State of the Art on: Smart objects for gesture monitoring of elderly daily life

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1. Introduction to the research topic

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. My work concentrates on sensorized grasping objects, so daily-life items the patient can handle and use, and the analysis, evaluation and interpretation of the signals recorded on board by the objects themselves.

As the general research area's focal points are the elderly behaviour, the decay of their physical and/or cognitive capacities and its consequences on motion, we are able to find publications on different journals, like:

- **IEEE Internet of Things Journal**

H index: 31, Impact Factor 5.863, Scimago Quartile 2017: Q1.
Published since 2014, this journal accepts articles on IoT in its many aspects, like its architecture, services, applications and social implications.

- **IEEE Sensors Journal**

H index: 89, Impact Factor 2.617, Scimago Quartile 2017: Q1/Q2.
A peer reviewed journal regarding to sensors and application of devices for sensing, focusing on the sensors technologies concerning the IEEE.

- **Journal of Gerontology (Series A and B)**

H index: 163, Impact Factor 4.902, Scimago Quartile 2017: Q1.
As the first journals on aging published in the US, publishes articles on biological, health related, psychological and social aspects of aging.

- **Journal of Applied Physiology**

H index: 204, Impact Factor: 3.056, Scimago Quartile 2017: Q1.
This journal was founded in 1948 and publishes articles from different areas of applied physiology: I selected it as many papers regarding adaptation mechanisms of the body to aging are published here.

- **Biomedical Signal Processing and Control**

H index: 41, Impact Factor: 2.5, Scimago Quartile 2017: Q1/Q2.
Published by Elsevier, this journal contains both papers about signals and image analysis, and practical and application-based researches regarding methods and devices used in diagnosis, patient monitoring and treatment.

- **Journal of Motor Behavior**

H index: 61, Impact Factor 1.327, Scimago Quartile 2017: Q2.
Published by Taylor & Francis, this venue focuses on works aimed to understand motor control from various disciplinary perspectives, like biomechanical, neurophysiological and electrophysiological. Mathematical modelings and descriptions on analytical techniques are frequently found in the submissions.

- **Experimental brain research**

H index: 150, Impact Factor: 1.806, Scimago Quartile 2017: Q2.
This journal was founded in 1966 and focuses on neurosciences, the study of the nervous system and its pathologies. I selected it because, as our research concentrates on geriatric patients, the aging of the brain and its consequences, our specific topic could fit perfectly into the area of interest of the journal.

- **Journal of Aging Research**

H index: 35, Impact Factor: 1.53, Acceptance Rate: 32%, Scimago Quartile 2017: Q2.
Is an open access journal publishing papers on gerontology, geriatric medicine, and other studies on aging population.

- **PLoS ONE**

H index: 241, Impact Factor: 3.54, Acceptance Rate: 69%, Scimago Quartile 2017: Q1.
Open Access journal considered a public library of all disciplines within science and medicine.
Its slogan is 'Accelerating the publication of peer reviewed science', it does not exclude papers on the basis of the subject area and it has a very high acceptance rate: all these characteristics lead most of the scientific community to criticize PLoS ONE for publishing "uninteresting", "unimpactful" science. However, PLoS ONE ensures that each submission is carefully peer-reviewed and evaluated before the publication.

The selection of journals was made considering a general knowledge of the area and some ranking parameters, like the H index, the Impact Factor and the evaluation of the quartile in Scimago journal rank, an index that describes the relative importance of a venue in a certain scientific area. Specifically, Scimago creates annually, using an internal rating system, one or more rankings including a set of journals, that can be divided into four equal groups or quartiles: Q1 comprises the quarter of the journals with the highest values, and so on, until Q4, comprising the quarter with the lowest values.

1.1. Preliminaries

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 multi-actor platform capable to provide assistance and monitoring for elderlies at home, preventing their too early relocation to nursery homes.
One of the planned service layers consists in a set of sensorized objects, used to retrieve easily data on motion and handling pressure, without the need to instrument the elder. Data is then used to define indexes available for the caregivers and the other components of the MoveCare project, with the aim to reinforce and tighten the whole system.

The presented research topic will follow specifically the development the smart objects, a ball, a pen and a handle (a cylindrical object that can be integrated into a tool of daily use for the elderly, e.g. a watering can, a brush) and the analysis of the data measured by the sensors placed on them.
The main sensors present on the objects are a compact MEMS (MicroElectroMechanical System) inertial unit, comprising 3D accelerometers and gyroscopes; specifically, inside the ball there is an absolute pressure sensor, on the tip of the pen there is also a set of strain gauges to measure tip pressure, while five FSR (Force-Sensing Resistor) are located on the handle to measure the grasping pressure.
Data will be collected by and internal ultra-low power CPU, stored onboard and then, when the devices are put on charge in their stations, sent via BLE (Bluetooth Low Energy) to the Community Based Activity Center (CBAC) Home station; the station will then send data to the datacenter, where it will be analyzed.

Considering the variability and the complexity of uncontrolled sensor outputs, many have shown interest to develop the best tools to extract specific signals of interest; an example of a complete review is provided by [Bravi et al. 2011]. The review aims at identifying and organizing criteria to evaluate variability analysis techniques for clinical applications and could be useful to identify the most suitable one for a project among the complexity of existing methodologies.

In the case of study, data will be analyzed in time and frequency [examples in Teulings et al. 1997; Nikonovas et al. 2004; Shiffman, 1992] after a preprocessing phase in which signals will be adequately sampled, windowed, transformed in frequency domain through fast Fourier transform and filtered to eliminate noisy frequencies, in order to enhance their significant portion [Ravi et al. 2005; Hylton ed al. 2013].
The cleaned data will be converted into a set of features, i.e. mathematical and statistical representations that summarize the data by extracting important characteristics [Nanopoulos et al, 2001] and then these features will be analysed by data mining algorithms to find patterns that indicate the presence or not of abnormalities [Gallagher, 2014].
Some of the features that could be extracted are mean values of the signals, standard deviations, skewness of axis sensor values for the inertial measurements, variances, signal to noise ratios and dynamic time warping (a computation of the difference in value between two points that should correspond in two time series that are being compared) [Martin et al. 2015; Gorniak et al. 2009; Gallagher, 2014].
Some more specific indicators will include, in relation with the pen, tremor, writing speed, smoothness of the trajectory, number of lifts and in-air time, while, considering the handle, tremor and other parameters calculated from the power spectrum, like median frequency, peak intensity, spectral power in different frequency ranges, center frequency, frequency dispersion and so on.

In general, we will be looking for a significant change of the indicators extracted over the months from the registrations, identifying changes typical of age and signs of cognitive decline: a comparison of the newest values with previously available baseline, week and month values will be assured.

1.2. Research topic

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].

MoveCare Hierarchical Platform aims to help elders with physical and cognitive problems 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, a camera for gesture analysis 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, that are obviously spaced in time.
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.

2 Main related works

2.1. Classification of the 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.

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.

The scope of this research is to confirm and further identify the extremes of the relationship between handgrip, hand strength and hand writing data with cognitive decline, using not formalized data: relying on unstructured and not clearly classifiable data is the downside of getting measurements from unobtrusive technologies.
Finding how to individuate significant patterns inside the big set of information the sensors will capture is the core of the whole research topic.

2.2. Brief description of the main related works

A wide knowledge regarding the aging process and the loss of fluidity and capability in performing activities is needed to understand the physiological and pathological aspects of motion impairment in elderlies.
In [Fried et al. 2001], a standardized definition of frailty as a clinical syndrome reported to increase with age is proposed, consisting in the assessment of the presence of at least three of the following characteristics: unintentional weight loss, self-reported exhaustion, weakness (grip strength), slow walking speed and low physical activity. While grip strength, assessed through the sensorized handle, can be clearly considered a predictive sign of frailty, handwriting performance, assessed through the smart pen, cannot be associated to the traditional frailty phenotype; however, even if requiring further study, the predictive ability of handwriting measures could be helpful.

Considering hand movements, older adults are slower both in performing them and in the 'deceleration phase' after the movement is completed: this depends on higher response times, on less efficiency of the perceptual feedback produced by the visual system, less ability to produce high forces and on loss of coordination and flexibility [Chen, 2013; Walker et al. 1997].
As visual and hearing abilities decline, also short-term memory is reduced: all of these, combined with mobility reduction, contribute to a loss of confidence of the elder [Chen, 2013], that impacts further on the movement genesis: older adults tend to prevent errors when producing the movement [Walker et al. 1997], and this characteristic is testified specifically for our case in many studies on hand grip characteristic in older people [Kinoshita et al. 1996; Gilles et al. 2003]. According to [Falconer et al. 1991], who tested and validated the theory presented in [Williams et al. 1982], hand functionality, assessed through a test, is correlated to functional dependency in elderly, meaning that a lack of manual skills could be one of the factors responsible for institutionalization of the subjects.

Hand function begins to drop slowly after the age of 65 years as a consequence of a combination of local structural changes (reduction of muscle mass, changes in skeletal tissue, nail changes, loss in mechanoreceptors) and a less tight neural control [Carmeli et al. 2003].

Kelly J. Cole dedicated his attention to the topic of fingertip force responses in precision pinch grip performed by older adults continuously since 1991.
In [Cole, 1991], it was demonstrated that, as skin in elderlies is slipperier due to impaired sudomotor functioning, older adults produce in precision pinch grip a grasp force twice than young subjects, that can be considered as a 'safety margin' that the elderly applies not to drop the object. Moreover, as a response to tactile sensibility impairment, time needed to manipulate an object increased of 25-40% at the age of 70 years.
Subsequently, it was proved [Cole et al. 1994] that instability in pinch grip force (and so, successive increased force) is not affected by peripheral reorganization of muscles typical of older adults.
Similar results were exposed in [Kinoshita,et al. 1996]: monitoring precision grip lifting forces, fluctuations, longer application times and a general decline in force production were found among older adults, confirming that precision grip force control capacity decreases with age, because of characteristics of the skin, lower cutaneous sensibility, and impairment in central nervous system functions.
In [Cole et al. 1999], it is discussed that, whether solely skin slipperiness explained safety margin increases till 60 years old, afterwards also additional factors, related to the decline in sensory function and the delay in adjusting to new surface patterns, but not related to unpredictable changes of weight of the object, contribute to elevate grip force.
When changing unexpectedly tangential load on a handle held using precision grip [Cole et al. 2001], older people respond with a larger peak force compared to young adults, in addition to a response latency that increases as the load decreases. Instead, performing the 'nut and rod task' (sliding a nut from a rod, a common test to study manual slowing) using various shapes of oriented rods [Cole et al. 2010], showed a much longer time of performance for elderlies, as they exerted greater force impulses in vertical direction and lower ability to control external moments applied to objects, compared to young adults; slowing can be considered a strategy to avoid motion errors.

Confirmations and extensions for the described results regarded the assessment of the adaptation of grip forces at the variations of load and object-finger interface, in static conditions [Danion et al. 2007], during up and down movements of the object [Gilles et al. 2003], for freely movable objects [Parikh et al.2012], or while transporting fragile objects [Gorniak et al. 2011].

A step forward was taken by [Martin et al. 2015], that studied the relationship among age, grip strength and dexterity, finding that age and strength predict significant different types of hand dexterity in adults. Moreover, it was one of the first not to concentrate only on precision grips or any other kind of fingertip grips, but he confronted the grasp on a small cylindric handle and the whole hand prehension on a large one, like it would be in the case of our sensorized handles, obtaining similar results.
Deeper analysis on the whole hand prehension grasp on its own, expected forces and movement patterns would be needed to build stable foundations for further studies.

Other studies concentrated on the generic study of the activity of the upper limb [Repnik et al. 2018], others on the relationships between aging, neuromuscular functioning of the upper limbs and the consequences on the arm-hand effector system, exemplified by increased physiological tremor [Morrison et al. 2009; Morrison et al. 2012], a characteristic of the old hand that can enhance loss of dexterity.

All the works proposed before are related to 'laboratory based' experiments; many studies about long term monitoring of physical activities in older adults during their daily life can be found in the literature, however, most of the times body-worn sensors (e.g. pedometers, accelerometers, gyroscopes or combinations of the three) are used [De Bruin et al. 2008; Taraldsen et al. 2012].
In these frameworks, the aim is either the 'activity counting', by assessing countable variables, like the number of steps or the energy expenditure per day (obtained from the amplitude of accelerometer signals), the 'activity recognition', by recognizing posture, transitions and activities performed during the day (e.g. tremor in parkinsonian patients) etc., or the 'activity patterns', i.e. a group or series of activities performed together on which other parameters (e.g. mean duration) are inferred.
However, it is preferable not to use wearable sensors for long term monitoring, for feasibility and adherence problems, as they limit with their size performances and comfort of the elderly, resulting as poorly accepted. The challenge for wearable motion-sensing is to reach a good level of evaluation in real life settings, without resulting uncomfortable for the subject.

Concerning handwriting, it can be considered a continuous cognitive-motor task, that starts from holding a pen (pinch grip) and requires the integrity of sensitivity and motor skills to be performed.
Many agree that changes in handwriting are associated with age: [Marzinotto et al. 2016] conducted a study in which various handwriting styles were found by means of clustering algorithms, and their correlation with age was confirmed using unsupervised techniques. In particular, aging was associated with a change in distribution of velocity profiles, an increase of in-air time and number of pen lifts, a lower writing speed and pen pressure, an irregular writing rhythm and shape of characters, and a total loss of smoothness in the trajectory. This phenomenon is due to the decline, associated with age, in executive functions (a system of high-level cognitive functions that regulate planification, control and coordination processes [Rosenblum et al. 2013]) and to the deterioration of sensory processing abilities in elderlies [Engel-Yeger et al. 2012].

[Camicioli et al. 2015] tried to identify a relationship between the global definition of frailty and the characteristics of handwriting, with no success, but suggested that handwriting parameters could still be associated with specific aspects of frailty.
Other studies agree on the fact that neurodegenerative pathologies, like Alzheimer [De Stefano et al. 2018] and Parkinson diseases [De Stefano et al. 2018, Walton, 1997], affect handwriting and that reported alterations can be used as diagnostic signs for those diseases. In fact, Alzheimer disease causes unnecessary gasps difficulties in maintaining a straight horizontal reference line when writing, while Parkinson disease handwriting is characterized by micrographia and velocity and fluency reductions. As it was confirmed that measures potentially able to identify various stages of Parkinson exist, there is the possibility to use pattern recognition techniques for early diagnosis of the disease.

2.3. Discussion

Considering the previously described works, it is evident that they are mainly based on observations done during a laboratory testing session with the elder, in which the subject was shown what to do, was instructed on what trying not to do, and was monitored cautiously during the whole movement. This protocol provides useful information on how to handle data, as the way data was retrieved is known and fixed.

The aim of MoveCare is to provide forms of transparent monitoring, hiding sensors into smart objects of daily use, distancing both from experiment-like sessions and wearable units, while adding capabilities not present on already commercially available Ambient Assisted Living systems.
The need to limit in any case the presence of bulky and visible recharge/transmission stations to be associated with the sensorized objects, is to take into consideration.

Moreover, as the scope is to unobtrusively monitor at home daily activities of the elder, without causing discomfort or frustrating the subject with annoying instructions on how to use the object, the way and the frequency of how to use the smart handle and the smart pen is left completely free. As a consequence, is fundamental to find how to understand the unstructured data collected by the objects during the sessions.
Considering the first step of extracting some characteristics features from the longitudinal data done, specific patterns and trends are going to be searched using data analysis tools. Comparisons of the inferences with previous results and with

known patterns of disease will be the final task, in order to assess if the subject is experiencing cognitive degeneration or not.

As a further matter, most of the aforementioned works regarding grip, even if overall accurate and offering a thorough analysis of the movement, do not focus on whole hand prehension grip, the typical handle grasp. Using a handle, we generally observe a steadier grasp than precision pinch grip and so there is needing to further verify how knowledge and findings on precision pinch can be applicable in the case of handle grasp.

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