the force exerted (the cause) on an object is rendered through the displacement (the effect). The result is a representation that is more immediate and more intuitive.
• In VR dimensional perception, being naturally 3D, is much more effective. This is also a key point in reha- bilitative medicine where proper 3D perception (of both the user and the environment) is fundamental.

(a) Traditional camera view.

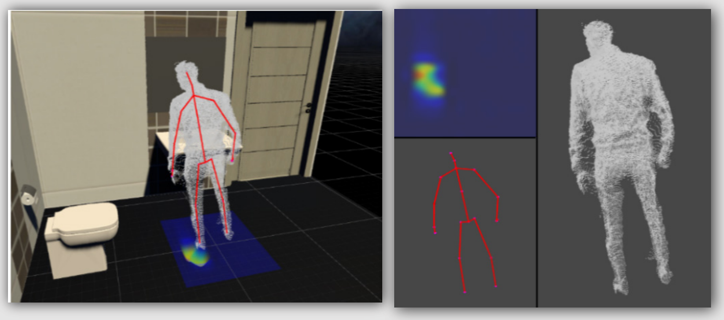
(b) ToF 3D camera view.

(c) The "best" viewpoint.

Fig. 3: Different viewpoints available in 3D with respect to a traditional camera view.

and thus without influencing their natural behaviour while performing daily routine actions fundamental to restore their autonomy. The innovative developed VR interface gives also to the clinicians the possibility to know parameters that are usually hidden to the human eye, such as physiological parameters and exchanged forces.

The clinician will be able to evaluate, in an aggregated view, gestures, interactions with the environment and the per- son's physiological parameters via an immersive virtual reality framework. The main innovation is the fact that the system will go beyond the subjective view of the therapist being able to collect a quantitative and objective view that embodies not only the subject interactions with the environment but also the user internal status via physiological parameters thus al- lowing, for the first time in clinical rehabilitation protocols, an empathic observational experience. The data provided by the system are innumerable. The actual use for clinical protocols has still to be explored in the clinic context through the use of ad hoc rehabilitative protocols able to exploit the full potential of the new paradigm.



(a) Data reported in a virtual context (model) of the environment.

(b) Traditional way to display data.

Fig. 4: Domotic scenario with the following relevant data acquired: patient shape, motion (estimated via skeletonization), pressure on the floor

Fig. 5: Example of animating a toilet seat as a function of the actual user force exerted on it. The force (i.e. the cause) is made visible through the displacement (i.e. the effect). This representation best suits the human brain's perception of force. In this example, vertical motion is displayed as a function of the total weight, while rotation as a function of its unbalance.

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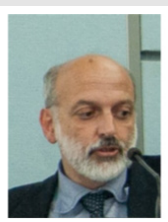

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