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Development of 3D Boiler Header Template using Webots

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Abstract

Offline boiler header inspection is a tedious process if done manually since the opening is very small to insert big instruments and tools while the length can range up to 20 m. The geometry can also be complex since boiler tubes are connected to these headers from different directions. Designing of robots to assist in offline boiler header inspections can be made easier if a simulator is available for deciding the parameters of the robot. This paper describes the development of a 3D boiler header pipe environment template for boiler header inspection robot (BHIR) using Webots. The purpose is to use it as a simulator for the development of BHIR prototypes. Firstly, 3D boiler header pipe environment is constructed by using Pro Engineer (Pro\E). Next, Virtual Reality Modeling Language or VRML97 is used to convert file from Pro\E world file to Webots world file. Finally, simulations are carried out to verify the effectiveness of the developed 3D boiler header environment template. Results show the advantages of having the simulator for modeling and designing of BHIR prototypes.

1. Introduction

Currently, there are many in-pipe inspection robots developed such as TubeCrawler (Tubulo robot) [1], AirGapCrawler [2], SPRING [3] and etc. They were designed with different configurations and functionalities which are for inspection in power plants.

Power plant installations require periodic inspections in many of its components. However, these components are usually complex by design and access to these components are generally limited due to a number of constrains [4]. Due to these reasons, a robot system has been proposed to access boiler headers in Tenaga Nasional Berhad (TNB) thermal power plants. To develop a robot (boiler header pipe inspection robot) and inspection methods to be used in real application in thermal power plants in TNB, some conceptual designs and prototyping must be executed, and field tests must be conducted to test the developed robot.

Consequently, simulation is a good platform to perform field tests where it provides a safe-environment, easy-handling and is also less expensive compared to field test in the real environment [5]-[15]. It also provides a platform for exploration of a robot's capability and its parameters before it is implemented in a real application [16]. There are a lot of simulation engines that can be used for research and development of robots such as Cyberbotics's Webots, Energid's, OpenSim, Simbad, etc. [17].

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In this paper, Webots simulator is used to develop a 3D boiler header pipe environment. It is because Webots is the most practical simulator to be used in the area of robotics (*Retrieved on 23 April 2011 from   http://cyberbotics.com/guide.pdf*). 3D boiler header pipe environment template configuration is based on the actual boiler header database in TNB. The detail of the development of a 3D boiler header environment is described in the paper. Finally, virtual experiments were carried out to prove the effectiveness of the 3D boiler header pipe template as a testing-field for boiler header inspection robot prototypes.

2. Methodology

Webots software is used to develop a boiler header template in a simulation environment. Even though Webots software provides many standard templates for robotic simulations, they also allow user to develop a template based on requirement of the project, research etc. To design a template using Webots simulator, user should know that for complex 3D model, it requires the usage of a 3D modeling software which is compatible with the VRML97 (or VRML 2.0) to generate the model before exporting it to the Webots simulator. 3D modeling software recommended by Cyberbotics, the developer for Webots are 3D Studio Max, Maya, AutoCAD, Pro Engineer, AC3D, or Art Of Illusion [17].

In this paper, Pro Engineer (Pro\E) software is used to design the 3D boiler header pipe environment before exporting it to the Webots simulator. There is a technique to apply a 3D complex design from Pro Engineer simulator into the Webots simulator. The technique used in the development of the 3D boiler header environment is described as follows:

2.1. Pro Engineer Software

Fig. 1 (a), (b), shows two different configuration of 3D boiler header pipe modeling is designed by using Pro\E. Fig. 1 (a) shows a boiler header pipe with parallel entrance and Fig. 1 (b) shows a boiler header pipe with perpendicular entrance, both with boiler tubes along the header.
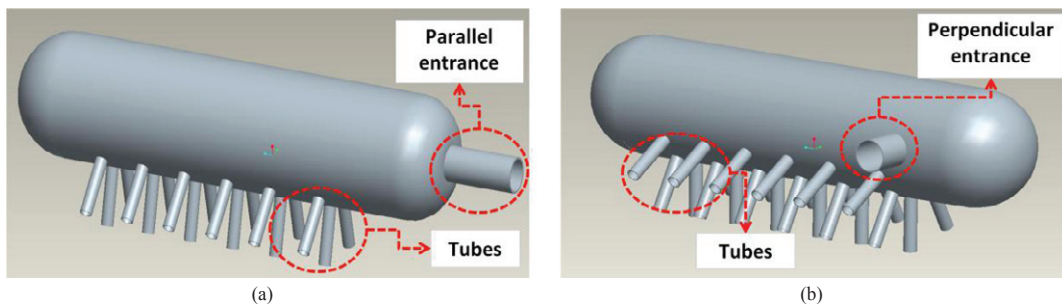

Fig. 1. (a) Parallel boiler header entrance with tubes; (b) Perpendicular boiler header entrance with tubes

2.2. VRML97 or VRML 2.0

After 3D boiler header pipe environment is designed using Pro/E, the 3D boiler header pipe design is saved in VRML97 or VRML 2.0 file where a ".wrl" file will be created. The ".wrl" file means it is in world file which VRML file format is used to represent a complex 3D object created for Webots. This file is saved as "boilerheader.wrl" and need to modified or edited using text editor. The modifying techniques taken from VRML file to Webots simulator is described as follows:

a. First, "boilerheader.wrl" file is opened in a text editor such as Microsoft WordPad. Example of a 3D boiler header model code is shown in Fig. 2.
b. Next, "boilerheader.wrl" file is modified by removing unwanted codes or coding which causes error in Webots simulator. Fig. 3 shows a flowchart which is representing a step taken to modify "boilerheader.wrl" file (file from Pro\E to VRML).
c. Finally, the modified "boilerheader.wrl" file is saved to overwrite the previous file.

2.3. Exporting to Webots Simulator

The modified "boilerheader.wrl" file is now ready to be used in the Webots simulator. First, Webots will import the modified "boilerheader.wrl" file into the Webot simulator. Then, the boundaries are assigned around 3D boiler header pipe

which allows the imported 3D boiler header pipe to work with other objects or environments in the Webots simulator. Once these steps are taken, simulations using the 3D boiler header environment template can be conducted.

```
#VRML V2.0 utf8

PROTO Header_Info [
field SFString vendor "Parametric Technology Corporation"
field SFString product "Pro/ENGINEER"
field SFString version ""
field SFString sceneFile ""]
{ }

PROTO Node_Info [
field SFString node_type ""
field SFString node_name ""]
{ }

PROTO Geom_Type [
field SFString geom_type_s "T_Empty"
field SFInt32 trg_qual 1]
{ }
.
```
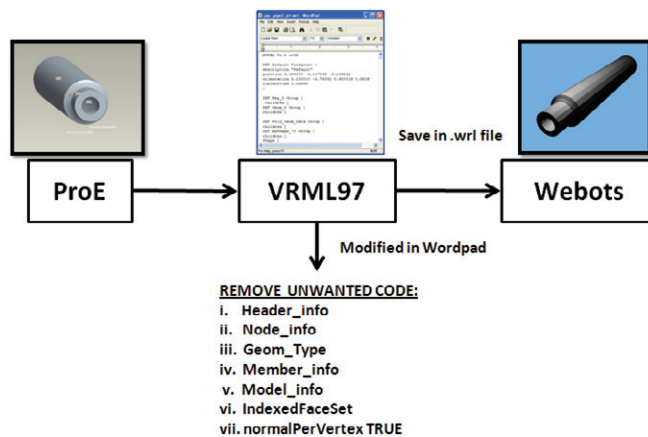
Fig. 2. Boiler header template coding in VRML 2.0 file

Fig. 3. Flowchart for boiler header template coding for Webots

3. Experimental Results

In order to validate the effectiveness and the reliability of the developed boiler header template, a series of simulations have been conducted. Fig. 4 shows the experimental environment of 3D boiler header pipe with parallel entrance that imitates a real boiler header pipe. However, a real boiler header pipe in TNB thermal power plants may have many tubes with perpendicular entrance and some with parallel entrance. The arrow in Fig. 4 shows the path of the robot moving in the 3D boiler header pipe.

3.1. Boiler Header Configuration in Webots

Fig. 5 shows an illustration of the configuration of the 3D boiler header pipe with parallel entrance which is used in this simulation. The 3D boiler header pipe with parallel entrance is a horizontal pipe with entrance diameter of 80mm used for 3D Webots environment. It is based on the actual boiler header pipe diameter which range from 80mm to 100mm. The diameter of the main body of a boiler header pipe can range between 150mm up to 800mm. The length can range from 1m to 25m.

For simulation purposes, the diameter of the main body of the boiler header pipe is designed with a diameter of 100mm (0.1m) and the total length of 1m. Between the entrance and main body of the boiler header pipe, there is a slope at a 45° inclination. This is to test the robot's capability to run through boiler headers with complex geometry.
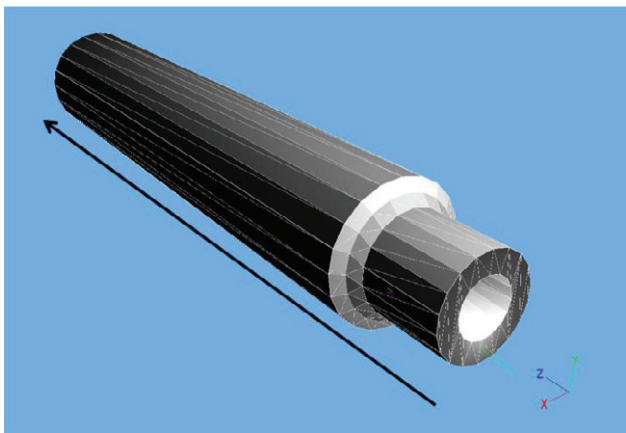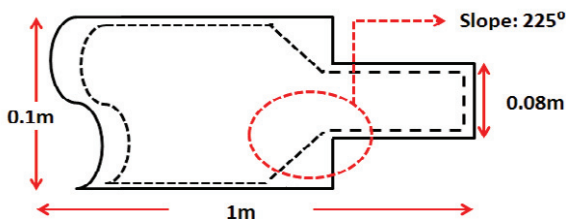
Fig. 4. Boiler header experimental environment

Fig. 5. Boiler header experimental environment

3.2. Boiler Header Inspection Robot

Boiler header inspection robot is designed with a dimension of 0.06 x 0.09 x 0.03m inside the Webots environment. This is based on our actual prototype size. Fig. 6 shows the boiler header inspection robot which is used to test the 3D boiler header pipe environment inside the Webots software.

3.3. Simulation results

Table 1 shows the parameters of the boiler header inside the Webots software. Table 2 shows the results of the robot performance inside the boiler header. Simulations were conducted for four different robot mass; 0.1kg, 0.2kg, 0.3kg and 0.4kg. The speed of the robot is set to $0.01m/s^2$.
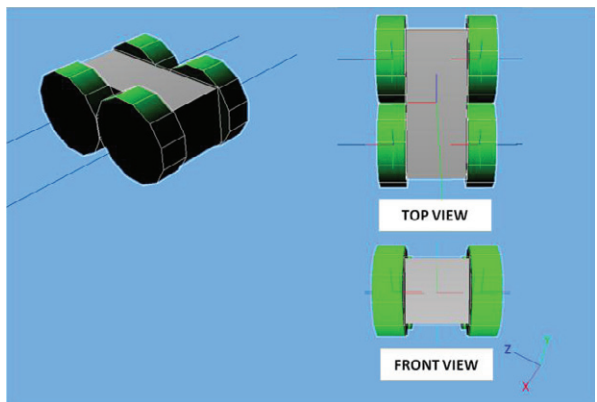

Fig. 6. Boiler Header Inspection Robot Configuration

Table 1. Parameters of the boiler header inside Webots software

Parameter	Value
Density	$1000kg/m^3$
Bounce velocity	0.01m/s
Coulomb Friction	1
Force Dependent Slip	0

Table 2. Simulation results for boiler header inspection robots with different mass

Robot Weight (kg)	Simulation result
0.1	Topple
0.2	No Slip/Topple
0.3	Slip
0.4	Topple

The result shows that robot with a mass of 0.1kg is not stable to go down the slope which causes it to topple. The same applies to the robot with a mass of 0.4kg. But even though it toppled during moving down the slope, it is still moving forward.

The result for the robot with a mass of 0.2kg is very convincing. From this result, it shows that 0.2kg mass is reliable for the robot with the specified dimension and can be applied to the actual prototype. If the mass is increased to 0.3kg, the robot started to slip. Fig. 7 shows the result before and after the simulation.

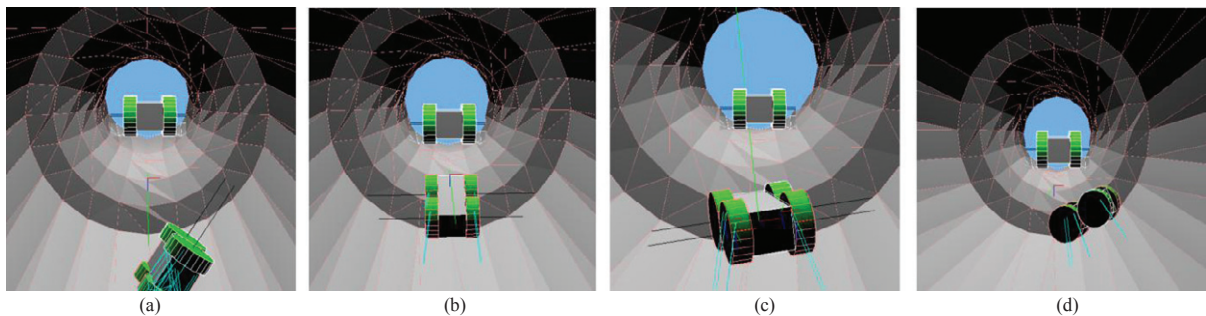| (a) | (b) | (c) | (d) |

Fig. 7. (a) 0.1kg robot is toppled and cannot move; (b) 0.2kg robot is successful; (c) 0.3kg robot slipped; (d) 0.4kg robot toppled

On top of this, the performance of the robot can be further monitored by integrating sensors such as accelerometer, gyroscope, encoders etc inside the Webots environment.

Conclusion

This paper is presented a template of 3D boiler header pipe in the Webots software, which can be used for testing for different configurations and sizes of boiler headers for inspection robot simulations. It is because this template can be modified from smallest size boiler headers until the biggest size boiler headers. This paper explained the steps necessary for developing the template for the Webots simulator. Simulations were conducted to show the advantages of having this template in order to optimize the size and weight of the boiler header inspection robot prototype before the actual fabrication and development. It can be said that the simulations have shown and validate the importance and potential of the template. Further improvements can be made by including sensor modules into the robot to track its performance inside the boiler header environment.

Acknowledgements

References

[1] Patrick S, Frederic R Olivier TDN, Gilles C, Roland M, Hannes Bleuler. Tubulo – A Train-like Miniture Inspection Climbing Robot for Ferromagnetics Tubes. 1st Conference on Applied Robotics for Power Plant Industry. 2010. p.1-5.

[2] Wolfgang F, Gilles C, Roland S, RolandM. Robotics Crawler for Inspecting Generators with Very Narrow Air Gaps. IEEE International Conference on Mechatronics. 2009. p. 1-5.

[3] Takashi N, Koichi O, Itaru T. Developement of a Simulation Model for Inner-gas-pipe Inspection Robot: SPRING. Proceedings of SICE Annual Conference. 2010. p.902-904.

[4] Gilles C, Andreas B, Wolfgang F, Christoph H, Fabien T, Roland S, Patrick S, Frederic R, Francesco M, Roland M. Highly Compact Robots for Inspection of Power Palnts. 1st International Conference on Applied Robotics for the Power Industry. 2010. p. 1-6.

[5] Pedro N, J.Norberto P, A.Paulo M. Robot Path Simulation: A Low Cost Solution Based on CAD. IEEE Conference on Robotics Automation and Mechatronics. 2010. p. 333-338.

[6] Aiman Musa MO, Reza G, Hun-ok L, Atsuo T, Semi-Passive Dynamic Walking for Biped Walking Robot Using Controlable Joint Stiffness Based on Dynamic Simulation. IEEE/ASME International Conference on Advance Intelligent Mechatronics. 2009. p. 1600-1605

[7] Leonimer FM, Silvia GSC, Jose AF, Marcela HK. Dynamics Design and simulation for mobile Robots Navigation Systems. IEEE International Conference on Robotics and Biomemetics. 2009. p. 2133-2138.

[8] Li H, Hua X, Xiao-hong J, Zhi-geng P. IRMSS: An Interactive Robotics Modeling Simulation System Based on MSRS. International Conference Audio Language and Image Processing. 2010. p. 926-931.

[9] Liang D, Keiji N, Keisuke S, Andres M, Kazuya Y, Haibo G, Zongquan D. Terramechanics-based High Fedility Dynamics Simulation for Wheeled Mobile Robot on Deformable Rough Terrain. IEEE International Conference on Robotics and Automation. 2010. p. 4922-4927.

[10] Chin-hong C, Knoll A, Christian B, Javier E, Yang C. Examining Robotics System with Shape Adjustable Manupulator under Dynamics Environments: From Simulation to Varification. IEEE International Symposium on Computational Intelligence in Robotics And Automation. 2009. p.72-77.

[11] Weiping L, Haojie Z. The Research on Intelligent Algorithms in the Simulation System of Robotics Soccers. 2nd International Conference on Signal Processing Systems. 2010. p. V3-326 –V3-328.

[12] Nandy S, Shome SN, Tanmay T, Chakraborty G, Kumar CS. Detailed Slip Dynamics for Nonholonomic Mobile Robotics System. IEEE International Conference on Mechatronics and Automation. 2011. p. 519-524.

[13] Juergen R, Michel S. Virtual Robotics Robotics Testbeds: A Foundtion for e-Robotics in Space, in Industry- and in the Woods Developements in E-Systems Engineering. 2011. p. 496-501.

[14] Abraham G, Jake T, Christoper P, Hong-kyu L, Gordon KL. An ANAS- Based Multi-Sensor Structure for a Mobile Robotic System. IEEE Symposium on Computational Intelligence in Control and Automation. 2011. p. 143-148.

[15] Saddek B, Matthieu G, Felix I, Imen K, Nguyen T. Desining Automation Robots: Towords a More Dependable Software Architecture. IEEE Robotics and Automation Magazine. 2009. p. 67-77.

[16] Seung-Woo S, Eui-Jin K, Chan-Ho L, Sang-Ho L, Sung-Hyun J, Jong-Sung H. Developement of a Novel HyRoHILS System and Its Application to Parameter Identificaion of an Industrial Robot. 41st International Symposium on Robotics and 6th German Conference on Robotics. 2010. p. 1-5.

[17] Yong-Ho Y, mohammed A, Roemmermmann, Frank K. A Simulation – Based Design of Extraterrresterial Six-Legged Robot System. 35th Annual Conference of IEEE Industrial Electronics. 2009. p. 2181-2186.