Research Paper
Journal of Aerospace System Engineering
Vol.14, No.2, pp.36-43 (2020)
EISSN 2508-7150
http://dx.doi.org/10.20910/JASE.2020.14.2.36

Spherical Robot for Planetary Explorations: An Approach to Educating Concepts of Mechatronics and Robotics to High School Students

Sooyoung Kim [1]·Seonje Kim[2] · Byungkyu Kim [1,†]· Soumen Sen [3]

[1]*School of Aerospace and Mechanical Engineering, Korea Aerospace Univ.*
[2]*Dept. of Aerospace Engineering and Mechanical Engineering, Korea Aerospace Univ.*
[3]*CSIR Central Mechanical Engineering Research Institute, Durgapur, India*

Abstract

Many countries and international organizations have carried out rover missions to explore planetary surfaces. Accordingly, the demand for mechatronics education, which is closely related to building exploratory robots, is also steadily increasing. However, due to the complexity in understanding the background information needed for mechatronics, it is hard for pre-college students to study such process. In this study, we suggest an educational platform for mechatronics using a combined robot kit with a spherical robot and a smartphone application. To provide a visual understanding, the dynamic model of the robot is constructed while analyzing the error between actual driving and a simulation, and the educational algorithm of the game and a feedback method are proposed to improve the learning efficacy by considering the user's level of knowledge of mechatronics. We use this educational spherical robot to develop a curling game platform that can impart engineering education even when students lack significant knowledge.

Key Words : Mechatronics education, Engineering education, Spherical robot, Educational game, Curling game

1. Introduction

1.1 Objective

Space robots have been used to carry out missions to explore the Moon and Mars [1-2]. However, there are no Korean space robots currently functioning on any planet. Therefore, the Korean government has made plans to explore the Moon and Mars by 2022 and 2030, respectively. At NASA, various educational programs have been developed to learn how to control planetary and exploratory spherical robots and to learn other concepts about the process [3]. Mechatronics is the field that is closely related to processes for this kind of education [4]. However, it is a difficult subject to access in higher education due to a lack of engineering expertise and background knowledge needed, the considerable amount of time and space to accommodate study, and the high cost of a university education [5-6]. Although interest in mechatronics has increased among high school students steadily over the last 15 years, there is a limited availability of mechatronics engineering in high school curricula. To overcome this, field experience, or a practical approach to learning, is proposed [7]. This will develop a more concrete, intuitive understanding of concepts via familiar processes of physical manipulation rather than an abstract, theoretical approach that can result in a misunderstanding of spatial relationships and how they relate to important theoretical engineering concepts. Therefore, in this paper, we present a spherical robot with a companion smartphone application for robot operation that are prepackaged as a toy and an educational kit that can be used in school or at home. One of the main advantages of such format is that it helps mitigate the high costs of engineering coursework in higher education and laboratory/field experience. The trainee can intuitively understand fundamental, general mechatronics engineering concepts and processes through toy assembly, software operation, and toy redesign. Another advantage of this approach is it only requires practical, simplified engineering knowledge and intuition to complete all steps and processes.

Competitive training methods and gamification (learning by using games) have shown better results regarding trainee

---

Received: Mar. 31, 2020 Revised: Apr. 20, 2020 Accepted: Apr. 22, 2020
† Corresponding Author
Tel: +82-2-300-0101, E-mail: bkim@kau.ac.kr

motivation and educational achievement than other conventional educational methods [8]. In this study, the curling sport (aiming a 'stone' to reach a target) is implemented to produce the controls and logical rules to assemble the spherical robots. We propose a new robot sport in which trainees compete by using a spherical robot as a 'stone' to achieve a score. The trainee adjusts the spherical robot body itself or changes the operating parameters in the application to try and obtain the highest score to win the game. In this process, the trainee can analyze operational errors by using internal simulations, thereby learning the process of identifying problems, their causes, and making corrections. This process mirrors a real-world design process of mechatronics engineering. The program also suggests hardware redesign methods to correct the errors, allowing for simultaneous multi-disciplinary learning in the course of the sports competition.

1.2 Establishing idea

1.2.1 Educational algorithm

The mechatronics engineering approach consists of 1) using a variable to calculate the predicted value based on physics, 2) checking the result by inputting the variables, and 3) resetting the variables by comparing their predicted values [9]. Hardware is needed to confirm the input, and the software is used to guide the process to adjust the predictions and reset the variables. To provide an intuitive understanding of the hardware, we adopted a spherical robot driven by two DC motors, and the software was developed to predict the movement of the robot's path according to the movement of the motors. In addition, it is also designed to understand the engineering process by encouraging students to analyze the reasons why the theoretical assumptions and the results are different in the process of manipulating the robot. Finally, they figure out how to reassemble or adjust the variables.

1.2.2 Hardware platform

The entire assembled mechanical system should be made for the educator to also enable a theoretical study. Therefore, for easy understanding by the educator, the mechanical system is composed of pre-manufactured assembly parts. Also, to facilitate trainee access, it is a simple mechanical model. The whole assembled system is shown is Fig. 1. We conceived a system in which a simple spherical robot (driven by only 2 motors and wheels) is controlled by a student-coded program. Through this system, the educator can easily observe and monitor how the hardware system that contains motors and wheels responds and reacts to changes in the software.

1.2.3 Software design

The software consists of a smartphone application and is primarily a tool for the students to better understand the rules of the game (curling) and to obtain information on the physics generated or used in the engineering process. Considering the level of knowledge of the trainees, the hardware requires more theoretical background. Therefore, a practical GUI (graphical user interface) is used to adjust the variables rather introducing an in-depth explanation of the theoretical process behind the variables. The GUI consists of a series of drag-and-drop blocks and slider controls, as shown in Fig. 2. This sidesteps the complexity of any coding required or deep knowledge of languages such as C++ and Python.

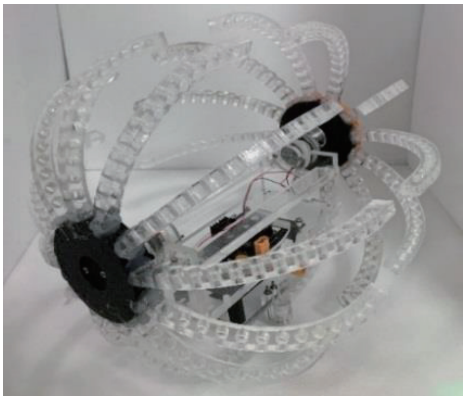

Fig. 1 Spherical robot

Spherical Robot Controller

Fig. 2 Android application developed by an app inventor

Fig. 3 Experimental study executed by high school students to survey the educational effectiveness

1.2.4 Applying curling sport rules

Robot sports, such as drone soccer and robot fighting, play a big role in robot education. Sports using robots can provide an interesting and natural setting for coding education for engineering and software development. As for the robot sport, we considered curling (Fig.3) given the success of the 2018 Pyeongchang Olympic in Korea that resulted in an increased interest in winter sports and in particularly for curling, which received the most attention among many of the winter sports events. Spherical robots mimic the action of curling stones, and the subjects determine their path and speed by inputting the control values. In this process, it is challenging to reach the exact same path as the theoretical path according to the value for the input. Therefore, to win the curling game, trainees have to improve their predicted path by incrementally adjusting the input value or re-assembling the hardware as per the application's instructions. This allows participants to intuitively learn about the engineering approaches.

2. Design and analysis

Simple and accurate design is important regarding the theoretical behavior of the hardware and software for high school education. In addition, the source or cause of errors must be sufficiently understandable with a knowledge of physics that can be learned in high school. Therefore, a study is conducted to verify whether the spherical robot kit can be used for educational purposes through a simple concept design, dynamics, and structural stability analysis that minimize the driving errors.

2.1 Hardware design

2.1.1 Mechanism of the spherical robot

One example of spherical robot operation was discussed by Richard Chase and Abraham Panda in their publication, "A review of active mechanical driving principles of spherical robots." In their study, a spherical robot can be driven in front of the robot by using a ‘Hamster mechanism’ (rotating the exoskeleton structure by controlling the structure inside the exoskeleton [9]. The hamster mechanism enables forward/reverse motion control of the spherical robots through the principle of the BCO (Barycenter offset) (Fig. 4). Thus, if the center of mass can be adjusted, the spherical structure can change direction to roll in the desired direction.

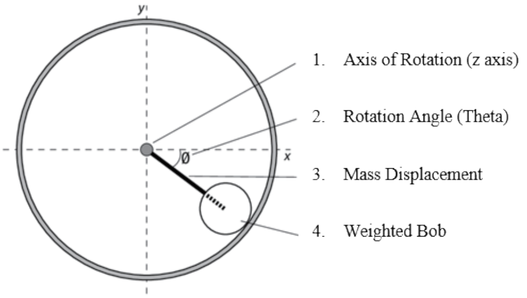

Fig. 4 Steering method of a spherical robot using a pendulum

This method allows the sphere to be highly maneuverable and controllable in all directions. However, the mechanism to achieve this control will be more complex and involves a need for nonlinear systems. The mechanism that drives the robot is a pendulum, so the maximum speed of the mechanism is limited by and dependent on the weight of this pendulum. Since this robot is intended for education and should meet the aforementioned goals of having a simple and intuitive operation, we developed a robot mechanism that has simple and intuitive structures.

The steering method of the car can be viewed as a more intuitive way of driving compared to the cases mentioned above. As the car moves forward, the two rotating front wheels face different directions, as shown in Fig. 5. This causes the individual front wheels to move in arched paths of different radii (with different lengths), and the car rotates towards the rotating wheel following the path with the smaller radius. The extensions of each four wheels meet at one point. This indicates that the inner wheel travels in a smaller radius than the outer wheel. In this study, a steering method similar to the vehicle shown in Fig. 5 is used. To replicate this control concept, the spherical exoskeleton of the robot shown in Fig. 6 is split into two left/right hemispheres, and they function in the same way as the wheels do in Fig. 5.

The difference in the rotational speed or direction of the rotation of each hemispherical wheel causes them to follow different paths with different radii. For example, if the left half rotates at a higher speed, it moves along a longer path with a relatively larger radius than the right wheel, causing the robot to steer to the right. Furthermore, if the rotation is reversed (one half moves forward and the other in reverse), the robot will be stationary and simply pivots or rotates in the same location.

Compared to the Hamster mechanism, this control mechanism does not allow for free maneuverability in all directions. However, the advantage is that the control mechanism and structure are relatively simple and allow the robot to pivot in place and quickly change direction. The simplicity of this mechanism is more appropriate for educational purposes, is more intuitive, and allows the educator to illustrate the mechanical process more clearly and easily.

This proposed control mechanism requires that the two hemispheres, or wheels, be driven by individual motors. Therefore, the design requires considering the stresses and inertia applied to the rotating shafts connected to each wheel.

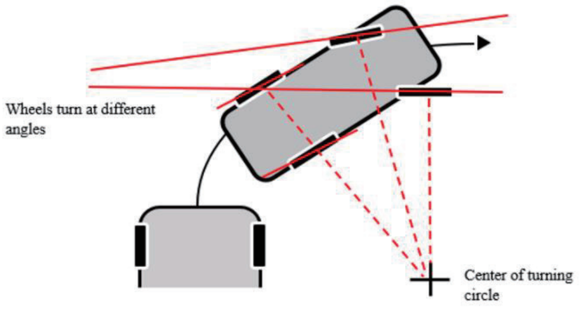

Fig. 5 Car’s steering

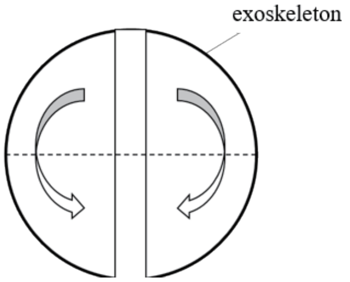

Fig. 6 Spherical robot with two wheels rotating

2.1.2 Exoskeleton-shaped designing

The assembly process of the exoskeleton-shaped wheels can be more complex than that for typical spherical wheels, but manufacturing prefabricated assembly kits simplifies the process and makes it more economical. Using prefabricated kits allows high school students to more easily understand the different aspects of differential wheel rotation and how they influence the movement of the mechanism. In addition, a more intuitive analysis is possible because unpredictable errors caused by a lack of friction (as in a curling stone) can be minimized by the process of working towards reaching a target point. The diameter of the exoskeleton was set to 330 mm (similar to the curling stone), and the exoskeleton of the skeleton-type lightweight structure was designed as shown in Fig. 1. The exoskeleton is designed in the form of two hemispherical, skeletal wheels separated in the middle from left to right, and the two exoskeletons are made up of 12 legs and one disk holding them together.

2.1.3 Inner part design

The main function of the inner part is to adjust the moment of inertia generated in the part itself. Ease of reassembly makes it possible to easily tune the robot's movement when errors occur, and it moves along an undesired path. Also, if an adjustment setting number rises above a predetermined reference point, a process that cannot be explained by high school physics alone will appear. The adjustment settings are simplified and limited to minimize these scenarios because they would be difficult to understand when high school students analyze the engineering feedback, thereby negatively impacting their learning process.

The role of the inner structure is to provide space and support for the major components of the system, such as the MCU (micro controller unit), motor driver and Bluetooth module. If the inertia moment of the internal structure is not large enough, the force of the motor causes the internal structure, not the exoskeleton, to rotate. Therefore, the design takes into consideration the moment of inertia, both on the inside and the outside. To increase the moment of inertia of the internal structure, the weight of the structure itself or the distance of the structure's material point from the motor shaft should increase. Considering the different ways to control the internal structure inertia mentioned above and the predetermined 330 mm diameter of the robot, the internal structure was designed to be 220mm wide, and the distance between the motor shaft and the internal structure was 70 mm.

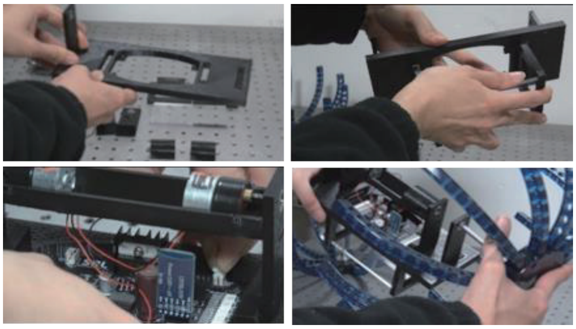

Fig. 7 Structure for ease of assembly of the robot for educational purposes

2.1.4 Assembly of exterior frames and internal structures

The exoskeleton and the internal structure are joined by the motor shaft. Figure 7 shows the simple components of the inner and outer frame. This modular design eases the assembly process and makes it easier for students to understand the working principles of the robots and receive feedback from the engineering concepts.

2.1.5 Structures to protect the motor shaft

Another educational goal in the assembly of robots is to aid students' understanding of the main drive components. A misaligned assembly of the drive components results in unexpected path deviations, and these can be corrected and adjusted through reassembly. In spite of designing simple, durable components that withstand a frequent reassembly process, the mechanism design was also designed to ensure consistent, accurate engineering measurements and analysis.

The inner/external structures are joined by the motor's shaft. This means that the shaft should be designed to withstand the force and torque incurred by the structure's movements, or otherwise be protected by some other kind of structure. In case of our product, the motor is the kind of product. To compensate for this, a structural housing had to be designed to protect the shaft, and the following two design criteria were used when designing this housing:

1) Disperse the shear stress acting on the motor shaft by making a part that covers the shaft itself
2) Provide a way to connect the inner parts to a component that makes contact with the ground or surface

First, the motor shaft housing was designed by machining aluminum into a structural part that houses the thin motor shaft so that the shear stresses acting on the motor shaft by the weight of the robot are dispersed.

As a second method, structures connecting to the bottom of the internal structure were fabricated and mounted. This internal structure is defined as the robot arm. In the absence of the robot arm, the weight of the entire robot is only supported by the exoskeleton. This would mean that the entire weight of the device would be transferred to the motor shaft, stressing it to a level that it is not designed to accommodate. When the robot arm is fitted, it transfers the weight of the robot to the ground and relieves this load on the motor. The arm is also equipped with a protective device that dampens external shocks to help protect the internal devices from damage if the robot crashes.

2.2 Interpreting geometry design results

Dynamic and structural interpretations are required to identify and resolve problems that had been predicted before a design feature was actually produced. The two predicted problems are as follows:

1) The bars of the exoskeleton wheels might be damaged by the stresses and loads imposed during operation.
2) The torque of the motor might produce torsion on the internal structure and cause it to deform or displace.

To assess the potential of the first problem to occur, a structural analysis was done to determine where the maximum shear stress acts on the structure, and according to the results, an appropriate material was selected. A second analysis was performed to verify if the torsional effects described in the second problem could occur. This analysis consisted of representing in a formula the relationship between the torque of the motor, the inertial moment of the internal/external structure, and the angular acceleration of the internal/external structure. According to these results, the strength and suitability of the internal/external structure design was verified.

2.2.1 Structure analysis

A lightweight exoskeleton structure was designed, and it consists of a bar and a hole in the exoskeleton with a matching diameter. Each wheel bar is fastened to a disk and joined to the motor shaft. In this structure, the point with highest stress concentration with breaking would occur and can be easily predicted, and the point is marked at the starting point of the exoskeleton shape.

The analysis was performed as a stress simulation by assuming a 10 N force of three types acting where the exoskeleton contacts the surface of the ground. The three types of forces analyzed were vertical to the ground, parallel to the ground, and at an angle of 45° to the ground. Each type of force was defined by considering the supporting point at which the wheel-bar is coupled with the disk.

Figure 8 shows the results of stress analysis for the three cases mentioned above. From the left, the first diagram shows the vertical force, the middle diagram is parallel, and the third is 45 degrees. The cold color (blue) means it is under a low stress, and the hot color (red) means it is under a high stress. According to the stress analysis, the maximum stress that was subjected on the wheel-bar was 8.49 MPa, and its location point was the same as predicted in Fig. 8 (vertical to the ground). As a result of the above analysis, ABS (Acrylonitrile Butadiene Styrene) was determined as a suitable material for the exoskeleton, considering a stability factor of 2. (ABS has a yield stress of 20 MPa to 70 MPa.)

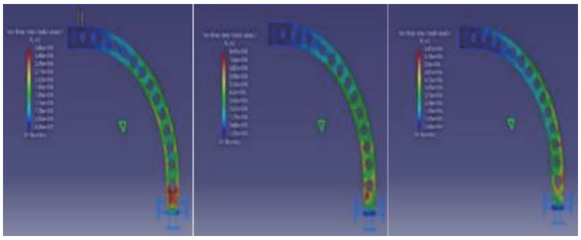

Fig. 8 Analysis of the load with vertical loads on the ground (From left, each forces' applying angles are vertical, parallel and a direction 45° to the ground)

2.2.2 Dynamic analysis

To check the second possible problem of whether the internal structure would experience torsion caused by the torque of the motor, the kinetic equation of the internal/external structure's inertia moment and motor torque was induced to simulate the rotation angle of the internal/external structure.

In the Kinetic equation, the output torque of the motor is represented as *T*, the moment of inertia of the inner/external parts to the motor shaft as J_i, J_o, the rotation angle caused by torque *T* on internal/external parts as θ_i, θ_o, and the mass of the internal parts as *m*. The maximum distance between the internal structure's center of gravity and the motor shaft was 73.146 mm, and for this dynamic analysis it is indicated as *r*. Using ABS as the selected material, J_i, J_o, m_i are calculated as follows:

Table 1 Calculations of physical properties based on spherical robot specifications

J_i (kg · m^2)	0.0004852
J_o (kg · m^2)	0.005
m_i (kg)	0.490
r (mm)	73.146

Then, the relationship between $T, J_i, J_o, \theta_i, , \theta_i$ and r is determined by the following sequence.

The torque which acts on the internal structure is expressed as Eq. 1

$$J_i\ddot{\theta}_i = 2T - r\, m_i g sin\theta_i \qquad (1)$$

Then, assuming θ_i vibration is a relatively small angle, Eq. 1 is linearized according to Eq. 2

$$J_i\ddot{\theta}_i = 2T - r\, m_i g\theta_i \qquad (2)$$

In Eq. 2, as the torque of motor's output is equal to the sum of the torque acting on and rotating the exoskeleton while incorporating the loss of output caused by friction between the exoskeleton and ground, Eq. 2 can be re-written as Eq. 3

$$\mathrm{T} = J_o\ddot{\theta}_o + \mathrm{f}\theta_o \text{ (}\mathbf{f}\text{ is friction coefficient)} \qquad (3)$$

Summarizing the above equations, T can be represented by $\theta_o\ and\ \theta_i$ as

$$\mathrm{T} = J_o\ddot{\theta}_o + \mathrm{f}\theta_o = \frac{1}{2}(J_i\ddot{\theta}_i + r\, m_i g\theta_i) \qquad (4)$$

and then the transfer functions for input T and output θ_i, θ_o are expressed as

$$G_o(s) = \frac{\theta_o}{T} = \frac{1}{J_o s^2 + fs} \qquad (5)$$

$$G_i(s) = \frac{\theta_i}{T} = \frac{2}{J_i s^2 + r\, m_i} \qquad (6)$$

The simulations were performed assuming the friction coefficient f is 0.7 (the friction coefficient of a marble surface, where we tested the robot).

The results showed that a torque input of 1 kgf·m makes the external wheel rotate at 85.71 rpm and the internal structure vibrate at a small angle of about 0.1 rad (≈5.7°).

2.3 Educational design

Since mechatronics engineering is a combination of both hardware and software design, adequate educational training that integrates both disciplines is required throughout the entire process, as shown in Fig. 9. This study aims to achieve this through a process to precisely hit a target while playing a curling game. In order to obtain a higher score in the competition, the trainees need to compare the simulated target destination generated by the app settings with the actual arrival point for the robot. If the actual path doesn't match the path the trainee expected, the software program will provide information about the cause of the error. If they want to know more details about the error, the trainees follow a predefined training routine or process according to the full engineering guidelines. The physical background that exists within the guidelines provides a more accurate picture of the path of the spherical robot. It also provides guidelines for any errors that may arise during assembly. This allows the trainees to follow a procedure for hardware calibration or reassembly, or to make decisions about whether to make changes to variables in the software that may affect the path of the spherical robot. In this process, trainees can make a choice of which set of variables to follow later. The feedback system using engineering guidelines enables the trainees to learn engineering more intuitively because it is a more practical learning process done in the field.

3. Result and discussion

3.1 Simulation results: development of a smartphone application

The simulation program is based on Matlab, and the results can be monitored via a Bluetooth connection between the robot and the smartphone. Trainees predict the robot's final location, and they can adjust the trajectory by adjusting variables based on a comparison with actual driving. In addition to the reassembly of the robot itself, it is possible to learn the processes of mechatronics engineering by adjusting the software variables.

In this process, the theoretical simulation involves predicting the position of the robot by knowing the rotating speed and direction of both wheels. This course consists of high school-level physics, and the students can understand the basis of the simulation results through the application and can make intuitive predictions accordingly.

The equations used to predict the position of the robot by incorporating the speed and direction of rotation of both wheels were derived by the following process.

v_1 and v_2 respectively represent the left/right wheel velocity. When the robot's position vector is measured every three seconds relative to its starting point, representing the nth measurement position and the *n+1* measurement position as vectors, results in $\overrightarrow{P_n}$ and $\overrightarrow{P_{n+1}}$, respectively, and the difference is $\overrightarrow{P_nP_{n+1}}$. Using this, obtain $\overrightarrow{P_n}$as follows.

$$\left|\overrightarrow{P_nP_{n+1}}\right| = v_0\Delta t \ \ (v_0 = \frac{v_1+v_2}{2}) \qquad (7)$$

$$\overrightarrow{P_nP_{n+1}} = \overrightarrow{P_{n+1}} - \overrightarrow{P_n} = \left|\overrightarrow{P_nP_{n+1}}\right|(-sin\theta, cos\theta) \qquad (8)$$

$$\overrightarrow{P_{n+1}} = \overrightarrow{P_n} + \left|\overrightarrow{P_nP_{n+1}}\right|(-sin\theta, cos\theta) \qquad (9)$$

$$\overrightarrow{P_n} = \sum_0^n\left|\overrightarrow{P_{k-1}P_k}\right|(-sin\theta, cos\theta) \qquad (10)$$

(θ is the angular displacement)

Meanwhile, when *L* is incorporated into the calculation as the distance between the points where two wheels come into contact with the ground, the difference in speed between each angular displacement θ and the angular velocity w is as follows.

$$\mathrm{w} = \frac{d\theta}{dt} = \frac{v_1 - v_2}{L} \qquad (11)$$

$$\theta = \frac{(v_2 - v_1)}{L}\mathrm{t} \qquad (12)$$

To express this differential's influence on linear movement over a unit of time, Eq. 10's Δt is replaced with micro-time *dt* and Eq. 12 is substituted for θ, so the robot's location vector at *t* seconds is as follows:

$$\lim_{\Delta t\to 0}\overrightarrow{P_n} = \lim_{\Delta t\to 0}\sum_0^n\left|\overrightarrow{P_{k-1}P_k}\right|(-sin\theta, cos\theta) \qquad (13)$$

$$\vec{P} = \int_0^t \frac{v_1+v_2}{2}\left(-\sin\left(\frac{(v_2-v_1)}{L}\right), \cos\left(\frac{(v_2-v_1)}{L}\right)\right)\mathrm{tdt} \qquad (14)$$

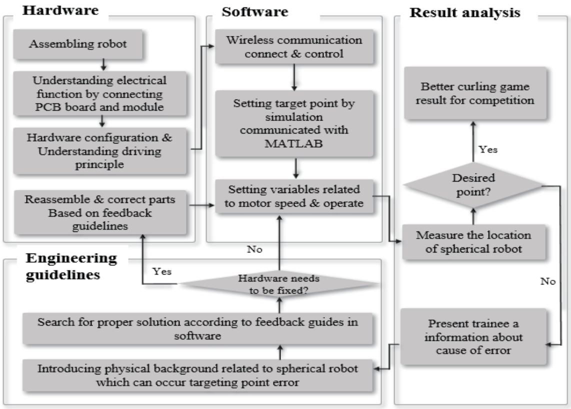

Fig. 9 Overall educational design process for the system

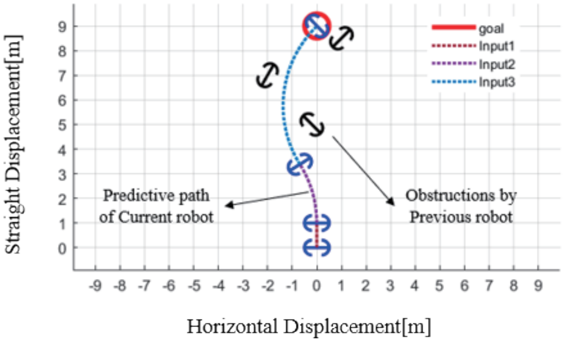

Fig. 10 Drive simulation results

Based on the above equation, random wheel speeds (v_1, v_2)were selected to simulate the robot's path of travel.

Figure 10 shows the results of the drive simulation. Through this simulation, a trainee can visually predict the robot position. In the simulation, a visualization tool shows the theoretical robot path in blue according to its calculated position. The trainee can also adjust their robot's path to avoid other trainee robots according to their existing position, shown in black on the screen. When comparing the differences between the theoretical and actual paths of travel, errors and differences occur for the following reasons:

1) Slippage or loss of traction in either/both wheels is not considered in the simulation.
2) The simulation was based on a cylindrical wheel, but the shape of the wheel is composed of only a skeleton with intermittent contact points on the ground rather than a continuous cylinder or contact patch.
3) During robot operation, the distance L between the ground contact points of the wheels varies because of deflection in the exoskeleton and the elasticity of the ABS material.
4) Since the robot is spherical in shape, changes in its path are affected by small changes in its center of gravity, resulting in path errors.

The above potential causes for error were not identified in the simulation process, so the students could independently investigate the errors and enhance their learning experience. This practical process of trial-and-error with the prefabricated, modular construction of the robot kit allows students to more naturally learn concepts through intuition, as was mentioned previously in the introduction.

3.2 Assessment of learning: simulation and trails

The corresponding instructions have been added to help high school students find a more accurate path while playing the curling games. Although the simulation itself requires only a high school level of engineering knowledge, it helps students understand there are more complex underlying engineering concepts that influence the process. This encourages students to pursue further study and acquire the necessary theoretical knowledge to successfully compete in the game and improve the accuracy of their robot's operation. Furthermore, aside from theory and knowledge, the simulation also teaches students that intuition, trial-and-error, and practical knowledge are important factors in engineering. As shown in Fig. 11, in order to encourage high school students to more readily use their intuition, the use of equations is minimized, and diagrams and graphics are included in the engineering guidelines to better understand the physical movements of the different configurations.

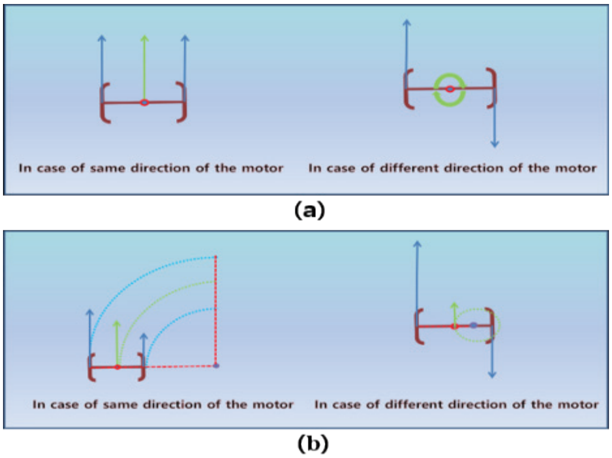

Fig. 11 Educational guidelines to study the engineering feedback. (a) Driven by the same motor speed (b) Driven by a different motor speed

3.3 Discussions

The process of making adjustments according to the simulation results and engineering guidelines presented above will be based on the rules of the curling game. Also, by the rule, the trainee can obtain engineering feedback without guidelines, and this can be an advantage to win the game. Therefore, the more the feedback process is the repeated, the better the trainee can learn and understand important concepts and variables in order to win the competition. As shown in Fig. 12, the engineering guidelines start with the process by which the trainee chooses the problem. The reasons why the robot didn't follow the correct path are analyzed in detail for each situation so that the particular problem can be identified. After that, we present knowledge on the physics and technical issues that can cause errors in each situation and how to solve such problems. The problem solving method may be the same even if different problems occur in each situation.

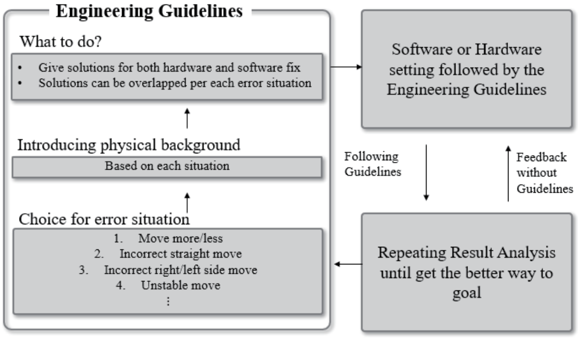

Fig. 12 Process of the engineering guidelines

4. Conclusions

This article presents the development of a spherical robot as a learning platform that offers mechatronics education to high school students. The secondary goal is to spread awareness of the technology that is used for autonomous planetary explorations. The objective is to propose a method to teach mechatronics and robotics intuitively by noticing and understanding the underlying engineering principles by playing a game. The spherical robot is configured to mimic a stone in the game of curling to familiarize students with programming, control, and operation of exploratory robots. The designed spherical robot is controlled by a smart phone application that can change the specific variables that control the robot.

The article then presents the construction of the spherical robot, followed by a design analysis of some of the critical components. The outer skeleton that serves as a wheel is constructed to withstand anticipated loads during operation, even though it consists only of a plastic skeleton rather than having a cylindrical shape. The suitability of the construction was verified via a load analysis. The delineation of the educational robot platform is then divided into hardware construction, software architecture, suitable engineering processes, and evaluation.

With the design considering the inertia ratio, the internal structure proved to be able to rotate using the motor torque.

The structure was designed through a simulation using the equation of the relationship between torque and the angular velocity of the internal/external structure, and the actual robot was confirmed to be driven in a manner similar to the simulation.

The actual robot operation is conducted by high school students following curling game rules. Students can understand the difference between the theoretically-predicted movements in the simulation and real movements by controlling the robot and the smartphone. To obtain a better score from the curling game, students should reassemble the robot or change the input value by following the mechanical feedback guidelines that are represented in the diagrams and graphics. This leads students to have an intuitive understanding of the approaches of mechatronics engineering.

In conclusion, this article proposes a method to provide mechatronics and robotics education in high school standard curriculum through a hands-on demonstration and visual coding to operate the spherical robot while participating in a game of curling.

Acknowledgement

This work was supported by a 2019 Korea Aerospace University faculty research grant.

References

[1] A. Agogino, V. SunSpiral, and D. Atkinson, “Super Ball Bot - structures for planetary landing and exploration,” *NASA Innovative Advanced Concepts (NIAC) Program, Final Report*, 2013 (http://www.nasa.gov/sites/default/files/files/Agogino_SuperBallBot.pdf)

[2] H. S. Lee, S. G. Cho, D. K. Lee and B. K. Lee, “Design of Transformable spherical robot based on multi-linkage structure abstract,” *Journal of Aerospace System Engineering*, Vol. 11, No. 6, pp. 26-33, Dec. 2017

[3] S. Nag, J. G. Katz and A. Saenz-Otero “Collaborative Gaming and Competition for CS-STEM Education using SPHERES Zero Robotics,” *Acta Astronautica*, vol. 83, pp. 145-174, Feb.-Mar. 2013

[4] Li, Q.Z.Li, W. Zhang, and L. Chen, “Design for control - A concurrent engineering approach for mechatronic systems design Mechatronics,” *IEEE/ASME Transactions on Mechatronics*, vol. 6, no. 2, pp. 161–169, July 2001

[5] F. Cajas, “The role of research in improving learning technological concepts and skills: the context of technological literacy,” *International Journal of Technology and Design Education*, vol. 12, pp. 175-188, Oct. 2002

[6] M. Garmendia, J. Guisasola and E. Sierra, “First-year engineering students' difficulties in visualization and drawing tasks,” *European Journal of Engineering Education*, vol.32, no.3, pp. 315-323, Jun. 2007

[7] J. Goodman, “Making Early Field Experience Meaningful: a critical approach,” *Journal of Education for Teaching*, vol 12, no. 2, pp. 109-125, 1986

[8] M. Virvou, G. Katsionis, and K. Manos, “Combining Software Games with Education: Evaluation of its Educational Effectiveness,” *Educational Technology & Society*, vol. 8, no. 2, pp. 54-65, 2005

[9] Richard Chase, Abhilash Pandya, “A review of active mechanical driving principles of spherical robots,” *Journal of Robotics*, vol.1, pp. 13-23, Nov. 2012