Computational Intelligence in Detecting Abnormal Pressure in the Diabetic Foot

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INTRODUCTION

Plantar pressure measurement has gained steady popularity in the research field. From aiding in the evaluation of gait patterns and athletic training, to producing custom footwear and orthothics, plantar pressure measurement has become an indispensable tool (Bergin et al., 2012; Bus, 2012; Bus, Haspels, & Busch-Westbroek, 2011; Cavanagh & Bus, 2010). Interest has sparked particularly in diabetic foot research following findings that a high, or abnormal plantar pressure distribution puts diabetic, especially diabetic neuropathic individuals at greater risk of foot ulceration (Tong, Acharya, Chua, & Tan, 2011). Diabetic foot ulcers are the leading cause of non-traumatic lower limb amputations in Australia and around the world (AIHW, 2010; Bergin et al., 2012; Frykberg et al., 2006). However the diverse nature of diabetic patients with varying foot types, and different stages and severity of the disease, combined with the complexity of the plantar pressure data have made the early detection of abnormal plantar pressure distributions quite a difficult task from medical and research perspectives. Consequently, a plantar pressure threshold above which patients are at risk of foot ulceration has yet to be established. Diabetic foot research has instead largely focused on the treatment of existing foot ulcers, and the prevention of secondary ulcers by using various types of footwear to offload pressure at previous ulcer sites (Bus, 2012; Cavanagh & Bus, 2010). The prediction of ulcer development in diabetic patients has been limited to clinical screenings and risk evaluations. These methods are heavily reliant on human interpretation, which not only makes the detection of sensitive shifts in plantar pressure difficult, but it also insures unavoidable human error (Boulton et al., 2008; Lavery & Armstrong, 2012; Wu, Driver, Wrobel, & Armstrong, 2007). It is therefore of paramount importance that an automated method capable of identifying the plantar pressure patterns typically associated with diabetic foot ulceration is established, so that at-risk individuals can receive the necessary care to prevent plantar surface injury.

Computational intelligence is proving to be a proficient and accurate method in dealing with large, complex and ambiguous datasets. Models based on computational intelligence techniques are capable of learning, recognising, and classifying patterns in the data. These models are being increasingly used to improve medical diagnosis and decision support systems, while lessening the burden on human resources (Gudadhe, Wankhade, & Dongre, 2010; Jayalakshmi & Santhakumaran, 2010; Temurtas, Yumusak, & Temurtas, 2009; Yoon, Park, Kim, & Baek, 2013).

In this article, we examine the use of computational intelligence techniques as diagnostic support systems, and review the benefits and limitations these techniques may present in current and future applications.

BACKGROUND

Today's ever-changing lifestyle has seen the manifestation of a diabetic epidemic become deeply ingrained into our society. The diabetic population has shifted over recent years towards being an alarmingly younger, and more overweight population. The growing incidence of diabetes diagnosis throughout the world has sparked many health concerns, instigating a wave of diabetic research to not only deal with the disease itself, but also the many consequent, and often quite debilitating, complications brought about by diabetes. Foot ulcers, in particular, have proven to be a great cause for concern as one of the most severe complications to affect diabetic individuals on a global scale. In fact foot ulcers can have detrimental effects on a diabetic patient's wellbeing and quality of life. Moreover, management and treatment of these ulcers places a substantial financial burden on both patients and the healthcare system (Snyder & Hanft, 2009; Winkley et al., 2012; Winkley, Stahl, Chalder, Edmonds, & Ismail, 2009).

The likelihood of foot ulceration is relative to the number of risk factors a diabetic individual is predisposed to developing (Martin, Beraldo, Passeri, Freitas, & Pace, 2012). Many risk factors stem from the progressive damage to nerves in the peripheral nervous system, known widely as peripheral neuropathy, which can cause numbness, weakness, pain and often a partial or complete loss of sensation in the limbs. Additionally, neuropathy is also known to cause anatomical and structural changes to the foot, and deformities such as claw or hammer toe, callus formation, and limited joint movements are commonly observed with diabetes (Lavery & Armstrong, 2012). Foot deformity alone can cause significant increases in the plantar pressure distribution of a diabetic patient. In the instance that both foot deformity and impaired sensation on the plantar aspect of the foot are present, a diabetic individual becomes 12 times more likely to develop a foot ulcer due to being unable to feel the onset of foot injury, which increases the likelihood of exposing the plantar site of injury to further damage due to high pressure during daily activity (Aguilar Rebolledo, Teran Soto, & Escobedo de la Pen, 2011; Lavery & Armstrong, 2012; Martin et al., 2012).

Figure 1 shows the plantar pressure distribution of a diabetic individual in comparison to a normal foot. High plantar pressure is often observed in the centre of the forefoot, as this pressure assists in generating forward propulsion during walking. Consequently, a reduction in the overall forefoot pressure generated during gait (Figure 1) can lead to slower walking speed, which is common with diabetic patients (Ko, Hughes, & Lewis, 2012). The high pressure localised in the mid forefoot (Figure 1, Figure 2) is also a prominent feature observed in the plantar pressure of diabetic patients (Ko et al., 2012).

AUTOMATED PLANTAR PRESSURE CLASSIFICATION

Classification of diabetic plantar pressure parameters using computational intelligence techniques has been examined by a faction of researchers. These studies have focused around identifying three different conditions of the foot: i) normal, ii) diabetic and iii) diabetic neuropathic. The following section reviews the computational techniques of neural networks, fuzzy logic and Gaussian mixture models, and examines their proficiency for this complex classification problem.

Figure 1. Plantar pressure distribution of a normal and diabetic foot
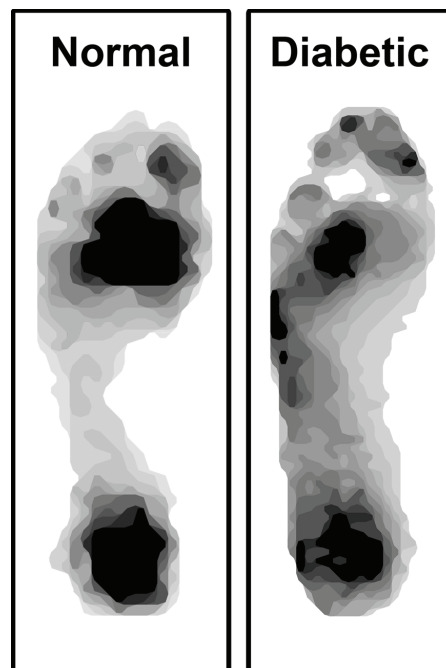
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