35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

Development of a Monitoring System for Physical Frailty in Independent Elderly*

David J. Hewson, *Member, IEEE,* Rana Jaber, Aly Chkeir, Ali Hammoud, Dhruv Gupta, Jennifer Bassement, Joan Vermeulen, Sandeep Yadav, Luc de Witte, and Jacques Duchêne, *Senior Member, IEEE*

***Abstract*— Frailty is of increasing concern due to the associated decrease in independence of elderly who suffer from the condition. An innovative system was designed in order to objectively quantify the level of frailty based on a series of remote tests, each of which used objects similar to those found in peoples' homes. A modified ball, known as the Grip-ball was used to evaluate maximal grip force and exhaustion during an entirely remote assessment. A smartphone equipped with a tri-axial accelerometer was used to estimate gait velocity and physical activity level. Finally, a bathroom scale was used to assess involuntary weight loss. The smart phone processes all of the data generated, before it is transferred to a remote server where the user, their entourage, and any medical professionals with authorization can access the data. This innovative system could enable the onset of frailty to be detected early, thus giving sufficient time for a targeted intervention program to be implemented, thereby increasing independence for elderly users.**

I. Introduction

The concept of physical frailty is widely used, although the exact definition has yet to be agreed upon [1]. Typically, a frail person is considered to be someone who is elderly and cannot respond to stressors, resulting in a series of adverse outcomes, ranging from disability to death [2]. The necessity to develop an easy-to-use screening tool for use in either general practice of for an auto-evaluation was stressed by a joint European, Canadian, and American Geriatric Advisory Panel [1]. The most widely used frailty test currently available was developed by Fried and colleagues [3]. This test has five components, three of which are evaluated by questions, while the other two are evaluated by simple tests. The questions are used to determine any involuntary weight loss over the previous year, physical activity level, and exhaustion. The two tests used evaluate grip strength and walking speed. A modified frailty instrument, based on that of Fried, was developed as part of the SHARE project [4]. Most of the items were modified for the SHARE-FI including a decrease from the 17-item physical activity questionnaire of Fried to single question, and the replacement of walking speed assessment with two questions on functional difficulties. A question on the appetite of the person being evaluated was used instead of the question on involuntary weight loss.

Although the tests outlined above are easy to administer, they both involve primarily questions rather than objective measurement. Accordingly, a new system was developed for which all of the subjective measures were replaced by electronic devices. This system is presented, including preliminary results from all the devices.

II. Automatic Monitoring System for Physical Frailty

A three-component system had been developed in order to estimate physical frailty based on the Fried criteria. Each of the devices was designed to be as non-invasive as possible in order that users could administer the tests themselves on a daily basis. The combined system can be seen in Fig. 1.

A. Weight loss

Body weight is monitored using a digital bathroom scale that communicates wirelessly via Bluetooth with a mobile phone. The scale used in the evaluation is the Smart Body Scale (Nantcare, LLC, Phoenix, AZ, USA), with an additional functionality added in order to provide information on balance quality [5]. The Fried index of frailty does not include balance, however other indexes such as that developed by Studenski and colleagues does include balance [6]. The results of the balance studies are not reported here, but can be found in [5] and [7].

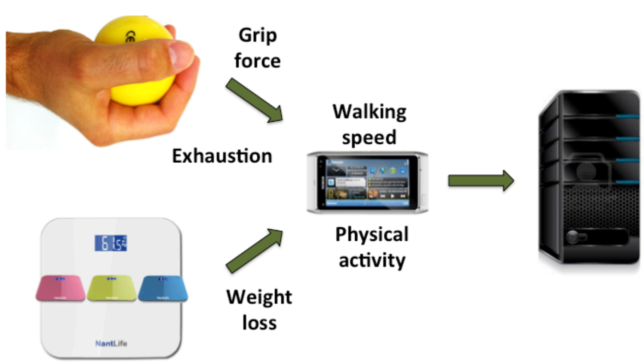

Figure 1. Physical frailty monitoring system

*This research was supported by several different funding bodies including the French National Research Agency (PréDICA project: Bathroom Scale), the Champagne-Ardenne Regional Council and the European Regional Development Fund (Domo-Grip and Disca-Grip Projects: Grip-ball; ARPEGE project: combined frailty pack); and the Netherlands Foundation for Health Research and Development (ZonMw) for the longitudinal evaluation of the system.

The following authors are with the University of Technology of Troyes (UTT), Troyes, France: D.J. Hewson (phone: +33 611565436; fax: +33 325 718 456; e-mail david.hewson@utt.fr); R. Jaber (e-mail: rana.jaber@utt.fr); A. Chkeir (e-mail: aly.chkeir@utt.fr); A. Hammoud (e-mail: ali.hammoud@utt.fr); J. Bassement (e-mail: jennifer.bassement@utt.fr); D. Gupta (e-mail: dhruv.gupta@utt.fr); J. Duchêne (e-mail: jacques.duchene@utt.fr). J. Vermeulen is with Maastricht University, Maastricht, The Netherlands (e-mail: j.vermeulen@maastrichtuniversity.nl). Luc de Witte is with CAPHRI, Maastricht University, Maastricht, The Netherlands (e-mail: luc.dewitte@zuyd.nl); S. Yadav is with the Indian Instiute of Technology Jodhpur, India (e-mail : sy@iitj.ac.in).

B. Grip-strength

Most of the dynamometers used to evaluate grip strength such as the Jamar (Sammons and Preston, Bolingbrook, IL, USA), are poorly suited for remote auto-measurement, as they have no communication capability. In contrast, the device used in this system, the Grip-ball, which is based on an inflatable ball that incorporates a pressure measurement system, can communicate wirelessly via Bluetooth to a mobile phone, or indeed any other compatible device such as a tablet PC or computer [8, 9].

C. Exhaustion

The Grip-ball can be used for an evaluation of muscular fatigue during sustained contraction. It could be possible to link such fatigue with the exhaustion used in the Fried definition of frailty. The fatigue data from the sustained contraction is then sent wirelessly to the mobile phone, which is used to relay information to a remote server.

D. Physical activity

Tri-axial accelerometer technology incorporated in a mobile phone was used to monitor physical activity [10]. The mobile phone used was a Nokia N8 (Nokia Corporation, Espoo, Finland). Physical activity levels were estimated based on the acceleration levels measured during the time the phone was in the pocket or on the belt of the user. An assessment of the overall activity level of the subject can be calculated based on the overall amount of acceleration present in all the three axes.

E. Gait velocity

An estimation of gait velocity was also obtained from the mobile phone. The simplest method for gait velocity measurement is to count the number of steps identified from the acceleration signals, and then calculate gait velocity based on the stride length of the user, measured at regular intervals throughout the use of the system.

III. RESULTS

The results presented in this paper were collected in a series of different experiments using all of the three devices. These trials took place in France, The Netherlands, and in India. All subjects who participated in the trials were provided with detailed information about the investigation and gave their informed consent, with ethical approval obtained for trials in each of the three countries.

A. Weight loss

Data from a subject monitored over one year are shown in Fig. 2. The protocol in place required the user to step onto the bathroom scale every morning to be weighed. In the data shown in Fig. 2, the subject performed 370 tests over the 365-day period of the study. The longest gap between measures occurred once, when the subject went two consecutive days without being weighed. On seven different occasions the subject did get weighed, meaning there was a total of nine days without a measurement. However, on fourteen separate occasions the subject weighed themselves twice the same day. The subject shown recorded an unintentional weight-loss of 5.1 kg, corresponding to a loss of 9% of body weight, exceeding the 5% weight loss in one year criteria used by Fried.

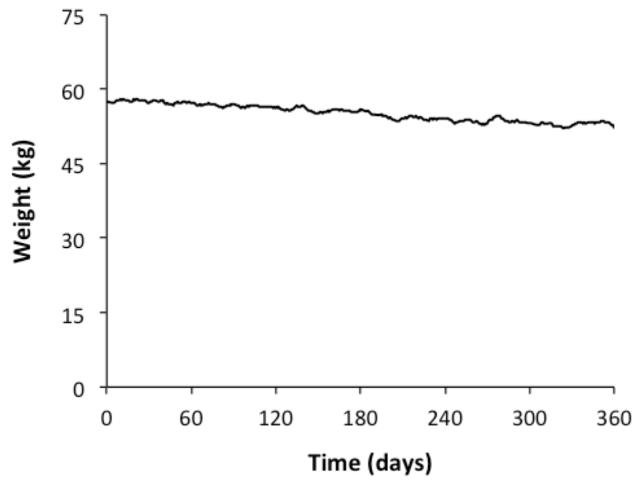

Figure 2. Body weight recorded remotely from an elderly subject over one year.

B. Grip strength

Data from a maximal grip strength test are shown in Fig. 3. Subjects were required to squeeze the Grip-ball for three seconds, with feedback provided on the screen of the mobile phone. The pressure obtained from the Grip-ball was converted into force based on a model developed previously and reported in [11].

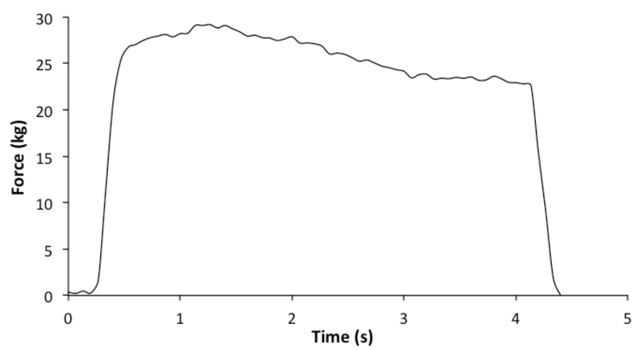

Figure 3. Maximal grip strength contraction for a control subject.

C. Exhaustion

The Grip-ball was also used for a test of fatigue in which subjects were required to perform a maximal sustained contraction (Fig. 4). A model is currently under development in order to produce an estimate of exhaustion based on the fatiguing contraction.

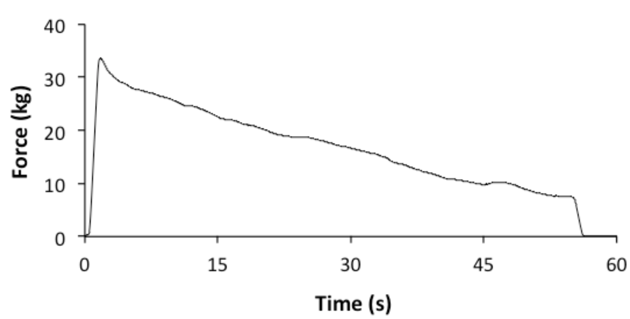

Figure 4. Example of a fatiguing maximal grip strength contraction for a control subject.

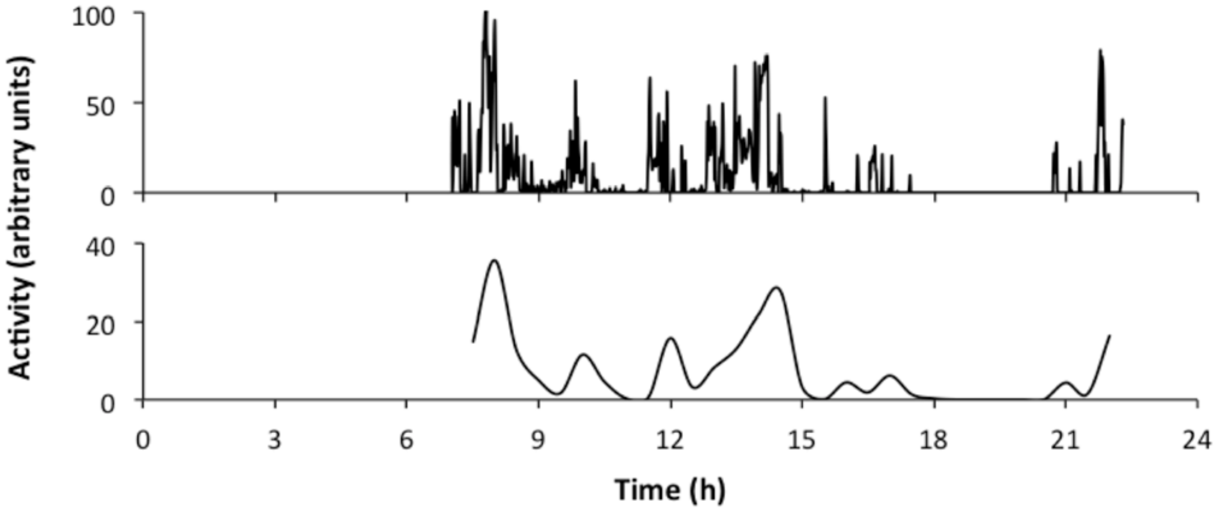

Figure 5. Example of an entire day's activity of an elderly subject recording using the smartphone. The upper trace shows the activity calculated every minute while the lower trace is for activity calculated every 30 minutes.

D. *Physical activity*

An example of a recording from the pocket of an elderly subject is shown in Fig. 5. An assessment of the overall activity level of the subject was made based on the overall amount of acceleration present in all the three axes, with values calculated both each minute and every 30 minutes shown.

E. *Gait velocity*

An example of a gait velocity estimation obtained from an elderly subject wearing the phone on their belt and walking at a self-chosen speed is shown in Fig. 6. The sum of the squares of the acceleration signals from each of the three axes was calculated for each data point, before the square root was taken. No adjustment was made for gravity. Each peak corresponds to a footfall, with the larger peaks corresponding to the foot-strike on the side on which the phone was worn on the belt. The gait velocity for the subject shown was estimated as 0.65 $m.s^{-1}$, based on a stride length of 0.72 m and a step frequency of 54 steps per minute.

IV. DISCUSSION

A complete system capable of assessing each of the five elements of the Fried fragility index has been developed. The system can be used for remote monitoring without requiring an investigator to be present. At the present time, each element of the system was developed independently prior to a large-scale longitudinal assessment in which technological performance, diagnostic capability, as well as usage and acceptability will be evaluated.

In respect to the creation of a frailty index based on the measurements obtained from all the devices, additional clinical comparisons are required. Such information will be available at the end of the diagnostic evaluation currently underway in the ARPEGE program. The performance of the system will be compared to both the Fried [3] and SEGA [12] frailty indexes. Depending on the results obtained, it could be possible to either quantify the Fried index, or to develop a new index based on the devices developed.

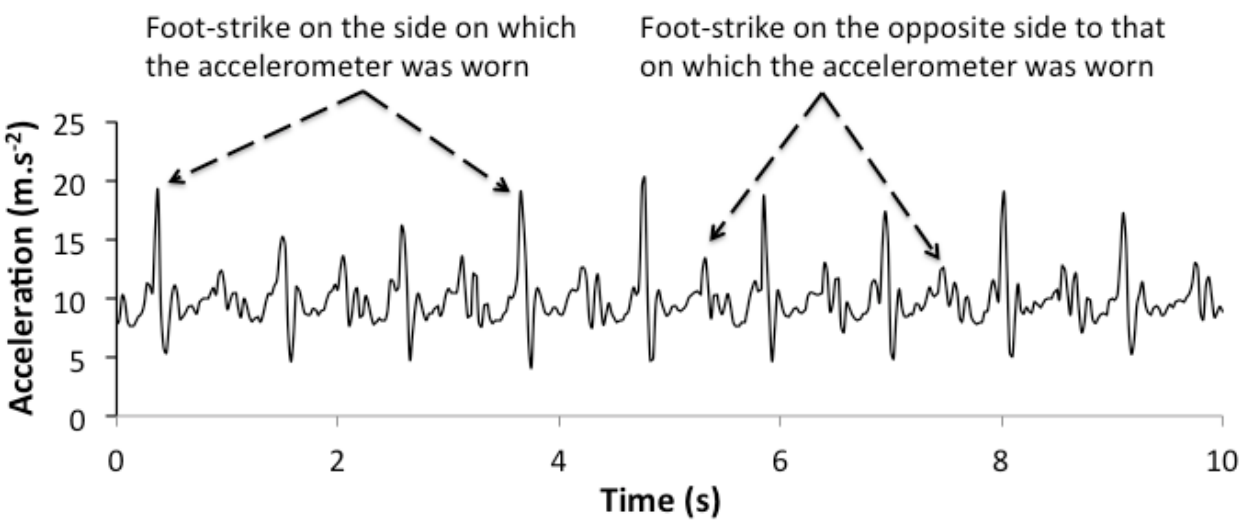

Figure 6. Example of a gait signal from an elderly subject walking at a self-chosen speed.

In respect to the individual devices used in the system, each of the devices has been tested independently. The bathroom scale, or Balance Quality Tester (BQT) has already undergone an evaluation of usage related to its function as a balance tester [5]. The addition of impedancemetry in the next version of the scale currently under development will enable fat-free mass to be estimated, thus enabling information related to sarcopenia to be obtained.

The Grip-ball has been shown to provide a reliable and valid assessment of maximal grip force [9], with a good predictive equation between the pressure measured and the force applied to the ball [11]. Further work is needed in order to calculate population norms for the Grip-ball, in particular for frail elderly subjects.

The use of a test of muscular fatigue instead of the exhaustion questions used by Fried merits a more detailed investigation. The decrease in fatigue during the trial could be due to peripheral or central fatigue, or a combination of both. Additional work is planned in this area.

The Fried estimation of physical activity is performed by use of the Minnesota Leisure Time Activity Questionnaire (MLTAQ) [13]. In contrast to a subjective questionnaire, the use of objective measures of physical activity such as that provided by accelerometers has been shown to have a stronger correlation with frailty [14]. A validation study is currently underway, with the smartphone compared to the ActiGraph (ActiGraph, Pensacola, FL, USA). The results so far are very encouraging, with an R^2 of 0.97 obtained for the subject shown when the two systems were compared for activity assessed every 30 minutes.

Gait velocity was estimated based on estimated step length and a step-counting algorithm. Although such an approach gives satisfactory results in a laboratory setting, it remains to be seen whether such a method would work for daily activity when users might vary their stride length considerably throughout the day. Accordingly, several different solutions are being tested, such as a double integration of the vertical acceleration signal during walking in order to estimate step length [15]. It would also be possible to use the mobile phone's GPS sensor to measure walking velocity when subjects are outside. In addition to a mobile-phone-based approach, an independent gait velocity sensor for indoor use is also under development.

V. CONCLUSION

All of the individual components of the frailty monitoring pack described in this article have been individually validated. The next step is to validate the ensemble in respect to its capacity to diagnose frailty. To this end, the ARPEGE program, which has recently started, will screen elderly detected as being at risk of becoming frail using the system described here, as well as other frailty tests. Following the initial screening, each subject will be re-evaluated after six and then 12 months by both the technological system and the clinical frailty tests. None of this testing will be performed in a remote setting. In contrast to the diagnostic evaluation of ARPEGE, a remote monitoring trial is also underway in the Netherlands. In this trial, subjects will be assessed via daily recording in their own homes. The combined result of both programs could be a system that is capable of detecting an early onset of the pre-frail condition early enough for a multi-factorial intervention program to be put in place.

ACKNOWLEDGMENT

The authors are grateful to the assistance of the Indian Institute of Technology Jodhpur for provision of the gait analysis system used during the validation of the gait velocity measurement system and the work of Dibya Mishra and Dheerendra Yadav in the development of the step counting algorithm. The authors are also grateful to Dr Arvind Mathur, Director of the S.N. Medical College, Jodhpur, India, for clinical expertise provided during testing in Jodhpur.

REFERENCES

[1] G. Abellan van Kan, Y. Rolland, H. Bergman, J. E. Morley, S. B. Kritchevsky, and B. Vellas, "The I.A.N.A Task Force on frailty assessment of older people in clinical practice," *J Nutr Health Aging,* vol. 12, pp. 29-37, 2008.

[2] E. Topinková, "Aging, Disability and Frailty," *Ann Nutr Metab,* vol. 52, pp. 6-11, 2008.

[3] L. P. Fried, C. M. Tangen, J. Walston, A. B. Newman, C. Hirsch, J. Gottdiener, T. Seeman, R. Tracy, W. J. Kop, G. Burke, and M. A. McBurnie, "Frailty in Older Adults: Evidence for a Phenotype," *J Gerontol A Biol Sci Med Sci,* vol. 56, pp. M146-157, 2001.

[4] R. Romero-Ortuno, "The frailty instrument of the survey of health, ageing and retirement in Europe (SHARE-FI) predicts mortality beyond age, comorbidities, disability, self-rated health, education and depression," *Eur Geriatr Med,* vol. 2, pp. 323-326, 2011.

[5] J. Duchêne and D. J. Hewson, "Using a modified bathroom scale for long-term balance quality assessment: relevance, usability and acceptability," *J Telemed Telecare,* vol. 17, pp. 421-426, 2011.

[6] S. Studenski, R. P. Hayes, R. Q. Leibowitz, R. Bode, L. Lavery, J. Walston, P. Duncan, and S. Perera, "Clinical Global Impression of Change in Physical Frailty: development of a measure based on clinical judgment," *J Am Geriatr Soc,* vol. 52, pp. 1560-6, 2004.

[7] J. Vermeulen, J. C. L. Neyens, M. D. Spreeuwenberg, E. van Rossum, D. J. Hewson, J. Duchêne, and L. P. de Witte, "Construct validity of a modified bathroom scale that can measure balance in elderly people," *J Am Med Dir Assoc,* vol. 13, pp. 665.e1-e5, 2012.

[8] A. Chkeir, R. Jaber, D. J. Hewson, and J. Duchêne, "Reliability and validity of the Grip-Ball dynamometer for grip-strength measurement," presented at the IEEE Eng Med Biol Soc, San Diego, CA, USA, 28 Aug - 01 Sep, 2012.

[9] R. Jaber, D. J. Hewson, and J. Duchêne, "Design and validation of the Grip-ball for measurement of hand grip strength," *Med Eng Phys,* vol. 34, pp. 1356-1361, 2012.

[10] T. Iso and K. Yamazaki, "Gait analyzer based on a cell phone with a single three-axis accelerometer," presented at the MobileHCI 2006, Espoo, Finland, 12-15 Sep 2006.

[11] A. Chkeir, R. Jaber, D. J. Hewson, and J. Duchêne, "Estimation of grip force using the Grip-ball dynamometer," Submitted to *Med Eng Phys,* 2013.

[12] D. Schoevaerdts, S. Biettlot, B. Malhomme, C. Rezette, J.-B. Gillet, D. Vanpee, P. Cornette, and C. Swine, "[In French] Identification précoce du profil gériatrique en salle d'urgences : présentation de la grille SEGA," *Rev Geriatrie,* vol. 29, pp. 169-178, 2004.

[13] H. Taylor, D. J. Jacobs, B. Schucker, J. Knudsen, A. Leon, and G. Debacker, "A questionnaire for the assessment of leisure time physical activities," *J Chron Dis,* vol. 31, pp. 741-755, 1978.

[14] O. Theou, J. M. Jakobi, A. A. Vandervoort, and G. R. Jones, "A comparison of physical activity (PA) assessment tools across levels of frailty," *Arch Gerontol Geriatr,* vol. 54, pp. e307-e314, 2012.

[15] D. Alvarez, R. C. Gonzalez, A. Lopez, and J. C. Alvarez, "Comparison of step length estimators from weareable accelerometer devices," presented at the IEEE Eng Med Biol Soc, New York, NY, USA, 30 Aug - 03 Sep, 2006.