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Improving Children's Manipulative Movement Delays Detection Based on Sensor and IoT Technology

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Abstract A common obstacle encountered when measuring manipulative motor skills is inaccuracy in recording results, which leads to repeated data collection. This results in ineffective and inconsistent measurements. Advances in sensor and IoT technology have created opportunities for more accurate, efficient, and objective early detection of manipulative skills. Therefore, this study aims to design a sensor- and IoT-based early detection system for manipulative motor skills to improve the effectiveness and efficiency of data collection, resulting in effective and accurate detection. This research and development involved nine experts: three motor experts, three measurement test experts, and three technology experts. Fifty children aged 6-10 years participated in a field trial using a purposive sampling method. After data collection, the Pearson correlation coefficient was analyzed. The results of the study indicate that the analytical tool produced is classified as high across all aspects, and the test-retest reliability test yielded a regression ($r = 0.930$; $P < 0.05$), indicating significant performance and a high correlation coefficient. The study's findings indicate that this sensor-based and Internet of Things-based measuring tool can collect more comprehensive motor skill data than manual techniques. This integrated system reduces errors and allows for faster and more precise measurements. Furthermore, this technology is expected to provide tangible benefits for educators and coaches in monitoring children's motor skill development in a more measurable, methodical, and sustainable manner. Therefore, this discovery could be a useful way to improve the standards of motor skill teaching and assessment.

Keywords Measuring Tools, Manipulative Skills, Sensors, IoT, Children

1. Introduction

Motor skills are basic abilities that children must have from an early age [1], [2], which play an important role in children's health and development [3]. Well-developed motor skills help children in their daily activities such as physical, motor, mental and social development, enabling them to fully participate in the environment [4]. Motor skills play an important role in carrying out movement and are an important factor in future physical activities [5]. Failure to develop children's motor skills from an early age has an impact on children's development throughout their lives [6].

Manipulative motor skills, such as throwing, catching, and hitting, are an important part of children's motor development [7], [8]. These skills not only support physical activity, but also contribute to children's social, emotional, and cognitive development [9], [10]. Obstacles in measurement result in delays in identifying children's motor skills early on, which results in children not developing properly. Previous measurements have been carried out, however, the process of measuring manipulative skills still uses manual measurements, which often experiences obstacles such as bias in observation, involving many research members, using a long time and tends to be less effective in obtaining research data. Measuring motor skills is a priority for identifying children's motor skills early on. With motor skills that are known early on, it can be understood what motor skills should be given to children who experience motor delays. However, the process of measuring these skills is often done manually, which tends to be subjective, less accurate, involves many people and takes a long time. Measuring motor skills in children is a top priority for PJOK which can help teachers and coaches support the development of motor skills needed by individuals [11], [12], [13].

Sensors and IoT are technologies that have begun to develop in the current era. The development of sensors has developed messages that can detect movements that are quite difficult to detect, therefore sensor technology promises ease in measurement. The advancement of IoT technology continues to develop and begins to combine with sensors such as sending data obtained from sensors, therefore sensors make sophisticated technology to facilitate research in measurement. Sensor technology and IoT are the right technologies for measuring and facilitating data delivery in research.

To overcome certain limitations, it is necessary to design a technology-based measuring instrument that is able to provide objective, accurate, and efficient data. In this context, the integration of sensors with IoT technology is an innovative approach. Sensors can be used to detect movement parameters precisely, while IoT technology allows the data to be sent and analyzed instantly over the network. The results combined between IoT and sensors can be seen on the screen, showing how many scores are obtained by children in performing manipulative skills. The purpose of this study is to design a measuring instrument for manipulative component motor skills based on sensors and IoT. This development is expected to be able to support the measurement of manipulative component motor skills in real time by researchers, educators, trainers and stakeholders. The design of this measurement system is expected to be able to support efforts to improve the quality of physical education and support children's skills. This study assumes that with technological advances it becomes effective in measuring motor skills.

2. Materials and Methods

2.1. Design and Participants

This research is a research and development (R&D) study aimed at designing a motor skills measurement instrument, specifically a sensor- and IoT-based manipulative component, and testing its validity and reliability. Nine experts were involved in the feasibility assessment: three motor skills experts, three measurement test experts, and three technology experts. The experts involved in this study are lecturers at Padang State University, Indonesia. A total of 50 elementary school children participated in the field trial. Participants were children aged 6–10 years, consisting of boys and girls, who had parental permission to participate in the field trial and did not have physical disabilities. The Padang State University Ethics Committee approved the study under No. 082/KEPK-UNP/10/2025. Prior to participation, all parents or legal guardians provided clearly explained written consent. The researchers closely monitored the children throughout the study, and safety measures were implemented, such as the use of light sensors, non-hazardous materials, and monitoring to ensure that electronic devices did not hinder natural movement or cause physical problems. This sampling method is called purposive sampling.

2.2. Procedures and Instruments

The methods used in this study include designing and developing the form of the tool, testing and refining the tool, and field trials. Sensor and IoT-based manipulative component measuring tools are designed by technology experts, or non-experts involved in research. The design of the tool consists of: a series of sensors, Internet of Things, LCD, Arduino, NodeMCU ESP 32, Spreadsheet, Light Dependent Resistor (LDR), Transmitter Receiver Radio Module nRF24L01. The assessment indicators of the proposed measurement system are presented in the form of a questionnaire that has been prepared and discussed with experts. In order for the tool to measure what should be measured, this validation seeks to ensure the suitability and accuracy of the designed tool. The development of expert validation test items is based on the theory of elementary school children's motor development which refers to gross motor skills. The scale used is the Likert scale, which is intended for experts to measure the motor aspects being measured. The results of expert assessments were processed using Aiken's $V \geq 0.75$ valid analysis [14]. Instruments to assess children's motor skills must be developed in accordance with a motor development framework that is appropriate to the child's age and developmental stage. According to Griffiths & Billard [15], elementary school students are in the basic movement phase, which includes basic movement skills including running, jumping, walking, throwing, and catching. This ability serves as a foundation for the development of more complex movements later on. Proficiency in these basic movements is essential for success in sports and other physical activities [16].

Validation data and expert opinions were reviewed for improvement, in order to reach an agreement for field testing. The purpose of conducting a field trial was to determine the system constraints in collecting data on motor skills of sensor-based manipulative components and IoT. Retesting was carried out to obtain a reliability test of the tool by means of two repetition tests. The first and second test times were one week, which were given to subjects in the same situation.

The procedures and stages of implementing the field test are: a) the sample is fitted with a bracelet that is connected to the sensor, b) the sample prepares to carry out manipulative movements such as throwing, catching, kicking and bouncing the ball, c) after the instructions from the researcher are started, the sample carries out the test item, d) this implementation is carried out for 60 seconds per test item, e) the highest score is taken from the two repetitions (the results will be displayed on the LCD and stored on the connected computer).

2.3. Product Specifications

The use of sensors and IoT technology combines; (a) LCD is useful for directly viewing the results obtained during testing, (b) microcontroller is the brain of technology to control the input and output of electronic circuits in general Arduino consists of two parts, namely Hardware in the form of an input/output board and Arduino IDE Software to write programs and drivers for connection to a computer. (c) NodeMCU ESP32 is a technology that has the ability to connect to a wifi network that allows devices to communicate with other devices. (d) Google sheets is a web-based application that allows users to create, update, and modify in real time, and to collaborate with anyone, anytime, and anywhere. (e) Light Dependent Resistor (LDR) is a resistor whose value varies depending on the strength of the light it receives, and this gadget is commonly used as a light detector or light conversion meter. (f) The nRF24L01 Radio Transmitter Receiver Module is a module that enables long-distance or wireless communication using 2.4 GHz RF waves. The nRF24L01 module has hardware in the form of Enhanced ShockBurst baseband circuitry and protocol accelerators for high-speed communication. Furthermore, this module offers a real ULP solution feature that functions as a power consumption saver, resulting in energy savings. This module can also be used to produce medical equipment, sports, children's toys, and other game equipment.

2.4. Statistical Analysis

The analysis used at this stage employed the Pearson correlation coefficient to analyze test-retest reliability. This stage uses the help of the IBM SPSS V24 device.

3. Results and Discussion

The installation of a sensor-based and Internet of Things (IoT) measurement system at various manipulation skill stations is shown in Figure 1. To record movement patterns during activities such as kicking, throwing, hitting, and catching, sensors are attached to the child's wrist. A microcontroller receives movement data, which is then transmitted wirelessly via the nRF24L01 module and analyzed by the ESP32 for IoT integration. The information is then instantly and automatically saved to Google Sheets. This flow makes data collection methods, communication routes, and sensor placement clear in an organized and transparent manner.

The IoT-based data flow is shown in Figure 2, which shows how the sensor signals are processed by the microcontroller, sent through the nRF24L01 module, and stored in Google Sheets via ESP32 wireless communication. The motion data flows from the first detection to cloud-based storage.

3.1. Validity

Based on expert assessment of the sensor and IoT-based manipulative component motor skill measuring instrument from all aspects, it can be submitted to the category (V = 0.867). The overall results were obtained from various aspects such as the Suitability aspect from 9 experts getting (V = 0.939 / SD = 0.036), the Accuracy aspect from 9 experts getting (V = 0.843 / SD = 0.102), the Ease aspect from 9 experts (V = 0.813 / SD = 0.137), and the Particality aspect from 9 experts getting a value (V = 0.872 / SD = 0.06). More details can be seen in Table 1. ICC assessment data = 0.795, which is used to support the measurement and alignment of views related to the Intraclass Correlation Coefficient of the research which can be seen in Table 2.

With an average overall validity value of 0.867 ± 0.044, the results of the validity table analysis indicate that this research instrument is of very good quality. The suitability of the instrument to the measurement objectives is confirmed by the Suitability aspect, which obtained the highest score (0.939 ± 0.036). Conversely, the Ease of Use component obtained the lowest score (0.813 ± 0.137), indicating that the assessors' evaluations vary. Thus, all aspects are valid. Therefore, it can be said that this instrument is valid and suitable for use.

The Single Measures value is 0.301 with a confidence interval range of 0.159–0.517, and the Average Measures value is 0.795 with an interval of 0.629–0.906, based on the results of the reliability test using the Intraclass Correlation Coefficient (ICC). Significant results are indicated by a p-value of 0.000 (<0.05). This indicates that although the average reliability of the assessment is very good and consistent, the dependability between individual assessors is still low. Therefore, when used collectively by several assessors, this instrument can be considered dependent, making it suitable for use in research by considering increasing the consistency of individual assessors.

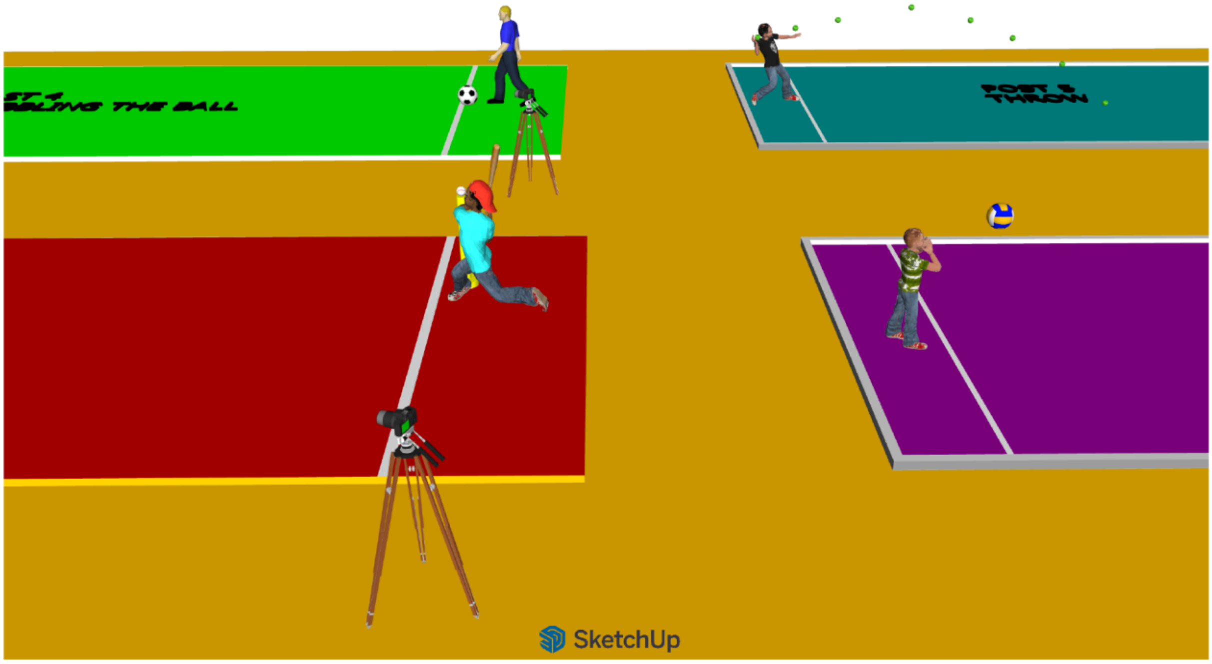

Figure 1. Measurement Structure Design

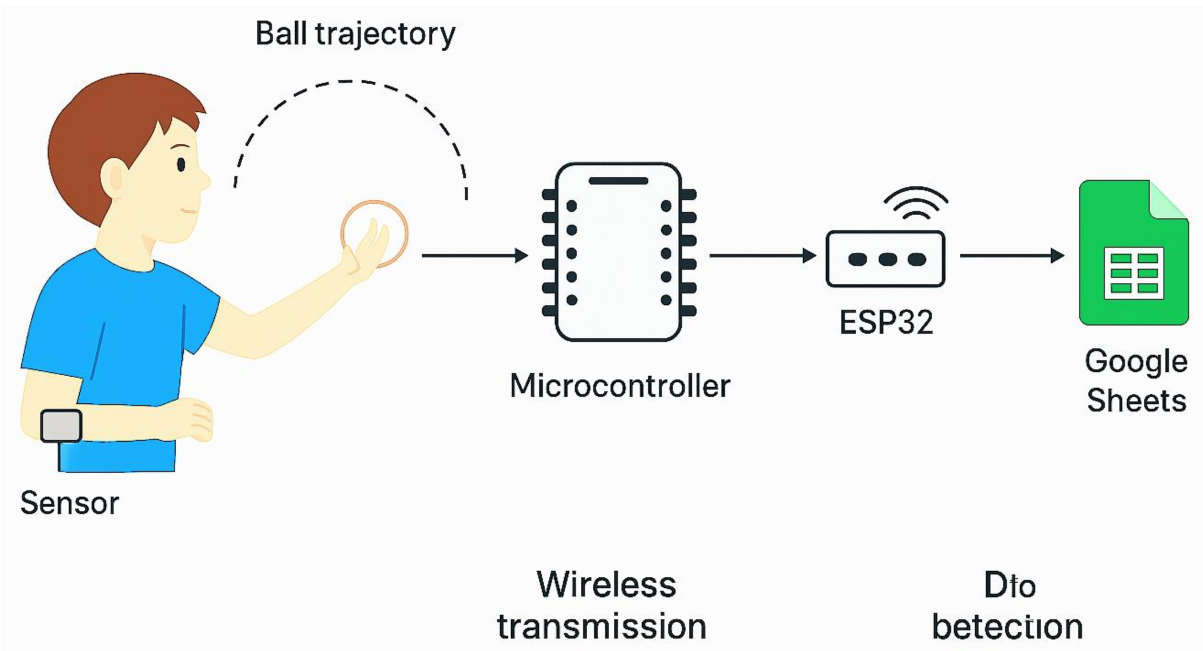

Figure 2. IoT-based data flow

Table 1. Validity Index

Aspect	Items	Raters									∑s	n(c-1)	V Index	M ± SD
		S1	S2	S3	S4	S5	S6	S7	S8	S9				
Suitability	1	4	4	4	3	4	3	4	3	4	33	36	0,917	0,939 ± 0,036
	2	4	4	4	4	4	4	3	4	4	35	36	0,972	
	3	4	3	4	4	4	4	4	3	4	34	36	0,944	
	4	4	4	4	3	4	4	4	4	4	35	36	0,972	
	5	4	4	3	3	4	4	3	3	4	32	36	0,889	
Accuracy	1	4	3	4	3	4	4	3	4	4	33	36	0,917	0,843 ± 0,102
	2	3	4	3	4	4	3	3	4	3	31	36	0,861	
	3	4	3	3	4	3	4	3	4	4	32	36	0,889	
	4	3	3	2	2	3	3	2	2	3	23	36	0,639	
	5	3	4	3	4	4	4	3	4	3	32	36	0,889	
	6	4	3	4	3	3	4	3	4	3	31	36	0,861	
Ease	1	3	4	3	4	3	4	3	4	3	31	36	0,861	0,813 ± 0,137
	2	3	4	3	4	4	4	3	4	4	33	36	0,917	
	3	3	2	3	2	2	3	2	3	2	22	36	0,611	
	4	4	3	4	3	4	3	4	3	3	31	36	0,861	
Particality	1	4	4	4	4	4	3	4	3	4	34	36	0,944	0,872 ± 0,061
	2	4	2	3	4	3	4	3	2	3	28	36	0,778	
	3	3	4	3	4	3	4	3	4	4	32	36	0,889	
	4	4	3	3	4	3	4	4	3	4	32	36	0,889	
	5	3	4	3	3	3	4	3	4	4	31	36	0,861	
All aspects		**72**	**69**	**67**	**69**	**70**	**74**	**64**	**69**	**71**				**0,867 ± 0,044**

Table 2. Intraclass Correlation Coefficient

	Intraclass Correlation Coefficient a	95% Confidence Interval		F			
		Lower Bound	Upper Bound	Value	df1	df2	P
Single Measures	0,301b	0,159	0,517	4,991	19	152	0,000
Average Measures	0,795c	0,629	0,906	4,991	19	152	0,000

Confidence Interval; Intraclass Correlation Coefficient; Single Measures; Average Measures; Significant (P<0.05).

a. Type A intraclass correlation coefficients using an absolute agreement definition.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

3.2. Reliability

Based on the results of the reliability test (Table 3), the correlation coefficient on the measuring instrument of manipulative component motor skills is in the high category and is consistent with data collection, where a high correlation coefficient indicates consistent results and accuracy in a measuring instrument. The higher the correlation level, the more it can be believed that the measurement results are not just coincidence, but a real reflection of what is measured, so that data-based decisions can be more accurate and reliable in various conditions, by showing regression analysis and significant relationships ($p < 0.005$).

Table 3. Test-retest reliability

No Test	N	R	P
Test 1	25	0.930	0.000
Test 2	25	0.930	0.000

**. Correlation is significant at the 0.01 level (2-tailed).

The development of a sensor-based and IoT-based manipulative component motor skill measurement tool has a high validity and reliability value with retesting (V=0.867: r=0.930: P<0.05). The results obtained after the first and second tests with a 7-day testing interval with the same situation and conditions showed sig results (P<0.05). Thus, it can be said that the sensor-based and IoT-based manipulative component motor skill measurement tool has a consistent value in data collection.

Validity and reliability are requirements that must be met in developing measuring instruments[17]. Validity plays a role in measuring the accuracy of the instrument to be measured, while reliability is the consistency of data obtained after repeated measurements in the same situation [18], [19]. High validity can help researchers in collecting data during data collection [20]. Instrument validity, researchers involved nine experts to obtain optimal products [21]. The experts involved are responsible for validating the instrument and suggestions from experts are very much needed in its development [22]. Instrument development needs to involve two to twenty experts in their fields [23].

The resulting tool is a technological and sports innovation that aims to collect data on motor skills of manipulative components in children. Sensor technology is a breakthrough innovation in measurement that allows for real-time performance data collection. Several researchers have linked technology and sports that can analyze and collect large amounts of data [24], [25], such as developing a practical and reliable motor skills measurement tool for locomotor components. This study involved 65 school children in kindergarten [26]. Sensor technology has an impact on transparent data collection [27], and can detect human motion accurately using smartphone sensors [28]. The developed system makes it easier to measure manipulative component motor skills and reduces bias in data collection, in contrast to the manual model, which involves many researchers and takes a long time.

The results of this study are in line with previous studies showing that technology-supported assessment can reduce bias in human calculations and improve accuracy in motor learning evaluation [29], [30], similar advantages of sensor-based systems applied to preschool children's locomotor skills [26], and intelligent sensors that can be displayed to identify movements in dynamic situations [27]. In a similar context, Alshammari and Albalawi [28] emphasized how well IoT-enhanced sensors produce reliable movement data. The excellent correlation coefficient in this study (r = 0.930) adds to the evidence that sensor-IoT integration can facilitate objective and real-time assessment of children's motor learning.

With the presence of this device, it can make it easier for researchers, stakeholders and can be used as guidelines and references in conducting future research. However, this study has limitations that need to be reported, such as the measurement system for the motor skills of the manipulative component being tested on children aged 6 to 10 years and the placement of sensors that have not made the sample comfortable in making movements, such as the system being placed on the hand resembling a bracelet, for the future so that it can be tested on children under 6 years old to detect the motor skills of the manipulative component as early as possible, and create a system that is more comfortable for the sample to use. The design of this measuring instrument involves institutions in the first year of funding, and the design of large-scale measuring instrument testing and early childhood testing is carried out in the following year. Determining the norm for the level of motor skills of the manipulative component needs to be displayed on the measuring instrument.

4. Conclusions

Based on the results of the researcher's development, the sensor-based and Internet of Things manipulative component motor skill measurement tool has succeeded in producing measurement technology. The manipulative skill measurement tool has a high validity value and has been assessed by experts before conducting a field test. This system can be tested in the field to determine its reliability value. The results obtained after the field test showed a high reliability value, which is the measurement system is reliable in assessing the motor skills of the manipulative component. It is hoped that the development of this measuring instrument will greatly assist researchers in assessing children's motor skills related to the manipulative component. To collect more comprehensive and instructive data, the developed instrument facilitates measurement and analysis and increases accuracy. In addition, this system provides a way to ensure that future data collection is more precise and efficient.

From a pedagogical perspective, this technology provides coaches and educators with objective, real-time data that can be used to detect manipulative motor disorders early. Teachers can monitor progress, create customized training programs, and conduct regular assessments with minimal preparation time by viewing performance scores directly on the LCD screen and automatically recording them in a cloud-based spreadsheet. This facilitates early intervention for children who need additional assistance with motor development and supports competency-based education.

The researchers suggest that to develop appropriate norms, larger and more diverse study samples are needed to obtain normative data on children's manipulative skills across age groups, not just one area. This would enhance the instrument's external validity and support its application in broader educational and clinical settings. The creation of a manipulative component motor skills instrument that considers all aspects would be a significant advancement in the field of education and assessment of children's manipulative component motor skills.

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