A dynamic annotation tool to support in-home autism intervention

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Overview

The Michelangelo Project is an EU funded project that aims to utilize a range of emerging healthcare technologies to provide personalised in-home intervention strategies for children with autism spectrum disorder. It is anticipated that through analysis of behavioural and physiological data, acquired during therapeutic sessions clinicians will be able to assess the intermediate outcomes of a therapeutic intervention and adapt it according to the evolution and efficacy of the treatment. Supporting this analysis are a suite of technologies collecting both behavioural and neurological data ranging from wearable EEG, environmental video and a set of pervasive and physiological sensor systems. Initially, the project will focus on the target skills of joint attention and imitation. This paper describes the proposed use of a data annotation tool referred to as DANTE (Dynamic ANnotation Tool for smart Environments) used to augment and label the behavioral data recorded during the therapeutic interventions. Furthermore, DANTE will be used to highlight and correlate behavioural changes with neurological features, extracted from EEG recordings. This paper presents the rationale for the use of the DANTE system within the Michelangelo Project, highlighting its role in supporting the analysis of both behavioural and neurological data to support therapeutic autism interventions.

Introduction

Autism is a pervasive developmental disorder that is usually diagnosed in children by the age of 3 [1, 2]. Affecting three times as many males as females, autism is thought to affect approximately 1 in 100 children; a number that has significantly increased over the past three decades [3]. Although little is actually understood about the underlying reasons for this increase, it is perceived that the rise in cases may be partially attributed to improvements in clinical practice, in conjunction with an increased awareness of the disorder amongst parents and educators [4]. Typically, children with autism exhibit impairments in three main areas: (1) social imagination, (2) communication and (3) social interaction [5]. Such impairments often lead to impediments in typical social and adaptive functioning that can result in the display of challenging behaviours by the child, e.g. tantrums, aggression, self-harm and hyperactivity [6], which can pose significant difficulties for parents, family members and carers [7]. While a cure for autism does not yet exist, several approaches have been established to help improve social behaviours (i.e. communication, language, play, life-skills), subsequently reducing the onset of challenging behaviours.

Background

The Michelangelo Project is an EU funded project that intends to support the assessment and therapy of autism outside of the clinical environment. The project aims to empower parents and their children through the development of a technology-based cost-effective solution to support in-home therapeutic intervention. The project is currently in its first year of development and is focusing on three stands of research:

- to embed state-of-the-art emerging healthcare technologies within a home environment to support intensive therapeutic behavioural intervention while maintaining clinical support via remote communication solutions.
- to undertake exploratory research, which utilises a pervasive EEG system to investigate neurofeedback as a method to stimulate neuroregulation and metabolic functioning in children with autism.
- to investigate and analyse any potential correlation between exhibited behavioural characteristics and neurological brain activity.

To achieve this vision, the Project is proposing to evaluate a number of pervasive sensor-based technologies to record both physiological measurements such as heart rate, sweat index and body temperature in addition to embedding video monitoring systems utilizing low cost web cameras to monitor observable behaviours. Furthermore, to support neurofeedback investigations, the Project is aiming to incorporate the development of a novel wearable EEG system, with the aim of achieving a device that is less invasive than traditional QEEG systems. Traditionally, QEEG is used to capture electrical patterns from the surface of the scalp to reflect cortical electrical activity or 'brain waves'. By assessing these patterns it is possible to characterise the brain's response to specific environmental stimuli. QEEG has been employed widely to characterise the brain connectivity anomalies in autistic children [8]. Nevertheless, due to the invasiveness of QEEG (10-20 electrodes) this approach can only be conducted within a clinical environment thereby introducing an artificial nature the observation. Michelangelo is proposing the use of a pervasive wearable EEG system (6-8 electrodes) that can by worn outside of the clinical environment. The system will be used to assist in the personalisation of therapeutic interventions based on features extracted from the brain mapping of a child in response to stimuli utilised during both clinical and home-based therapy sessions.

Given that behavioural characterisation is an extremely complex paradigm to model, taking into consideration the wide spectrum of social interaction impairments and the variety of situations to analyse, the Michelangelo Project will focus on the observation of interactions with specific regard to the skills acquisition of joint attention and imitation tasks. Technology solutions can be used within this context to support behavioural characterisations, providing new methods to define quantitative measurements in order to express the quality of social interactions. In particular, techniques well known within the field of Computer Vision, such as object tracking, gesture and expression recognition, can provide a valid assessment to measure the quality of such interactions, therefore providing a quantitative measure of improvements during interactions. Furthermore, the main advantage of using computer vision techniques is the ability to provide a valid assessment with a minimum degree of invasiveness [9, 10]. Indeed, computer video analysis permits behavioural observation and characterisation in a natural environment with the advantage of avoiding further perturbation by using invasive tools that could affect the normal behaviour of children with autism within the same context.

Although traditional QEEG data has been investigated in an effort to identify signal deviations in the brain mappings of children affected with autism [11] the use of a new wearable EEG introduces the potential of further analysing and understanding the signals generated by EEG. For this purpose, an annotation tool can be utilised that reduces the efforts associate with such an analysis by offering an integrated environment within which the EEG data is presented together with synchronised video and a set of physiological measurements such as heart rate, sweat index and body temperature.

In summary, it is evident that an assessment of the quality of social interactions is required, along with a tool to support the contextual characterisation of EEG signals. The solution proposed by the Michelangelo Project aims to address both of these aspects through the use of the DANTE system [12, 13].

Overview of the DANTE System

As previously introduced, the approach adopted within the Michelangelo Project aims to minimise modulation effects through the building of a pervasive, wearable EEG that eventually allows the patient to become "unaware" of its presence. In this sense, the inclusion of an additional video system for behavioural annotation is validated, as it does not introduce any further technology that may be considered invasive. Consequently, the use of DANTE for data annotation is a particularly suitable approach due to both its non-invasive nature and the fact that it does not add elements that could potentially affect or bias the data being measured.

DANTE uses video monitoring approaches to provide a time-stamped annotation for other sensor technology deployed in an environment. In the case of Michelangelo, DANTE will be used to generate labeled datasets that will be used to support the early stage characterisation of data acquired from the wearable EEG system. These labeled datasets will provide the opportunity to interpret the diagnostic value of each sensor technology being investigated. This will support clinicians to link, for example, an increase in heart-rate with the presentation of a particular stimulus thereby assisting to identify positive reinforcing objects or to highlight non-verbal discomfort during some intervention by monitoring an increase sweat.

DANTE uses a set of cameras in order to record video observations that are subsequently utilised for both automatic data annotation, based on techniques from computer vision, and manual data annotation and refinement, based on a Graphical User Inteface facility to review recorded videos. The recorded video can be used to manually annotate and label data acquired from time synchronised sensors, thus providing further support for the analysis of signals obtained from the wearable EEG system. Currently, one of the issues to be investigated within the Project is the characterisation of EEG signals as no previous example datasets are available to Project team.

Within the DANTE system, the use of computer vision techniques for object tracking provides the basis for defining an assessment of the quality of interactions, by utilising quantitative descriptions of movements obtained from instantaneous information on object positions. Video analysis provides an optimal perspective with which to perform observations and qualitative/quantitative measurements on joint attention tasks such as gaze and point following, along with determining the latency and quality of performance for imitation tasks, for example, comparing the time for which a stimulus is presented (from the video) with the time at which a response occurs. Each camera can identify objects that have been 'tagged' with custom fiducial markers. Once a tagged object has been detected, the system can report on the location and orientation of the object. Figure 1 shows a typical example of a fiducial marker, along with a tagged cup.

By 'knowing' the exact position of objects (in 3D space), the system is able to approximate the trajectories of the objects, extracting information related to the speed and acceleration of the objects, thus providing a basis for comparing the quality of a child's performance engaging with tasks, such as the imitation task, through the analysis and comparison of different movements.

An additional benefit of using DANTE resides in its ability to perform automatic data labeling through the analysis of movements and object recognition. Automatic annotation is performed using computer vision algorithms that analyse the frames of video in order to detect and identify a predictable set of actions and interactions in real-time. Subsequently, automatic annotations are based on the integration of different tracking techniques:

- *Marker Tracking*: objects are tagged with fiducial markers allowing object recognition through marker recognition.
- *Colour/Shape Tracking*: objects are recognized based on their colour or shape without the use of markers.

Combining both tracking techniques permits automatic annotation at different levels; while marker tracking provides accurate information related to object location and orientation, colour/shape tracking is useful in cases where the use of marker would be considered too invasive (i.e. skin tracking can be utilised to track limb/body movements). Subsequently, using both tracking techniques within the DANTE system, it is possible to automatically detect and collect information pertaining to the presence or absence of an object, the position and orientation of an object, the detection of movement, together with object-object, object-person and person-person interactions. Thus, the tracking techniques provide a basis for building a measure of the quality of interactions, in addition to refined data labeling during the analysis of pervasive EEG signals. This results in a number of advantages including:

- a reduction in the effort required for manual annotation
- a reduction in the amount of recorded data required through the automatic suspension of video recording when no tracking is being performed
- a set of refined search options that allow the annotation of portions of video without the necessity for the doctor/clinician to review the entire recording (e.g. it is possible to search only the portion of video that contains a subset of the objects involved).

DANTE as a Tool for Data Analysis

Considering the design of a wearable EEG system, one of the main challenges lies in the analysis and identification of the patterns within the acquired signals. Within this context, the DANTE system provides an integrated environment that will permit the analysis and annotation of recorded EEG data while simultaneously reviewing the video captured during each therapy session. The manual annotation will build upon a course-level automatic annotation in order to make the labeling process as simple as possible. An ad-hoc, configurable user interface for data annotation can be presented and customised according to the purposes of the set of actions that are to be annotated. Figure 2 presents an example of the user interface used during the manual annotation of a synchronised video and sensor data recording.

Data annotation performed through video footage can be utilised to label the corresponding synchronised wearable EEG data, resulting in the production of a labeled dataset. Such a dataset offer huge benefits for future analysis. For example, a simple query on the labeled dataset may be used in order to retrieve all subsets of wearable EEG data that are related to the same stimulus. Reviewing the video recordings during the process of data labelling allows doctor/clinicians to annotate portions of the overall dataset by grouping the data in relation to the currently ongoing action displayed in the video. Within this context, the added value of the DANTE system is the provision of a tool that partially automates a process which would otherwise be time-consuming process and which is typically performed manually without the use of any specific software tool.

Summary

The DANTE system is a non-invasive tool for the recording, detection and annotation of reactive behaviours captured during observation sessions. The use of a video-based annotation tool provides an optimal perspective with which to assess the quality of both the social interaction and task performance of autistic children, thus facilitating the refinement of personalised therapeutic interventions by a doctor/clinician. Furthermore, by refining techniques from computer vision during the future development of DANTE, the techniques may potentially attain a degree of stability that permits them to be used automatically. This would allow for the video cameras to be eventually be considered as another sensor, thereby removing issues related to the privacy of the individual being monitored. Taking into consideration that the DANTE system will be utilised within the overarching Michelangelo Project it is considered that the creation of a labelled dataset will be useful for the research community beyond the scope of the Project itself. Subsequently, such annotated data may be exported and utilised within the development of future context-aware pervasive healthcare systems. The Michelangelo Project is funded by the European Commission's Cooperation programme under grant 288241.

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Figures

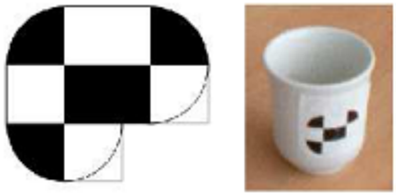

Figure 1: A fiducial marker (left) and ‘tagged’ cup (right)

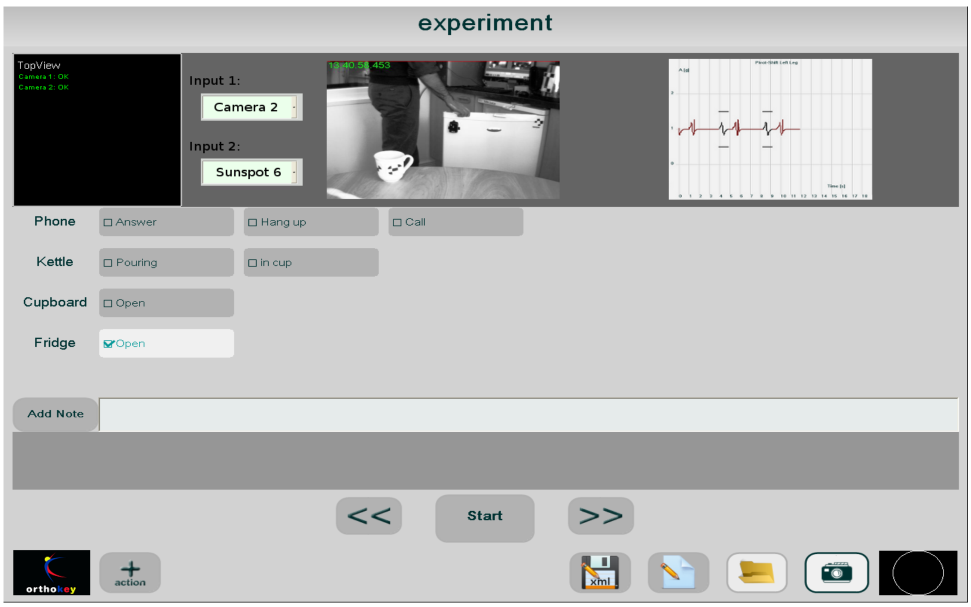

Figure 2: A screenshot of DANTE’s manual annotation user interface showing the video and the synchronized data fragment. The set of annotation labels is configurable and allows the association of portions of the data to specific actions performed by the user.