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Development of Inverse Kinematics Learning Media Using Hexapod Robot for Robotics Course

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Abstract. This study aims to (1) get an inverse kinematic learning media design, (2) find out inverse kinematic learning media performance, (3) find out feasibility level of inverse kinematic learning media using hexapod robot. This type of research is research and development using ADDIE model, with stages: (1) Analysis, (2) Design, (3) Develop, (4) Implement, and (5) Evaluate. The object of research is hexapod robot. The subjects of research are students of Electronic Engineering Education Study Program who took the concentration of Industrial Electronics. Methods of data collection using classroom observation and questionnaires. The data analysis technique is descriptive qualitative analysis. The result of this research and development shows: (1) inverse kinematic learning media design using hexapod robot, (2) the performance through black box testing get result 100%. Each robot's feet can move with an average axis error percentage x of 7,4%, y of 11,67% and z of 7,87% and produces 14 types of movement, (3) feasibility level of learning media based on the assessment of material expert obtained 94,46% (very feasible), media expert obtained 96,2% (very feasible), and users obtained 80,99% (feasible).

1. Introduction

Robotics is one of the developing fields which is quite fast in recent times. Robotics is a field that applies science in a tool, science make it has artificial intelligence and able to do a decent human's job [1]. These tools widely used by users (industry) to facilitate and lighten work. Besides, it can increase quality and quantity in the production process. Through robotics courses, Department of Electronics and Informatics Engineering Education in Faculty of Engineering, Yogyakarta State University teaches various topics about robotics field. So that it can increase competences of participants students in robotics field. The observation results show that learning robotics courses in the Department Electronics and Informatics Engineering Education still has limited media. This case, cause some competencies not accomplished as well. These competencies are between others, 1) understanding the basics of analysis kinematic, 2) understand the servo configuration, and 3) understand the working principle of legged robots yet reached. These three competencies can be packaged simultaneously in single learning media, the form of learning media is a legged robot.

Based on the description above, you can identified several problems, 1) lack of supporting learning media attainment of competence to understand the basics kinematic analysis, understand servo configuration, and understand the working principle of legged robots, 2) competence to understand the basics of analysis kinematic, understand servo configuration, and understand the working principle of legged robots yet achieved, 3) there is no supporting media, cause difficulty in understanding the topics and implementation, and 4) media is needed which supports learning about inverse kinematic, servo and the working principle of the legged robot. This study aims to, 1) get the hexapod robot design as an inverse kinematic learning media, 2) knowing performance of inverse kinematic learning media, and 3) knowing the feasibility of inverse kinematic learning media.

Media is human, material, or events that can increase knowledge, skills, or attitudes of learners [2]. In the scope of teaching and learning, the media is a tool that has a function as a bridge for capture, process and compile information in verbal/non-verbal. Tool that serves to convey information in learning it is called learning media [3]. The tool is a book, tape recorder, cassette, video camera, video recorder, film, photo, picture, graphics, television, or computer [4].

Kinematics in a robot is a statement that describes the structural form of a robot mathematical geometry [1]. Kinematics as a science that studies about body movements without considering the force or moment is called kinematics [5]. In robotics, kinematics is divided by forward kinematics and inverse kinematics. There are have reverse function each other, forward kinematics is a mathematical analysis used to calculate the position and the end-effector orientation of the robot based on the angular magnitude of each joint [5]. Inverse kinematics is a mathematical analysis used to calculate the coordinate value (in cartesian) of the edge the arm (end-effector) to be the magnitude of the angle every joint of the robot arm. The most basic way to solve the kinematics equations i.e. using trigonometric equations [1].

The hexapod robot is one type a legged robot, drive system in this robot is legs that composed of several degree of freedom (DOF) so it moves in all directions without having to perform additional maneuvers.

2. Methods

This type of research is research and development using ADDIE model. ADDIE is acronym for Analysis – Design – Develop – Implement – Evaluation [6]. This model commonly used for product development concept. ADDIE model merely a process that serves as a guiding for complex situations. Besides, has good structure due to each ADDIE stages are connected to each other and evaluated every stage. It makes ADDIE appropriate for developing educational product and learning resources. All stages are description in picture below:

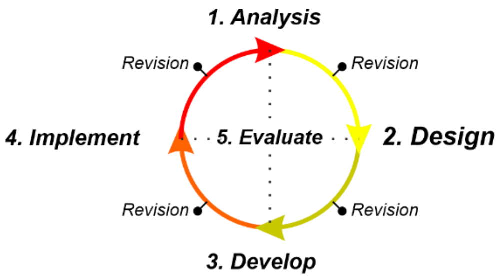

Figure 1. ADDIE model [6]

Every stage in ADDIE has common procedures. In first stage (Analysis) has six procedures, they are 1) validate the performance gap, 2) determine instructional goals, 3) confirm the intended audience, 4) identify required resources, 5) determine potential delivery systems, and 6) compose a project management plan. In second stage (Design) has four procedures, they are 1) conduct a task inventory, 2) compose performance objectives, 3) generate testing strategies, and 4) calculate return on investment. In third stage (Develop) has six procedures, they are 1) generate content, 2) select or develop supporting media, 3) develop guidance for the student, 4) develop guidance for the teacher, 5) conduct formative revisions, and 6) conduct a pilot test. In forth stage (Implement) has two procedures, they are preparing the teacher and student. Last stage (Evaluate) has three procedures, they are 1) determine evaluation criteria, 2) select evaluation tools, and 3) conduct evaluations. Evaluate is connected to all stages for evaluating and giving revision in every stages.

2.1. Time, location, data collection and analysis

This research conducted in Department of Electronics Engineering Education, Faculty of Engineering, Yogyakarta State University from September 2nd, 2019 to December 2nd, 2019. The object of this research is inverse kinematic learning media (hexapod robot) with 3 degrees of freedom in each his feet and the subject of this research are several expert lecturers and students who took Industrial Electronics field study in Electronics Engineering Education Department.

This research uses several methods in data collection, 1) classroom observation, with the type of non-observation participants and 2) questionnaire with a Likert scale which consists of 4 choice answers. The tools used for collection research data through a measurement is instruments [7]. Instrument research can be in the form of questionnaires, test, scale multilevel, interview guidelines, guidelines observation, and checklist [8]. The instrument used in this study in the form of observation guidelines, questionnaires, and checklist point.

Data analysis techniques used for knowing the feasibility level of the media is quantitative descriptive analysis techniques. This technique analysis aims to present and analysis data obtained so that it is meaningful and communicative [9]. Testing the level of feasibility tested with using a questionnaire filled out by several expert lecturers and users according to weighting of scores. The score grades are explaining in table below:

Table 1. Questionnaire Score Criteria

Criteria	Score
Totally Agree (TA)	4
Agree (A)	3
Disagree (D)	2
Totally Disagree (TD)	1

After getting the result from respondents, the next steps are:

a. Determine the eligibility interval, the eligibility interval is divided into 4 classes
b. Determine the maximum and minimal score interval

$$\mathrm{X}_{\text{maximum}} = 4 \text{ x total point} \quad (1)$$
$$\mathrm{X}_{\text{minimal}} = 1 \text{ x total point} \quad (2)$$

c. Determine the mean ($\overline{\mathrm{X}}$) and standard deviation (SD)

$$\overline{\mathrm{X}} = \frac{1}{2}\,(\mathrm{X}_{\text{maximum}} + \mathrm{X}_{\text{minimal}}) \quad (3)$$
$$\mathrm{SD} = \frac{1}{6}\,(\mathrm{X}_{\text{maximum}} - \mathrm{X}_{\text{minimal}}) \quad (4)$$

d. Develop interval class to get distribution score in curve

$$4 \text{ class} = 6 \text{ SD}$$
$$\text{class} = \frac{6\text{ SD}}{4} = 1{,}5 \text{ SD} \quad (5)$$

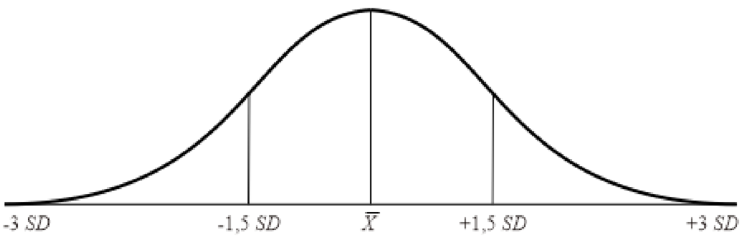

Figure 2. Distribution Curve

To conclude the feasibility of assessment from distribution curve we get interval score for media feasibility. Media feasibility divided by 4 classes. The divided classes are description in table below:

Table 2. Media Feasibility Interval

Interval Score	Classes
$\bar{X} + 1{,}5\ SB < x \le \bar{X} + 3\ SB$	Very Feasible
$\bar{X} < x \le \bar{X} + 1{,}5\ SB$	Feasible
$\bar{X} - 1{,}5\ SB < x \le \bar{X}$	Unfeasible
$\bar{X} - 3\ SB < x \le \bar{X} - 1{,}5\ SB$	Very Unfeasible

Media feasibility score can convert to percentage using the formula below:

$$\text{Feasibility } (\%) = \frac{\text{average score}}{\text{maximum score}} \text{ x } 100\% \tag{6}$$

3. Results and discussion

3.1. Learning media design

The design of hexapod robot overall has 3 degree of freedom (DOF) each leg. We get robot leg construction in figure 4 based on simplification from insect leg construction in figure 3, this simplification due to some joints on insect *using* for climbing. Besides, robot leg construction using 3 DOF provides a good flexibility of robot movement.

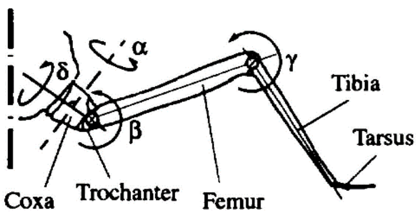

Figure 3. Insect leg construction [10]

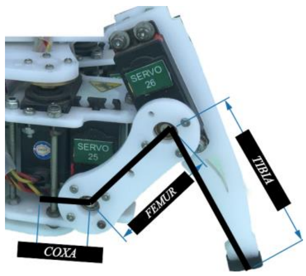

Figure 4. Robot leg construction

Learning media has a design in diagram form like following below:

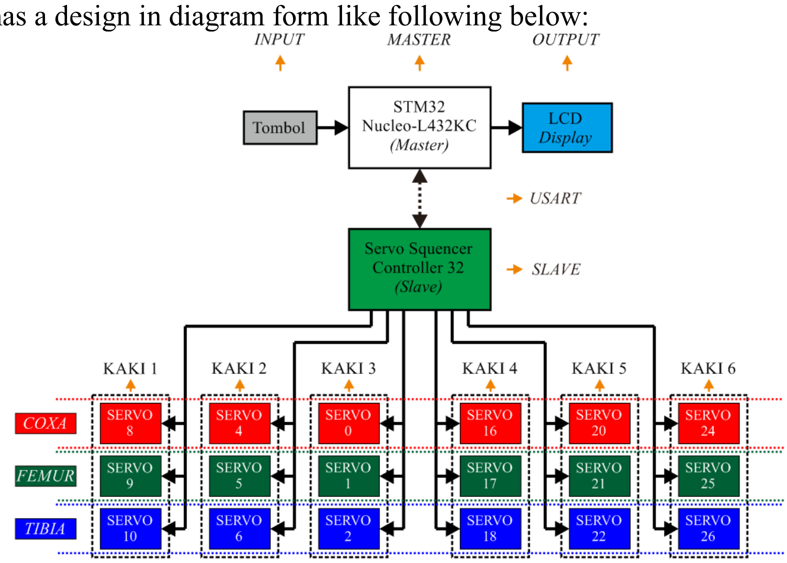

Figure 5. Hexapod robot block diagram

The hexapod robot is divided into 2 block (system block as master and servo block as slave) which are connected by USART between blocks. System block is controller master that functions to process data and main algorithm. Servo block is controller slave that functions to controlling all servo in according to the instructions in USART.

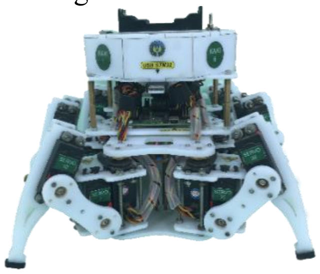

Figure 6. Front view

Figure 7. Top view

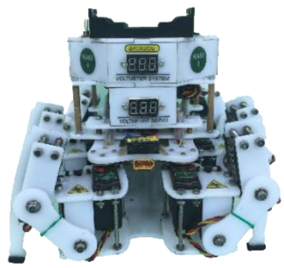

Figure 8. Rear view

Design learning media in the form of robot completely aims to provide the students with real application experience of inverse kinematic in a robot. In developing hexapod robot as learning media of inverse kinematic also supported with developing learning module and job sheet. Learning module can be used as learning resource about inverse kinematic theory and fundamental explanation about inverse kinematic learning media form software and hardware that used. Job sheet can be used as learning media guidelines for students in studying and practice inverse kinematic independently. Other than students, learning module and job sheet can be used for lecturer as reference to teaching about inverse kinematic.

Figure 9. Learning Module

Figure 10. Job sheet

3.2. Learning media performance

Learning media performance is tested by black box, servo calibration, x, y and z axis effect and robot movement testing. The result of media performance is described below:

3.2.1. Black box testing

Black box testing aims to determine the function of each input and output of learning media [11]. Learning media is declared good when each input and output functions are working good too. This test is conducted by media experts and several users.

Table 3. Black box result

Aspect	Point	Resp. 1 (%)	Resp. 2 (%)	Resp. 3 (%)	Resp. 4 (%)
Input	1, 2, 3, 4, 5, 6, 7, 8	100	100	100	100
Output	9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29	100	100	100	100
Port USB	30, 31	100	100	100	100
Program Menu	32, 33	100	100	100	100

From 4 respondents, the result of black box test is 100% functional of input and output that mean the learning media is working properly and no errors are detected.

3.2.2. Servo calibration testing

Table 4. Servo calibration result

Leg Number	Servo Number	Default Servo Pulse	Offset Servo
	0	1800	-10
1	1	1500	-46
	2	1500	40
	4	1500	-40
2	5	1500	-60
	6	1500	0
	8	1200	-56
3	9	1500	51
	10	1500	-98
	16	1200	-100
4	17	1500	-2
	18	1500	44
	20	1500	6-
5	21	1500	-100
	22	1500	35
	24	1800	27
6	25	1500	-8
	26	1500	-10

Every servo has a different starting point in mechanical, so value of offset servo must be adjusted to make same starting point. Offset servo is value that used to calibrate servo, so get a same robot's leg starting position in each axis. Wrong calibration can cause error in x, y and z axis position.

3.2.3. X, Y, and Z axis effect testing

Table 5. X, Y, and Z axis effect result

Leg Number	Error Average Each Leg (%)		
	X	Y	Z
1	8,33	10	12,776
2	6,67	10	5
3	8,33	10	6,67
4	3,89	20	6,11
5	8,89	10	10
6	8,33	10	6,67
Error Average	7,4%	11,67%	7,87%

To get error value every axis needs to be measure each leg. There are errors in measurement x, y, and z axis caused by offset servo value, design mechanic is not precision and manual measurement of axis displacement using a ruler resulting lot of error.

3.2.4. Robot movement testing

Table 6. Robot movement result

Input				Output
w	X	y	z	Robot Movement
0	0	10	16	Forward
0	10	10	0	Slide to right
0	10	10	10	Diagonal to right (forward)
0	-10	10	10	Diagonal to left (forward)
0	0	10	-16	Backward
0	-10	10	0	Slide to left
0	10	10	-10	Diagonal to right (backward)
0	-10	10	-10	Diagonal to left (backward)
5	0	10	0	Rotate to left
-5	0	10	0	Rotate to right
5	0	10	16	Turn to left (forward)
-5	0	10	16	Turn to right (forward)
5	0	10	-16	Turn to left (backward)
-5	0	10	-16	Turn to right (backward)

Robot movement can be reach from change and combine value w, x, y, and z axis. If w is positive, the robot will rotate to the left, if w is negative, the robot will rotate to the right. If x is positive, the robot will move to the right, if x is negative, the robot will move to the left. If y is positive, the robot's leg is raised higher, while if y is negative, the robot's leg will push down. If z is positive, the robot will move forward, whereas if z is negative, the robot will move backwards.

3.3. Learning media feasibility level

The feasibility level of learning media products is carried out on three subjects, there are based on material experts, media experts and users (students). Feasibility level is described in graphic below:

3.3.1. Based on material expert

Feasibility level based on learning materials in all aspect of 21 items with details of 8 items for content, 7 items for instructional and 6 items for technical aspects. The maximum score from all aspects is 84 and minimum score is 21.

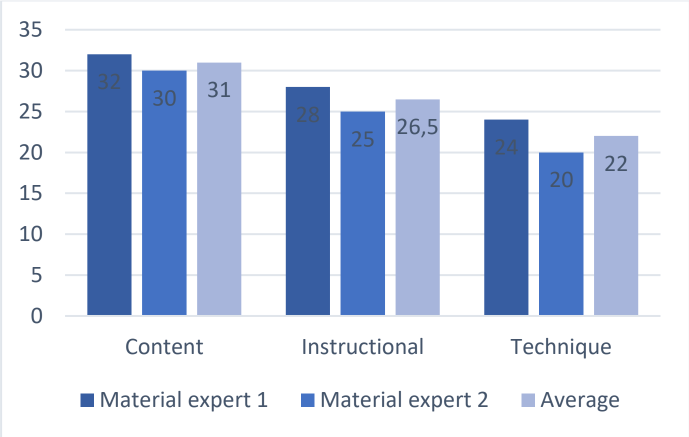

Figure 11. Feasibility of material expert graphics

The results of the assessment by two material experts based on three aspects (content, instructional, and technique) on graphics figure 11, feasibility of material by material expert 1 get total score 84, material expert 2 get total score 75 and total of average score is 79,5 (94,64%).

3.3.2. Based on media expert

Feasibility level based on learning media in all aspect of 23 items with details of 6 items for content, 7 items for instructional and 10 items for technical aspects. The maximum score from all aspects is 92 and minimum score is 23.

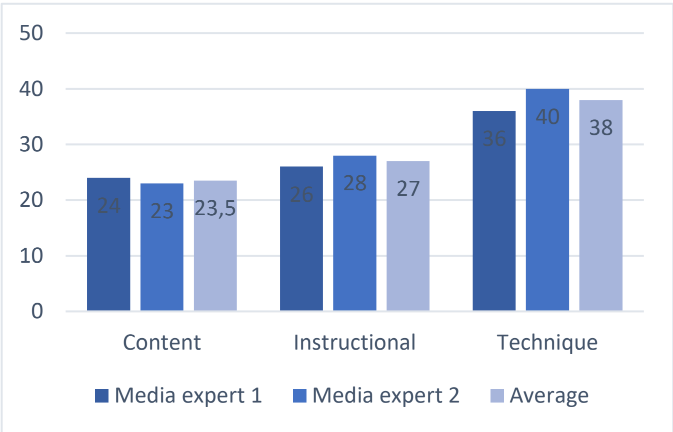

Figure 12. Feasibility of media expert graphics

The results of the assessment by two media experts based on three aspects (content, instructional, and technique) on graphics figure 12, feasibility of media by material expert 1 get total score 86, media expert 2 get total score 91 and total of average score is 88,5 (96,2%).

3.3.3. Based on users (students)

Feasibility level based on learning media in all aspect of 24 items with details of 7 items for content, 8 items for instructional and 9 items for technical aspects. The maximum score from all aspects is 96 and minimum score is 24.

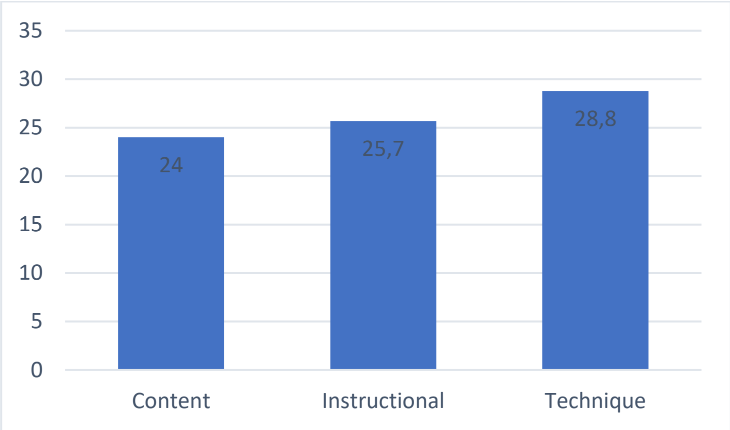

Figure 13. Feasibility of user graphics

The results of the assessment by users based on three aspects (content, instructional, and technique) on graphics figure 13. Testing result of 20 users who are studying at Industrial Electronics field get total average score 77,8 (80,99%).

4. Conclusion

Based on research and discussion can be concluded, 1) inverse kinematic learning media can be delivered by using hexapod robot with 6 degree of freedom (DOF) each leg, 2) the performance through black box testing get result 100%. Each robot's feet can move with an average axis error percentage x of 7,4%, y of 11,67% and z of 7,87% and produces 14 types of movement, 3) feasibility level of learning media based on the assessment of material expert obtained 94,46% (very feasible), media expert obtained 96,2% (very feasible), and users obtained 80,99% (feasible).

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