Non-intrusive Patient Monitoring for Supporting General Practitioners in Following Diseases Evolution

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Abstract. Current patient follow-up practices held by General Practitioners (GPs) are often unstructured. Due to the high number of patients and time limitations, data collection and trend analysis is often performed only for a small number of critical patients. An increasing demand is coming from the physician community for having a set of supporting tools for reducing the time needed to process patient data and speed-up the diagnosis process. Furthermore, the possibility of monitoring patient activities at home would provide less biased and more significant data. Unfortunately, however, current solutions are not able to collect reliable data without the intervention of formal caregivers. This paper proposes an improved version of some medically-backed techniques in an unobtrusive platform to monitor patients at home. Data are automatically collected and analyzed to provide GPs with the current status of the monitored patients and their health trend, contributing in a more precise and reliable decision making.

Keywords: eHealth, patient, tele-monitoring, General Practitioners.

1 Introduction

Demographic changes in terms of aging of population and evolution of habits led to an observable increase of the incidence of chronic diseases. In particular, elderly population is developing new needs and demanding an increasing support aimed at detecting and handling diseases as soon as possible. In fact, if not correctly and promptly detected and addressed, several diseases can become chronic, requiring personalized, specialized and costly treatments.

Currently, General Practitioners (GPs) pay much effort in gaining highly precise, single values of patients physiological state, such as blood pressure, blood values, or diagnostics exams. With respect to analyzing single values, more insights can be gained from the evolution of those values. However a too sparse sampling, over time, can hinder the significance of a study on the evolution of

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values. In fact, some studies [13] exploit a set of measurements over time to develop trend analysis, intercept the occurrence of changes in health status.

A particular condition characterized by a high risk of developing into a more dramatic and difficult one is the so called *frailty*, defined as "a distinctive health state related to the ageing process in which multiple body systems gradually lose their in-built reserves and enhances the risk of adverse outcomes in the elderly." [1] Several situations of frailty [11], requiring support by specialized personnel, can be identified among elderly people [2]. The state and the evolution of selected subjects can be described by different indexes, obtained from various motion and vital signals. Based on these indexes, people requiring healthcare interventions can be classified into a set of categories. The main categories are [9]: Chronic conditions (47%), Acute illness (25%), Trauma/injury or poisoning (8%), Dental (7%), Routine preventative health care (6%), Pregnancy/birth (4%), others (3%). The "chronic segment" is huge not only in terms of number of affected patients, but also in terms of costs for the health system. For a multitude of reasons, in most countries, the existing health structures cannot host all chronic patients. Nevertheless, these patients need a continuous support and monitoring in order to stabilize their condition and detect critical events in time. In addition, even though comorbidities should to be considered for these patients, they are often neglected by the existing practices, hiding possible situations of risk.

The role of the GPs is crucial, as most of non-critical patients live at home. Usually, to update anamneses, GPs use to evaluate patients in their own ambulatories. Unfortunately, mainly for monetary reasons, each GP is in charge of providing basic care for a high number of patients, with the consequence that the time reserved for each of them is often too low to acquire a complete personal state, both in physical and cognitive terms. The difficulty to deliver care given by GPs to patients over a long time period is exacerbated in rural and isolated environments, where ambulatories are not easily reachable and are only used in cases of acute illness, and not for prevention. On one hand, we have to consider that most patients can live independently even in the presence of little physical and health problems. On the other hand, difficulties related to the distance that patients need to cover to reach the ambulatory in terms of time, costs, mobility, etc. Even when these difficulties can be overcome, there is still a high chance that the data collected by the GPs are related only to a subset of events and patient states, similarly to the well known *white coat syndrome* [18], as some may not be manifest or reported by the patients, when they are visited.

Evidence exists about a correlation between motor activities and physical and mental state [21]. Thus, also in the case of elderly, the analysis of motor behavior can provide valuable information for GPs about possible alterations of health state. In fact, there are evidences from large-scale pilot studies [21] and [10] about the benefits of a continuous data collection regarding motion, during patients' daily living, to support the classical sparse and occasional medical examinations. Therefore, continuous monitoring performed at home could be essential not only

[1] `http://www.bgs.org.uk/index.php/frailty-explained`

to follow the evolution of overall patient state, but also to catch sporadic events that could reveal the occurrence of new comorbidities.

The public health system can be described as a chain of loosely coupled (sometimes disjoint) entities. New forms of professional associations of practitioners, such as the Italian "Associazione Funzionale Territoriale" (AFT), focus on providing an integrated care, in which some forms of specializations are coupled with General Practitioners duties. This new fragment of health system can benefit from a technological contribution. Information and Communication Technology (ICT) can play an important role to link together such entities and maintain a coherent and updated history of each patient, as well as to enable new monitoring and therapy procedures. Indeed, telehealth has already been announced several times as a solution to the above mentioned problems. However, telehealth requires the development of a new approach to simplify GPs' duties.

In this work we explore the possibility of integrating technology in the practices of GPs, to restructure some of the processes. According to [17], motor performance analysis can provide reliable information, and it can be used to develop health factors and indexes. Until now, such an analysis is carried out manually by health professionists [21]. There is, however, the possibility to execute some physical *tests* [2] automatically, and still achieve meaningful and accurate results. Exploiting the increasing availability of wearable motion sensors and vision based systems, we propose the development of an unobtrusive system for monitoring human activities in real-life scenarios. The aggregation of the acquired data can provide valuable information on the state evolution of patients, leading to enrich the number of parameters relevant for the diagnoses performed by physicians. In particular, we propose two specific procedures for gathering patient motor activities in two different contexts.

The next paragraphs are organized as follows: Section 2 presents the proposed methodology; Section 3 describes the motor tests considered in this work; Section 4 illustrates two possible scenarios in which the tests can be executed; finally Section 5 concludes the paper and provides some future steps.

2 Reference Methodology

The typical current practice followed by GPs in their ambulatory is to visit patients to gather both specific and general information by executing classical physical examinations and data transcriptions. Generally, the visit is followed by offline activities that have to be performed in a second phase to avoid interference with the visit. This process is schematically illustrated in Figure 1.

Possible offline operations are: *information organization, trends and alert analysis, etc.* However, such a phase split requires much more effort and time, with respect to a single phase procedure.

[2] The term *test* is used to denote a procedure performed on a patient to record a set of parameters aimed at assessing his/her activity.

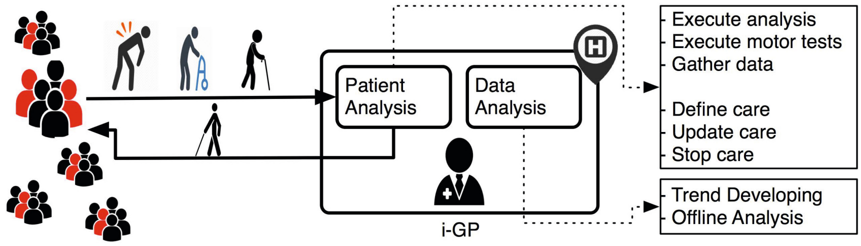

Fig. 1. Set of current GPs' practices

The proposed approach is to adopt a reference methodology considered as the current state of the art [21,10] and exploit the available technology to automatize the various required steps, including the execution of motor tests.

The reference methodology considered in this paper is schematically illustrated in Figure 2.

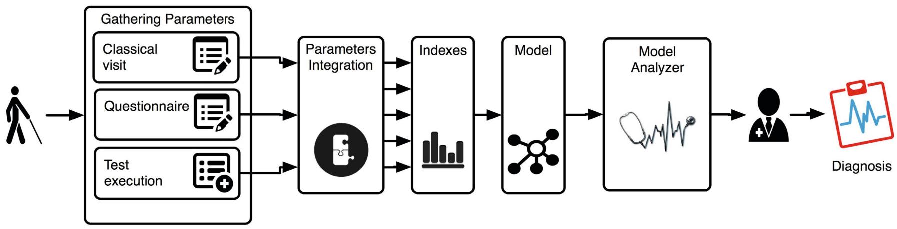

Fig. 2. Block diagram of the reference methodology

According to this approach, classical data obtained by physical examinations are integrated with patient's general details (acquired through proper questionnaires) and other parameters deriving from the execution of specific motor tests. Indexes indicating patient's general status are then derived by a set of algorithms and inserted into a model that can be analyzed to support the physician in diagnosis and therapy definition.

The next section presents two motor tests that can be included in the reference methodology described above.

3 Considered Motor Tests

Motor tests, in particular of lower extremities, can provide valuable information about particular conditions and patient state [20]. For instance, the analysis of the locomotion activity can produce the following indexes [21,10]: *Global fitness, Stride Regularity in medio-lateral direction, Forward stepping smoothness, Stepping symmetry*, and *Forward stepping regularity*.

Our goal is to define a set of procedures for deriving these indexes exploiting pervasive and wearable technologies.

The following sections describe two specific tests considered as a state of practice in the medical environment: the gait speed and the sit-to-stand test.

3.1 Gait Speed

The first test we present is also known as "*Gait speed calculation*". In such a practice the patient walks over a known distance and time is recorded. The patient has to walk at usual pace, starting from a standing static condition and the average speed is calculated dividing the covered distance by the execution time. To standardize the procedure, distances are expressed in meters and time in seconds. The covered distance for this test is generally between 4 and 10 meters. A model to be used for this test is proposed by Guralnkik et al [12] for 4-m gait speed. The execution of the gait speed test is schematically illustrated in Figure 3.

The aforementioned test is generally integrated by additional patients' variables, like sex, age, ethnicity, height, weight, body mass index (BMI), smoking and alcohol habits, use of mobility aids, etc. The **prediction's** accuracy of such a complex model does not significantly differ from the results obtained with a more simplified model with takes into account only patient's *sex* and *age* coupled with his *motor performance* related to the executed test [21] [17].

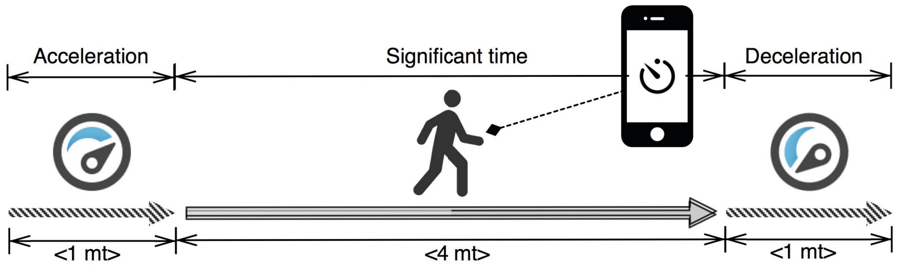

Fig. 3. Gait Speed test

3.2 Sit-to-Stand

Another interesting and standardized procedure is the "*Sit-to-Stand*" (SiSt) test [3]: the patient is seated on an armless adjustable chair, whose seat must be placed at knee height; the patient must fold the arms across his/her chest, while his/hers feet have to be positioned at approximately 10 cm of distance from each other, with the shanks positioned at an approximately 10 degrees angle relative to the vertical axis. The complete movement/cycle is composed of sitting, flexion, extension, standing, flexion, extension, sitting phases, as shown in Figure 4. This simple test can be utilized differently: considering the total time needed to perform the test [12], averaging the measures over the five repetitions obtaining more significant data [8] or as numbers of times the patient stands in 30 seconds to assess endurance and leg strength.

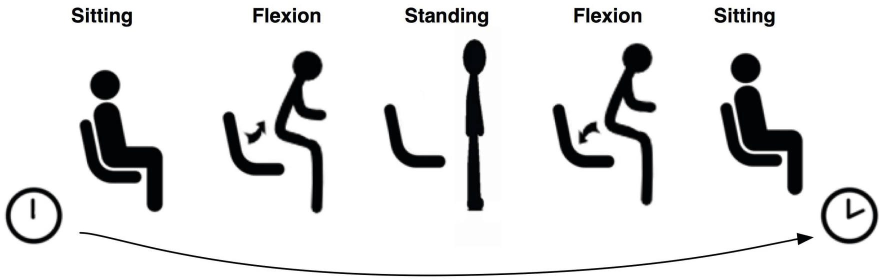

Fig. 4. Sit-to-Stand test

3.3 Technology for Index Extraction

To derive the physical status indexes described above in a way that is both cost effective and easy to use, while providing high-quality data two technology solutions can be adopted: patients could use a single smartphone, exploiting its on-board kinematic sensors, carrying it in their pocket; or, they could wear simple independent wireless motion sensors, as done in [5,19,6], connected to a smartphone through a wireless link.

For example, in the case of *gait speed test*, a waist mounted accelerometer, combined with other similar sensors [23,15] can provide traveled distance and speed, using dead reckoning techniques [22], and medio-lateral and frontal symmetry, exploiting auto-correlation of the signal along the medio-lateral direction [1]. Similarly, for the *sitting-standing test*, we can obtain another series of characterizing parameters, such as the time from sitting to standing, by segmenting the signal provided by a waist mounted accelerometer, detecting the overall sequence of positions of the waist while performing the complete test. Another fruitful choice is to use visual sensors [16], such as the Microsoft Kinect or other cameras endorsed with a depth sensor, taking advantage of image processing and analysis. With respect to kinematic sensing, visual sensing has less precision and resolution, but more information can be derived about body postures, as evidenced by several existing studies [4,14].

The next section describes two scenario in which this technologies can be used.

4 Scenarios

Exploiting the large variety of sensing and communication devices offered by modern technology in the *gait speed* and *sit to stand* practices, GPs will be enabled to quickly perform more precise tests on the patients. In addition, by processing the acquired data through proper algorithms, it is possible to provide physicians with a valuable support for a faster and more reliable diagnosis. In the following, we propose two possible scenarios where the tests described above can be effectively adopted. In fact, *the reduction of the time of treatments* is a key milestone, as pointed out in [7]. They involve different actors for the execution of this tests.

The first scenario is illustrated in Figure 5 and considers a single patient wearing a personal sensing system in his/her own environment.

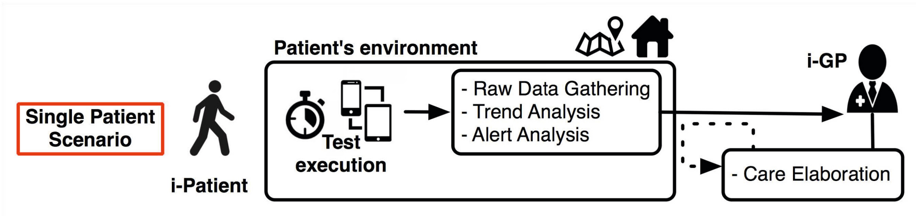

Fig. 5. Proposed Single patient scenario node in healthcare chain

The second scenario, illustrated in Figure 6, considers the possibility of using more complex and costly equipment that can be shared by more users in specialized healthcare centers managed by volunteer associations with help of semi-formal caregivers.

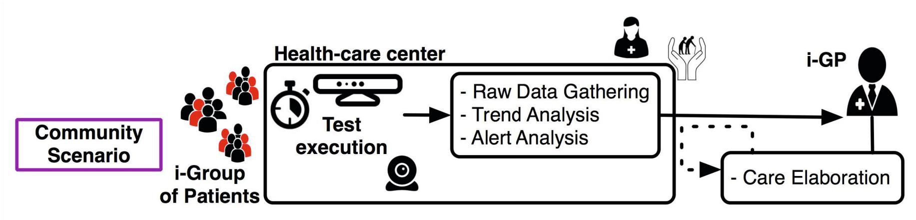

Fig. 6. Proposed Community scenario node in healthcare chain

4.1 Single Patient Scenario

In the single patient scenario, tests are performed using an inertial wearable sensor. The required operations to perform the test are depicted in Figure 7.

For the first setup, the user starts downloading the app suggested by the physician, Task (a). Then, once the user wants to execute the test he/she moves

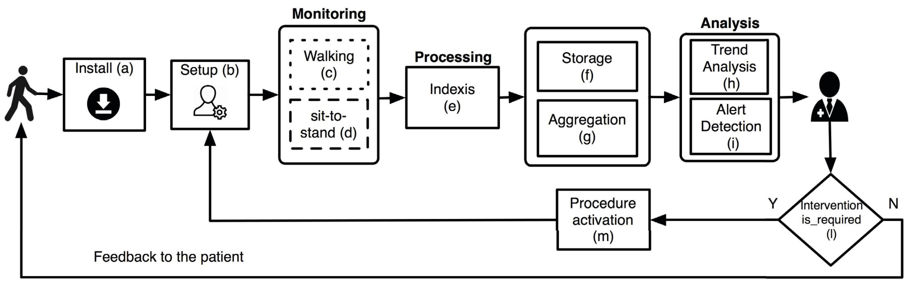

Fig. 7. Single patient scenario's procedure

to Task (b), wearing the sensor. Then, the user is guided by the app in performing Task (c), walking, in the case of the gait test, or Task (d), SiSt, in the case of the sit-to-stand test. In both cases, sensory data are sent to the smartphone, where a set of algorithms process them to compute the performance indexes, Task (e). Such indexes are then stored, Task (f), and aggregated in time, Task(g), for performing trend analysis, Task (h), and alert detection, Task (i).

In the case of a detection of critical or anomalous situations, the related parameters are notified to the GP, who can evaluate the situation, Task (i), and decide the appropriate procedure to be activated, notifying the user.

4.2 Associations Scenario

The second scenario we propose consists in delegating the data gathering phase to associations or charity organizations that have among their personnel at least some semi-formal caregivers. The practice for data extraction could be the same, using simple sensors and smartphones, as already described for the first scenario, or improved using more complex equipment. When using more expensive sensors, procedures can involve multiple users. Moreover, provided that huge amounts of data will be collected for the executed tests, statistical analysis can be performed

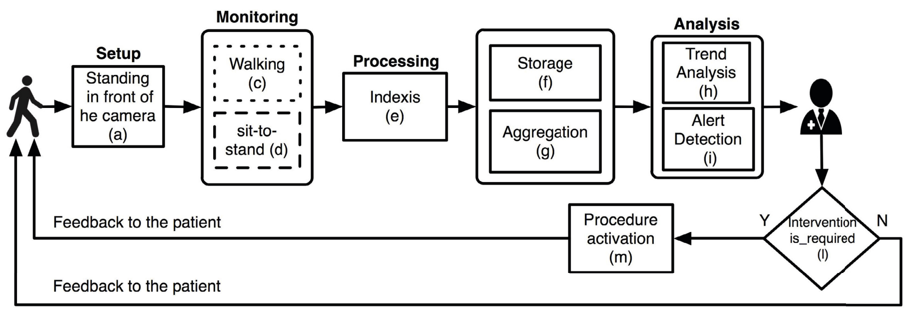

Fig. 8. Community scenario's procedure

to derive useful results for further research studies. The sequence of involved tasks is reported in Figure 8. The setup phase, Task (a), requires the patient just to stand in front of a camera in order to be recognized. After that, the normal test execution is similar to the process described in the first scenario. Given the simplicity of the setup, the time required for each patient (recognition and tests execution) is relatively short, (in the order of seconds).

5 Conclusions

This paper presented a set of technological solutions for achieving faster, simpler as well as more reliable and reproducible motor testing procedures. Two established test procedures, namely the “Gait Speed” and “Sit-to-Stand” tests, have been considered to compute specific patients health indexes derived by healthcare experts. Taking into account some critical factors we proposed to simplify and innovate the presented tests execution and management. Indeed we investigated how to relax some technological constraints to achieved the same results. According to current resources in terms of actors and technology we identify some requirements and deployment scenarios. Based on the several studies in the literature, we believe that the proposed unobtrusive and simplified data collection, the automatic production of trend analysis for diagnosis support especially for chronically suffering patients, will bring considerable benefits to the public health system. We envision that the time required to perform the entire process of data collection, analysis, diagnosis and care delivering will be reduced. In the future, we plan to implement the proposed approach and develop new techniques and tests that will be integrated into the presented working-chain.

The development of a diffuse adoption of sensing and monitoring technology, carried out by the deployment of the equipment needed in the described scenarios, involving a huge number of patients and participants, could represent a valuable opportunity to test new algorithms against real data, thus attracting even more researchers to invest effort and knowledge in the development of new and smarter solutions.

References

1. Avvenuti, M., Casella, A., Cesarini, D.: Using gait symmetry to virtually align a triaxial accelerometer during running and walking. Electronics Letters 49(2), 120–121 (2013)
2. Bavazzano, A., Badiani, E., Bandinelli, S., Benvenuti, F., Berni, G., Biagini, C.A., Briganti, N., Cai, M., Canavacci, L., Carriero, G., Cavallini, M.C., Francesconi, P., Gabbani, L., Galantini, P., Giraldi, M., Lombardi, B., Magnolfi, S., Michelotti, F., Nastruzzi, A., Rossi, C., Tomei, A., Tonelli, L.: Frailty in elderly people. Technical report, Regional Health Council, Tuscany Region, Italy (2015)
3. Beauchet, O., Dubost, V., Herrmann, F., Rabilloud, M., Gonthier, R., Kressig, R.W.: Relationship between dual-task related gait changes and intrinsic risk factors for falls among transitional frail older adults. Aging Clinical and Experimental Research 17(4), 270–275 (2005)

4. Benetazzo, F., Iarlori, S., Ferracuti, F., Giantomassi, A., Ortenzi, D., Freddi, A., Monteriu, A., Capecci, M., Ceravolo, M.G., Innocenzi, S., Longo, S.: Low cost rgb-d vision based system for on-line performance evaluation of motor disabilities rehabilitation at home. In: Proceedings of the 5th Forum Italiano on Ambient Assisted Living ForItAAL. IEEE (2014)
5. Buonocunto, P., Marinoni, M.: Tracking limbs motion using a wireless network of inertial measurement units. In: 2014 9th IEEE International Symposium on Industrial Embedded Systems (SIES), pp. 66–76. IEEE (2014)
6. Burns, A., Greene, B.R., McGrath, M.J., O'Shea, T.J., Kuris, B., Ayer, S.M., Stroiescu, F., Cionca, V.: Shimmer–a wireless sensor platform for noninvasive biomedical research. IEEE Sensors Journal 10(9), 1527–1534 (2010)
7. Calvaresi, D., Claudi, A., Dragoni, A.F., Yu, E., Accattoli, D., Sernani, P.: A goal-oriented requirements engineering approach for the ambient assisted living domain. In: Proceedings of the 7th International Conference on PErvasive Technologies Related to Assistive Environments, p. 20. ACM (2014)
8. Cao, H., Plichta, M.M., Schäfer, A., Haddad, L., Grimm, O., Schneider, M., Esslinger, C., Kirsch, P., Meyer-Lindenberg, A., Tost, H.: Test–retest reliability of fmri-based graph theoretical properties during working memory, emotion processing, and resting state. Neuroimage 84, 888–900 (2014)
9. Conway, P., Goodrich, K., Machlin, S., Sasse, B., Cohen, J.: Patient-centered care categorization of us health care expenditures. Health Services Research 46(2), 479–490 (2011)
10. Deshpande, N., Metter, E.J., Bandinelli, S., Guralnik, J., Ferrucci, L.: Gait speed under varied challenges and cognitive decline in older persons: A prospective study. Age and Ageing, afp093 (2009)
11. Fried, L.P., Tangen, C.M., Walston, J., Newman, A.B., Hirsch, C., Gottdiener, J., Seeman, T., Tracy, R., Kop, W.J., Burke, G., et al.: Frailty in older adults evidence for a phenotype. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences 56(3), M146–M157 (2001)
12. Guralnik, J.M., Ferrucci, L., Pieper, C.F., Leveille, S.G., Markides, K.S., Ostir, G.V., Studenski, S., Berkman, L.F., Wallace, R.B.: Lower extremity function and subsequent disability consistency across studies, predictive models, and value of gait speed alone compared with the short physical performance battery. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences 55(4), M221–M231 (2000)
13. Hope, C., Lewis, C., Perry, I., Gamble, A.: Computed trend analysis in automated patient monitoring systems. British Journal of Anaesthesia 45(5), 440–449 (1973)
14. Iarlori, S., Ferracuti, F., Giantomassi, A., Longhi, S.: RGB-D video monitoring system to assess the dementia disease state based on recurrent neural networks with parametric bias action recognition and DAFS index evaluation. In: Miesenberger, K., Fels, D., Archambault, D., Peňáz, P., Zagler, W. (eds.) ICCHP 2014, Part II. LNCS, vol. 8548, pp. 156–163. Springer, Heidelberg (2014)
15. Mannini, A., Sabatini, A.M.: Walking speed estimation using foot-mounted inertial sensors: Comparing machine learning and strap-down integration methods. Medical Engineering & Physics 36(10), 1312–1321 (2014)
16. Obdrzalek, S., Kurillo, G., Ofli, F., Bajcsy, R., Seto, E., Jimison, H., Pavel, M.: Accuracy and robustness of kinect pose estimation in the context of coaching of elderly population. In: 2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), pp. 1188–1193. IEEE (2012)

17. Peters, D.M., Fritz, S.L., Krotish, D.E.: Assessing the reliability and validity of a shorter walk test compared with the 10-meter walk test for measurements of gait speed in healthy, older adults. Journal of Geriatric Physical Therapy 36(1), 24–30 (2013)
18. Pickering, T.G., Eguchi, K., Kario, K.: Masked hypertension: A review. Hypertension Research 30(6), 479 (2007)
19. Roetenberg, D., Luinge, H., Slycke, P.: Xsens mvn: full 6dof human motion tracking using miniature inertial sensors. Xsens Motion Technologies BV, Tech. Rep. (2009)
20. Stenholm, S., Guralnik, J.M., Bandinelli, S., Ferrucci, L.: The prognostic value of repeated measures of lower extremity performance: Should we measure more than once? The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, glt175 (2013)
21. Studenski, S., Perera, S., Patel, K., Rosano, C., Faulkner, K., Inzitari, M., Brach, J., Chandler, J., Cawthon, P., Connor, E.B., et al.: Gait speed and survival in older adults. JAMA 305(1), 50–58 (2011)
22. Tian, Z., Zhang, Y., Zhou, M., Liu, Y.: Pedestrian dead reckoning for marg navigation using a smartphone. EURASIP Journal on Advances in Signal Processing 2014(1), 1–9 (2014)
23. Trojaniello, D., Cereatti, A., Pelosin, E., Avanzino, L., Mirelman, A., Hausdorff, J.M., Della Croce, U.: Estimation of step-by-step spatio-temporal parameters of normal and impaired gait using shank-mounted magneto-inertial sensors: application to elderly, hemiparetic, parkinsonian and choreic gait. Journal of Neuroengineering and Rehabilitation 11(1), 152 (2014)