Telehealthcare Computing Platform with Multifaceted (Wearable, Implantable, Non-Invasive) Sensors

Proposed by Fei Hu; Only for UA students learning purpose

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1. Introduction

The top 3 leading causes of death in America are heart disease, cancel, and stroke [1]. Every 4 minutes a person dies from stroke [2]. In the world stroke is the No.2 leading cause of death [2]. Stroke is also the leading cause of disability among adults in the U.S., and more than 4 million people in the U.S. have suffered a stroke and are living with the after-effects [2]. Currently the entire nation spends more than $28 billion per year for the cost of seeing stroke physicians and nurses [2]. Fig.1 (a) shows conventional lab-intensive stroke rehabilitation scenario occurred in hospital. For the most common ischemic stroke, the *in-hospital* cost is around $1600 per day [4]. One of the PIs (Dr. Brown) has participated in the design of a rehab-training machine (Fig.1 (b)) that has much less therapist involvement than conventional scheme. However, it still requires the patient to visit the hospital or the therapist.

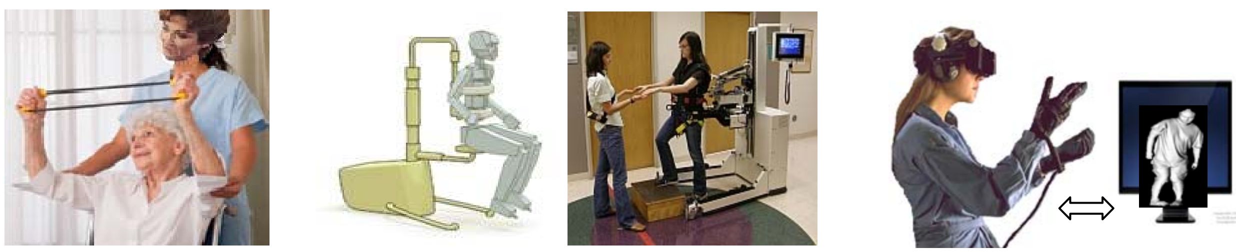


Fig.1 (a) Labor-intensive Rehab; (b) Our designed rahab-training machine [xx] ; (c) Tele-Rehabilitation system

Therefore, the establishment of a systematic platform for **Off-Hospital Tele-Rehabilitation *(OHTR)*** is extremely important to avoid or greatly reduce labor-intensive stroke treatment. The OHTR aims to provide an automatic, adaptive body flexibility training for normal cognition recovery. Especially, the Virtual-Reality (VR) based OHTR system (Fig,1 (c)) [xx] could use take-home, wearable devices (such as digital glove and Head Mounted Display (HDT)) to achieve automatic rehabilitation training (a simple process is to change the interactive computer game difficulty level). Besides stroke, other neuro-disorders *(such as autism, seizure and Parkinson's Disease)* can also benefit from the OHTR systems.

Project Goal: This goal of this project is to build a comprehensive, three-layer (Fig.2) Tele-Rehabilitation Computing Research Infrastructure (**TR-CRI**), which is a significant extension of the simple VR-based OHTR platform (as shown in Fig.1 (c)) through the integration of multifaceted (Wearable, Implantable, Non-Invasive) devices with cognitive information processing (such as a patient's symptom extraction) and context learning (such as the hand flexibility level) capabilities. Specifically, we will focus on the following three objectives to implement such a three-layer TR-CRI (Fig.2) (Section 5 has details):

Objective 1: (**Assembly Layer**) This layer will assemble three types of devices (WIN - Wearable, Implantable, and Non-invasive) into a comprehensive **tele-rehabilitation (TR)** control platform.

The motivation of building such a **WIN (Wearable, Implantable, and Non-invasive)** based OHTR platform is to achieve a comprehensive rehabilitation signal monitoring: (1) **Wearable devices**: fNIR provides brain signal variations and can be used to analyze patient neuro-disorder recovery level; Digital glove reflects patient hand flexibility level; RFID mini-readers can identify surrounding objects (such as pill name in a medicine bottle); In addition, the patient also wears *medical sensors* and an eye tracker to detect body parameters (such as heart beat rate). (2) **Implantable medical devices (IMDs)**: Currently more than 2.5 million U.S. persons rely on IMDs for disease control (such as neurostimulators, pacemakers, insulin pump, etc.) [x]. Demand for IMDs increases 8.3% annually [x]. Neuro-disorder patients (such as Parkinson's disease) could use neurostimulator to control nerving system. Cardiac rehabilitation patients need to adapt to the electric pulse effects from the pacemakers. This project will use both commercial IMDs and a customized pacemaker (section 5.1.2) to test TR control accuracy. **(3) Non-invasive devices**: We will use radio tomography (RT) [x], pyroelectric sensors [x], and other **low-cost** sensors to collect the patient's behaviors (such as gait, trajectory, etc.) for neuro-disorder analysis.

In the Assembly Layer we will design JavaSpace [xx] based mobile agents (MAs) for WIN devices control. There will be 4 types of MAs (Fig.2): VR gaming, physiological monitoring, motion disorder detection, and patient tracking. Each MA is an independent hardware/software co-operation unit [xx].

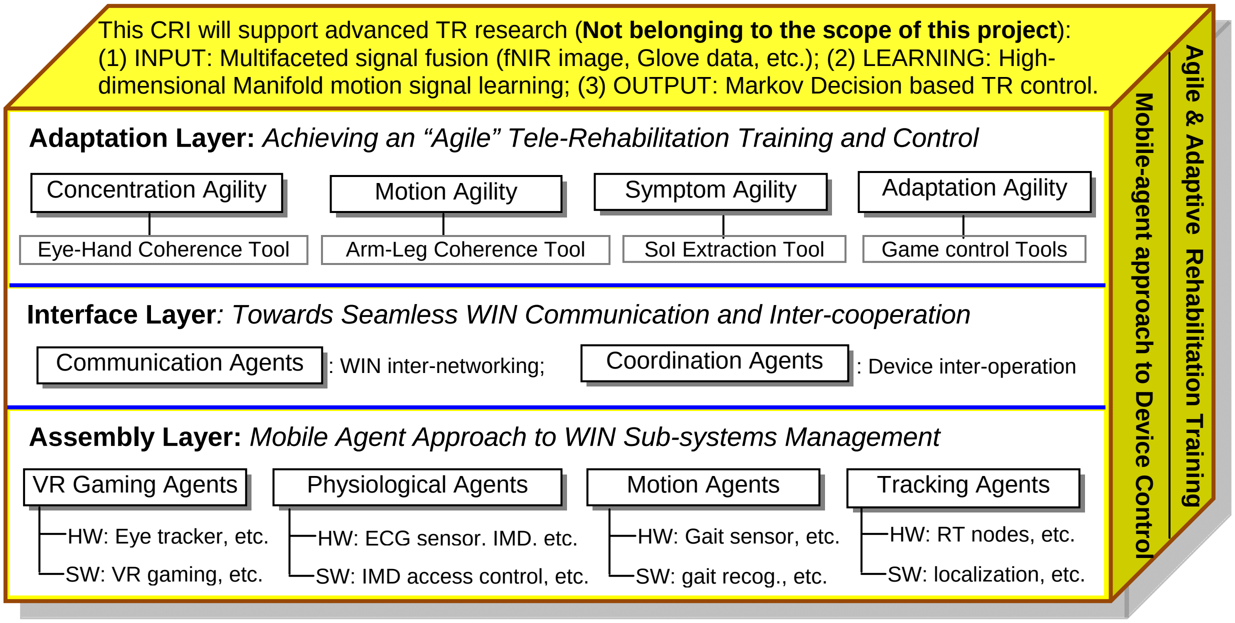


Fig.2 Three-layer, multifaceted TR-CRI architecture

Objective 2: (**Interface Layer**) This layer aims to achieve a seamless interconnection of WIN devices for patient safety, medical device interoperability, and rehabilitation information exchange,

The interoperation interlocking among medical devices is very important to patient safety. For example, a pacemaker increases its pulse strength only when the medical sensors find out that the patient has a critically low heart beat rate. This project will customize a re-programmable pacemaker for sensor-IMD interoperation test. Besides the design of *Coordination agents* for device coordination, we will also build *Communication agents* to achieve WIN device internetworking (Fig.2).

Objective 3: (**Adaptation Layer**) This layer will have open-source software tools for the analysis of the patient body flexibility and coherence for an agile and adaptive control of TR process.

The indication of TR progress is the increasing levels of body flexibility and coherence. In the Adaptation Layer we will build different types of software tools (see Fig.2) to measure: (1) **Concentration Agility** (Can the patient concentrate on the game well with good eye-hand coherence?), (2) **Motion Agility** (Can the patient balance his or her body well with good arm-leg coherence?), (3) **Symptom Agility** (Can the system recognize the patient's symptoms accurately through medical signal analysis?), and (4) **Adaptation Agility** (Can the system learn and adapt to the TR progress well?).

It should be emphasized that *the focus of this project is to establish a computing infrastructure instead of conducting advanced OHTR research*. Therefore, all of the above mentioned MAs / tools design will focus on the most fundamental TR functionalities. On the other hand, for the convenience of future extension, we will design *open-source* software with *modular, interface-friendly* program structure.

2. Infrastructure Development Plan

2.0 Big Picture

This project will establish a cognitive, SoI-adaptive tele-rehabilitation research platform with multifaceted WIN devices. Its operation principle is shown in Fig.8.

The **Wearable** devices mainly include three types: (1) *Game interaction devices* (we will use fNIR band, HDT, eye tracker, and digital glove). They directly reflect the patient's hand, eye, and mind adaptation progress during Virtual-Reality (VR) game play. (2) *Medical sensors*: They mainly include ECG (Electrocardiography, to measure heart beat rhythm), EMG (Electromyography, to measure muscle activities), accelerometers (to measure movement), SpO2 (to measure Oxygen saturation), and other wearable skin sensors. (3) *RFID mini-reader*: It can read the RFID tags of surrounding objects. This is extremely helpful to vision impaired or elder patients who can hear the RFID reader's speaker's beep or sound when wrong medicine will be taken.

The **Implantable** medical devices (**IMDs**) are becoming more and more important in sustainable disease treatment due to their automatic organ control. This platform will use both commercial ICDs and a self-customized wireless pacemaker for platform test.

The **Non-invasive** sensors include radio tomography nodes for patient localization, pyroelectric / photonic sensors for gait disorder detection, acoustic sensors for patient voice detection.

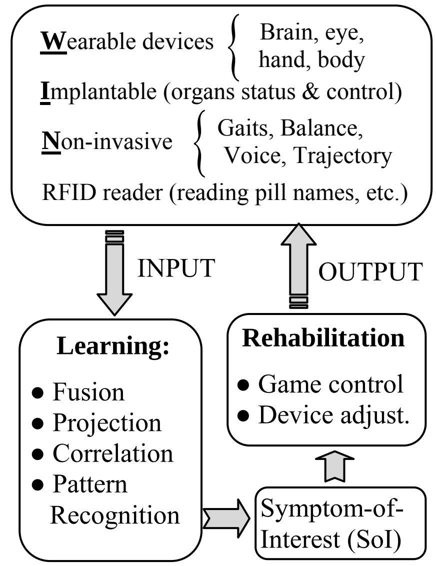


Fig.8 Platform operation principle

Information Flow: The signals transferred between WIN devices include inputs (passive data collection) and outputs (active control). As shown in **Fig.8**, all device status data is collected and sent to the server for **Symptom-of-Interest (SoI)** learning. We will design the *machine learning* tools (Section 6.3) to achieve sensor fusion, signal projection (to visualize complex multi-biometric signals in low-dimensional subspace), signal correlation analysis (such as finding the patient's eye-hand coordination capability via correlation analysis of eye tracker and digital glove signals), and pattern recognition (such as identifying heart attack events based on ECG processing). The learning result is SoIs (e.g., the patient showed satisfied cognitive capability for the current game level). The SoIs will be used to achieve rehabilitation adaptation, which includes two aspects: (1) Game control: the game level should change based on the patient's cognition status; (2) Device adjustment: Some devices need to reconfigure themselves in order to adapt to the patient's status. For example, the neurostimulator could be weakened if the patient has shown good post-stroke rehabilitation training effects.

2.1 Assembly Layer: Towards a Mobile Agent Management

In the lowest layer of our platform (i.e., the Assembly Layer, see Fig.2), we need to ensure that all hardware and software drivers function as what we desire. More importantly, the same class of devices (such as eye tracker and digital glove that all belong to VR gaming sub-system) should seamlessly work together, and some software modules should be able to migrate from one device to another in the same sub-system. For example, in order to support higher layer (say, Adaptation Layer) eye-hand coordination check, the eye tracker's parameter readings needs to be migrated to the digital glove's software threads for trajectory matching analysis. As another example, the body sensors' signals (ECG, EMG, SpO2, etc.) need to be migrated to the server's game control threads for game stimulation /difficulty level adjustment.

For the convenience of sub-system management and software thread migration, we propose to use a mobile agent approach to manage all WIN devices in the Assembly Layer. Without loss of generality, we define an ***agent*** as independent *hardware/software co-operation unit* (such as a sensor with gait pattern recognition software). We propose to use JavaSpaces [xx] from Sun for the management of distributed objects (including task progress and signals in each agent) between WIN devices. JavaSpace technology offers much of the same functionality required in a mobile multi-agent system (MAS); movement of objects, message handling, sharing of objects, etc. The message exchange between mobile agents is implemented in JaveSpace through its Message Objects and a procedure of Deliver – Write– Listen &Take - Deliver [xx] (see Fig.xx). Here the Communication Agent will be discussed in Interface Layer (section 6.2).

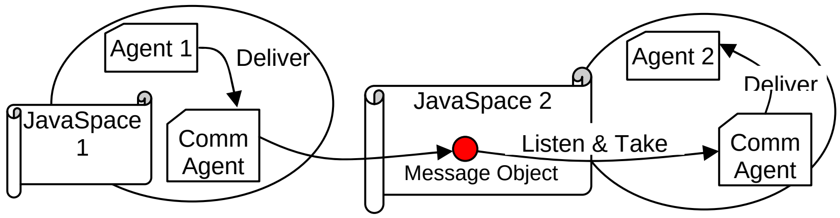


Fig.xx Message Exchange between Mobile Agents

Especially, in *Assembly Layer* we will manage four categories of mobile agents (Fig.xx shows their deployment locations): (1) **VR Gaming Agents**: They control the basic functions of virtual-reality based game interaction devices. They are responsible of data collections including eye focus, hand movement trajectory, brain activity patterns and game topics. They also utilize the Communication Agents and Coordination Agents (section 6.2) to analyze the coherence levels between eyes, hands, and brain. (2) **Physiological Monitoring Agents**: They run in the body sensors (such as ECG, EMG, SpO2, etc.) to collect real-time physiological signals. They also run in the IMDs to collect organ status data (such as heart pulse level). Those agents could interact with V-R gaming agents in order to control the game stimulation level based on the patient's health status. (3) **Motion-Disorder Detection Agents**: They run in non-invasive sensors, especially the gait recognition sensors, in order to monitor the patient's motion-disorder and imbalance status. They provide direct indication of neuro-disorder levels for a patient. (4) **Patient Tracking Agents**: They control the operations of Radio Tomography (RT) nodes as well as RFID readers/tags. They can help to find out the locations of the patient (thus linking to motion disorder data for better symptom analysis). The RFID devices can also detect the surrounding objects such as finding out a medicine bottle.

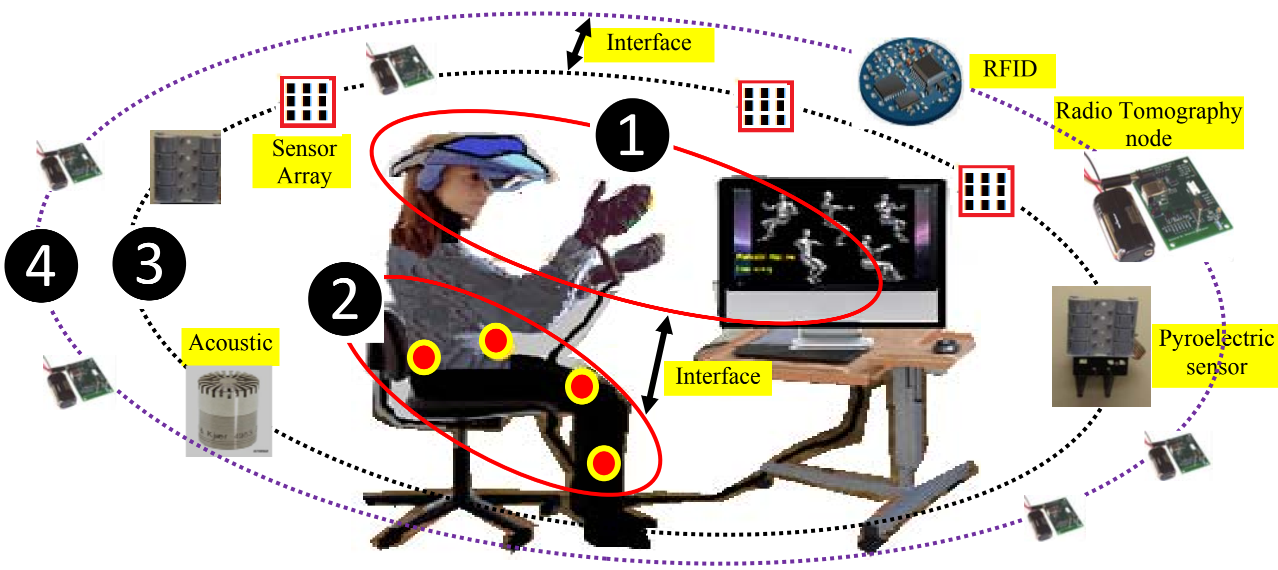


Fig.xx Multi-agent Architecture (❶VR Agent; ❷ Physiological Agent; ❸ Motion Agent; ❹ Tracking Agent)

2.1.1 VR Gaming Agents: They are used to control the operations of the following Virtual Reality devices: As shown in Fig.10 (1), our platform will use the HDT from xx Inc. [xx] to provide the patient a virtual gaming interaction environment. The fNIR band (Fig.10 (2)) could be worn in the forehead

Fig.9 (1) HDT [xx] (2) fNIR band [xx] (3) Eye Tracker [xx] (4) Digital Glove [xx] (5) Glove study model

to measure brain activation images of the motor cortex during game play. The activation patterns could be extracted from fNIR signals to analyze the Unilaterality of Motor Cortex (UMC). UMC should increase when the rehabilitation training gets successful. The eye tracker (Fig.10 (3)) could be used to determine how well the patient could concentrate on a game event. Note that we can also use contact-free (non-invasive) eye tracker integrated with the server's monitor (just like a laptop's built-in video camera) [xx]. This is useful if the HDT and eye tracker cannot fit into each other in the head. The digital glove (Fig.10 (4)) reflects the hand flexibility and strength. Its signals will be compared to the data from fNIR and eye tracker. Their signal pattern correlation result indicates the patient's motion-mind consistency level.

Agents design: We will design the mobile agents with the following objectives: (1) For the eye tracker, we will ensure that it obtains accurate, real-time measurement of the patient attention span, and also ensure that such a attention span could reflect the patient's focus capability when the game frequently changes events. (2) For the fNIR band, we will achieve the satisfactory spatial and temporal resolution of its signals in the motor cortex, and can extract game-related brain activation patterns. (3) For the digital glove, the agent should be able to perform gesture recognitions based on Hidden Markov Model (HMM). Such a HMM-based agent can recognize more Ranges of Hand Motions (RHMs) besides the 26-letter and other simple hand gestures provided by the manufacturer [xx]. Fig. 10 (5) shows the glove model with accelerometers in each finger joint. We will use it to build HMM transition matrixes.

2.1.2 Physiological Monitoring Agents (PMAs): These agents are used to collect the stoke patient's body data (such as heart beat rhythm, muscle activities, etc.) for multiple purposes: (1) we need to adjust the game exciting level based on the patient's body response. An action-intensive game should be stopped if the patient shows a heart beat rate over 130. (2) Besides hand motions from the digital glove, many rehabilitation tasks need to train the patient's legs and other body locations. The EMG sensors combined with others (such as accelerometers in the legs and weight sensors in the seat) could be used to measure other motion status. The PI (Hu) has conducted research on the low-power design of medical sensors [xx]. For patient safety and signal detection accuracy, in real clinical (human subject) test (section 7), we will use **FDA** (Food and Drug Administration)**-approved** medical sensors from xx Inc. [xx].

We will also use EMG sensor (to measure muscle activities) and 3-axis accelerometers (attached to arms /legs) to measure the patient's arm /leg motions. *Those body movements, together with the digital glove data, reflect the patient's entire body flexibility and coherence level* (Section 6.3 has more details).

The PMAs can be also used to control IMDs. IMDs have been widely used for treating various chronic ailments such as cardiac arrhythmia, Parkinson's disease, etc. Examples of IMDs include neurostimulators, implantable cardioverter defibrillators (ICDs), pacemakers, and others. The motivation of including IMDs in the system comes from two facts: (1) unlike wearable medical sensors, the IMDs can provide more accurate measurements due to direct organ touch. *(2) Rehabilitation training could achieve better effects when using real-time IMD control.* For instance, during cardiac rehabilitation, we could increase the pacemaker's electric pulse strength if the patient shows a low SpO2 (oxygen saturation) due to agitated emotion response to an exciting game.

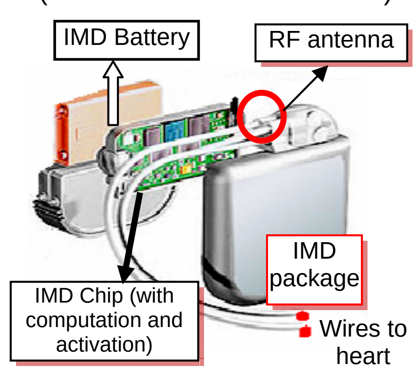


Fig.12 IMD architecture (pacemaker)

The PI has conducted significant research on IMD access and security issues [xx, xx]. In this project, we will integrate two types of IMDs to our platform: one is the clinically recycled IMDs from Dr. Kevin Fu (please see his **support letter**). Those commercial IMDs allow us to perform simple IMD status readings. In addition, **in order to make the IMD support re-programming (such as ComA execution), we will customize a pacemaker** with the typical IMD architecture as shown in Fig.xx. The leads and wires of the pacemaker will be provided by Dr. Jian Huan (a senior personnel) who is a cardiologist in a medical school. Our IMD will use a tissue-compliant miniature antenna, which will be designed through our advanced ferrite magnetic material manufacturing machines (with the assistance of the senior personnel Dr. Yang-Ki Hong, and integrate the antenna with other IMD circuit components (including radio transceiver, pacemaker leads, pulse wire, etc.) for Zigbee-compliant [xx] wireless access. Fig.16 shows our pilot work in IMD antenna design in a simulated human tissue environment (skin-fat-muscle).

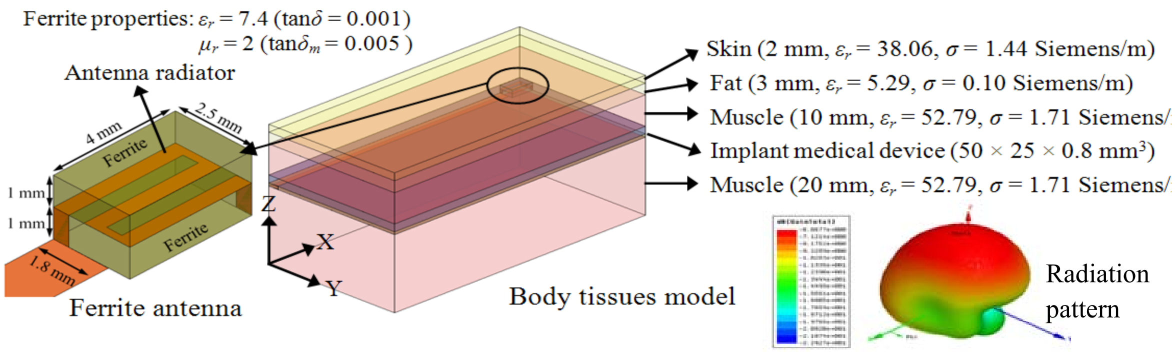


Fig.15 Preliminary antenna design (simulation) and body tissues model of the implantable ferrite antenna.

2.1.3 Motion-Disorder Detection Agents: This type of agents can control the functions of gait sensors for motion disorder / body imbalance detection (Fig.16). The agents can also perform gait pattern recognition via machine learning algorithms. Because we target a home-oriented rehabilitation system, the gait sensors can provide important at-home patient behavior data for the doctor's reference (Note: those gait data can be sent to the doctor's server via home Internet). If the patient shows less and less motion disorders with the progress of OHTR training, it indicates the positive effects of rehabilitation. The PIs have built a Pyroelectric Sensor Network (PSN) [xx] to recognize normal / abnormal patients' gaits (Fig.16 (1)). To generate rich visibility modes from human thermal sources, we attach a Fresnel lens to each pyroelectric sensor (see Fig.16 (2)). The acoustic sensor is also sensitive to the patient's walking strength and patterns through 50~100Hz signal pattern analysis [xx].

Fig.16 (1) Gait sensor array; (2) Pyroelectric sensor & lens; (3) Acoustic sensor; (4) Disorder / imbalance

2.1.4 Patient Tracking Agents: These agents control radio tomography (RT) nodes and RFID readers/tags to keep track of the patient's locations and to recognize the surrounding objects (such as medicine bottles). We have used RFID mini-reader M1 (Fig.17 (1)) to identify medicine bottles (Fig.17 (2)). The tracking agent design will use our designed wireless board as RT node (Fig.17 (3)) and adopt the RT software created by Utah [xx] for patient trajectory tracking.

Fig.17 (1) RFID reader; (2) Medicine detection; (3) Designed RT Node; (4) RT Principle; (5) RT spectrum [xx]

The patient's location data is very useful for patient behavior and living style analysis. For example, a big headache that many doctors have is not sure when and where (at home) a patient shows true neuro-symptoms. Radio tomography (RT) [xx] is a new technology for privacy-protected object tracking. It has certain similarity to computed tomography (CT) concept used in medical imaging system. However, RT uses wireless nodes deployed around an area to create many signal projections (Fig.17 (4)), which can be used to reconstruct the image of the moving object (Fig.17 (5)) [xx]. RT is superior to conventional, camera-based tracking system due to a few reasons: first, it uses low-cost wireless nodes (instead of expensive cameras) to estimates people locations through the measurement of radio signal strength (RSS); second, it can be even deployed even outside the house while cameras need direct object observations and good lighting conditions; third, perhaps the most important reason, many patients do not feel comfortable about the video-based behavior monitoring. They prefer to keep their life privacy via non-picture tracking systems. RT only records locations of patients without storing personal pictures.

2.2 Interface Layer: Design of Communication and Coordination Agents

Following the above mobile agent framework, in *Interface Layer* we will further build two types of mobile agents to achieve device interactions and coordination during a rehabilitation task:

2.2.1 Communication Agents: Communication agents (ComAs) are responsible for the inter-networking of all WIN devices. Networks based on Bluetooth, sensor networking, Wi-Fi or other wireless protocols have been well studied and deployed [xx-xx]. A ComA could help to achieve a few important data communication tasks: (1) VR-Server communications: all V-R devices could use wireless or wired interfaces to communicate with the server. A ComA can provide desired communication performance including data rates, image quality, and measurement resolution. (2) Medical Sensors & RFID Integration: The ComA can ensure seamless interface communications between RFID mini-reader and wireless mote. (3) Distributed Sensor Networking: Based on our previous pyroelectric sensor network (PSN) design [xx], we will build a ComA with the inter-networking of all motion / tracking agents. (4) IMD-Server Communications: A ComA will be responsible for the IMD status data access from a server.

2.2.2 Coordination Agents: There exists tight coupling and coordination among the above discussed WIN devices' operations. The Coordination agents will support: (1) Inter-operation between VR (virtual Reality) devices and the server: the server will increase its game difficulty levels ONLY when the coherency analysis software (section 6.3) shows satisfactory patient cognition and physical capability enhancement through signal analysis from VR devices (eye tracker, fNIR, and digital glove). (2) Inter-operation agent between medical sensors/IMDs and the server: The server shall adjust its game stimulation levels based on the SoI extraction results from the patient's body signals (collected from wearable body sensors and IMDs). For instance, in a certain time the heart may not tolerate over-exciting games. (3) IMD safety: The IMDs will never change its operation parameters without strict safety analysis from the entire OHTR system. For instance, a neuro-stimulator increases its pulse strength only when an authenticated server finds out that the patient has shows decreasing nerve response levels. In this project, we will use our customized pacemaker as the example, and design an IMD control tool that could **securely** adjust the pacemaker's pulse level based on the server's SoI analysis results (section 6.3).

2.3 Adaptation Layer: Achieving an *Agile* Tele-Rehabilitation Training

In the Adaptation Layer, our goal is to create a few software tools (to be run by the different mobile agents in Assembly / Interface Layers) in order to achieve the following rehabilitation agilities:

2.3.1 Concentration Agility: An important indication of rehabilitation progress is to see the improvement of the patient's anti-distraction capability. The eye-tracker can provide a quantitative measurement of the patient's eye focus level by tracking the eyeball's movement in real time. This project will design an **eye-hand coherence analysis tool** (briefly called *E-H tool*) to perform real-time trajectory matching analysis between the eye tracker's values and the mouse cursor (could be controlled by the digital glove) position data. For those two time series, we will use DTW (Dynamic Time Warping) [xx] to quantify their matching level. Regarding the game topic, we will select interesting treasure hunting games with adjustable searching path complexities. In Fig.xx, the marked spots show the eye tracker's capture results, and the cursor indicates the patient's hand movements.

Fig.xx Treasure Hunting Game for focus training

2.3.2 Motion Agility: Another important metric for rehabilitation training effects is to measure the patient's entire body flexibility and coordination level. Around fifteen 3-axis accelerometers are attached to the joints of the arms and legs to record their movement positions (relative values). We will select motion coherence training games (Fig.xx), and build an **arm-leg coherence analysis tool** (briefly called *A-L tool*) to perform two phases of algorithms: (1) In the <u>Training</u> phase, for a specific game (that defines a desired arm/leg movement patterns), we will use our well-studied NMF (Non-negative matrix factorization) algorithm [xx] to project the arm/leg accelerometer data into a set of pre-defined feature basis functions. Note that the arms and legs' data will be trained separately. The principle of NMF is shown in Fig.xx. It actually sees the high-dimensional arm/leg signals as the composition of low-dimensional basis patterns and basis mapping weights (i.e. coefficients). Then the corresponding projection coefficients (in the format of arm-leg pairs) can be obtained and stored into a *pattern gallery* for later testing use. (2) In the <u>Testing</u> phase, we will project the testing arm/leg movement data into those pre-defined feature basis functions, and obtain the projection coefficients (a data sequence with arm-leg pairs), which will be compared to the pattern gallery data. If their matching level is above a preset threshold value (there are many distance metrics that could be used for the test of similarity level of two coefficient sequences), we could regard that the patient shows good arm-leg coherence level.


Fig.xx Arm-Leg coherency training game

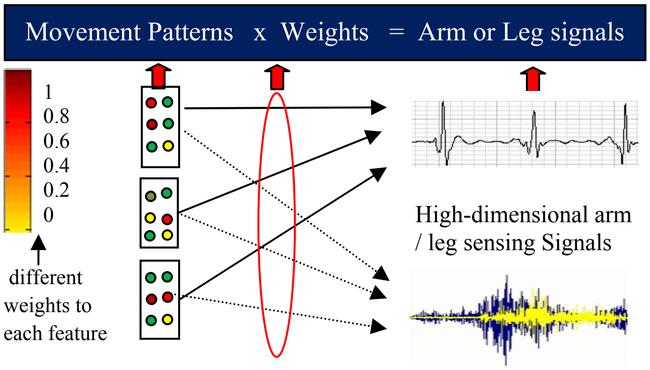


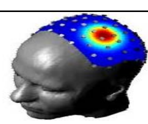
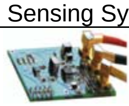
Fig.xx Principle of NMF for Arm/ Leg pattern identification

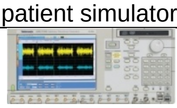
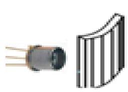
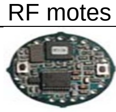
2.3.3 Symptom Agility: This refers to an efficient SoI (Symptom-of-Interest) extraction scheme from physiological monitoring devices (medical sensors and IMDs).Those SoIs are critical to patient health status analysis and rehabilitation game control. The symptom agility will be achieved through the design of **SoI extraction tool**. Although there are many efficient pattern recognition tools (such as neural networks [xx], wavelets [xx], etc.), our ECG learning [xx] and recent gait recognition [xx] indicate that both NMF (Fig.xx) and HMM [xx] could well capture interpretable symptoms through non-negative basis projection in NMF and anti-noise hidden Markov state learning in HMM. We will extend our ECG/gait learning schemes [xx, xx] to multi-modal medical sensing case (i.e., with ECG, EEG, EMG, SpO2, and IMD data) for efficient SoI learning. This infrastructure-oriented project will only focus on some frequently used SoIs in OHTR, such as seizure body shaking, brain semi-coma due to short-time intensive neuro-disorder, and premature heart beat. *A few medical doctors (neurologists) who are the co-PIs, will assist the PI with the design of the software tools for the recognition of those SoIs. They will also perform clinical tests to verify the accuracy of those tools based on the analysis of patients' measurements (Section 7)*.

2.3.4 Adaptation Agility: This refers to the adaptive platform control under different rehabilitation training conditions (such as the patient's training progress and health status). We will design two tools to achieve the adaptation agility: (1) Game Control Tools (GCTs): This refers to the game content change (from difficulty and stimulation perspective) based on the patient's SoIs and signal coherency analysis results. For instance, when the patient consistently shows low unilaterality of motor cortex in fNIR activation patterns, the server should decrease the game difficulty level. (2) Device Adjustment Tools (DATs): This refers to the IMD control software under different SoIs. As a DAT design example, we will program our self-designed pacemaker (section 6.1.2) to make it change output pulse strength based on different SoIs. The next-generation IMDs should have this adaptation capability.

It should be emphasized that the focus of this project is to establish computing infrastructure instead of conducting advanced OHTR research. Therefore, all of the above discussed tools will emphasize the software design of *the most fundamental functionalities* of the OHTR platform (Fig.8). On the other hand, we will design all software tools that allow convenient algorithm /parameter changes.

Table 1: Equipment (Detailed budget)

Equipment Name	Purpose	Source	Quantity	Price / cost
Part I. Virtual-Reality Gaming Sub-system (Total: ~$70K)				
 Digital Glove	For hand gesture capture (Re-programmable, with wireless signal transmissions)	5DT.com	**2** (with accessories)	~$7500 each; **Total: ~$15K**
 HMD	Head Mounted Display (HMD) can display the virtual game interaction environment	5DT.com	**1** (Model: 800-40 3D)	**Total: ~ $10K**
 fNIR	Functional Near-InfreRed (fNIR) Brain Imaging shows different patterns during Rehab training	Biopac.com	**1** (Model: fNIR 300)	**Total: ~$35K**
 Eye Tracker	It determines how well the patient could concentrate on a game event	Mirametrix.com	**1**	**Total: ~$6K**
 VR Game system	It provides controllable Virtual Reality game play and interactions	Amusitronix.com	**1**	**Total: ~$4K**
Part II. Physiological Monitoring Sub-system (~30K)				
 EEG Sensing System	Real-time display of EEG-sensed brain signal patterns	Emotive.com	**2**	$750 each **Total: $1,500**
 ECG sensing system	Records the heart beat patterns	shimmer-research.com	**2**	~$2,250 each; **Total: ~$4,500**

 EMG Sensors	Wireless EMG sensor to detect muscle movement.	shimmer-research.com	**20** (attached to different body positions)	~$200 each; **Total: $4,000**
 **SpO2 sensor**	Wireless pulse oximeter with SpO2 measurement	Made from FaceLake Inc.	**5**	~$120 each; **Total: $600**
 Blood pressure sensor	wireless blood pressure sensor to measure real-time blood pressure change (high/low)	quickmedical.com	**5**	~$200 each; **Total: $1,000**
 Cardiac patient simulator	To generate abnormal heart beat signals	Medi Cal Instruments, ecgsimulators.com	**4**	Price: ~$300 **Total: $1,200**
 Wave Generator	To generate different signals for medical sensors' detection	Agilent Technologies	**2**	$7,500 each; **Total: $15K**
 Reprogrammable Pacemaker	To test the rehabilitation-adaptive IMD (Implantable Medical Devices) control (note existing commercial one does not allow flexible re-programming	We will customize it from COTS chips and our ferrite miniature antenna. Co-PI (Huang) will provide heart leads and wires	**3**	For each: chip components fee: ~$300; Antenna design fee: $200. PCB manufact. fee: ~ $500; **Total: ~$3,000**
Part III. Motion Detection Sub-system (~$15K)				
 Motion Detection Kit	With motion detection capability via its accelerometers and gyroscopes, as well as wireless kit	shimmer-research.com	**5**	$2200 each; **Total: $11K**
 Pyroelectric sensors + Fresnal Lens	For patient gait recognition	Sensor is only $8 each; but the plastic lens needs to be manufactured in companies.	**30** lens (~$100 each)	**Total lens cost: ~$3,000**
 Acoustic sensors	For patient walking sound recognition	Letsmakerobots.com	**20**	~$60 each; **Total: $1,200**
Part IV. Tracking Sub-system (~$35K)				
 RF motes	To serve radio tomography (RT) nodes	Memsic.com (model: Locus motes)	**24** sets (with interface boards)	~$500 each set; **Total: $12K**
 RFID reader	To read RFID tags attached in medicine or other places	From SkyeRead Inc.	**5**	~$200 each; **Total: $1,000**

 RFID Develop Kit (ALR-9900)	Verification of subject identity (calibration tools)	Alien Inc.	**2**	Each kit: ~$2,000 **Total: $4,000**
 RF detector	To detect radio signals' strength (for RT use)	spyZone: www.spyzone.com	**2**	Price: $750 **Total: $1,500**
 Spectrum Analyzer	To analyze RF commu. Features / interference (for RT use)	Agilent Technologies	**2**	Price: ~$7,500 **Total: $15K**
			Total cost:	**~$150,000**