

# Cyberphysical System with Virtual Reality for Intelligent Motion Recognition and Training

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**ABSTRACT:** In this paper, we propose to build a comprehensive cyberphysical system (CPS) with virtual reality (VR) and intelligent sensors for motion recognition and training. We use both wearable wireless sensors (such as electrocardiogram, motion sensors) and nonintrusive wireless sensors (such as gait sensors) to monitor the motion training status. We first provide our CPS architecture. Then we focus on motion training from three perspectives: 1) VR—first we introduce how we can use motion capture camera to trace the motions; 2) gait recognition—we have invented low-cost small wireless pyroelectric sensor, which can recognize different gaits through Bayesian pattern learning. It can automatically measure gait training effects; and 3) gesture recognition—to quickly tell what motions the subject is doing, we propose a low-cost, low-complexity motion recognition system with 3-axis accelerometers. We will provide hardware and software design. Our experimental results validate the efficiency and accuracy of our CPS design.

**KEYWORDS :** Cyber-physical system (CPS), motion training, virtual reality (VR), wireless sensors

## I. INTRODUCTION

The top three leading causes of death in many countries, especially in developing or developed countries, are heart disease, cancer, and stroke. Among those, stroke is one of the most typical reasons to cause permanent disability among adults. In this paper, we propose a cyberphysical system (CPS) with intelligent sensor data mining and motion analysis. It can be potentially used for next-generation rehabilitation due to its cyber controlled, automatic motion analysis. Such a CPS allows a patient to interact with a VR game. The motion sensors worn by the patient can automatically tell which gesture the patient is performing, and the worn medical sensors can tell the patient's health status.

## II. EXISTING SYSTEM

In the existing method we normally have conventional manual in-hospital post-stroke motion training method. A robot-aided training system could significantly reduce physical therapists (PTs)' involvement due to its intelligent patient motion assistance. Conventional rehabilitation systems are based on labor-intensive and therapist-assisted manual recovery. Such high-cost, in-clinic treatment still dominates today's rehabilitation. Robot-aided rehabilitation platforms have been used in clinics to reduce therapy assistance [3]. An ankle robot was developed at MIT for neurorehabilitation of stroke patients [4]. VR-based platforms have been proposed recently. In a system with a pneumatic glove and immersive VR environment was proposed for post-stroke rehabilitative training. However, very little work has designed an integrated low-cost sensing and VR system for automatic rehabilitation purpose. Our system will use low-cost wireless gait/motion sensors and low-complexity data processing. **Disadvantages:** It is labor intensive and expensive. It still requires the patient to visit the hospitals due to the high-cost, heavy-size robot system.

### III. PROPOSED SYSTEM

This paper will present our CPS design, especially about the automatic gait/gesture recognition mechanisms. We will focus on motion recognition, which includes gait and gesture recognition. While gait recognition aims to extract the intrinsic walking/running patterns for body balancing analysis, gesture recognition aims to analyze the coherence level between all limbs and see if the patient can achieve certain standard limb motions. For gait recognition, we will explain how our system can automatically recognize different gait patterns during walking or running. Such patterns can tell the body balancing levels of a patient. For gesture recognition, we will use low-cost three-axis accelerometers to automatically recognize the patient's motions (such as raising right arm). This paper has made three contributions as follows. 1) First, we propose a low-cost VR system with motion recognition. We use low-cost Microsoft Kinect (<\$200) as well as its software development kit to automatically recognize human motions. Such a system can help the patient to see clearly how well his or her body interacts with the VR scenes. This can significantly motivate the patient to finish each training phase via interesting VR games. 2) We have invented low-cost pyroelectric sensor, which uses wireless thermal sensing to capture different gait patterns. We have designed intelligent sensing data analysis algorithms which can extract the most important features from binary raw sensor data. We propose to use Bayesian non-negative matrix factorization (NMF) model to accurately recognize different gait patterns. Third, we have designed an accurate limb motion (gesture) recognition system. By using multiple, low-cost, 3-axis, wireless accelerometers in the joints of limbs, we are able to automatically recognize dozens of limb gestures. Such a low-cost gesture recognition system is important to home-oriented motion training since it automatically tells the similarity between the patient's gesture and the standard ones (prestored in the gesture database). Table I summarizes the pros and cons of the proposed three motion training approaches to be elaborated later. As we can see, they have their own application scenarios, and can complement with each other. For example, although Kinect-based, 3-D reconstruction can help to visualize the body motion images, it involves complex image processing, and also does not have accurate gait/gesture capture.

### IV. CPS ARCHITECTURE

Our goal is to achieve the integration of VR and multifaceted [wearable, implantable, noninvasive (WIN)] sensing (Fig. 3 shows a logical architecture). The implantable medial devices and radio frequency identification (RFID) have been studied before and will be integrated into the system. The devices mainly include three types. 1) *Game Interaction Devices (Such as Digital Glove)*: They directly reflect the patient's hand adaptation progress during VR game play. 2) *Medical Sensors*: They mainly include electrocardiography (ECG, to measure heart beat rhythm), electromyography (EMG, to measure muscle activities), accelerometers (to measure movement), SpO2 (to measure Oxygen saturation), and other wearable sensors. 3) *RFID Mini-Reader*: It can read the RFID tags attached to surrounding objects. This is helpful to vision impaired or elder patients who can hear the beep of RFID reader's speaker in dangerous situations (e.g., when wrong medicine bottle is grabbed). The noninvasive sensors include pyroelectric/photonic sensors for gait disorder detection. This article has been accepted for inclusion in a future issue of this journal. Content is final as presented, with the exception of pagination. A. *Information Flow* The signals transferred among WIN devices include inputs (i.e., patient/device signal collections) and outputs (i.e., device/game control commands). As shown in Fig. 3, all device/patient status data are collected and sent to the server for symptom-of-interest (SoI) learning. Our system uses machine learning tools to achieve data fusion, signal projection (to visualize complex signals in low-dimensional subspace), signal correlation analysis (such as finding the patient's body coordination level), and pattern recognition (such as identifying heart attack events based on ECG processing). The learning results (for example, the patient shows satisfied cognitive capability for the current game level), can be used to achieve training adaptation, which includes two aspects. 1) *Game Control*: The game level should change based on the patient's training progress. 2) *Device Adjustment*: Some devices need to reconfigure themselves to adapt to the patient's status. In the lowest layer of our platform, we need to ensure that all hardware/software drivers work as what we expect. Moreover, devices of the same subsystem should seamlessly work together, and some software threads should be able to migrate from one device to another in the same subsystem. Here, thread migration means that we can use the same programming object with the function definition of action matching between

the previous object and the new one. For example, the body sensors' signal pattern recognition thread needs to be migrated to the server's game control thread for game adjustment. For the convenience of subsystem management and software thread migration, we propose to use an MA approach to manage all sensing and acting devices. Without loss of generality, we define an agent as independent hardware/software co-operation unit (such as a digital glove with hand gesture recognition software). The message exchange and thread.

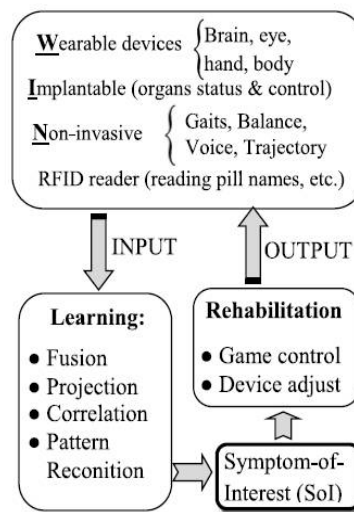


Fig 1: CPS internal architecture

#### IV. BODY MOTION RECONSTRUCTION FOR VIRTUAL REALITY

A VR systems can give the patient a virtual training environment through video games. For example, cooking is a basic life activity in the patient's life. However, it is not convenient for a PT to go with the patient for cooking training. In our CPS, a patient can use digital glove to interact with a virtual scene. Our system adopt inexpensive depth cameras— Microsoft Kinects (<\$200), to capture 3-D human motions at video rate. We can avoid the interference between cameras through only three Kinects deployed two Kinects capture the upper part and lower part of a human body, respectively, and the third Kinect is used to capture the middle body part. The Kinect IR emitter projects a pattern of a light throughout the room. The receiver then compares this data to a hard-coded image and generates a depth map [see Fig. 11(right)]. A skeleton is then applied to the body-like object in the depth map. To utilize Kinect to automatically recognize the patient's body gesture and then generate the corresponding skeleton, an open source application called be the controller (BTC) was used to build the database of poses and gestures.

#### V. GAIT REHABILITATION

In many rehabilitation training tasks, we are interested in the capture of different abnormal gaits. By comparing them with a prestored gait pattern database (through a pattern distance model), we will get to know the body training progress. Although the above Kinect-based system can tell the basic body motions, it has a few shortcomings. First, the depth image processing involves complex image pixel analysis and huge memory overhead, which makes real-time motion recognition to implement. Second, Kinect can only provide a coarse gait/gesture reconstruction. It cannot accurately capture the minor changes of body motions. Thus it cannot be used to analyze the quantitative rehabilitation progress levels for a gait training, which needs an accurate capture of body movement patterns during gait training. Our designed low-cost wireless pyroelectric sensors could detect the gait of an approaching walker through a highly sensitive thermal sensor that can discriminate among

very minor thermal changes. Through the binary processing of the raw analog thermal signals, as well as using efficient machine learning algorithms, our system can recognize the normal gaits of different walkers. Our final goal is to extend our previous work to the recognition of different abnormal gaits (compared to healthy people's well-balanced gait patterns). Such an extension is not trivial due to two reasons. 1) *Higher Gait Recognition Accuracy Is Needed*: While it is relatively easier to detect different walkers' normal gaits due to people's obvious walking habit differences, it is difficult to distinguish among various abnormal gaits due to their minor differences. For example, the borderland between two types of motor disorders (epileptic seizures and paroxysmal movement disorders) is not obvious [6]. It needs high-fidelity gait recognition schemes to distinguish among the following motor disorders: episodic ataxia, stereotypies, drop attacks, paroxysmal kinesigenic dyskinesia, and other symptoms. In order to achieve higher resolution gait recognition, we have redesigned our pyroelectric sensors with a richer gait sensing mode. Inspired by the insect's compound eyes (Fig. 13), we have designed the Fresnel lens with interleaved, small thermal signal filters. Such a special lens architecture could segment the surrounding thermal detection space into many delicate regions, and thus improve the gait detection sensitivity by checking which regions have signals. We have invented low-cost, small-size, and wireless gait sensor.

## VII. EXPERIMENTAL RESULT

A. *Multiagent-Based CPS Management* we have implemented multiagent-based model in Java development environment (JADE). A group of devices can use JADE to implement sharing of data and control. Our agent control architecture. We have programmed the agent behaviors and built four communication components: 1) message format and content definitions; 2) searching agents for communication purpose; 3) the sending/receiving mechanism between agents; and 4) message filtering function. We have also developed a belief, desire, and intention (BDI)-based agent behavior control scheme. The beliefs are derived from motion training status and results (such as gait/gesture training progress levels). We then formulate the possible desires based on the available beliefs. A new set of intentions and decisions can be generated based on previous BDIs. Generally, a simple agent behavior (such as sending out a sensing data sample) has low complexity intentions. However, a complicated agent behavior (such as multiagent interaction behavior) has high-complexity intentions. For JADE programming convenience, we further classify the agents into four types. 1) *Sensing Agents*: They detect medical, gait, or motion signals. 2) *Decision Agents*: They are abstract software units for device control purpose. For example, the VR games can be controlled based on the training progress. A better body flexibility can indicate that it is the time to upgrade the game difficulty level. 3) *Action Agents*: They are devices that can be reprogrammed in order to change their actions. For example, a reprogrammable treadmill can change its running speed. 4) *Database Agents*: They can update the gait/gesture databases. In our experiments, we have investigated three types of agent behaviors: 1) simple—such as generating a depth image; 2) high—such as NMF-based gesture recognition; and 3) medium—such as calculating 3-D body reconstruction.



(a) Kinect-based image capture system. (b) Three-dimensional reconstruction GUI.



(a) Three-dimensional reconstruction of "right leg rise." (b) Three-dimensional reconstruction of "arm wave."

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