Embedded System for Athletes’ Performance Evaluation Through Jump Tests

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***Abstract*—The ability to quantify an athlete’s progress aids in facilitating their trajectory towards elite competition. Simultaneously, wearable technology represents a non-invasive means for measuring sports variables, as it does not interfere with the normal course of the activity. Considering these principles, an embedded system is introduced for the performance assessment of an athlete. The system can provide the evaluator with variables associated with three different jump tests, leveraging the capabilities of a highly integrated sensor such as the SensorTile STEVAL-STLCS01V1. Furthermore, a dedicated GitHub repository provides access to tables containing results and demographic data from the evaluated population.**

***Keywords*—Embedded Systems, Wearable Technology, Sports, Jump Test , Performance Evaluation.**

I. INTRODUCTION

Development of high-level athletes in Latin America is significantly influenced by an intrinsic passion for sports, socioeconomic challenges and limited resources. Technological innovations, ranging from state-of-the-art training facilities to data analytics and performance monitoring tools, play a pivotal role in enhancing athlete development. Accessible and locally-developed technologies not only provide athletes with cutting-edge resources but also contribute to overcoming resource limitations.

The continuous evaluation of an athlete’s progress enables the detection of training deficiencies, physical fatigue, and the adjustment of training programs [1]. One approach to accomplish this is through the implementation of jump tests.

Vertical jumping ability stands as a pivotal skill across a spectrum of sports disciplines, playing an indispensable role in activities that demand explosive jumping [2]. This aptitude is essential for executing powerful volleyball strikes, achieving remarkable heights in athletics, and mastering complex jumps in artistic gymnastics, among others. Additionally, the vertical jump is a good predictor of strength of lower limbs, and the horizontal jumps is highly associated with sprint and maximal speed performance [3].

There are different approaches to assess jumping evaluation. Force platforms [4], optical devices [5], digital cameras [6] and IMU sensors (accelerometers) [7]. In Latin America, however, an important factor impacts on the sensors selection: the access to these devices. Force platforms and optical devices have a high price, making IMU sensors and digital cameras the first choice.

IMU sensors are widely used as measurement devices in sports, given their flexibility and size [8], [9]. Furthermore, this type of sensors do not require complex installation or signal conditioning requirements. This features makes them suitable for use in portable embedded systems.

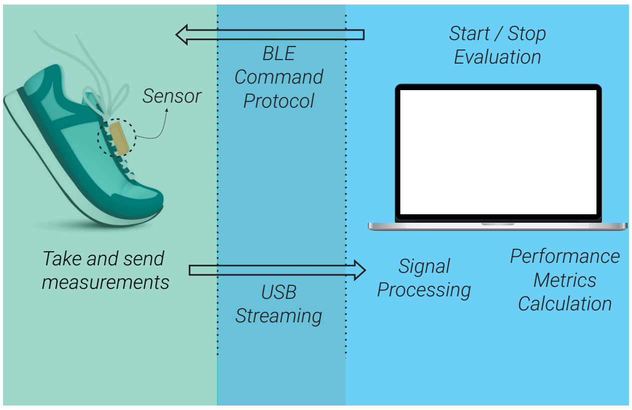

Fig. 1: Overview of the system.

In this paper, an embedded system designed for jump test evaluation is presented. The system performs data logging and real-time estimation of relevant variables associated to three standard jump tests: the counter movement jump (CMJ), abalakov jump (ABK) and drop jump (DJ). The aim is for this device to serve as a reliable and affordable alternative, contributing to the promotion and dissemination of sports and professionalism.

II. MATERIALS AND METHODS

Within this section, we will outline both the hardware employed for measurement and the data acquisition protocol that was implemented.

A. Hardware

In the development of methodologies for measuring sports variables, one of the primary requirements that is not to impede the proper development of the activity. In this context, the size, placement, and autonomy of the utilized sensors emerge as critical factors.

Our prototype for the measurement system was developed using a SensorTile STEVAL-STLCS01V1 board from ST. This highly integrated chip (13.5 x 13.5 mm) is centered around a STM32L476 ARM Cortex-M4 32-bit microprocessor, incorporating low-power, high-precision inertial sensors, a barometric pressure sensor, and a Bluetooth low energy network processor. The SensorTile aligns with the size, power consumption, and sensor quantity constraints necessary for assessing variables related to jumping. The design process involved an initial phase dedicated to evaluating the performance of the datalogging and transmission subsystems given different sensor positions and detection thresholds. The determination to place the sensor on the instep of the jumper’s foot was rooted in its proximity to the ground, mitigating the risk of breakage during testing.

TABLE I: Subjects Database Information

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22
Age [Years]	25	24	23	20	29	31	23	23	24	20	23	23	28	24	24	21	21	17	21	18	19	28
Gender	Male	Male	Female	Male	Female	Male	Male	Male	Male	Male	Male	Female	Male	Male	Male	Male	Male	Female	Female	Male	Male	Male
Height [cm]	180	170	153	173	156	168	174	174	177	170	183	166	193	166	185	175	170	181	162	177	171	176
Activity Level [Times/Week]	2	0	1	4	4	4	2	0	4	0	4	0	3	2	0	0	0	6	5	6	6	3
BMI	22,53	20,03	21,32	19,28	23,01	23,88	20,58	26,72	25,88	18,55	24,22	17,81	23,89	20,32	19,78	26,31	20,38	21,03	23,28	23,43	25,24	20,92

The accuracy of the phenomenon's measurement is not significantly affected by the sensor placement, as measurements along the three coordinate axes enable easy detection of takeoff and landing, reflected as measurement peaks. Additionally, interlacing the sensor with the shoe laces minimizes interference with the execution of exercises.

Figure 1 depicts a visual summary of the system. A simplified graphical user interface (GUI) enabled interaction with the system through START and STOP buttons via the Bluetooth command protocol. Raw measurements along the three axes of the gyroscope and accelerometer are measured at 200 Hz and transmitted to a PC via USB, the L2 norm of the accelerometer measurements is also sent . Following the completion of the jump, the system generates a CSV file containing detailed jump information. The evaluator has the option to display performance metrics on the GUI if desired. These metrics are calculated offline after the jump execution, using the equations provided in Sec II-C.

B. Data acquisition Protocol

1) ***Participants:*** All of the participants were provided with informed consent about the execution of the protocol. They were also given the possibility to retire at any point of the evaluation.

The protocol was executed by 22 individuals (n=22), encompassing both males and females with diverse age ranges (17 to 28) and different physical conditions. The detailed information declared by each participant, plus the Body Mass Index (BMI) calculated as $BMI = Weight/(Height)^2$, is summarized in Table I.

2) ***Procedure:*** For the execution of the tests, the procedure was divided into three major stages, with participants completing them in the following sequence:

2-A) Warm up: The warm up routine started with 5 to 10 minutes of static cycling to elevate heart rates. Subsequently, mobility and lower body strength exercises were performed, completing 8-10 repetitions per exercise.

In the last stage of the warm up, the subjects were instructed to perform two specific jumps: multi-jumps, and drop jumps. This exercises are a specific and preparatory warm-up for the testing, as they are similar in execution and technique to the jumps test [10]. Each subject completed a total of 3 sets of the aforementioned exercises.

A modified Borg scale was used to assess whether the athlete was ready to begin the test. If it's not, they were asked to perform one set of the warm-up again without the static cycling.

2-B) Technical Instruction: After the subjects completed the warm up, they were instructed by the SCP about the the proper techniques to perform ABK, CMJ and DJ jumps.

- ***Abalakov Jump:*** The ABK is an explosive jump requiring participants to exert maximal effort to achieve maximum height. The jump initiates with a downward movement, involving flexion of the hip, legs, and ankles, accompanied by a backward arm motion. This is succeeded by an intense extension of the lower limb joints, leveraging the actions of the arms to enhance propulsion and execute the jump. During takeoff, the legs are expected to maintain full extension throughout the flight phase. The jumper is required to land precisely in the same location where they initiated the jump, landing on the tips of their toes.
- ***Counter Movement Jump:*** The CMJ is performed in a similar wat to the ABK, with the difference that there is no arm action. Hands are placed on the waist, compelling the participant to rely exclusively on leg strength to execute the jump.
- ***Drop Jump:*** This particular test introduces a greater level of complexity compared to the other two jumps. In the first stage, the athlete steps off from a 40cm-high platform,allowing themselves to drop freely to the ground. Upon landing on the ground, the participant must quickly execute a powerful jump with the goal of minimizing ground contact time while achieving significant height. The conclusion of the test requires the jumper to land with legs extended precisely at the starting point. Similar to the CMJ, hands are positioned on the waist.

After the instruction, the athletes were given 3 practice attempts to familiarize wit the evaluation.

2-C) Data Collection:

Each subject was required to perform 3 attempts of each jump (ABK, CMJ, DJ), with 2 minutes of passive rest between the jumps. The execution order of the tests was randomly assigned.

The evaluator installed the accelerometer in the shoe of the participant. The subjects were instructed to perform the vertical jump after a start signal given by the evaluator, and to maintain their position four seconds after the landing phase was completed.

C. Performance Metrics

The assessment of jumpers' performance incorporated four standard metrics: Flight Time (FT), Jump Height (JH), Impulse (IM), and Energy (E), as outlined in previous studies [11], [12]. In the context of the Drop Jump evaluation, two additional metrics were introduced: contact time and the modified Reactive Strength Index (RSI).

The FT metric measures the time interval between the instant of take-off and landing during vertical jumping. Depending on the context or sport, to know how much time a player can be in the air can be a key factor in determining success. E.g. in sports like long jump or high jump, achieving a higher flight time can result in covering more distance.

The JH and FT measures are highly related. According to the principles of jumping physics, JH can be estimated using a jumper's FT, as follows:

TABLE II: Top 6 Results for the ABK and CMJ tests sorted by flight time.

ABK

	Flight Time [ms]	Jump Height [cm]	Impulse [Kg. m/s]	Energy [Joule]
S20	691,38	58,56	248,66	421,20
S22	661,31	53,57	209,98	340,21
S1	658,36	53,10	235,49	379,85
S11	650,62	51,86	258,55	412,14
S18	633,25	49,12	213,79	331,69
S19	625,24	47,89	187,19	286,74

CMJ

	Flight Time [ms]	Jump Height [cm]	Impulse [Kg. m/s]	Energy [Joule]
S20	665,05	54,18	239,19	389,73
S22	615,61	46,42	195,47	294,81
S18	608,18	45,31	205,33	305,95
S11	603,17	44,57	239,69	354,21
S1	600,12	44,12	214,66	315,62
S19	596,02	43,52	178,44	260,57

$$JH = \frac{t_{flight} * g}{8}, \tag{1}$$

where g represents the absolute value of gravitational acceleration ($-9.8m.s^{-2}$). The ground contact phase of the jump starts when the jumper is stationary ($v_i = 0$ at t_i) and ends with the instant of takeoff (at t_{to}). The impulse generated by the jumper's body weight during this phase equals the impulse resulting from the ground reaction force (F_{GRF}), giving

$$IM = \int_{t_i}^{t_{to}} (F_{GRF} - mg)\, dt \; = \; mv_{to}, \tag{2}$$

with v_{to} being the jumper's velocity at takeoff, and m the body mass.

Similarly to the IM calculation, the energy of the jump can be estimated by appliying the work-energy theorem to the ground contact phase of the jump, giving:

$$E = \int_{y_i}^{y_{to}} (F_{GRF} - mg)\, dt \; = \; \frac{1}{2} mv_{to}^2, \tag{3}$$

To effectively evaluate the jumper's performance on the DJ exercise, the Reactive Strength Index (RSI) is introduced. The RSI is a measure of an individual's ability to generate explosive force and react quickly to a rapid change in movement direction. It is commonly employed in assessing an athlete's ability to absorb and quickly produce force, which is crucial in sports that involve rapid changes in direction. A higher RSI is generally indicative of better reactive strength and the ability to efficiently use the stretch-shortening cycle during explosive movements. The formula for calculating the Reactive Strength Index is typically the ratio of flight time to ground contact time (or contact time) during a jump.

III. RESULTS

This section shows an insight on the internal signals of the system, as well as an overall evaluation on the performance of the test subjects. Further information about demographic data of the participants and their results are made available in a GitHub repository.[1]

A. Internal data processing

Inside our system, the 3-axis accelerometer measurements are combined using the L2 norm (Eq. (4)), and smoothed with a 10-point moving average filter. Both operations are C coded inside the chip. A graphical representation of these signals is presented in Figure 2, with blue and black colors respectively.

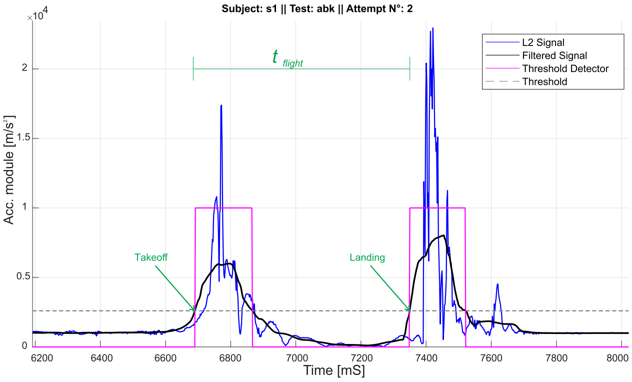

Fig. 2: Internal signals of the system. The 3-axis accelerometer is processed to obtain the L2 norm of the signal. After that, a threshold-based detector allows the system to determine the take-off and landing instants.

$$L2\, signal = \sqrt{(Acc_x)^2 + (Acc_y)^2 + (Acc_z)^2} \tag{4}$$

The system employs a threshold-based detector (highlighted in pink) to ascertain the take-off and landing instants. Subsequently, this crucial keypoints are used for the calculation of the aforementioned metrics.

B. Performance evaluation

In order to thoroughly analyze the data, the information obtained from the jump tests (Tables II and III) was correlated with the information in Table I.

Upon analyzing the correlation between the information provided by the sensor in the tests and the individual subjects' data, it was observed that those jumpers who declared a higher level of training are the ones who achieved superior performance in the tests. Conversely, those with lower levels of weekly activity displayed less favorable results.

The top six results for ABK and CMJ are outlined in Table II. Both tables are sorted based on the jump height achieved in the best attempt by each subject, as this variable is the most crucial to measure in these tests. It can be quickly seen that subject 20, (hereafter referred to as S20) excelled in every variable. Based on the information presented in Table I, this participant not only declared an activity level surpassing the average but is also among the youngest jumpers, potentially providing insight into the noteworthy results observed across the evaluations.

In the case of female athletes, their results were lower than the best jump heights achieved by male participants. This can be attributed to the distinct physiological characteristics in strength and power levels between genders. Subjects 18 and 19 reported similar levels of physical activity and achieved the best results among the female

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[1] **https://github.com/JeremiasGaia/JumpTestPerformance.git**

population. Furthermore, these jumpers demonstrated a performance superior to the overall average.

As shown in Table III, S20 also exhibited the best performance among the participants for de DJ test. It is noteworthy that, S20 achieved the highest RSI, indicating its capability to transfer a greater amount of energy in less ground contact time than the other participants.

Despite securing the second-best result in the evaluations involving ABK and CMJ, S22 did not maintain this standing in the DJ assessment. This discrepancy finds explanation through the RSI. Notably, the jumper exhibited a contact time twice as long as that of S20 and applied less energy. Thus, it can be inferred that while this subject possesses good lower extremity strength, there is a deficiency in reactive capacity for energy transfer after the descent.

C. Comparison with a Commercial System

In order to test the accuracy of our system's results an Axon Jump Model T jump platform was used. This is a standard measurement device among Argentinian high-level athletes. This 1 x 0.8 m platform works as a switch, indicating contact/no contact to the PC program, that triggers a high-resolution cronometer (1 mseg) and measures the time lapse between take-off and landing foot contacts during the different phases of jump tests. All calculations are made in the host PC.

Three subjects were randomly chosen to perform three extra CMJ and ABK jumps. This time, in addition to the embedded system attached to their foot, the subjects were placed on the jump platform. Table IV shows the best time results for each jumper.

TABLE III: Drop Jump results sorted by RSI.

	Flight Time [ms]	Jump Height [cm]	RSI	Impulse [Kg. m/s]	Energy [Joule]	Contact Time
S20	667,93	54,65	2,88	240,23	393,12	232,25
S1	544,56	36,33	2,35	194,79	259,88	232,05
S9	561,85	38,67	2,19	223,27	307,34	256,25
S6	537,71	35,42	2,15	177,59	233,95	250,06
S3	471,29	27,21	2,00	115,24	133,06	235,65
S19	570,67	39,89	1,90	170,85	238,88	300,26
S2	481,91	28,45	1,84	136,72	161,43	262,52
S18	613,53	46,11	1,83	207,13	311,35	335,35
S12	536,42	35,25	1,70	129,06	169,61	315,77
S13	561,49	38,62	1,70	244,87	336,85	330,94
S11	584,92	41,91	1,54	232,44	333,11	379,92
S16	486,59	29,00	1,52	192,17	229,10	319,71
S4	550,04	37,06	1,44	155,51	209,57	381,09
S21	607,95	45,28	1,43	219,85	327,45	425,39
S7	524,17	33,66	1,42	160,01	205,49	370,11
S17	541,15	35,87	1,40	156,18	207,07	387,80
S8	503,36	31,04	1,39	199,54	246,08	361,44
S10	570,31	39,84	1,36	149,79	209,29	420,72
S15	483,45	28,63	1,35	160,37	189,96	356,92
S22	566,64	39,33	1,31	179,92	249,78	431,07

TABLE IV: Flight Time measurement: Comparison with a jump platform

		Jump Platform	Ours	Difference
S1	ABK	584 ms	590.005 ms	6.005 ms
	CMJ	528 ms	520.106 ms	-7.894 ms
S2	ABK	648 ms	656.673 ms	8.673 ms
	CMJ	592 ms	598.667 ms	6.667 ms
S3	ABK	488 ms	492.474 ms	-4.474 ms
	CMJ	496 ms	495.903 ms	0.097 ms

IV. CONCLUSIONS

The measurements obtained through our embedded system demonstrated consistency with the test results and subjects' data. Consequently, our embedded design successfully executed data logging of pertinent variables associated with the Counter-Movement Jump (CMJ), Abalakov Jump (ABK), and Drop Jump (DJ) tests.

In comparison with a commercial jump platform, our system has shown to achieve good results up to a certain offset. A discrepancy of ± 10 ms between measurements was observed. Nevertheless, the Axon Jump manual does not specify a confidence interval for its measurements, which strengthens our confidence in the results provided by our system.

Additionally, by leveraging the capabilities of the SensorTile STEVAL-STLCS01V1, this device is able to serve as a reliable and affordable alternative to measure an athlete's performance on jump tests.

It should be noted that, as this is a preliminary design aimed at demonstrating the capability of estimating variables using low-cost sensors, the system was powered via a USB cable during testing. Evaluations are currently being conducted on code optimizations, power consumption, and processing for future application in an optimized version.

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