3D Smart User Interactive System with Real-Time Responding Tele-Robotic Proprioceptive Information

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***Abstract*—Feedback of proprioceptive information is essential for many tele-robotic systems, especially those designed to undertake tasks concerning hazardous environments and for efficient out-of-sight remote control applications. Given highly sensitive nature of these applications, even small errors (e.g. less than one degree of displacement in robot posture) can cause unnecessary risk. Thus, accurate feedback of proprioceptive information, as well as a technique to precisely interpret this information, is significant to operator. In this paper, we introduce a framework that uses pulse feedback mechanism to measure the proprioceptive information of a robot operating over real-time wireless communication and represent it in 3D model user interface. The 3D user interface enhances the interpretation of proprioceptive information to help operator to visualize the real-time relative position of the robot. The paper also provides results that demonstrate how the framework allows synchronization between 3D model and tele-robot to be achieved in real-time over wireless communications.**

Keywords – Proprioceptive Information, Tele-robotics, Pulse Feedback, 3D User Interface, Real-time synchronization

I. Introduction

Nowadays, tele-operation technologies have been widely applied in many areas including military, medicals industries and even house-hold usages. Tele-operation concerns the manipulation of remote entities, robots or machines by local machines or computers [1]. Tele-robotics involves the remote manipulating of a robot with from a distance which provides the operator with a sense of security and comfort by remaining at a command center. Tele-robotics has typically been used to deal with hazardous materials and in dangerous or remote areas such as nuclear plant and deep ocean exploration, where it is often beyond the abilities of humans to undertake these tasks. An additional factor in these environments is that the robot is generally out-of-sight and so information about its position and status must also be provided to the operator.

Visual information in robotics generally refers to First Person View (FPV) of the tele-robot itself. In other words, FPV is to see what the robot sees. FPV can be easily implemented by attaching a camera on the robot, enabling the operator to visualize the surrounding remote environment. Unfortunately, with the FPV visual information, the operator will never notice the proprioceptive information of the robot about its body parts' and the angles of each linkage joint. Proprioception is defined as the sense of the relative position and orientation of neighbouring parts of the body [2]. It is the feedback of the body's dimensional state in order to aid the perception of motion [3].

Given the application of tele-robotics in highly sensitive and hazardous situations, single degree displacement of the robot's body parts is massively significant to the operator, who relies on the proprioceptive information to make decisions on manipulation. The accuracy of the angular degree of each joint is therefore significantly critical as errors in the displacement of robot may impact on the ability to undertake the remote task and hence affect the safety of the operator or loss revenue.

To solve the problem, a Third Person View (TPV) on the robot is required. TPV refers to one point-of-view over the first person. In other words, TPV is to see on the robot itself instead of its surrounding environment. With TPV, the operator can be fully aware of the proprioceptive information about the angles of each linkage joint in the robot. In this paper, a framework is proposed in order to gain an accurate TPV of a robot through pulse feedback which is generated from encoder of the motor and transmitted over a short range wireless personal area network to the operator. This paper shows that this method provides a much more accurate degree of angle and non-flapping degree value. Furthermore, the TPV is presented as a 3D model in a user interface that is simultaneously updated based on pulse-feedback from the robot when its movement has been changed. An additional advantage of interpreting the proprioceptive information in a 3D model user interface is to aid visualization of the current position of robotic arm allowing the operator to easily identify the angle of each linkage joint in the robotic arm and hence give the appropriate commands to control the robot, for example in gripping a highly dangerous object.

The remainder of this paper is organized as follows: Section II reviews the related work; Section III discusses the proposed framework; Section IV constructs the experimental platform; Sections V and VI introduce the framework consisting of the pulse feedback algorithm and backlash compensation respectively into the experimental setup; Section VII shows the outcome results and finally the conclusion of the works is presented in Section VIII.

II. RELATED WORKS

A. *Reliability of Pulse Feedback*

The majority of robots use motors such as servo and direct current motor for their mechanical motion displacement, and the control system theory of motors is broadly categorized into either open loop or closed loop known as feedback loop [4]. Open loop control systems are unsuitable for robotic systems used in critical environments, because they do not provide any feedback to notify whether the motor has reached the expected position. Close loop control [4] is therefore a necessity whenever there is a concern about the trajectories a robot must take, as it provides continuous feedback information. Based on the feedback pulses, the controller/motor driver can be notified whether the motor has reached the position given by the operator. In [5], the researchers implemented a servo motor with an incremental encoder attached that was used to ensure the motor has arrived at the correct position. The result showed that based on pulse feedback from encoder, the positional control mechanism was able to reliably drive motor onto the precise trajectory.

B. *Joint Angle Measurement*

In order to get a precise movement attitude and degree feedback to form proprioceptive information from the real environment, many researchers have implemented additional sensors. The selection of the sensors to measure the robotic arm joint angle is critical. Accelerometers are the most popular choice to measure angles, however angle measurement system using accelerometers has many limitations which include difficulties in sensor calibration, poor accuracy (e.g. a maximum error of 5.5% from the range of -90 to +90), the repeatability error is 3 % [6], temperature and heat convection of accelerometer affects the accuracy as well [7], and the angular movement of the robot will also affect the accelerometer’s angle measurement which needed a compensation from gyroscope sensor. Even through with the combination of a gyroscope, the angle value will still vary depends on gravity.

Another option for measuring linear angle is to attach a potentiometer onto the joint. This is a much more accurate and stable measurement, but its limitation is the small range of resolution that the potentiometer can be rotated. For example, the standard potentiometer has only 0° to 210° rotation.

C. *Presentation of Proprioceptive Information*

One of the key factors of tele-robotics is the design of the user interface which determines the controllability of the system. There are many devices can be developed as a user interface system of tele-robotics such as computer, laptop, control console, personal digital assistant (PDA) and smartphone. Walker and Miller [8] applied a smartphone to manipulate his tele-robot by using accelerometers as control inputs for tele-operation. It also features FPV visual information and partial TPV. The attached camera was pointing to the remote environment including the gripper of the robot which provided only TPV on the gripper. Xiaoli Yang *et al.* [9] stated that a 3D graphical model user interface will provide a more realistic interface which can help the user to remotely control the robot or part of the robot or part of it, such as the arm, for easier manipulation. However, the way they output the 3D graphical model did not really concern whether their real robot has reached the expected position according to given commands.

III. PROPOSED FRAMEWORK

An angle measurement algorithm based on pulse feedback mechanism is proposed in order to have accurate feedback of proprioceptive information. The resulting framework presents this information into 3D graphical model for the user interface. Within the angle measurement algorithm, gear ratio calculation and backlash compensation have also been included to make the algorithm more practical in order to address the concerns of reality robot design. All systems involving interaction may also have consideration of time synchronization and information synchronization. In the proposed framework, network time protocol (NTP) [10] has been utilized to ensure time synchronization between the 3D user interface and the tele-robot. Information synchronization, may specifically refer to posture synchronization in this paper, is to have identical latest information between systems.

The posture synchronization between the 3D virtual environment and the tele-robotic physical environment is achieved by feeding back the motor encoder pulses feedback over a short-range wireless (Bluetooth) network to the 3D graphical model user interface. In other words, every single movement of the motor is captured by the optical encoder and the pulse signals are sent to controller of the robot. The controller will store an accumulated value of the encoder pulses, and then keep sending the latest accumulated value to the operator environment through the Bluetooth network. Based on the received value, the user interface will process the gear ratio calculation and backlash compensation and finally update the 3D graphical model as a virtual TVP. Moreover, the accurateness of pulse-feedback based angular degree is also being proven by using potentiometer values as reference for each joint. The reference of potentiometer values compared in real-time to the degree value of angle algorithm.

IV. EXPERIMENTAL PLATFORM

The experimental platform was used in this paper consisted of two systems: an Android based 3D user interface and a LEGO Mindstorms NXT [11] based tele-robot, with point-to-point Bluetooth communication as shown in Figure 1. The programming language was used in both environment are Java and the 3D interface was built using Unity3 game engine software [12]. Moreover, the tele-robotic environment was constructed with all LEGO materials such as NXT motors, Mindstorms NXT 2.0 (as the controller), sensors and many of interlocking plastic bricks. In addition, the real-time clock synchronization was achieved by using a NTP in order to maintain time synchronization. As the sequence diagram in Figure 1 shows, the manipulation is always triggered by user environment which issues the displacement command to the tele-robot and then the tele-robot will keep acknowledging with its current accumulative pulse feedback.

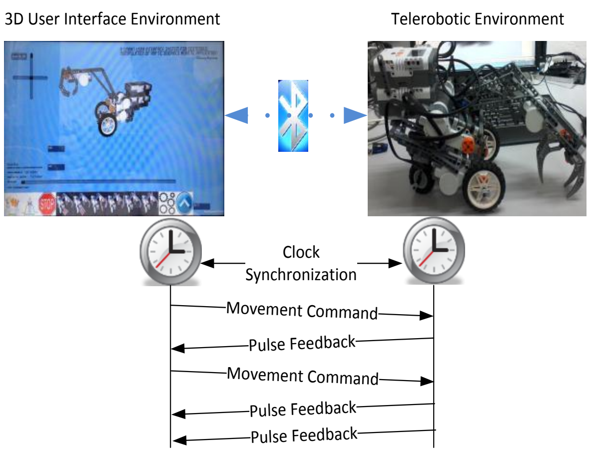

Figure 1. Overall illustration of experimental platform

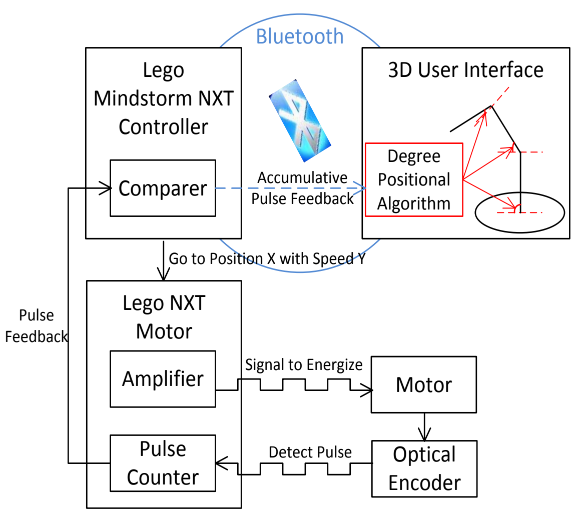

Figure 2. Transmission of pulse feedback between tele-robotic and user interface

To trigger the actuation of robot, the user interface will transmit a movement command which comprises the direction and speed of a particular joint. Once the command has been received by robot, the joint's motor will react based on the command. As the flowchart in Figure 2 shows, during the rotation movement of the motor, the NXT controller captures every single pulse signal that generated by optical encoder and accumulates the pulse value. The accumulated pulse value keeps feeding back to 3D user interface via Bluetooth network. In the 3D user interface, the accumulated pulses values are used to update the posture of virtual robot. The optical encoder returns to the LEGO NXT motor with an accuracy of 1 degree resolution per pulse [13]. This means that a single increment or decrement from the accumulated pulse will trigger 1 degree update to the joint angle.

V. ENCODER PULSE MEASUREMENT IN GEAR SYSTEM

The majority of robot motors involve gear systems into their posture movement and it is necessary to work out the encoder pulse measurement in related to the gear system. Because of this, the gear ratio will determine the angle changes of robotic joint when a rotation movement is made by the motor. In general, every gear system has its own gear ratio calculation which depends on different type of gear system design. For instance, the gears involved in our platform for the robotic arm system which include a worm gear (as a driving gear), a compound gears and a driven gear. Figure 3 shows the gear system of this platform and their specifications are given in Table 1.

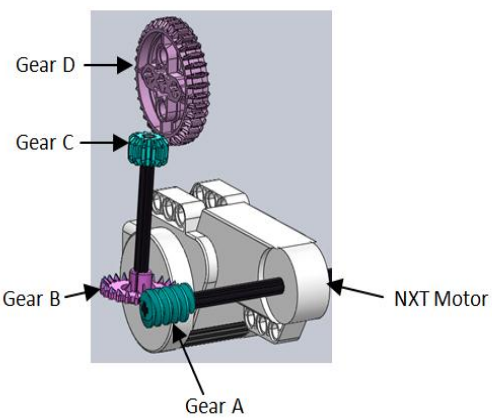

Figure 3. Gear system of the tele-robotic arm system

Gear	Teeth	Description
A	1	Driver Gear (Worm Gear)
B	24	Driven of Compound Gear
C	12	Driver of Compound Gear
D	36	Driven Gear

TABLE1. TEETH SPECIFICATION OF EACH GEAR

Every gear system has a different gear ratio calculation based on the design. In other words, the different angular velocity of the input gear produces a different output gear angular velocity. Based on the gear system design in our platform, the formula of the gear ratio is shown in equation (1) and (2).

$$Single\ Compound\ Gear\ Ratio = \frac{Driven\ of\ Compound\ Gear}{Driver\ Gear} X \frac{Driven\ Gear}{Driver\ of\ Compound\ Gear} \quad (1)$$

where the ratio calculation is:

$$Single\ Compound\ Gear\ Ratio = \frac{24}{1} X \frac{36}{12} = 72 \quad (2)$$

The result of the gear ratio based on the gear system design is 72 pulses equal 1 degree of movement of robotic joint. Based on the value of the gear ratio calculation, it can be determined how many degree of rotate of the robotic joint each degree of the motor rotation drives, as shown in equation (3) and (4).

$$Degree\ per\ Pulse = \frac{Single\ Degree\ of\ Robotic\ Joint}{Single\ Compound\ Gear\ Ratio} \quad (3)$$

where the calculation is:

$$Degree\ per\ Pulse = \frac{1}{72} = 0.013888 \quad (4)$$

The result is that a single pulse received will trigger 0.013888 degree rotation movement of the robotic joint in both 3D and tele-robot environments. This means that each single pulse generated from optical encoder will drive the robotic arm to turn 0.01388 degree; also the 3D model simultaneously updated. However, there is another unpreventable mechanical factor, gear backlash, which will affect the accuracy of our proposed framework. Therefore, the backlash compensation has also been considered into our framework to gain accurateness.

VI. Gear Backlash Compensation

Backlash as defined by J.Franklin and R.Henry H. in [14] as "a rotational arc clearance formed between a pair of mounted gears or the distance by which the tooth thickness of one gear exceeds the tooth space of the mating gear. Factors affecting the amount backlash required in a gear train include errors in profile, pitch, tooth thickness, helix angle and centre distance, and runout."

In our proposed framework, a small backlash can jeopardize the accuracy of proprioceptive presentation. It is because whenever there is a change in direction of the motor movement a gear backlash will occur. Every gear system has this unavoidable backlash issue. It depends on how big is the gap between gears, the greater gap and the bigger backlash has to be compensated, in other words to fill up the gap. However, the value of gear backlash is quite consistent and the pulses required to compensate for backlash can be captured in the following experiment shown in Figure 4.

The backlash compensation is to move the motor pulse-by-pulse until it about to move the robotic arm, and then record down the backlash pulse of the gear system. This test is performed repeatedly by changing the direction of the rotation of the gear system in order to get the average accumulative pulses. The flow chart in Figure 5 below shows the steps of gear backlash compensation and the result showed that the value of pulses which consumed in filling the backlash gap is 220 pulses in our gear design.

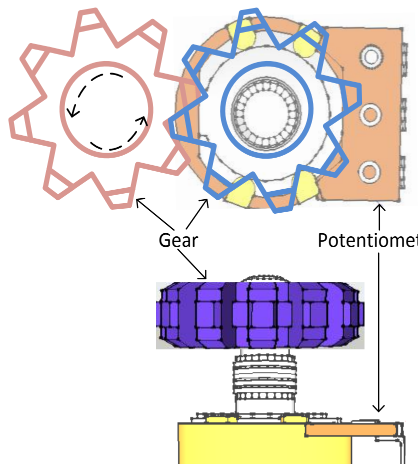

Figure 4. Gear backlash captured by potentiometer

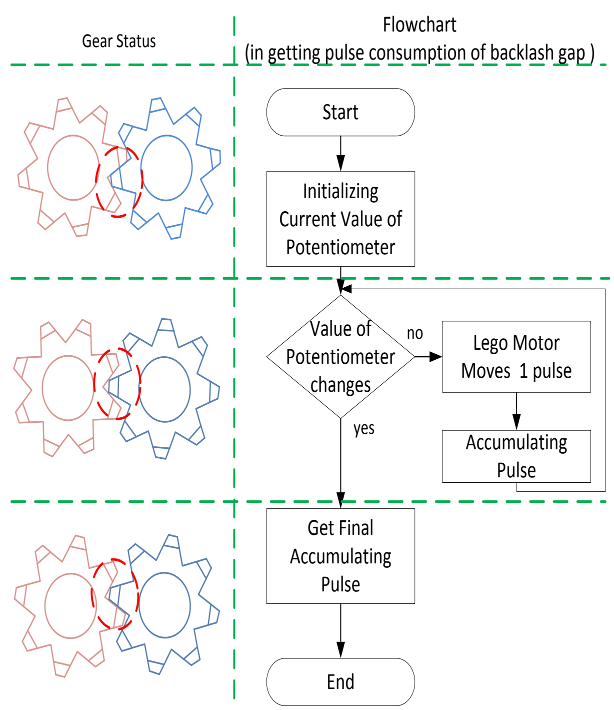

Figure 5. Getting consumed pulses in gear backlash compensation

VII. DISCUSSION OF RESULTS

With our proposed framework, we compared the accuracy of positional degree with the potentiometer. Figure 6 shows that from the beginning of the task to 240 seconds, the robotic arm position was going down from 57 degrees to 0 degree; then lifted up to 30 degrees in 380 seconds; down again to 19 degree at 600 second and finally lift up to 33 degrees. The total duration of the experiment was 15 minutes involved 4 directional changes. Figure 6 also indicates that the pulse feedback mechanism with backlash compensation is able to provide reliable angular degree output without the aid of other angular sensors. By using the potentiometer as the reference, the proposed framework demonstrates the accurateness is as accurate as potentiometer.

Figure 7 and 8 are broken down to 5 second interval. Figure 7 shows that the accuracy of degree movement between the 3D user interface and one of the robotic joints with referencing value of the potentiometer is less than 0.5 degree; Figure 8 indicates that the time latency of updating the both trigger value between 3D user interface and potentiometer. The average delay gap is approximately 0.2 seconds and the maximum is 0.5 seconds. The reason of having updating delay gap is due to the resolution of potentiometer and pulse feedback is unequal. In other words, the 3D user interface is based on receiving pulse feedback to update the angular degree, but the potentiometer is based on resistance changes. So they might have different time to update their value changes. Hence, comparing with potentiometer, our proposed framework is more real-time.

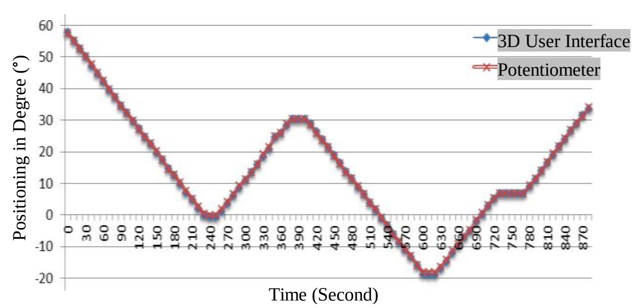

Figure 6. Degree movement of robotic arm between 3D user interface and potentiometer.

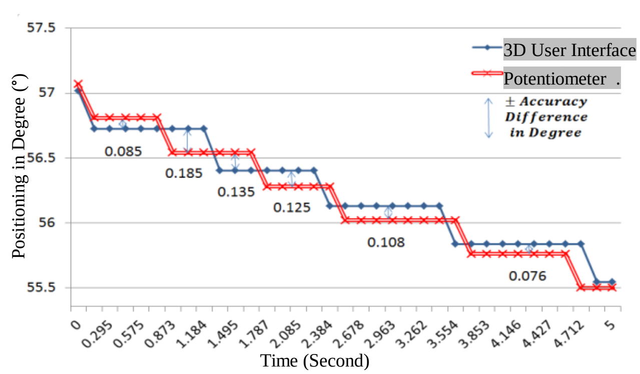

Figure 7. Accurateness of degree movement

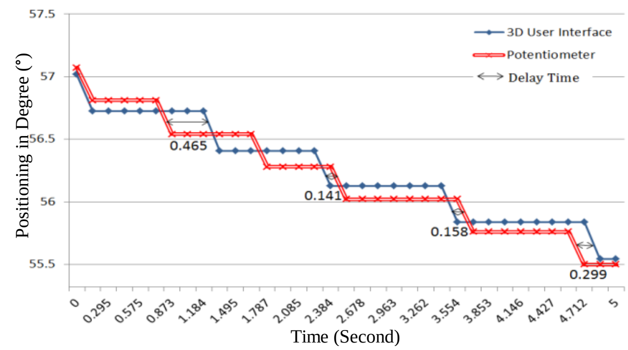

Figure 8. Time latency of angular degree information being updated between 3D user interface and potentiometer

VIII. CONCLUSIONS

The contribution of tele-robotics provides people to manipulate robotic systems without the concern of distance. Nevertheless, it is an essential to be fully aware the physical posture of the robot, in order to make manipulations more practical and precisely, especially when dealing with highly critical and sensitive tasks. Therefore, the proprioceptive information of the robot itself is significantly important to the operator. Without implementing extra angular or coordination degree sensors, we proposed a framework that uses a pulse feedback mechanism to measure the degree angle of each robotic joint. The algorithm also includes the concern of the gear system design and compensation for gear backlash. Consideration of these factors ensures that the proposed framework is as accurate as other sensors and the accurateness has also been proven by the result with less than ±0.5 degree discrepancy.

Furthermore, feedback of the remote robot's proprioception information has been presented as a 3D graphical model in a user interface. Proprioceptive information can be presented clearly in 3D model because of the virtual model of robotics which has its own coordinate frame for each part of component. Robotic proprioception in 3D graphical model not only enhances the experience of operator but also gain the awareness in degree positional detail of every robotic joint. The framework also addresses time and information synchronization and employs a NTP to maintain clock synchronization between the robot and 3D user interface when operating over a wireless network.

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REFERENCES

[1] K. M. Yap, A. Marshall, W. Yu, ”Providing QoS for Multimodal System Traffic Flows in Distributed Haptic Virtual Environments,” IEEE Global Information Infrastructure Symposium, 2-5 July 2007, Marrakech, Morocco, ISBN: 978-1-4244-1376-8, pp. 153-158.

[2] J. P. Gunderson, L. F. Gunderson, "Robots, Reasoning, and Reification", Springer; 1st Edition. 2nd Printing. 2008 edition (November 26, 2008), pp. 188

[3] R. LeMoyne, C. Coroian, T. Mastroianni, W. Wu, W. Grundfest and W. Kaiser, "Virtual proprioception with real-time step detection and processing," in Engineering in Medicine and Biology Society, 2008. EMBS 2008. 30th Annual International Conference of the IEEE, Vancouver, BC, 2008.

[4] J. L. Fuller "Robotics: Introduction, Programing, and Projects", 1999, New Jersey, Prentive-Hall Inc

[5] X. Chen, Y. He, X. Shen and Q. Chen, "Development of a pulse-type servo drive system and the application on a 3-axises robot," 2010 2nd International Asia Conference on Informatics in Control, Automation and Robotics (CAR), 2010, pp. 404-406, doi: 10.1109/CAR.2010.5456811

[6] H. Huang, "Design of Tilt Angle Measurement System," 2nd International Conference on Applied Robotics for the Power Industry (CARPI), Sept. 2012, pp. 560-562, doi: 10.1109/CARPI.2012.6356378

[7] J. Mackley and S. Nahavandi, "Active temperature compensation for an accelerometer based angle measuring device,” World Automation Congress, Proceedings, Volume 16, June 2004, pp. 383–388, Print ISBN: 1-889335-21-5.

[8] A. M. Walker, D. P. Miller, "Tele-operated Robot Control Using Attitude Aware Smartphones", HRI’12, March 2012, Boston, Massachusetts, USA. ACM 978-1-4503-1063-5/12/03.

[9] X. Yang, D. C. Petriu, T. E. Whalen, E. M. Petriu, "A Web-Based 3D Virtual Robot Remote Control System", CCECE 2004- CCGEI 2004, Niagara Falls, May/mai 20040-7803-8253-6/04/517.00 02004 IEEE.

[10] Mills, David L., “Network Time Synchronization: the Network Time Protocol on Earth and in Space,” Second Edition, CRC Press, 2011, pp. 466.

[11] LEGO, "Lego Mindstorms," LEGO Group, 2012. [Online]. Available: http://mindstorms.lego.com/. [Accessed 23 December 2012].

[12] Unity Technologies, 2012. [Online]. Available: http://unity3d.com. [Accessed 23 December 2012].

[13] Philo, "NXT® motor internals," 17 December 2012. [Online]. Available: http://www.philohome.com/nxtmotor/nxtmotor.htm. [Accessed 23 December 2012].

[14] F.D. Jones, H. H. Ryffel, (1984), “Gear design simplified (3rd ed.)”, Industrial Press Inc., pp. 20, ISBN 978-0-8311-1159-5.