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A situation-aware system for the detection of motion disorders of patients with Autism Spectrum Disorders

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ABSTRACT

Patients with Autism Spectrum Disorders (ASD) show symptoms that in general fall into three areas: (1) social impairment; (2) communication difficulties; and, (3) repetitive and stereotyped behaviors. This paper presents a method and an infrastructure for the detection of the stereotyped motion disorders of patients with ASD. The method adopts Artificial Intelligence techniques for the identification of stereotyped motion disorders and the Situation-Awareness paradigm for the reduction of misclassifications and the extraction of further information useful for clinicians. Signals caught by accelerometers are pre-processed to obtain features that, in turn, are passed to the classifier that classifies the current temporal frame in order to detect stereotyped motions. Once a stereotyped motion is detected, events are generated for intelligent situation-aware components, which collect information related to the frequency and period of the day of the disorders, and help also to reduce false positives and misclassifications by verifying spatio-temporal constraints. Quantitatively, the off-line classifier has shown an accuracy of over 99%; whereas the on-line classifier has an accuracy of 92%. The research activity has been conducted in cooperation with clinicians of the Department of Child Psychiatry at the Children's Hospital Santobono-Pausilipon in Naples, a prototype is deployed and tested at the hospital.

1. Introduction

The Autism Spectrum Disorders (ASD) is a group of variable neurodevelopmental disorders that first arise during childhood, and generally follow a fixed progress without remission. Manifest symptoms gradually begin after the age of six months, become established by an age of two or three years and tend to continue through childhood and adulthood. They are distinguished not by a single symptom but by a characteristic triad of symptoms: impairments in social interaction; impairments in communication; and restricted interests and repetitive behavior (Filipek et al., 1999).

Thirty years ago autism was considered to be a rare childhood disorder most often associated with severe intellectual disabilities, a lack of social awareness and the absence of meaningful expressive language (Lotter, 1967). Today, the spectrum of autism disorders is now recognized as a set of common developmental disorders, with an estimated prevalence of, for example, about in every 110 children in the U.S. (Autism, 2006). The symptoms of ASD vary from one child to the next, but in general, they fall into three areas: (1) social impairment; (2) communication difficulties; and, (3) repetitive and stereotyped behaviors. Autistic individuals show many forms of stereotyped behaviors which the Repetitive Behavior Scale-Revised (RBS-R) Lam and Aman (2007) classifies in several categories, one of which being stereotyped movements such as hand flapping, head rolling, or body rocking.

This paper presents a method for the detection of the stereotyped motion disorders and it focuses on the automatic recognition of repetitive and stereotyped behaviors, with a specific emphasis on those that are symptoms of a status of anxiety or of isolation from the surrounding environment. The proposed system uses 3D-axis accelerometer data, whose waveforms, in the case of motion disorders, show clearly identifiable patterns. The method adopts Artificial Intelligence techniques for the detection of motions disorders, thus, a specifically designed Artificial Neural Network (ANN) classifies the temporal frames of patient gestures against such patterns and generates an event whenever a temporal frame is classified as a disorder. Such events are then processed by situation-aware intelligent agents with the aim both of obtaining temporal information useful for clinicians and of reducing misclassifications. The information purged of the misclassifications helps the clinicians to automatically collect reports useful for the tracking of the patient's history of gestures and anomalous behaviors as well. The off-line classifier has shown an accuracy of over 99%; the

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on-line an accuracy of 92%. The system is currently deployed at the Department of Child Psychiatry at the Children's Hospital Santobono-Pausilipon in Naples, in order to validate it against a variety of patients.

2. Theoretical background

2.1. Human behavior understanding

Understanding the nature of human activities is in itself a significant research question for many disciplinary traditions, such as psychology, sociology, and ergonomics. The variety of different perspectives creates problems, since each discipline may exploit different tactics to uncover the nature of human action. Understanding how to represent human achieving activities for the purpose of intelligent environments draws upon these different traditions, and represents a significant multidisciplinary challenge (Chalmers et al., 2006). The need to understand human behavior arose in video surveillance with the aim of detecting crimes. In video surveillance, the analysis is performed in two steps: the segmentation and tracking of human beings in video sequences, and the recognition and understanding of human behavior (Xu, Tang, Liu, & Zhang, 2010). Concerning the understanding of human behavior, two kinds of approach are available: template matching, which aims to extract motion features from the given image sequence and to match such features with predefined activity patterns, and state space that aims to formulate statistical models to recognize several human behaviors. Many research efforts to understand abnormal behavior have been made in the last few years. Some approaches use an internal list of anomalous patterns against which the current behavior is compared.

The effectiveness of such approaches, however, is limited to the set of abnormal behaviors statically defined and does not scale to other unforeseen possible abnormal behaviors. Other approaches inspired by the state space model are (Xiang & Gong, 2008) and (Loy, Xiang, & Gong, 2009). In such cases, all deviations from the normal state space are considered abnormal behaviors. The major drawback of such approaches is the reduced ability to correctly classify anomalous activities and behaviors. An emerging field of application for human behavior representation and recognition techniques is Ambient Intelligence (Cook, Augusto, & Jakkula, 2009). Nater, Grabner, and Gool (2010) propose a data-driven hierarchical approach for the analysis (by means of visual scenes) of human actions in ambient assisted living scenarios. In particular, the authors propose a novel representation and analysis approach, which relies on the learning of a model of normal human behavior in an unsupervised manner. A publicly available action recognition dataset is adopted to determine the micro-actions and to identify actions. This approach, however, focuses exclusively on human motion. Indeed, no kind of interaction with objects within the environment is taken into account. Moreover, anomalous behaviors are identified with deviations from the observed sequence of micro-actions (body motions) with respect to normal models. In Monekosso and Remagnino (2010), a model-based behavior analysis system for assisted living is proposed. The monitoring of human behavior is achieved with unsupervised learning algorithms. Behavior is defined as a recognizable pattern in a sequence of events or activities and is represented by means of Hidden Markov Models (HMM). The system is able to detect and classify human behavior against a predefined subset of normal behaviors. Deviations from normal behaviors are classified as anomalies, but such a situation requires further investigation by a human in order to correctly establish the nature of the anomaly. As far as stereotyped motion disorders are concerned, a few approaches based on template matching techniques have been proposed. In Min and Tewfik (2010), an approach based on Linear Predictive Coding is defined for the detection and characterization of behavioral patterns. In Goncalves, Rodrigues, Costa, and Soares (2012), the authors adopt the Microsoft Kinect device and gesture recognition algorithms to identify stereotyped motion disorders. On one hand, this method does not require any wearable device for the monitored user; on the other, motion disorders can be detected only when the user is located in a specific area opposite to the device. Albinali, Goodwin, and Intille (2009) and Albinali, Goodwin, and Intille (2012), have adopted wearable sensors and machine learning algorithms to identify the stereotyped motion disorders of children with autism. They have focused on two motion disorders: hand flapping and body rocking. As detailed later in this paper, our method differs from previous approaches because the results obtained by a classic classifier based on a machine learning algorithm (i.e. a neural network) are successively processed by intelligent agents that reduce misclassifications and infer further clinical information.

2.2. Situation Awareness

Situation-Awareness enhances the concept of the context (Lee, Lunney, Curran, & Santos, 2009) by including rich temporal and other structural aspects: time of day, a situation may only happen at a particular time of the day; duration, it may only last a certain length of time; frequency, it may only happen a certain number of times per week; and sequence, different situations may occur in a certain sequence (Ye, Dobson, & McKeever, 2011). As suggested by Ye et al. (2011), we should distinguish between Context and Situation-Awareness. Indeed, the authors propose the following definitions: the Primary Context is the full set of data caught by real and virtual sensors; the Secondary Context focuses on semantic information inferred and/or derived from the fusion of several data streams (primary contexts) an important kind of secondary context consisting in activities performed within the environment; a situation is, instead, an abstract state of affairs of interest for designers and applications, which is derived from the context and a hypothesis about how the observed context relates to factors of interest. In this paper we use the Artificial Neural Network to identify a piece of the secondary context, that related to special physical activities identified as motion disorders, and intelligent Prolog agents that exploit the Situation-Awareness paradigm to reason on temporal constraints in order to reduce misclassifications and obtain further information useful for the clinician.

The situation model has been described by using Situation Calculus (SC). The basic SC was designed by McCarthy (1963) and has been adopted to model dynamically changing worlds. Three basic kinds of SC are: *Actions*, which can be performed in the world and can be quantified; *Fluents*, that describe the state of the world (these are predicates and functions whose value may change depending on the situation); and *Situations*, which represent a history of action occurrences. A dynamic world is modeled through a series of situations as a result of various actions being performed within the world. The constant S0 denotes the initial situation; whereas, do(a, S) indicates the situation resulting from the execution of the action a in situation S. The dynamic world is axiomatized mainly by adding initial world axioms, effect axioms, and successor state axioms (Reiter, 2001). The initial world axioms describe the initial status of the environment, its objects, their position, their properties, etc. An effect axiom, instead, describes the effect on a fluent caused by the execution of an action in a specific situation. There must be specified for each fluent also the non-effect of the other actions. Intuitively, it is possible to state that a fluent's truth value is true after executing an action a if, and only if, the action has the effect of making the fluent true or, the fluent was already true before executing a and the action does not have the effect of making