



Hexagonal agility test time measurement device: a sensor-based smartphone solution

Dispositivo hexagonal para medir el tiempo de la prueba de agilidad: una solución para teléfonos inteligentes basada en sensores

Authors

Boy Indrayana¹
 Muhammad Eka Mardiyansyah
 Simbolon²
 Atri Widowati¹
 Sukendro¹
 Dzihan Khilmi Ayu Firdausi²
 Indra Dwisaputra³

¹ Universitas Jambi (Indonesia)
² Universitas Muhammadiyah
 Bangka Belitung (Indonesia)
³ Politeknik Manufaktur Negeri
 Bangka Belitung (Indonesia)

Corresponding author:
 Muhammad Eka Mardiyansyah
 Simbolon
 simbolon@unmuhbabel.ac.id

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Abstract

Introduction: Traditional agility measurements often rely on stopwatches and human responses, leading to low accuracy and consistency. Sensors have been used in some agility tests, but not in Hexagonal Agility Test (HAT).

Objective: This study was to develop a digital and Android-based automated timing measurement device for measuring athlete agility. We hypothesize that the HAT device can provide more accurate, instantaneous, and consistent measurement results.

Methodology: Forty-two coaching education students from Jambi University (33 males, 9 females; mean age of 19.3 ± 0.8 years, mean body mass of 59.1 ± 12.5 kg, and mean height of 166.4 ± 7.4 cm) participated in this study. Intra-rater reliability analysis was conducted for manual measurements and utilizing the developed HAT device.

Results: The analysis yielded highly satisfactory inter-rater reliability scores (ICC: 0.9) across all testing sessions. Furthermore, the average results of the test-retest for both testing methods demonstrated minimal variability between raters, indicating the HAT measurement's high reliability.

Discussion: The automated HAT device demonstrated high agreement with manual measurements but showed significant differences due to human response time and fatigue in manual stopwatch use. The HAT device provided faster and more consistent measurements.

Conclusions: The device accurately measures HAT agility but has limitations with the infrared sensor. Future work could explore alternative sensors and expand the device's application to other agility tests.

Keywords

Athlete agility; measurement device; sensor-based; sports performance; sports technology.

Resumen

Introducción: Las mediciones tradicionales de agilidad suelen basarse en cronómetros y respuestas humanas, lo que conlleva una baja precisión y consistencia. Si bien se han utilizado sensores en algunas pruebas de agilidad, no se emplean en la Prueba de Agilidad Hexagonal (HAT). **Objetivo:** Este estudio tuvo como objetivo desarrollar un dispositivo digital automatizado para la medición del tiempo, basado en Android, para evaluar la agilidad de los atletas. Nuestra hipótesis es que el dispositivo HAT proporcionará resultados de medición más precisos, instantáneos y consistentes.

Metodología: Cuarenta y dos estudiantes de formación de entrenadores de la Universidad de Jambi (33 hombres, 9 mujeres; edad media de $19,3 \pm 0,8$ años, masa corporal media de $59,1 \pm 12,5$ kg y estatura media de $166,4 \pm 7,4$ cm) participaron en este estudio. Se realizó un análisis de fiabilidad intra-observador para las mediciones manuales y utilizando el dispositivo HAT desarrollado.

Resultados: El análisis arrojó índices de fiabilidad inter-evaluador altamente satisfactorios (ICC: 0,9) en todas las sesiones de prueba. Además, los resultados promedio de la prueba-reprueba para ambos métodos de evaluación demostraron una variabilidad mínima entre evaluadores, lo que indica la alta fiabilidad de la medición HAT.

Discusión: El dispositivo HAT automatizado mostró una alta concordancia con las mediciones manuales, pero presentó diferencias significativas debido al tiempo de respuesta y la fatiga del usuario al utilizar el cronómetro manualmente. El dispositivo HAT proporcionó mediciones más rápidas y consistentes.

Conclusiones: El dispositivo mide con precisión la agilidad en la prueba HAT, pero presenta limitaciones con el sensor infrarrojo. En futuras investigaciones se podrían explorar sensores alternativos y ampliar la aplicación del dispositivo a otras pruebas de agilidad.

Palabras clave

Agilidad del atleta; dispositivo de medición; basado en sensores; rendimiento deportivo; tecnología deportiva.

Introduction

Measuring athlete agility is a crucial aspect in various sports, but current methods still face several challenges. Traditional agility measurements often use stopwatches and human response, which can result in low levels of accuracy and consistency (Arief et al., 2023; Nursuwars et al., 2020). The assessor's fatigue factor can also influence the measurement results (Arief et al., 2023). Several studies have developed tools for measuring athlete agility. However, the results of previous studies were still presented in Windows applications (Arief et al., 2023). The design of an IoT-based agility measurement system has been tested and resulted in a concept that can be implemented (Nursuwars et al., 2020), this athlete agility monitoring system was developed using sensor pads (Nursuwars et al., 2025).

There are various forms of athlete agility tests for various sports. One of these is the hexagonal agility test (HAT). Some forms of agility tests have utilized sensors in their implementation, but this has not been found in the HAT. The HAT has been shown to exhibit high test-retest reliability. One study reported an intraclass correlation coefficient (ICC) of 0.88, indicating high relative reliability (Hernández-Davo et al., 2021). Another study confirmed excellent test-retest reliability with ICC values of 0.938 for same-day tests and 0.924 for tests between different days (Beekhuizen et al., 2009). The HAT is a widely used measure of agility, particularly in sports such as tennis and soccer. It is a simple and easy-to-learn test that can be performed in a confined space, making it ideal for evaluating agility in a laboratory setting (Miranda et al., 2016). This test involves rapid changes of direction and is designed to assess an athlete's ability to move quickly and efficiently.

This study aims was to develop a digital and Android-based automated timing measurement device (HAT) for measuring athlete agility. We hypothesize that the device developed for measuring agility using this HAT can provide more accurate, instant, and consistent measurement results.

Method

The research method used is Research and Development (R&D). R&D is conducted in the development of sports instruments, testing the validity and reliability of the products/tools/instruments being developed, as has been done in previous research (Anstiss et al., 2018; Dimarucot & Macapagal, 2021; Qowiyyuridho et al., 2021; Quílez-Maimón et al., 2021). R&D is a study conducted in the context of product development, which involves problem identification, literature studies, product design and development, performance testing, evaluation, and explanation (Amaral Féris et al., 2021). In general, R&D is closely linked to a sustainable and robust innovation process. Specifically, current R&D efforts create a body of knowledge for adaptation and enhance the potential for future research to exploit technological opportunities (Sarpong et al., 2022).

Participants

Forty-two coaching students from Jambi University (i.e., 33 males, 9 females; 19.3 ± 0.8 years old; body mass 59.1 ± 12.5 kg; height 166.4 ± 7.4 cm) were enrolled in this study. The self-reported inclusion criteria were: 1) being a student in the coaching study program; 2) having attended at least eight taekwondo classes during the current semester; 3) not experiencing any major injuries or pathologies of the ankle, knee, or hip; and 4) exercising for more than three hours a week. Participants were asked to learn the HAT test procedure and perform the test at least twice before data collection. After understanding the HAT procedure, each participant wore a taekwondo uniform and was barefoot during data collection. Ethical approval for this study was obtained from the Universitas Jambi (No. 003/UN21.11/PT.01.05/SPK/2025) and all participants understood and verbally agreed that data collection was conducted for research purposes.

HAT automation time measurement device

The sensor hardware consists of two Sharp infrared sensors (GP2Y0A710KOF), each functioning as a start sensor and a counting/end sensor (Figure 1). The developed technology components are integrated into the sensor hardware design.

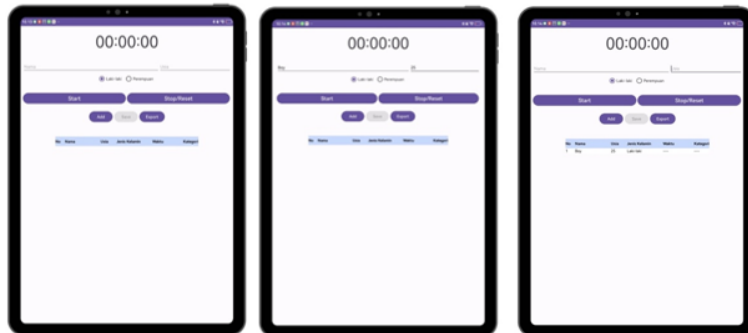


Figure 1. Realization of start/end sensor hardware.



After the basic principles were studied, the device application realization (Figure 2) Transmission Control Protocol/Internet Protocol (TCP/IP) facilitates communication between the sensor device and the application on the smartphone. The application realization on the smartphone includes a time display (Minutes: Seconds: Milliseconds); Input fields for the name and age of the testee; Gender selection; Start button; Stop/Reset button; Add, save, and export buttons; and a summary table of test results conducted by the testee. Predictions of the capabilities of the technology elements have been validated through modeling and simulation. Laboratory experiments have been able to ensure the feasibility of the software. All devices have been approved by the institutional review board of the Universitas Jambi and are labeled as devices with no significant risk.

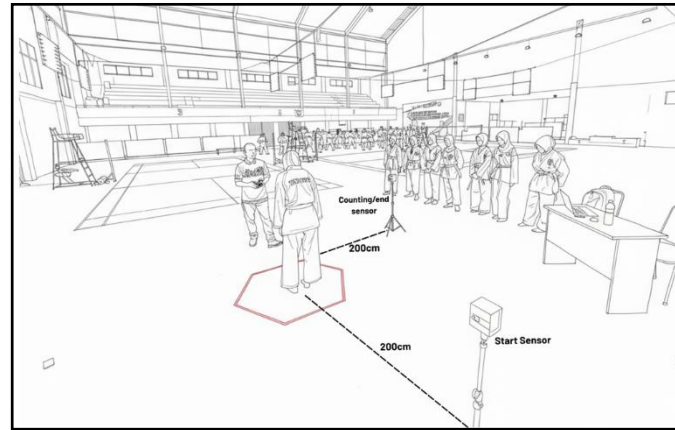
Figure 2. Realization of applications on smartphones.



Experimental environment

The device trial was conducted in the Badminton Hall of Jambi University (Figure 3). The hexagonal agility test layout, each side measuring 66 cm, was marked on the floor with tape (Figure 4). The start sensor was placed behind the participant or on the D line of the hexagon layout, 200 cm from the center of the hexagon. Meanwhile, the counting/end sensor was placed on the right side of the participant, 200 cm from the center of the hexagon, parallel to line A on the layout. The distance between the sensor and the participant was set at 190-240 cm. A Wi-Fi server, as a TCP/IP protocol, was placed around the sensor device and smartphone within a 5-meter radius. This arrangement, along with the wireless device, allowed participants to perform the task optimally and without the risk or worry of tripping over the sensor device.

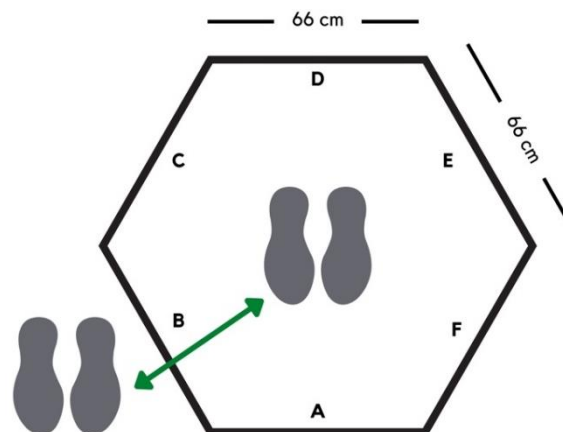
Figure 3. Experimental setup schematic including sensor device layout.



Hexagonal agility test (HAT) task

Participants were asked to warm up by running for seven minutes and then stretch before performing the test. Figure 4 shows the HAT schematic, the procedure for performing the hexagonal agility test (Hernández-Davo et al., 2021; Miranda et al., 2016) as follows: 1) The athlete stands in the center of the hexagon, facing line A; 2) throughout the test, the athlete must face line A; 3) at the GO/Start command, the stopwatch is started and the athlete jumps with both feet over line B and back to the center, then over line C and back to the center and so on; 4) when the athlete jumps over line A and back to the center, this is considered one circuit; 5) the participant completes three circuits; 6) after that, the stopwatch is stopped and the time is recorded; 7) each athlete gets two attempts; 8) if the athlete jumps over the wrong line or lands on the line, the test is repeated. The average time is taken from two hexagonal agility test runs with the developed device and manual measurements using a stopwatch operated by an experienced examiner. All participants sequentially complete the first attempt, then return to the second attempt. The waiting period (5-7 min) serves as a rest period between the two attempts.

Figure 4. Layout of hexagon agility test.



Data collection and analysis

We evaluated the agreement between the HAT time recordings using a stopwatch and a time-gated device we constructed. Descriptive statistics were calculated for all variables, and the Shapiro-Wilk test was used to assess the normality of the sample distribution. Not all data followed a normal distribution (Table 1). Inter-rater reliability between the time-gated product readings and the stopwatch was determined based on the intraclass correlation coefficient (ICC) (Lima et al., 2025). If the ICC value between

measurements is greater than 0.50, the measuring instrument being tested is considered to have appropriate stability; if it is greater than or equal to 0.80, it is considered to have high stability (Rusdiana et al., 2021). An ICC rating of 0.9 is considered excellent, a value of 0.9 to 0.75 is considered good, a value of 0.75 to 0.5 is considered moderate, and a value less than 0.5 is considered poor (Koo & Li, 2016; Peebles et al., 2018). The average value of the test-retest of each measurement method was calculated for statistical analysis. The Mann-Whitney U test was conducted to identify the two differences in the average performance measurements (Parente et al., 2019; Perrotta et al., 2023; Rusdiana et al., 2021). Rank biserial correlation was used to estimates of effect size (ES). A statistical tool called the Bland-Altman Plot is used to compare two measurement methods (Alzahrani et al., 2015; Bravi et al., 2023; Hui et al., 2018; Rusdiana et al., 2021). The Bland-Altman plot can be used for this assessment (Bian et al., 2022), indicating systematic error (bias) in the measurement results (Bruzzo et al., 2020; Gupta et al., 2009; Maeda et al., 2023; Stitt et al., 2021). Jamovi (Version 2.6.23.0) was used for all statistical analyses, with significance set at 0.05.

Results

The data from the manual test method for each session were normally distributed (test: 0.234; retest: 0.186; and mean test-retest: 0.202). However, the data from the test using the HAT device (test: 0.052; retest: 0.051; and mean test-retest: 0.051) were not normally distributed. The analysis results showed that the inter-rater reliability score was excellent (ICC: 0.9) across all testing sessions and also the average results of the test-retest for both testing methods, indicating minimal variability between raters for the HAT measurement (Table 1 and Figure 5).

Table 1. Reliability analysis and normality of data

Sessions	Mean (SD)		95% CI		Shapiro-Wilk p		ICC	
	M	A	M	A	M	A	Consistency	Agreement
Test	17.8 (2.63)	17.1 (2.47)	16.9-18.6	16.3-17.9	0.234	0.052	0.976	0.947
Retest	17.6 (2.62)	17.1 (2.49)	16.7-18.4	16.3-17.9	0.186	0.051	0.975	0.959
Average (test-retest)	17.7 (2.62)	17.1 (2.48)	16.8-18.5	16.3-17.9	0.202	0.051	0.976	0.954

A: Automation test using the HAT device; CI: Confidence interval (lower-upper); ICC: Intraclass correlation coefficient; M: Manual test using stopwatch.

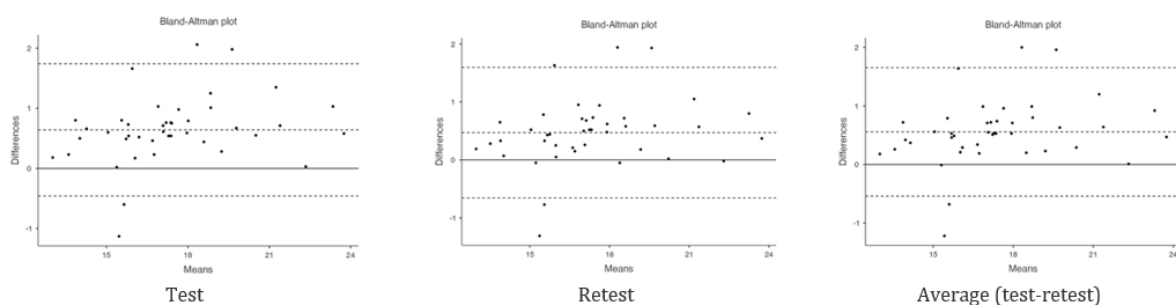
The main statistical results of the comparative analysis are summarized in Table 2. Statistically significant differences ($p < .001$, $ES = 0.819-0.875$ [large]) were found in each session between manual and HAT device measurements. Table 2 also reports the inter-rater root mean square error (RMSE) for each session.

Table 2. Comparative analysis each session

Sessions	Statistic	p	ES	RMSE
Test	847 ^U	<.001*	0.875	0.546
Retest	822 ^U	<.001*	0.819	0.563
Average (test-retest)	836 ^U	<.001*	0.852	0.547

ES: Effect size; RMSE: root mean square error; U = Mann-Whitney's U; * = Statistically significant differences at $p < 0.05$.

Figure 5. Bland-Altman Plots inter-raters' each session and average (test-retest).



Discussion

The primary objective of this study was to develop an automated HAT device that provides more accurate and consistent measurements. The HAT device demonstrated a high level of agreement with manual measurements. However, significant differences were found in each session between manual measurements and the HAT device. Although manual measurements used a stopwatch operated by an experienced examiner, human response likely contributed to the differences found in this study (Arief et al., 2023; Nursuwars et al., 2020). Manual use of a stopwatch introduces significant variability and potential for error due to human response time and fatigue, which can lead to inconsistent and less reliable measurements (Arief et al., 2023; Matkarimov et al., 2024). The HAT device's measurements were found to be several milliseconds faster than manual measurements using a stopwatch. Previous studies also found that measurements with the device were faster than manual measurements using a stopwatch (Dewanti & Hermawan, 2022).

Conclusions

The device we have developed has been demonstrated to accurately and consistently measure HAT time. However, the infrared sensor employed in this device does present certain limitations. Specifically, the infrared sensor is capable of detecting objects within a limited range of colors. Future research endeavors could explore alternative sensors that offer broader color detection capabilities. While this device was initially designed to specifically assess HAT agility, its performance could also be adapted to measure agility through alternative testing methodologies.

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Authors' and translators' details:

Boy Indrayana	boy_indrayana@unja.ac.id	Author
Muhammad Eka Mardiyansyah Simbolon	simbolon@unmuhbabel.ac.id	Author/ Translator
Atri Widowati	atri_widowati@unja.ac.id	Author
Sukendro	sukendro@unja.ac.id	Author
Dzihan Khilmi Ayu Firdausi	dzihanayu@unmuhbabel.ac.id	Author
Indra Dwisaputra	dwisaputra.indra@gmail.com	Author