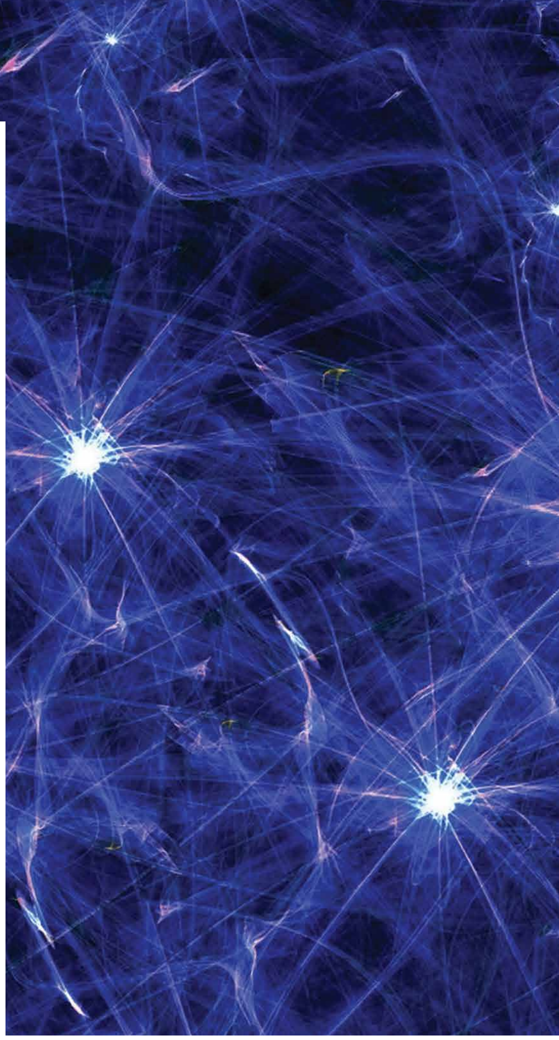
Virtual Reality and Robot-Based Rehabilitation for Post-Stroke Recovery

Dr Fei Hu

Scientia



VIRTUAL REALITY AND ROBOT-BASED REHABILITATION FOR POST-STROKE RECOVERY

Stroke survivors often lose some of their motor functions, and recovery can be a long and expensive process. By integrating virtual reality, robot, and motion capture technology, a low-cost solution can be developed that is more effective and accessible than current rehabilitation methods. Towards this aim, **Dr Fei Hu** and his team at the University of Alabama have made great strides in integrating technology from both the engineering and medical industries.

An estimated 15 million people a year suffer strokes, and stroke survivors are often afflicted with motor disabilities, due to damage in areas of the brain. Current therapies for helping patients restore their motor functions are expensive and labour-intensive, and the estimated cost of post-stroke treatment in the USA alone is $28 billion per year. With current treatments, patients can only expect to partially recover their movement capabilities, resulting in a severely reduced quality of life.

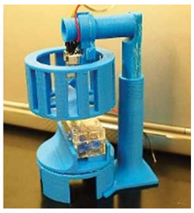
Recent advances in robotics have improved patient access to automated stroke rehabilitation systems. These systems can aid patients in recovering their lost motor skills, but are often bulky and expensive, and so cannot be used in the patient's home. Alternative equipment that is both cheaper and portable would greatly increase access, leading to greater rehabilitation success and reduced costs. One of the most promising areas of development involves the use of virtual reality, robots, and smart sensors.

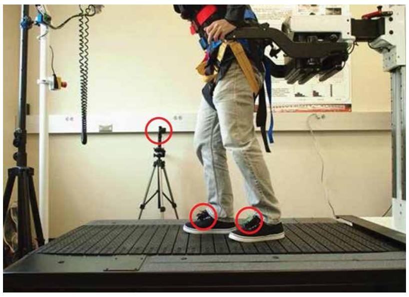
Motion sensing technology in computer games has been available for several years. These systems operate in a number of ways, but rely on the ability to identify the user's movements and translate them into in-game actions. If motion sensing could be applied to detecting the movement and posture of a stroke survivor, it could potentially be used for rehabilitation, helping them to recover their lost movement. Several types of motion or gesture sensing systems exist, including video or thermal cameras, accelerometers, gyroscopes and Microsoft Kinects, etc. Some of these systems are small enough to be built into smartphones, enabling the movement and orientation of a patient's phone to be measured.

Bringing Technologies Together

In computer games, the movements sensed are usually delicate and only small changes may be made as time goes on. This requires sensitive motion pattern detection. Also, the systems used by computer games rely on the recognition of specific actions and are relatively blunt in how they measure the user's activities. The sensors used today typically rely on accelerometers, which can detect movement, but cannot obtain accurate information about the actual position or posture of the user's limbs or body. One way of solving this problem is to use a thermal camera to detect the position and posture of the user. Dr Fei Hu and his colleagues at the University of Alabama have developed a system to achieve just this.

Providing feedback to the user on how well they have carried out an action would help the user to learn and improve, but the technology would need to be highly sensitive and sophisticated to achieve this. If this technology could be realised, it would provide a mechanism by which people with motor difficulties could re-learn a wide number of actions, and regain their motor skills in the process. Dr Fei Hu and his team have taken this concept further, integrating a number of systems (including virtual reality,





Thermal camera and plantar pressure sensor

‘In the future, we aim to upgrade our virtual reality system to augmented mixed reality, add new sensors to the data gloves to measure more delicate hand motions, program the robot in a more flexible style to emulate complex climbing actions, and create more exciting animation videos for virtual rehabilitation purposes’

video games, sensors, robot, etc.) together into a cyber-physical system (CPS) that can be used for physical rehabilitation. This technology is highly versatile, and has the potential to help patients suffering from a wide range of conditions.

The team’s CPS combines motion sensing with a virtual reality headset that shows the user their own motions in a virtual environment. This innovative low-cost system can accurately recognise patient movements and gestures, and provide feedback, and thus is ideal for automated rehabilitation applications.

Recent improvements by Dr Hu and his team have made the sensors on this system much more sensitive to the user’s movement, while at the same time reducing the amount of power they require. They have also redesigned the software that recognises movements, such as grabbing a cup or kicking a ball. Distinguishing between small, relatively delicate actions such as picking up a cup or grasping a door handle is vital if patients are to be able to recover their ability to perform these everyday tasks.

However, detecting movement is not the only important thing. Sensing disorders in the patient’s movements allows for diagnosis as well as training, and would enable the system to identify the type of rehabilitation required. The patient’s performance can also be recorded, allowing progress to be monitored remotely from a hospital, while the patient is at home.

Virtual Learning for the Real World

So, what does the team’s virtual environment look like? The virtual environment does not need to be totally immersive, nor does the patient need to be totally encased in a network of sensors. Using a wearable data glove, the system can detect both the position of the patient’s arm and their hand movements.

Through changing the shapes and colours of different objects, the environment provides feedback to the patient. This ‘biofeedback’ information can be displayed on a standard computer screen, and this will provide the patient with enough information. However, using virtual reality headsets, which are becoming much cheaper over time, can enhance the patient’s visualisation of the virtual environment and allows biofeedback to be overlaid on the real world.

When physical disabilities are more severe, more sophisticated systems are needed, such as a platform capable of dealing with sensors and feedback mechanisms for multiple parts of the body. Dr Hu and his team are currently developing such a system, with the support from the US National Science Foundation (NSF). ‘This platform can be used to perform post-stroke rehabilitation, pilot training, gesture correction, and other body training applications,’ says Dr Hu. The platform includes a virtual reality system with a suite of medical sensors to monitor patient condition and movement, and a software system to integrate the hardware units and signals from multiple sensors.

Currently, the team's multi-interface platform combines control and virtual reality systems with a reprogrammable treadmill, a data glove, an EMG (electromyography, used to assess muscle activity) and an ECG (electrocardiograph, used to measure heart activity). The platform's virtual reality system contains multiple simulations and scenarios, to allow for different patient training arrangements. However, the platform's architecture is designed to be flexible and is capable of being combined with other types of sensors and equipment.

One of the most important aspects of this platform is how it integrates readings from multiple sensors to give information about the patient's condition. Because each type of sensor produces data with different characteristics, Dr Hu and the team needed to develop a different data processing method for each sub-system in the platform. To do so, the team utilised their exceptional programming expertise, creating multiple '.dll' files to help the different components of the platform communicate with each other. These dll (dynamic link library) files are a common aspect of modern-day computing, and enable the sub-systems of most of our current technologies to work together.

However, none of this would work without the ability to properly identify patient movements, and a lot of work has also been carried out by Dr Hu and his team to develop rule sets and pattern recognition algorithms for each sensor (and in some cases, the integrated data from multiple sensors). These algorithms not only need to identify patient actions, but also provide instructions for the automated operation of the equipment (for example, adjusting the speed of the treadmill when the ECG shows that the patient's heart rate is too high). Significant time and effort has gone into these algorithms and the biofeedback representations and controls, to produce a fully integrated platform that brings all the components together as one functioning system.

Future Work

Dr Hu's goal is to develop a system that integrates highly sensitive motion sensors with a suite of other patient monitoring systems. He also aims to include RFID (radio-frequency identification) sensors that can provide information about the patient's environment (for example, to identify medicines in specific containers, or objects in the room as they move through it).

Another important goal that Dr Hu aims to achieve is the development of a sophisticated virtual/mixed 'game' environment that can be used for measurable patient rehabilitation. This environment would be able to automatically adjust itself based on the patient's training progress, and the patient's own condition. As the patient progressed or their condition improved, the virtual environment would change to maximise the effectiveness of the training program.

As mentioned above, properly fusing all the signals together from multiple sensors is vital, to allow a system like this to operate intelligently. Additionally, the correlations among all signals must be analysed in real time, to ensure that the simultaneous movements in different parts of the body are captured accurately as meaningful, specific motions. Dr Hu's team is working on a system that brings sensor signals together and simplifies their integration to recognise complex features, objects and specific actions.

'We aim to upgrade our virtual reality system to augmented mixed reality, add new sensors to the data gloves to measure more delicate hand motions, program the robot in a more flexible style to emulate complex climbing actions, and create more exciting animation videos for virtual rehabilitation purposes,' says Dr Hu.

In this future work, Dr Hu wants to integrate EEG signals from the patient's brain with their own movements, to provide deeper insights into how the training and rehabilitation process changes brain structure. His team also intends to work on machine learning approaches that will enable more complex patterns of the movement to be recognised from heterogeneous sensors.

Meet the researcher

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Dr Hu is currently a Professor at The University of Alabama in the US. After obtaining a BS at the School of Computer Science & Engineering of Shanghai Tiedao University in China in 1993, he graduated from the same university in 1996 with a Master's degree. In 1999, he achieved a PhD in Communication & Signal Processing at Tongji University in China, and a second PhD from Clarkson University, New York, USA in 2002. From 1999 to 2002, he acted as a Teaching Assistant then a Research Assistant at Clarkson University, and from 2002 to 2008 was an Assistant Professor at Kate Gleason College of Engineering at RIT in New York. After achieving an Associate Professorship in 2008, Dr Hu moved to the University of Alabama, where he became a Professor at the Department of Electrical and Computer Engineering in 2015. Dr Hu's research focuses on wireless networks, machine learning, Big Data and cybersecurity. He teaches a number of Electrical and Computer Engineering courses, and was voted the Best Teacher Award in 2007 at RIT. He has been an Associate Editor for a number of journals in his field, including Communications and Computer Security, International Journal of Communications, International Journal of Telemedicine & Applications and the IEEE Journal of Communication Surveys & Tutorials. He has over 200 publications in international journals and at conferences. His research has been supported by US NSF, DoD, and industry.

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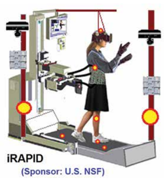

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