Research Project Proposal: Smart objects for gesture monitoring of elderly daily life

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1. Introduction to the problem

The topic I am focusing on can be included into a wide research on the use of objects for the unobtrusive and transparent monitoring of elderly daily life, in order to capture, through the identification of specific motion patterns, any signal of cognitive decline.

In industrialized countries a huge demographic change is happening, with the on-going increase of the elderly population and the certainty that it will grow significantly in the future. Between 2015 and 2030, the number of people in the world aged 60 years or over is expected to grow by 56%, from 900 million to 1.5 billion, and by 2050 this number is going to jump to 2 million [World Health Organization, 2015]. This phenomenon impacts on our society from many points of view, and the organization, the dimensioning and the costs of health is one of the most crucial [Crivellini et al. 2011]: there is the necessity to reorganize completely the health system, trying to diversify the ways to provide assistance, avoiding hospitalization of the elderlies when possible and curing them at home through telemedicine technology, improving at the same time the performances and the reliability of the sanitary system, while keeping costs contained.
At the same time, elderly people suffer of a combination of reduced vision, memory and mobility, generally considered as frailty, that progresses slowly over time and contributes to a loss of confidence, which in turn may cause infrequent participation in social activities, isolation and depression [Cornwell, et al. 2009], which is reported to be a risk factor for dementia [Valkanova et al. 2017]. Thus, on one side, monitoring of daily activities can be useful to detect signs of decline, on the other social activities and engagement are fundamental for the well-being of the elderly people [Chen, 2013]: the evidence suggests that integrated health and social care for elderlies contributes to improve their quality and quantity of life, without the need to increase costs [Araujo de Carvalho et al. 2017].

This research is part of a more general framework, the MoveCare (Multiple - actOrs Virtual Empatic CARegiver for the Elder) Project, a European Union funded initiative to create a platform capable to help pre-frail elders to be supported at home, their preferred environment, offering solutions tailored on each user, increasing their active period of life, helping them feeling included in society for a longer time.
The platform offers tools to stimulate the elders with cognitive and physical activities, while assisting their independent living at home, supporting socialization in a virtual community and continuously monitoring specific parameters, in order to detect early signs of decline and intervene promptly. Transparent monitoring is assured through the use of environmental sensors, instrumented everyday life objects, and instrumented soles to analyze gait; the continuity of the monitoring offered by MoveCare is able to go beyond any kind of traditional monitoring through geriatric visits.
Specifically, sensorized objects offer the opportunity to track subjects' gesture activity unobtrusively, contributing to keep track of the health state of the elder without affecting or impairing their wellbeing.

The objects this project proposal is focusing on are a smart pen, a smart ball and smart handles: the pen is used to collect information about the handwriting style of the elder; the smart ball is used standalone as an anti-stress ball and it is integrated in an exergame to detect maximum grip force; the handles are cylindrical objects that can be integrated into a tool of daily use for the elderly (e.g. a watering can, a brush) that will be used in stand-alone modality to collect data about gestures and grasping forces.

While a correlation between aging, loss of hand grip strength and handwriting capabilities and cognitive decline has been verified [for example, Martin et al. 2015, De Stefano et al. 2018], how from a continuative analysis of hand movements and forces it is possible to assess cognitive and/or physical decline is still not well known. In fact, the literature offers many examples of experiments and studies that monitored physical activity of the elderly, but they were all based on data collected during laboratory testing sessions in which the subject was instructed on what to do: following these protocols provides essential information on how to handle data, as the way data was retrieved is known and fixed.

Conversely, this research aim is to identify the extremes of the aforementioned relation using not formalized data: relying on unstructured and not clearly classifiable data is the downside of getting measurements from unobtrusive technologies.

2. Main related works

As many have assessed, ageing is associated with a decline in cognitive, sensory and motor abilities [Chen, 2013] and in the present time, in which the proportion of elderly population is increasing, there is the necessity more than ever to take the phenomenon into account [Crivellini et al. 2011].
Literature has shown the effects of ageing on motor ability [Chen, 2013], emphasizing the loss of fluidity and dexterity, especially when referring to hand performances, which have been shown to be less controlled, characterized by slower, less smooth and less coordinated movements [Martin et al. 2015].
Other works assessing the importance for older adults of being able to perform ADLs (Activities of Daily Living) [Stamm et al. 2016], explore deeply the causes and the consequences on elderly behavior of their limitations in functioning in various areas, highlighting how ADL disability is associated with a poor upper extremity muscle strength [Al Snih et al. 2004].

Hand grip strength, prehension force control [Kinoshita et al. 1996], precision gripping and lifting [Cole et al. 1999], presence of physiological tremor [Morrison et al. 2012] are the main characteristics of movement studied in literature, with the aim of evaluating hand grasp and control-action intrapersonal synergies [Gorniak et al. 2009].
While a correlation between aging, loss of hand grip strength and cognitive decline has been verified, how from a continuative analysis of hand movements and forces it is possible to assess cognitive decline is still not well known.
The main limit is the fact that there is almost no study on the correlation between cognitive assessment and the whole hand prehension grasp, so the kind of grip used with handles, while the existing works focus mainly on precision pinch grip.
In addition, literature focuses on experiments done as controlled sessions, where the movements of the subjects were visualized while they were been performed: in this specific case, there is no control on how and how long the subject will use the object and so there is no way to know in advance precisely what kind of data will be collected. Moreover, the sessions were limited in time, while in this case elderlies will be monitored for a longer period, in order to identify significant changes of data over time.

On the other hand, many studies exist testifying the presence of a correlation between neurodegenerative pathologies and handwriting [Walton, 1997; Marzinotto et al. 2016; De Stefano et al. 2018], underlying which characteristics of handwriting could be related simply to aging. The necessity to study specific pattern recognition techniques and to perform longitudinal studies has been highlighted, in order to provide an early diagnosis technique for this kind of pathologies.

Finding how to individuate significant patterns inside the big set of information the sensors will capture is the core of the whole research topic.

3. Research plan

The goal of the research consists in finding the algorithm able to extract information related to cognitive decline of the subject from data collected by the smart handles and the smart pen. The research has an applied nature, as it aims to obtain a methodology needed to gather significant information from unstructured data.

The smart handles contain a 3D accelerometer and a gyroscope, able to identify the orientation of the object, and five FSR (Force-Sensing Resistor) to measure grasping pressure; the smart pen contains the inertial unit as well and in addition there is a set of strain gauges on the tip to measure tip pressure; the smart ball additionally to the inertial sensors is embedded with an absolute pressure sensor to measure the change in pressure associated with the gesture of squeezing the inflated ball.

Ideally, data recorded longitudinally on the subjects for four months have to be analyzed to assess if, day by day and session by session, differences related to significant, but otherwise inappreciable, changes in the behavior of the subject have occurred.

It is important to remind that the objects are used by the subject at their will, for a non-fixed number of times during the day, for a not known period of time for every session, and in general the object could be used repeatedly for some minutes (e.g. while watering the flowers, the watering could be lifted, moved and then put back many times) or it could be left unused for many days.

All these considerations about the randomness of the context of the measurement must be taken into account while designing a methodology to analyze the data. A careful understanding, organization and labelling of the various signals is fundamental to find patterns and/or individuate significative changes in what should have been similar portions of recordings.

As a consequence, whether giving the subject partial directions on the use of the handle has to be evaluated: it could be useful to instruct the subject to perform a certain action at the beginning of each session to identify the 'start' of the recording or to 'calibrate' the object measurement by performing every time, before the actual use of the tool, a fixed set of movements, whose possible change session by session could be analyzed easily.
It could be helpful to identify a minimum length for the session too, to eliminate steadily parts of recordings that are not long enough to be meaningful.

My research will start in a moment in which raw data collected from the objects would have been already pre-processed, filtered, labelled and organized in a dataset; a set of features would have been already calculated.

The first task will be to conduct a study about the state of the art related to data mining and machine learning, in order to understand specifically why certain features have been chosen and calculated from the data, and to identify methods to analyse longitudinally the available features, in order to retrieve and study trends of the same features lately.

The second task will consist in the creation of a simulated dataset to use to test the algorithm that will be created in the third task: the dataset will be used as a clinical reference during the development of the algorithm.
The dataset it will contain both data from healthy subjects and data relatable to cognitive impaired subjects, from a slight to a severe stage.
Once having collected real data from healthy subjects, there will be the necessity to establish a structured protocol to construct the 'impaired' data by manipulating what will be available; one of the ideas to do so that need to be tested is, for example, adding white noise on normal subject recordings.

Implementing the algorithm will be the main task of the project; at the end, the validity of the algorithm will be tested on real data acquired in the pilot study.
This phase will consist in the development of two classifiers: classifiers of different levels of impairment and classifiers of longitudinal degeneration. The first classifier will be used to classify elderlies, according to their level of impairment, into three groups: we would like to assess if the classifier will be able, from the features measured by the smart objects, to assign the subjects to the correct class. The level of impairment will be defined based on a clinically used scale of hand dexterity. The second classifier will analyse if, from the indicators derived from the smart objects during the four-month pilot study, it is possible to identify early signs of gesture decline.

To assess if the identified algorithm could be used to distinguish different stages of cognitive decline in the subjects, it would be necessary to confront the outcome of data analysis with the results of tests able to evaluate the cognitive state of the patient; tests should be performed during the whole period of analysis to provide a continuous reference for the study.

Research timeline	**Jul 2019**	**Aug 2019**	**Sep 2019**	**Oct 2019**	**Nov 2019**	**Dec 2019**	**Jan 2020**	**Feb 2020**	**Mar 2020**
SOTA on Machine Learning									
Simulated Dataset									
Classifiers for impairment level									
Classifiers for longitudinal degeneration									
Testing									

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