Real-Time Stand-Up Evaluation Using Low-Cost Hardware

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Abstract: In this study, we've equipped an ordinary chair with budget-friendly electronics capable of tracking the temporal distribution of weight changes. This electronic system is specifically crafted to analyze typical human motions, such as sitting down and standing up. These everyday movements greatly affect different motor skills, such as walking patterns, the likelihood of falling, and insights into sarcopenia. However, there's no precise way to measure the quality of these actions, lacking an absolute standard. To tackle this issue, the developed analyzer incorporates variables like Smoothness and Percussion, aiming to enhance information and establish an objective metric in evaluating stand-up/sit-down actions. This approach not only introduces a more precise assessment but also provides clinicians with additional insights, making the evaluation more objective and informed.

1 INTRODUCTION

In the past few decades, Europe has undergone a significant demographic transition, presenting unprecedented challenges in caring for older individuals. Current healthcare systems, structured around the conventional medical approach to single acute illnesses, are largely unprepared to address the complex medical needs of older individuals dealing with often chronic multimorbidities, geriatric syndromes, and polypharmacy (Nishimura et al., 2017).

While extending life remains a crucial public health goal, the preservation of the capacity to live independently holds even greater significance. Disabling conditions not only burden individuals but also strain the sustainability of healthcare systems (Lindemann et al., 2003).

In this context, the geriatric syndrome of frailty and potential interventions targeting this condition have gained particular relevance (Anabitarte-García et al., 2021). The term 'frailty' in older individuals has garnered increasing interest, with various proposed definitions and assessment tools (Pozai et al., 2016). Despite the efforts of many researchers, a universally agreed-upon definition and standardized evaluation methodology are still elusive.

Sarcopenia, defined as the loss of skeletal muscle mass and strength due to aging, stands out as a major phenomenon in the aging process and a widely discussed topic in geriatric literature (Shum et al., 2009). Shifting the discussion towards the consequences of sarcopenia, such as reduced functional reserve linked to movement capacity, may facilitate the development of a framework and theoretical organization for the condition. This shift moves from a purely speculative response to an answer that can be effectively translated into clinical practice. Only in this case can we reach a consensus on what needs evaluation and how to assess it. Such a process is essential for gaining the endorsement of regulatory agencies, ensuring that sarcopenia and physical frailty become clinically recognized conditions and important targets for interventions (Hughes et al., 1994).

People are becoming more aware of sarcopenia as a consequence of aging, and it's linked to a higher chance of negative outcomes like falls, fractures, frailty, and mortality. Various methods have been suggested for evaluating muscle mass, strength, and physical performance in clinical trials. Although these tools have shown accuracy and reliability in re-

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search settings, applying many of them to everyday practice isn't straightforward.

In the present work, a budget-friendly electronics capable of tracking the temporal distribution of weight changes has been integrated into a chair to obtain relevant data from a commonly human posture: sitting and standing up. People perform this action several times throughout the day, and there is a relevant interaction between the quality of these actions and other motor capabilities (Nishimura et al., 2017) such as speed and other gait parameters, fall risk (Lindemann et al., 2003), or even information on sarcopenia (Pozai et al., 2016).

The quality of sitting or standing actions is not an absolute value, and there is currently no qualitative and objective measurement for this parameter. Time is the most important variable that can be measured and compared between different samples, but it is known that the distribution of energy around body parts can provide an additional source of information (Shum et al., 2009).

There are many tests that include a sitting/standing task, mainly in older people or in some types of rehabilitation, usually in relation to lower body strength or movement (Chow et al., 2019). One of the most popular is the Timed Up and Go test (Herman et al., 2011), which consists of getting up from a chair, walking several meters, turning 180 degrees, returning and sitting down again, and measuring the time spent. Another similar test consists of repeating the lifting of a chair, and there is a relationship between the two (Hughes et al., 1994).

However, the analysis of the stand-up/sit-down actions in the course of these tests still depends on the experience of the clinical staff, and new methods for the systematic evaluation of these actions are needed. Therefore, based on the designed analyzer, different variables (Smoothness and Percussion) have been defined to provide more information on the process and allow these measurements to be objectified.

2 MATERIALS AND METHODS

In the search for simplicity of use, we propose to use a routine action (getting up and sitting on a chair) as an indirect indicator of frailty. The main idea of this work is to analyze the temporal evolution of weight transfer from the chair to the feet of the individual when standing up. Likewise, during the sitting process, the opposite transfer will be studied: from the individual's feet to the chair. This section describes both the basic scheme of the proposed analyzer and the metrics used to quantify this process.

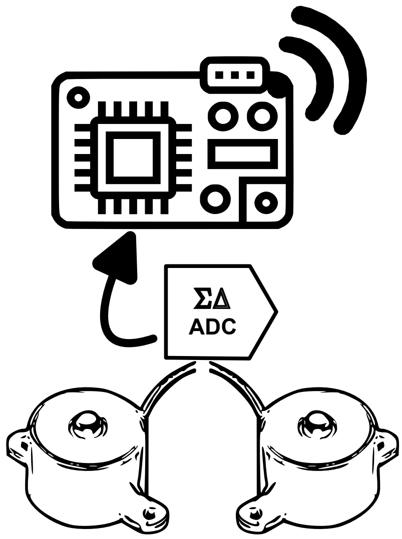

Figure 1: General description of the proposed device.

2.1 Instrumented Chair

Starting from a standard chair of height 50 cm without armrests to minimize the influence of the arms during analysis, four load cells are incorporated to each chair leg. Also, an electronic system is designed to interrogate these load cells with a high sampling frequency (1kHz) and send the data wirelessly to a control computer that allows synchronization with other systems. An scheme of the proposed design is depicted below:

Figure 2: Actual images of the prototype: the four compression load cells are the only contact points with the floor.

Four high precision FC23 compression load cells from TE Connectivity company capable of measuring from 0 to 226.80kg (500lbs) are located under each chair leg. The amplified Wheatstone bridge signal provided by each sensor is connected to a four-channel precision Delta-Sigma ADC (analog-to-digital converter) (ADS1219) capable of operating at 1kHz. With an effective resolution of 20 bits, it provides the load value of each of the sensors through the I2C (Inter-Integrated Circuit) bus. The ADC is interrogated by a generic microcontroller of the ESP32 family from Espressif Systems, which is a low-power system on a chip (SoC) with Wi-Fi and dual-mode Bluetooth capabilities. It is a dual core microcontroller with a clock rate up to 240 MHz which offers enough computational power and connectivity to implement signal preprocessing algorithms and send data over wireless.

In order to minimize noise, each measure given by the microcontroller is the average of 3 correlatives measures. All the data collected from each leg and the summation of them are sent via Wi-Fi to an external application at an effective frequency of 50 Hz. TCP (Transmission Control Protocol) protocol has been selected for this communication to guarantee that the data will arrive at the destination without errors and in the same order in which it was transmitted.

Once the prototype device is completed, a series of weights in the range of 10kg to 50kg are used to calibrate the response of each load cell. The device thus sends the aggregate weight data supported by the chair via Wi-Fi at a refresh rate of 50hz.

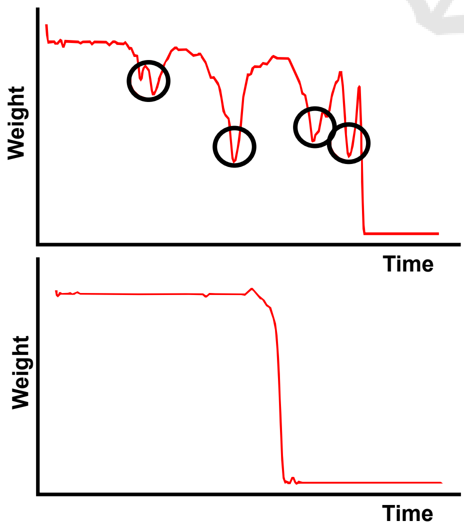

Figure 3: Graphic representation of the Smoothness curves. Pronounced peaks resulting from difficulties in standing (top). Smooth line without peaks indicating correct standing (bottom).

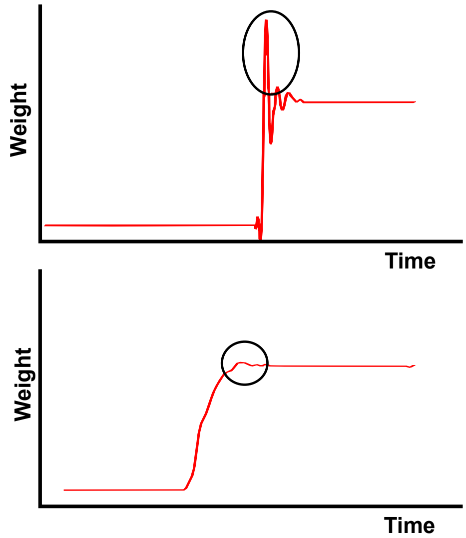

Figure 4: Graphic representation of the Percussion curves. Pronounced peak resulting from difficulties in sitting (top). Smooth curve without peaks indicating correct sitting (bottom).

2.2 Passive Parameters

As mentioned in the introduction, one of the aims is to create parameters that are capable of objectively quantifying the information provided by the Smart Chair, and since in the chair there are mainly two actions, sitting and standing, we propose a new parameter for each action, the Smoothness and the Percussion, respectively.

2.2.1 Smoothness (S)

Smoothness, S, can be defined as a value that provide information about the body dynamics when it is standing, and it is related to the number of attempts a person makes until they can get up. Each attempt involves an oscillation in the weight curve, and the magnitude of this oscillation together with the number of them generates a value of S. Mathematically, Smoothness can be defined as:

$$S = \begin{cases} 1 & n = 0 \\ 1 - K \cdot C & n > 0 \end{cases} \tag{1}$$

K being a variable that depends on the weight variations in the period prior to incorporation, with the form:

$$K = 1 - \frac{1}{n} \cdot \sum_{i=1}^{n} \left(\frac{x_i}{w} \right) \tag{2}$$

where n is the number of minimums registered, x_i is the value of each one of them, and w is the weight registered by the scale when the person is sitting at rest. Finally, C is a value that penalizes the number of minimums in the curve, so that if there are many important fluctuations, the Smoothness is less, and has the form:

$$C = \begin{cases} 0 & n = 1 \\ 1 + \frac{n}{10} \cdot \left(\frac{1}{K-1}\right) & 1 < n \leq 10 \\ \frac{1}{K} & n > 10 \end{cases} \quad (3)$$

This means that if the Smoothness is high, standing is more correct, and if it is low, person has more difficult to perform it. In addition, if $n > 0$, S is highly penalized, and if someone needs more than ten attempts, Smoothness is zero. On other hand, the reason a larger minimum is more penalized than a smaller one is because more energy has been expended. Therefore, when more energy is expended in a failed attempt, the penalty is greater.

2.2.2 Percussion (P)

The other theoretical parameter that we propose is the Percussion, P. In physics percussion refers to the great force ($F \cong \text{inf}$) exerted on an object at a given instant ($\Delta t \approx 0$). We use this term to refer to the force exerted by the human body when the person sits in the chair in relation to its force while sitting at rest. In other words, it is a value that relates the relative weight increase between the weight at rest and the weight at the time the person sits down, and is described by:

$$P = 1 - \frac{w_0}{w_s} \quad (4)$$

where w_0 is the weight measures by the chair when the person is sitting at rest, and w_s is the weight measures by the chair at the instant the person is down.

Accordingly, Percussion is strongly related with the low limbs force. If a healthy person performs this test, the value of P will be low, since they will gradually sit in the chair without sudden hits. However, if the person is not able to maintain his or her own weight in some point of the action, a peak in the weight curve will be generate by the hit and the Percussion will be higher. Percussion values values range from zero to a limit of one. The greater the weight increase with respect to the rest, the greater the value of the Percussion, whose limit is one for an infinite increase

2.3 Experimental Setup and Results

The proposed device has been installed into Photonics Engineering Group facilities at University of Cantabria. Leaving a free space of several meters in front of the chair, the chair is placed together with some marks on the floor in order to perform a reference test for the analysis of frailty: Timed up and Go (TUG) (Herman et al., 2011). The TUG consists of measuring the time it takes a person to get up from a chair, walk a few meters (3-4m) at his or her usual pace, turn around, return to the chair and sit down.

In order to establish the usability of the device, a study was carried out with volunteers without mobility problems to establish baseline values for the metrics developed and compare them with the reference time of the Timed Up and Go test. In addition, different specific tests have been carried out to test the detection extremes of the proposed variables.

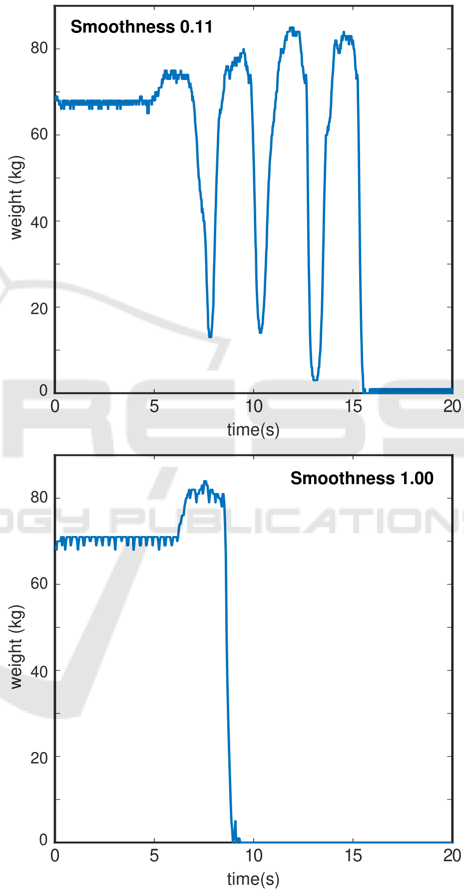

Figure 5: Simulation of weight change during the stand-up of a person with reduced mobility. The measured Smoothness for this change is $S = 0.11$.

2.3.1 Smoothness and Percussion Evaluation

The device has been used to evaluate the get-up and sit-up of 15 healthy volunteers (13 men and 2 women), within the TUG test whose characteristics have been summarized in Table 1. As expected, all the tests performed by the volunteers offer baseline parameters in accordance with the variable definitions.

Table 1: Characteristics of 15 volunteers. *Body Mass Index. Percussion and Smoothness are compared to the total time spent during the Timed Up and Go test.

Age (years)	Weight (Kg)	Height (m)	BMI (Kg/m2)	P	S	TUG time (s)
28	66	1.75	21.55	0.23	1	8.2
31	83	1.82	25.05	0.11	1	9.8
38	74	1.6	28.9	0.25	1	11.8
32	60	1.73	20.04	0.12	1	9.33
44	93	1.78	29.35	0.06	1	9.27
50	64	1.7	22.14	0.31	1	7.03
48	106	1.82	32	0.1	1	9
24	74	1.83	22.09	0.16	1	8.8
25	77	1.78	24.3	0.04	1	9.3
37	95	1.84	28.06	0.09	1	8.03
30	75	1.68	26.57	0.26	1	6.47
34	100	1.84	29.53	0.2	1	7.83
28	72	1.65	26.44	0.13	1	7.73
26	81	1.72	27.37	0.15	1	9.77
69	90	1.69	31.51	0.08	1	10.07

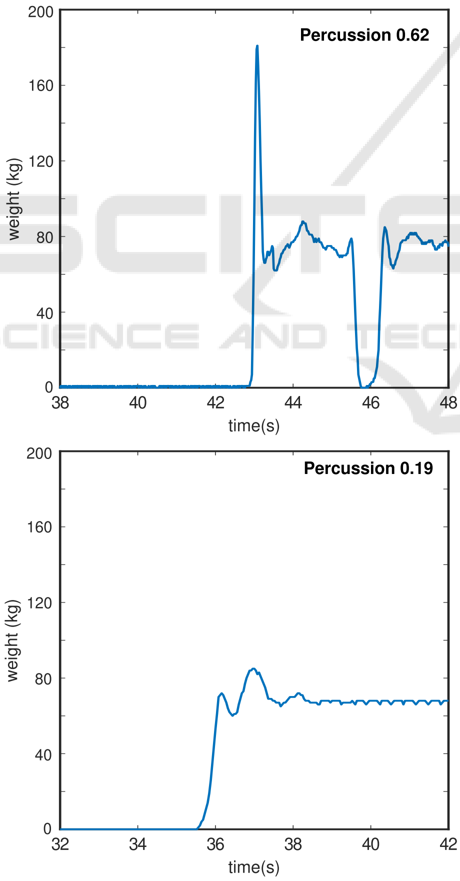

Figure 6: Simulation of weight change during the sit-down of a person with reduced mobility. The measured Percussion for this change is $S = 0.62$.

The Percussion variable, associated with the impact of sitting back in the chair, offers a high granularity allowing a complementary classification to the total time spent in the Timed Up and Go test. Smoothness, on the other hand, offers a warning when the person's mobility is quite impaired and needs several attempts to get up from the chair.

Since Smoothness is a parameter that will always provide 1 when the monitored persons have a degree of functional mobility, specific laboratory tests have been performed simulating scenarios in which a person needs several attempts (3) to finally be able to get up from the chair. The results of these tests can be seen in Figure 5.

Laboratory tests have also simulated situations in which the patient does not correctly control the action of sitting back in the chair. A typical situation for people with mobility problems is that they drop their body when sitting down, causing a sudden impact against the chair. The Percussion variable reflects this situation by offering a value higher than the reference values obtained in the initial tests. This situation is exhibited in figure 6.

3 SUMMARY AND CONCLUSIONS

This work presents a new non-invasive device and method that helps in the determination of the degree of physical functionality of patients. By using low-cost electronics, it is possible to obtain reliable and repetitive information of a widely repeated process in the daily routine of people: sitting down and getting up from a chair. The proposed device is based on instrumenting each of the four legs of a common chair without armrests with load cells. Using a 32-bit microcontroller with WiFi communication capability, the different load cells are interrogated by means of an analog-to-digital converter and the data is sent to a control computer. This platform allows us to obtain in real time the weight supported by the chair, being able to obtain different weight transfer profiles from the chair to the feet or vice versa. Using this tool as a basis, two new variables have been defined, Smoothness and Percussion, which try to provide objective values complementary to those currently used in the clinic. Both the device and the defined variables have been tested in laboratory conditions to obtain reference values for healthy individuals without mobility problems. Also, trying to find representative values for each of the variables, specific tests have been performed simulating that the patient does not offer a good motor function. Based on all these tests, it is concluded that both the device and the defined variables offer greater granularity in the quantification of standard tests used in clinical settings such as the Timed-Up-and-Go timing test. In summary, this work encompasses the design and testing of a easily deployable device in clinical environments. Both the device and the addressed variables are easy to understand, allowing for easy integration into the clinical monitoring of patients with various pathologies, even in tests currently employed such as the Timed-Up-and-Go. Such potential clinical integration will enhance the objective information available for assessments of complex processes, such as motor function, enabling better monitoring and early detection of critical situations.

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