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Patient handling activity recognition through pressure-map manifold learning using a footwear sensor

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ABSTRACT

The risk of overexertion injury caused by patient handling and movement activities causes chronic pain and other physical and social impairments among the nursing force. The accurate recognition of patient handling activities (PHA) is the first step to reduce injury risk for caregivers. The current practice on workplace activity recognition is neither accurate nor convenient to perform. In this paper, we propose a novel solution comprising a smart footwear device and an action manifold learning framework to address the challenge. The wearable device, called Smart Insole, is equipped with a rich set of sensors and can provide an unobtrusive approach to obtain and characterize the action information of patient handling activities. Our proposed action manifold learning (AML) framework extracts the intrinsic signature structure by projecting raw pressure data from a high-dimensional input space to a low-dimensional manifold space. This framework not only performs dimension reduction but also reduces motion artifacts, which is robust against the noise and inter-class/intra-class variation in PHA recognition. To validate the effectiveness of the proposed framework, we perform a pilot study with eight subjects including eight common activities in a nursing room. The intrinsic dimensionality of the manifold is estimated by comparing the residual variances of different dimensionality settings. The experimental results show the overall classification accuracy achieves 86.6%. Meanwhile, the qualitative profile and load level can also be classified with accuracies of 98.9% and 88.3%, respectively.

1. Introduction

All healthcare workers, especially nurses and hospital aids, face a wide range of hazards on the job, such as musculoskeletal disorders related to ergonomic hazards (Public Health Service, 2000). These disorders are associated with excessive back and shoulder loading due to manual patient handling, applying excessive force during pushing and/or pulling of objects, required use of awkward postures during patient care, and working long hours and shiftwork (Waters, Collins, Galinsky, & Caruso, 2006). In 2012 and annually thereafter, overexertion injuries, such as musculoskeletal disorders, low back pain and shoulder pain, accounted for nearly 70 million physician office visits in the United States (Work-related musculoskeletal). The high risk of occupational injuries contributes to severe nurse shortages. The demand for nurses is projected to grow by 22% by 2008, and unless market corrections are made, the nursing shortage may reach 800,000 vacant positions by 2020 (Projected supply, 2002).

The high injury rate of nurses is in part because there is no effective way to monitor the development of chronic injury and detect

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acute overexertion. As a result, preventive measures and response to injury is limited to physical therapy (Waters & Rockefeller, 2010) and workload rescheduling (Caruso & Waters, 2008). Currently, assessment of workplace exposure through observation is a common practice in ergonomics (Mathiassen, Liv, & Wahlström, 2013). However, visual assessments are subjective and may fail to accurately quantify physical exposure, integrate multi-faceted traits (Cavuoto & Nussbaum, 2014; Gallagher & Heberger, 2013; Garg & Kapellusch, 2009), and the observation duration and number of workers being observed may be limited (Paquet, Punnett, & Buchholz, 2001). As a result, automatic patient handling and movement activity recognition is important as a first step to reduce risk and prevent caregiver injury.

The development of advanced technology brings the possibility of more complete assessment and monitoring in the nursing workspace. One widely used approach is the computer vision system for monitoring user activity and behavior in nursing rooms (Garg, Owen, & Carlson, 1992). However, computer vision systems require costly installation and maintenance effort. The post-processing of data involves complex video and image algorithms, making the system costly. Furthermore, immobility, occlusion, and varying illuminations raise technical challenges in recognizing objects in video (Chen, Yang, & Wactlar, 2004; Hauptmann et al., 2004). Privacy in video monitoring is also a concern. A wearable sensing system, such as a miniaturized inertial motion unit (IMU), is a promising approach to caregiver monitoring due to the nature of the handling and movement tasks performed. To monitor complex patient handling activities, multiple IMU sensors attached on different body locations are often needed (Zhang, Wong, & Wu 2011; Zhang, Wu, Chen, & Wu, 2009); however, this is a hassle for long-term use and normal patient handling work (Naya, Ohmura, Takayanagi, Noma, & Kogure, 2006).

Compared to daily life activity (DLA) recognition (Alshurafa et al., 2014), patient handling activity (PHA) recognition is a challenging and substantially unexplored topic. PHA is a complex process and usually involves an interactive procedure between healthcare workers and loads (e.g., patients, medical instruments). Moreover, the characterization of PHA includes not only body postures but loads. Safe patient handling activities follow standardized procedures to prevent injury to both patients and caregivers, which are constrained by regulated operation, physical body kinematics, and the temporal constrains posed by the activities being performed. Given these constraints, PHA primitive, also called “action signature,” can be extracted and represented in a low-dimensional manifold space embedded in a high-dimensional input space. Furthermore, these manifolds capture the intrinsic geometry of activities and act as trajectories to characterize different PHAs. Action signatures are usually nonlinear and even twisted, so dimension reduction by linear model such as principal component analysis (PCA) fail to discover the underlying geometric structures.

We propose a novel solution to overcome the aforementioned obstacles in PHA recognition, which comprise a Smart Insole and an action manifold learning (AML) framework. Smart Insole is a novel footwear device that uses an advanced electronic textile (eTextile) fabric sensor technique providing accurate plantar pressure measurement in both ambulatory and static status. Smart Insole looks and feels like a normal insole without any extra cable, antenna, or adhesive equipment. It is also thin, light weight and easy to use, enabling unobtrusive monitoring of human activities.

Action manifold learning is able to project high-dimensional data into a low-dimensional manifold space. By capturing the fundamental signature of action, only the intrinsic primitive structure is preserved in this transform, whereas unrelated motion artifacts and noise are neglected. Therefore, AML not only performs dimension reduction but also suppresses motion artifacts and noise, which efficiently solves the variation problem in both inter-class and intra-class activities. In this proposed framework, raw pressure data are used rather than extracted statistical features, which are more robust because raw data utterly capture the direct pressure variation imposed by the activities.

We conduct a quantitative evaluation in a controlled environment and a real-life longitudinal study for the AML framework. The experimental results show our method succeeds in qualitative profile recognition, PHA recognition, and load estimation with the overall classification accuracy of 98.9%, 86.6%, and 88.3%, respectively.

The organization of the remaining paper is as follows. Section 2 introduces the background and preliminaries, including related work and Smart Insole design. Section 3 elaborates the action manifold learning framework on underfoot pressure maps. Section 4 provides the evaluation results for the proposed AML framework. Section 5 discusses the impact of the number of nearest neighbors, distance metrics, and generalization in the AML framework. Finally, the conclusion and future work are discussed in Section 6.[1]

2. Background and preliminaries

2.1. Related work

2.1.1. Wearable sensors in nursing activity recognition

Wearable sensors have been used to monitor human actions in the nursing environment. Kuwahara et al. (2003) proposed a wearable auto-event-recording system of medical nursing to capture significant events necessary for analyzing medical accidents. Momen and Fernie (2010) used a wireless Sony game controller to identify six nursing activities happening around a patient. They also identified the start and stop times of six simple nursing activities by attaching a single accelerometer sensor to the backs of eight nurses (Momen & Fernie, 2010). Recognizing the importance of awkward postures in the causation of work-related injuries among nurses, recent research efforts have focused on tracking specific postures adopted by nurses (Freitag, Ellegast, Dulon, & Nienhaus,

[1] An early version (Lin, Song, Xu, Cavuoto, & Xu, 2016) was presented at the first IEEE Conference on Connected Health: Applications, Systems and Engineering Technologies (CHASE 2016).