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Lower-Limb Rehabilitation at Home:
A Survey on Exercise Assessment and Initial Study on Exercise State Identification Toward Biofeedback

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ABSTRACT

Aging causes loss of muscle strength, especially on the lower limbs, resulting in a higher risk of injuries during functional activities. To regain mobility and strength from injuries, physiotherapy prescribes rehabilitation exercise to assist the patients' recovery. In this article, the authors survey the existing work in exercise assessment and state identification which contributes to innovating the biofeedback for patient home guidance. The initial study on a machine-learning-based model is proposed to identify the 4-state motion of rehabilitation exercise using wearable sensors on the lower limbs. The study analyses the impact of the feature extracted from the sensor signals while classifying using the linear kernel of the support vector machine method. The evaluation results show that the method has an average accuracy of 95.83% using the raw sensor signal, which has more impact than the sensor fused Euler and joint angles in the state prediction model. This study will both enable real-time biofeedback and provide complementary support to clinical assessment and performance tracking.

KEYWORDS

Euler Angle, Feature Engineering, MEMS, Rehabilitation Exercise Assessment, Supervised Learning, Wearable Sensor

INTRODUCTION

Disability greatly affect the quality of life of people all over the world. The world report on disability stated that the number of people having a disability will increase to over one billion people (World Health Organization, n.d.-b). The rising number is due to the fast ageing population, chronic health conditions and injuries. Rehabilitation is the compulsory procedure for recovery and prevention from further disabilities so as to reduce the risk of fall and hospital admission for the elderly (World Health Organization, n.d.-a) as well as to prevent and treat functional disability (Singh, 2002). Lower-limb injuries that need rehabilitation include osteoarthritis (Musumeci et al., 2014), knee injuries (orthoinfo, n.d.), Dynamic Knee Valgus (DKV) among althletes (Gornitzky et al., 2016) and post-reconstruction

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surgery (Paterno, 2015) etc. While rehabilitation is proven crucial, injury prevention during recovery is often overlooked. Thus, the patients are encouraged to have more regular supervision.

While clinical physiotherapy diagnoses and customized treatments often rely on the visual assessment of experienced physiotherapists, technology tools such as motion tracking system and wearable sensors have facilitated quantitative progress reporting and biofeedback for patients practicing at home. It is compulsory that the patient repeats the exercises as instructed during the clinic appointment. If patients fail to execute the correct motion or improper placement of the lower limbs while exercising, it would slow down the recovery progress or place unnecessary pressure on the joints concerned (Draper & Ballard, 1991). One consequential example of mis implementation is Dynamic Knee Valgus (DKV) (Padua, Bell, & Clark, 2012) which is a result of putting pressure on the knee joint by twisting it inward. It could escalate to Anterior Cruciate Ligament (ACL) rupture. Enabling assistive technology maximizes the accessibility and affordability of home rehabilitation, especially at the community level. In tandem with solving the issue of inadequate number of physiotherapists and caregivers for the ageing population, digital supervision of physiotherapy exercises are feasible and scalable solutions.

Wearable sensors, Internet of Things, and available devices serve to deliver clinical and quality health care to people at home or in a community. Realizing the importance of eHealth and the availability of motion tracking system, home-based rehabilitation has become a leading research topic in recent years. The collective information of MEMS sensors not only provides progress summary to the physiotherapist but also has the potential to assess and take earlier measures to prevent injuries while the exercise is being carried out in real time.

In this paper, we propose a machine learning model for human motion assessment for state identification to facilitate rehabilitation exercise assessment. Upon proposing the training model, the survey on state-of-art methods of exercise assessment and state recognition are summarised. The paper will provide the insight and impact of input features, the signal data and sensor-fused angular displacement, align with the performance of the pattern recognition model.

Exercise Assessment

The exercise assessment and screening are designed to analyse the posture, stability and movements to determine what injuries the patient is at risk of developing and what exercises will best improve his/her deficiencies to achieve the health goals. Exercise assessment can be broadly divided into two categories, namely, learning-based and rule-based. Rule-based methods use a set of rules to identify a new related activity. Learning-based methods refer to machine learning models that train data using pre-defined labels and predict the outcome of the data.

Rule-Based Approach

Rule-based approach focuses on setting rules based on the perception of correct postures and movements. For rehabilitation exercise, the rule-based framework is commonly defined using the joint angles and orientation of the body segment to distinguish rules for gestures and repetitive count.

Rule-based framework has been introduced as a gesture recognition method using the joint angles (parameters) obtained by sensor devices (equipment) in order to create sequences or sets of rules (rule types and methods). As the clinician uses visual assessment for the prognosis, visual equipment is frequently used for the rule-based framework. In particular, Kinect is used to extract the body segment orientation (Clark, Pua, Bryant, & Hunt, 2013) and joint angles (Bedregal, Costa, & Dimuro, 2006; Hachaj & Ogiela, 2014) as the inputs to form rules. However, other types of equipment such as Inertial Sensors (Bo, Hayashibe, & Poignet, 2011) and robotics (Akdo˘gan, Taçgın, & Adli, 2009) are also been used to obtain sensor data to derive the joint angles and orientation.

Figure 1 summarises the development of rule formation. It evolves from the monatomic configuration to the clearly defined types of rules. The evolution of rule-based methods could be considered to originate from defining sequences for finger joints angle (Bedregal et al., 2006). Each

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