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Original Article

Validation of the new technology sensor fusion K-50 based on data integration detected by GPS 50 Hz and inertial sensors

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Abstract
Advanced technology systems applied to sports are increasingly valid support for operators and technicians in the sector. Useful to improve the correct planning of training and therefore of the athlete as well as to the correct management of workloads developed during it and of the season. Studies carried out on the use of new dedicated technologies have shown how supportive they are for improving the performance and preparedness of the individual and the athlete in our case, mathematically developing real parameters for the sessions of the sport practiced (Barbero et a., 2010, Boyd et al., 2011, Brodie et al., 2016, Izzo et al., 2018). The attempt is to further reduce the error coefficient, of the same, the GPS in this case, the objective of this validation study is the validity and reliability of the advanced GPS device K-50 (K-Sport Universal, Ita). The test protocol was administered to 50 junior soccer students-players aged 17 ± 3 years by amateur sports clubs in Italy. The athletes were subjected to different types of stresses considered in the literature, significant in surveys with GPS (Izzo et al., 2018). The GPS device K-50 in our case is a tool, also equipped with inertial sensors (IMU) such as accelerometer, magnetometer, gyroscope, and it is the only one on the market that has the features to be able to use the technologies integrated into a calculation method integrated within the K-50 device, thanks to the use of a Sensor Fusion which allows more performing and sharper data quality. The results of the research protocol were compared using different methodologies for the calculation of some investigated parameters or using the GPS device with the Doppler effect, using the Sensor Fusion, and using the position calculation with different interpolations such as Lat-Lon 0.2 and Lat-Lon 0.05 (Latitude - longitude). In the end, the decidedly positive test results verify the validity of the device (GPS K-50). With the use of inertial systems enriched with the Sensor Fusion the error of the device in measuring the distances traveled is very close to zero with a standard deviation within the percentage limits.
Keywords: 50 Hz GPS, IMU, Sensor Fusion, performance analysis, external load

Introduction

Sports training is a technical-pedagogical process, in a performative function, of scientific quality with a complex structure that is based on the formation of the individual, first generic non-specific and then on a specific model of a specific sport's performance, to optimize the performance of the athlete (Gwangjae et al., 2016, Izzo et al., 2018, 2019). To properly organize and structure a correct work plan it is necessary to know the real stresses imposed by the competitions of the investigated sport obviously in relation to the real abilities and quality of the athlete (Osgnach et al., 2010, Castagna et al., 2016). The evolutionary path of the athlete and for which sport is probably linked, today more than ever, to the application in training of correct parameters obtained in an objective and unequivocal manner by the dedicated technology, thus resulting in more and more adequate and performing at all the different levels going from elite to amateur one, where the performance intended as an improvement of the individual will be a motivational element for the improvement of the learning qualities (Richard et al., 2013, Buchheit et al., 2014). The following study is focused on establishing, the validity and the accuracy of K-50 GPS, by relating it to the distance traveled, calculated through different methodologies such as the Sensor Fusion, the Doppler, Lat Lon 0.02, and Lat Lon 0.05, applying to the workgroup work protocols that proposes exercises that simulate walking, acceleration, deceleration and sprint movements (Duffield et al., 2010, Cummins et al., 2013, Rawstorn et al., 2014a,2014b, Kelly et al., 2014).

Means and Methods

The main objective of this study is to scientifically validate the K-50 including Sensor Fusion (K-50, K-Sport-Universal, Ita) through the use of a test protocol, moreover particularly linked to the sports activity subject to specific investigation (football) already from different authors with less frequent instruments, highlighting some significant elements such as speed, acceleration, and deceleration (Rampinini et al., 2014, 2015) The data shown below (Table 1) represent the percentage difference between the theoretical data and the

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data analyzed in the different types of analysis and represent the average and a statistical dispersion index that estimates the variability of the data obtained to have a minimum standard deviation.

Test n°	**Theoretical Distance (meters)**	**% Distance Sensor Fusion**	**Error (meters)**
Test 1	321	0,78%	2,5
Test 2	321	-0,81%	-2,06
Test 3	70	-0,28%	-0,19
Test 4	420	-0,38%	-1,05
Test 5	112	0,98%	-1,09

Table 1: Experimental summary

Our study used the Sensor Fusion K-50 with a sampling frequency of 50Hz, it is the most advanced product we can find today in the sports dedicated devices market. Innovation is not only given by the sampling frequency but also by a considerable difference compared with the other devices such as the "Sensor Fusion": the merger between the GPS chip and the IMUs, Inertial Measurement Units. The Sensor Fusion gives the device more possibilities to be able to calculate those indicators considered decisive for the performance such as KPI (Key Performance Indicators, K-Sport Uni.): high-speed distance, accelerations, decelerations.; This device proposes an accuracy that the only Doppler effect present in the other devices cannot accurately qualify, for example in these most important parameters such as the change of direction (CoD), the accelerations (AC), and the decelerations (DEC) are underestimated as per literature. The introduction and cooperation of GPS + IMU (Sensor Fusion) offer multiple ways to calculate key elements, minimizing the measurement errors of previous devices (1Hz - 5Hz - 10Hz - 15Hz and even 25Hz) on which all parameters were based on training with obvious imbalances in the reality of action (high margin of error) (Johnston RJ. et al 2014).

Fig. 1 GPS K-50

The K-50 was held inside the K-Shirt, which is a bib used to hold a device inside. The position has been studied making the device for the athlete less invasive. The t-shirt is made of Seemless fabric, highly technological that allows perfect adherence of the same and consequently of the instruments used (K-50), to the body analyzing in detail the athletes' technical skills and avoiding the margin of error that would result from a positioning of the devices in a not perfectly adherent way.

Fig 2. K-Shirt (K-sport-Universal Italy)

To analyze data obtained from K-50 was used the K-Fitness software (K-Sport), It's the dedicated program used to extract and above all process, the data found in the memory of the instrument, if not using the possibility to download live the data. Through the data loaded on the PC, thanks to the Software, technical operators are made legible (cleaned) due to the enormous amount of data acquired at a frequency of 50Hz, reducing them to the table and significantly clearing the reader. To evaluate the distance of tests was used a Metric Wheel (Odometer). The odometer, used as a Gold Standard, is a pre-Roman instrument, used to measure distances on the ground. It consists of a wheel of known circumference mounted on a special handle that is pushed by hand. Turning, the wheel transmits the movement to a pair of hands that indicate the distance traveled on a dial. Very reliable in its simplicity, but still replaceable with laser instruments, where available. Were used classic football training tools to delimit test routes

Validation protocol

The test protocol that was proposed for the validation of the instrument was designed in function of a specific gesture of the investigated sport. The validation protocol was submitted to a sample of 50 soccer players in the student category and juniors. Males, aged 17 ± 3 years, militant in amateur clubs (Marche region, Italy). The proposed test protocol has been performed by all the athletes, to whom, moreover, technical elements have been suggested for the development of the best performance. Athletes performed a 20-minute warm-up with free activity, including stretching and various exercises before the tests were performed. All participants to the validation were informed about the work and all expressed their consent to perform, minors with a consent signed by their parents. The protocol has been divided into 5 tests (Figure 3):

1. walking tour in a playing field with a perimeter of 321 meters maintaining a constant walk;
2. high-speed around the pitch with a 321 meters perimeter, developing a constant speed throughout the testing perimeter;
3. sprint on the 35 linear meters round trip twice with a complete three minutes recovery: sprint is made at maximum speed for 35 meters round trip;
4. 35-meter test with speed changes and high accelerations and decelerations in line with a return in linear sprint, decelerating on the last 5 meters, completing the walk section;
5. "shuttle" test on the 8 meters for 14 times where sprints are performed in maximum acceleration and deceleration for 14 consecutive times.
6.

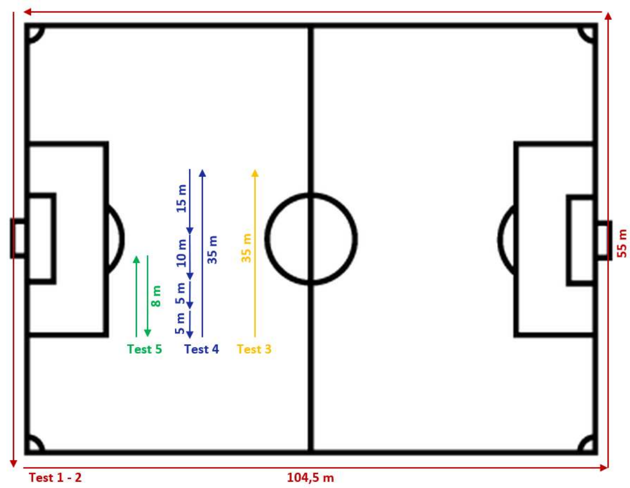


Fig 3. Tests Routes

Application Protocol

Before the execution of the tests, the bibs containing the K-50s (GPS + IMU with Sensor Fusion) were delivered and worn. Properly loaded and turned on, ready for use. The protocol begins with an explanation of the various tests. For the elaborations and the analyses, the percentage differences obtained from the tests carried out previously have been calculated by comparing the real datum, that is the distances measured by the operators following the protocol and the results obtained by analyzing the data measured by the K-50.

To create a uniformity of data, the average of the 50 individual data obtained for each test and their standard deviation has been calculated. For the analysis of the distances covered as above mentioned, four different methodologies have been used that calculate the distance:

- The calculation of the speed or the Doppler effect that calculates the distance using the speed with which the waves are transmitted between the device and the satellites;
- The Lat-Lon that analyzes the distance traveled using GPS positioning concerning latitude and longitude according to different interpolations (0.2 - 0.05), the choice of filters at 0.2 - 0.05 has been matured over the years by the experience of engineers of the group (ARGS);
- The "Sensor Fusion" is a firmware that allows the merger between the GPS chip and the IMU Inertial Measurement Unit (accelerometer, magnetometer, and gyroscope).

Each report obtained shows the recording of the tests performed during the day. Every single athlete's test was evaluated to be able to analyze the validity or otherwise of the test. Out of 50 individuals subjected to the study protocol, were discarded for an execution deemed incorrect of the tests.

Discussion

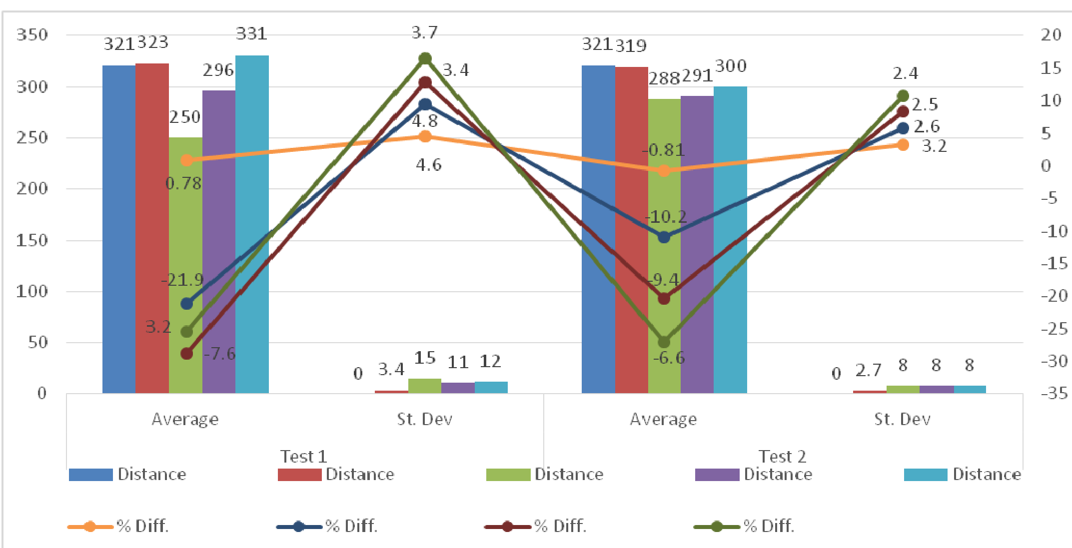
The work analysis divides data obtained in various types of tests and the results are described in the following in Table 2 and can be better visualized in Graph 1 and 2.

Test	Data	Distance					% Diff.			
		Real	Sensor Fusion	Doppler	Lat.Lon. 0.2	Lat.Lon. 0.5	Sensor Fusion	Doppler	Lat.Lon. 0.2	Lat.Lon. 0.5
Test 1	Average	321	323	250	296	331	0,78	-21,9	-7,6	3,2
	St. Dev	0	3,4	15	11	12	4,6	4,8	3,4	3,7
Test 2	Average	321	319	288	291	300	-0,81	-10,2	-9,4	-6,6
	St. Dev	0	2,7	8	8	8	3,2	2,6	2,5	2,4
Test 3	Average	70	70	67	67	69	-0,28	-4,3	-1,9	-
	St. Dev	0	1,2	2	5	6	0,8	7,8	7,9	-
Test 4	Average	420	418	390	388	406	-0,38	-7,14	-7,62	-3,33
	St. Dev	0	2,5	2,1	6,5	7,1	1,4	3,6	9,3	10,5
Test 5	Average	112	110,8	95	94	102	0,98	-15,4	-16,4	-9,3
	St. Dev	0	3,4	6	13	7	2,3	5,5	11,4	5,9

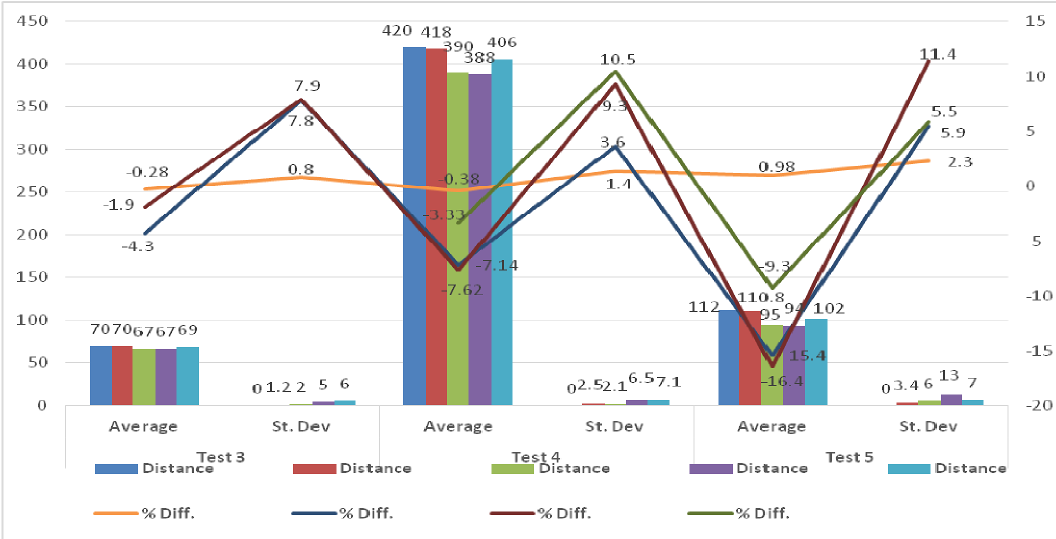
Tab. 2: Tests results average and St. Dev., on Distance and % Difference

Legenda

- Average: indicates the average of all the data obtained in the different measurements;
- Standard Deviation: indicates the standard deviation or an indicator of statistical dispersion;
- Real: indicates the test distance written on the protocol measured by the operators with the metric wheel and the metric webbing;
- Sensor Fusion Distance: indicates the distance calculated by the device using the cooperation of inertial sensors and the K-50 GPS chip;
- Doppler Distance: indicates the distance measured by the device using the Doppler effect:
- Latitude-Longitude 0.2 - 0.05 (LAT-LON): indicates the distance measured by the device using latitude and longitude with an interpolation of 0.2 - 0.05;
- % Sensor Fusion difference: indicates the percentage difference measured with the "Sensor Fusion" compared to the theoretical distance;
- % Doppler Difference: indicates the percentage difference measured with the doppler effect compared to the theoretical distance;
- % Latitude-Longitude Difference, 0.2 - 0.05: indicates the percentage difference between the data measured with Lat - Lon 0.2 - 0.05 and the theoretical data.



Graph. 1: Results for Test 1 and Test 2



Graph. 2: Results for Tests 3, 4 and 5

The tests were carried out on three different structures on three different days with 3 groups of different players to make the results and tests as variable as possible. The weather conditions were almost the same. The results of the first walking tour show a minimum percentage difference of 0.78% (equivalent to 2.50 meters of overestimation) analyzed with the Sensor Fusion which, as we can verify from the previous discussion, is the most appropriate analysis calculation to obtain accurate data. Looking at the data of the field lap at high speed we can see that the minimum percentage difference of -0.81% (equivalent to -2.06 meters of underestimation) is always analyzed with the Sensor Fusion. From this comparison, we can see that over a long distance traveled in a linear manner the increase in speed leads to a reduction of the error compared to the test performed with a gait in walking. Comparing the other tests we can see that in test n ° 3 where two round-trip sprints are carried out on the 35 meters (70 meters) we have a percentage difference of -0.28% (equivalent to -0.19 centimeters of underestimation) analyzed with the Sensor Fusion, in the test No. 4 on the 35 meters carried out with speed variations, high accelerations, and decelerations 6 times (420 meters - 48 accelerations and decelerations defined in the field by the position of the signaling cones, we can observe a percentage difference of -0,38% (equivalent to -1.05 meters of underestimation), instead, in the test n° 5 to "shuttle" on the 8 meters traveled 14 times (112 meters - 13 changes of direction) we have a percentage difference of 0.98% (equivalent to 1.09 meters of underestimation). From the comparison we can deduce that the percentage difference remains very low by linearly making high-intensity sprints, it rises with the speed variations reaching the peak, which falls perfectly within the limits of the validation having an error difference equivalent to -1.31 meters comparing, the 8-meter shuttle which involves many changes of direction, continuous accelerations, decelerations, and the 70-meter sprint.

Conclusions

Starting from the considerations that emerged following the results obtained, we focused on the average percentage difference and the standard deviation of the data obtained; indexes that identify the percentage of error of the device K-50 concerning the real datum of the real distance of the protocol. From the discussion of the data, we can observe that the use of the "Sensor Fusion" firmware is optimally attesting the detected error and an acceptable standard deviation. Particular attention has been paid to tests where numerous accelerations, decelerations, and changes of direction occur because they are normally those items with sharp changes in direction, which put the instrument in "trouble" and in which significant detection errors are often observed. The table below summarizes the percentage of error transformed into meters which are obtained using the calculation with the Sensor Fusion referred to the theoretical distance of the various tests carried out (Table 3 and Graph 3).

Test n°	**Theoretical Distance (meters)**	**% Distance Sensor Fusion**	**Error (meters)**
Test 1	321	0,78%	2,5
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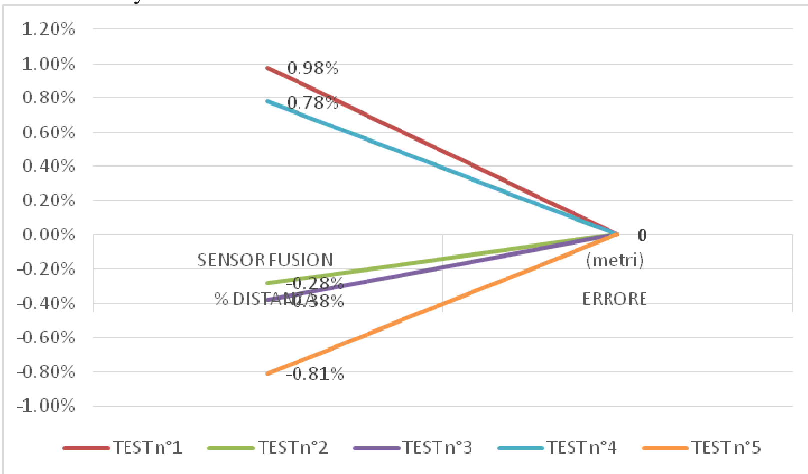
Tab.3: Experimental summary data



Graph.3: Error percentage for tests calculated with sensor fusion

Compared to the other devices the K-50 with the union between GPS and inertial sensors generating "Sensor Fusion" firmware, is possible to obtain data, very close to the real; that is to the distances measured with the metric wheel as per protocol. The above data is the average of all tests performed by all 46 athletes in the 3 days chosen for the tests. In the end, we could say that the validation of the device obtained by a test protocol and data collected by it underlines the assumption with a very high correlation rate resulting from the margin of error between real and instrumental data practically not relevant.

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Conceptualization: Izzo R., Palma A., Hosseini C.
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Formal analysis: Giovannelli M., Palma A.
Investigation: Palma A., Izzo R., Hosseini C.
Data curation: Cruciani A., Izzo R., Giovannelli M.
Statistical analysis: Cejudo A., Izzo R.
Writing, original draft preparation: Izzo R., Hosseini C.
Writing, review and editing: Izzo R., Cejudo A., Hosseini C.

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