SolidWorks Lego Mindstorm
and DS SolidWorks will have five (5) business days to, in its sole discretion, accept or reject such request. Contractor/Manufacturer: Dassault Systèmes SolidWorks Corporation, 175 Wyman Street, Waltham, Massachusetts 02451 USA.

The information and the software discussed in this document are subject to change without notice and are not commitments by Dassault Systèmes SolidWorks Corporation (DS SolidWorks).

No material may be reproduced or transmitted in any form or by any means, electronically or manually, for any purpose without the express written permission of DS SolidWorks.

The software discussed in this document is furnished under a license and may be used or copied only in accordance with the terms of the license. All warranties given by DS SolidWorks as to the software and documentation are set forth in the license agreement, and nothing stated in, or implied by, this document or its contents shall be considered or deemed a modification or amendment of any terms, including warranties, in the license agreement.

Patent Notices
SolidWorks® 3D mechanical CAD software is protected by U.S. Patents 5,815,154; 6,219,049; 6,219,055; 6,611,725; 6,844,877; 6,898,560; 6,906,712; 7,079,990; 7,477,262; 7,558,705; 7,571,079; 7,590,497; 7,643,027; 7,672,822; 7,685,518; 7,694,238; 7,853,940, 8,305,376, and foreign patents, (e.g., EP 1,116,190 B1 and JP 3,517,643).

eDrawings® software is protected by U.S. Patent 7,184,044; U.S. Patent 7,502,027; and Canadian Patent 2,318,706.

U.S. and foreign patents pending.

Trademark and Product Names for SolidWorks Products and Services
SolidWorks, 3D ContentCentral, 3D PartStream.NET, eDrawings, and the eDrawings logo are registered trademarks and FeatureManager is a jointly owned registered trademark of DS SolidWorks.

CircuitWorks, FloXpress, PhotoView 360, and TolAnalyst, are trademarks of DS SolidWorks.

FeatureWorks is a registered trademark of Geometric Ltd.


Other brand or product names are trademarks or registered trademarks of their respective holders.

COMMERCIAL COMPUTER SOFTWARE - PROPRIETARY
The Software is a “commercial item” as that term is defined at 48 C.F.R. 2.101 (OCT 1995), consisting of “commercial computer software” and “commercial software documentation” as such terms are used in 48 C.F.R. 12.212 (SEPT 1995) and is provided to the U.S. Government (a) for acquisition by or on behalf of civilian agencies, consistent with the policy set forth in 48 C.F.R. 12.212; or (b) for acquisition by or on behalf of units of the Department of Defense, consistent with the policies set forth in 48 C.F.R. 227.7202-1 (JUN 1995) and 227.7202-4 (JUN 1995).

In the event that you receive a request from any agency of the U.S. Government to provide Software with rights beyond those set forth above, you will notify DS SolidWorks of the scope of the request and DS SolidWorks will have five (5) business days to, in its sole discretion, accept or reject such request. Contractor/Manufacturer: Dassault Systèmes SolidWorks Corporation, 175 Wyman Street, Waltham, Massachusetts 02451 USA.

Copyright Notices for SolidWorks Standard, Premium, Professional, and Education Products
Portions of this software © 1986-2013 Siemens Product Lifecycle Management Software Inc. All rights reserved.

This work contains the following software owned by Siemens Industry Software Limited:

- D-Cubed™ 2D DCM © 2013. Siemens Industry Software Limited. All Rights Reserved.

Portions of this software © 1998-2013 Geometric Ltd.

Portions of this software incorporate PhysX™ by NVIDIA 2006-2010.

Portions of this software © 2001-2013 Luxology, LLC. All rights reserved, patents pending.

Portions of this software © 2007-2013 DriveWorks Ltd.

Copyright 1984-2010 Adobe Systems Inc. and its licensors. All rights reserved. Protected by U.S. Patents 5,929,866; 5,943,063; 6,289,364; 6,563,502; 6,639,593; 6,754,382; Patents Pending.

Adobe, the Adobe logo, Acrobat, the Adobe PDF logo, Distiller and Reader are registered trademarks or trademarks of Adobe Systems Inc. in the U.S. and other countries.

For more DS SolidWorks copyright information, see Help > About SolidWorks.

Copyright Notices for SolidWorks Simulation Products
Portions of this software © 2008 Solverson Software Corporation.

PCGLSS © 1992-2013 Computational Applications and System Integration, Inc. All rights reserved.

Copyright Notices for SolidWorks Enterprise PDM Product
Outside In® Viewer Technology, © 1992-2012 Oracle © 2011, Microsoft Corporation. All rights reserved.

Copyright Notices for eDrawings Products
Portions of this software © 2000-2013 Tech Soft 3D.

Portions of this software © 1995-1998 Jean-Loup Gailly and Mark Adler.

Portions of this software © 1998-2001 3Dconnexion.

Portions of this software © 1998-2013 Open Design Alliance. All rights reserved.

Portions of this software © 1995-2012 Spatial Corporation.

The eDrawings® for Windows® software is based in part on the work of the Independent JPEG Group.


Portions of eDrawings® for iPad® copyright © 2003-2005 Apple Computer Inc.
## Contents

### NXT SegWay Robot

- SegWay Transportation ................................................................. 1
- Project Description ........................................................................... 2
- Balance Control ................................................................................ 2
- SolidWorks Model ............................................................................ 3
- Important! .......................................................................................... 8
- SolidWorks Motion Model ................................................................. 12
  - Rigid Groups ................................................................................. 12
  - IF Statement .................................................................................. 17
  - Maximum torque ............................................................................. 20
  - PID Control .................................................................................... 24
- PID Control of SegWay Robot ............................................................. 26
  - Maximum Torque Limit ................................................................. 29
  - Tuning PID Control ....................................................................... 29
  - STEP Function .............................................................................. 30
When you complete this lesson, you will be able to:

- Setup a motion simulation.
- Use functions and expressions.
- Create a basic control system.
SegWay Transportation

SegWay Personal Transporter (PT) is the world’s first self balancing transportation device with two wheels. The mechanism is based on the principle of the inverted pendulum with advanced control to maintain balance at all times. To move, the rider leans forwards or backwards and the transporter accelerates in the proper direction to balance the system. Similarly, to take turns the rider leans sideways and the transporter adjusts the speed of both wheels. Handling feels natural because the amount of lean, measured by the gyroscope, controls the acceleration and the curvature of turns.

Project Description

In this project, you will simulate the SegWay robot built using the Lego Mindstorms NXT 2.0 kit. In the first part of the lesson, you will create a system control in SolidWorks Motion and compare it to the behavior of the robot. You will consider the following scenario.

- **Single Degree of Freedom (DOF) system**
  The rider and transporter are rigidly connected to form a single mass. The only degree of freedom is then the rotation about the axle.

The behavior of the robot under various circumstances can be viewed in video files supplied with the project and at [http://www.nxtprograms.com/NXT2/segway/](http://www.nxtprograms.com/NXT2/segway/).

Balance Control

The real SegWay transporter uses input from a gyroscope to control the stability and balance. Because a gyroscope is not part of the Lego kit, SegWay robot makes use of the light sensor. The sensor registers the light intensity when the robot is started. As the robot tilts, the light intensity changes and the robot reacts by adjusting power to motors #1 and #2. As a consequence, the robot cannot maintain vertical position; it tries to maintain the position at which it is started. It is therefore necessary to start the robot at near vertical orientation.
Follow the instructions below to build your SegWay robot assembly. All SolidWorks part files are supplied as part of this project, so you only need to mate them to create a final assembly. Because the basic assembly building skill is a prerequisite to this lesson, the steps below do not detail how to mate parts.

It is a good habit to think about the assembly building procedure ahead of time if we want to follow with a simulation in SolidWorks Motion. Proper methodology will result in a smooth and faster computation, while improperly built assemblies may cause the solver to lock and terminate the solution. First, review how the mechanism moves and how many degrees of freedom it features. Then decide on how to split the top level assembly into subassemblies. This is important because SolidWorks Motion typically considers subassemblies as rigid, resulting in a less complex model to solve.

**Tip:** The subassembly’s status can be changed from rigid to flexible. It is, however, recommended that you keep sub-assemblies set to rigid.

The procedure below recommends one way how to split the robot into individual subassemblies, which are then mated to create the full SegWay robot. You do not have to follow these steps rigorously. Rather, experiment and find your own way to build the SegWay robot.

Steps 1 to 8 suggest how to split the robot into the individual subassemblies. Steps 9 to 23 continue with the instructions on how to assemble the robot and orient it in the global coordinate system.

Build the following subassemblies.

1. **Horizontal connector.**
2 Left connector.

3 Right connector.
4 Lower horizontal connector.

5 Wheel and axle.
6 Left and right side of the rider bottom.

7 Arms and chest.

8 Rider’s head.
The following steps contain instructions to build the SegWay robot using the subassemblies and additional parts. Some suggested ways of mating the components are given in certain steps in order to eliminate redundant mates in the assembly. Redundant mates occur when two mates remove the same degree of freedom from a component. For example, when using a coincident and a concentric mate to mate a cylinder to a cylindrical hole in a block, both mates remove the rotation about the X and Y axis. This example can be seen in the image to the right. Reducing the redundant mates in an assembly helps to increase the accuracy of the motion simulation and reduce the potential for problems.

9 SegWay assembly.
Open a new assembly document.
Insert the CPU part, align it with the coordinate system and the planes as shown and Fix it.
Set the units to MMGS.
Save the assembly as Segway.SLDASM.

Note: Different orientations of the CPU is fine and would not have any effect on the accuracy of the simulation. However, to maintain consistency with the results published in this document, you must orient the CPU part as shown above.

10 Left and right connectors
Insert both the left and right connectors and mate them with the CPU.

Tip: While we recommend using hinge and concentric mates, other mate types are acceptable as well.

11 Motors.
Insert the Motor part for motors #1 and #2.
Mate them to the left and right connectors.
12 **Horizontal connector.**

Insert the horizontal connector and mate it to Motor parts #1 and #2.

13 **Rotors for motors #1 and #2.**

Add two Rotor parts and mate them to Motor #1 and #2.

**Tip:** We recommend that you use a concentric mate and a coincident mate between the Rotor origin and the side face of the Motor to connect the rotors with both motors. Doing this will remove any redundancies in the mates between these two parts.

14 **Axle and wheels.**

Insert the wheel and axle subassembly and mate it to the Rotor parts.

Insert the CrossTemplate part (configuration Five) and center it. Mate the CrossTemplate part to either of the two wheels and axle subassemblies (but not both).

**Important!**

Because the robot wheels are driven by two independent motors, the wheel and axle subassemblies on both sides must be disconnected. This way you could make the robot turn by adjusting power at either motor #1 and #2.

15 **Lower horizontal connector.**

Insert the lower horizontal connector subassembly and mate it to Motor #1 and #2.
16 **Left and right bottom sides of the rider.**
Mate both subassemblies to the horizontal connector.

17 **Motor #3 and its rotor.**
Insert new Motor and Rotor parts and mate them.
Insert two instances of All_Straight (configuration three) and two instances of BlueConnectorLong parts. Mate them to the new Motor #3 part, as shown in the figure.

18 **Connect Motor #3.**
Mate the Rotor from the previous step to the left and right bottom parts of the rider.
Notice, that Motor #3 can rotate about the Rotor axis. This degree of freedom will be eliminated in the following step.
19 Orient Motor #3.

Using the CrossTemplateWithCap (configuration Eight), align Motor #3 with the rest of the assembly so that it assumes a vertical position.

Make sure to eliminate the horizontal motion of the CrossTemplateWithCap part by adding an extra mate.

20 Rider’s head

Insert the head subassembly. Using two instances of the CrossConnectorLong part attach it to Motor #3.

Tip: We recommend that you use a concentric mate and a coincident mate between a point on the back edge of the Motor and edge of the All_Straight part in the rider’s head subassembly as seen in the image on the right. Doing this will remove any redundancies in the mates between these two parts.

21 Arms and chest.

Complete the SegWay robot assembly by attaching the arms and chest subassembly.
The next two steps insert the platform (Tabletop) and place the robot to its initial position and orientation.

22 **Tabletop.**

- Insert the Tabletop part.
- Position the Tabletop so that the robot is centered and closer to the back side. Orient it as shown by the triad in the figure and make it parallel to the assembly Top Plane.

- Use **Tangent** mates between the tires and the top face of the Tabletop so that the tires touch the surface.
- Fix Tabletop.

*Note:* Utilize **Use for positioning only** mates to align Tabletop with the Top Plane and for the **Tangent** mates. These mates are only used to position and orient the Tabletop part.

23 **Float robot.**

- Change the status of the CPU part from **Fixed** to **Float**.

*Note:* Floating the CPU makes the robot free and ready to move in SolidWorks Motion. Also, because the CPU was aligned with the assembly plane (step 9), the robot assumes a vertical position.
SolidWorks Motion Model

The following section will guide you through the setup of the simulation and basic controls in SolidWorks Motion. As you work through this part, you will gradually improve the control algorithm so that, in its final stage, it correlates with what you observe in reality.

It is assumed that you are familiar with the basics of the SolidWorks Motion software. If that is not the case, please ask your instructor to advise you on how to obtain more elementary training materials to make yourself comfortable with the software.

24 Motion study.

Add in SolidWorks Motion and insert a **New Motion Study** and change the **Type of Study** to **Motion Analysis**.

Rigid Groups

Review the top assembly mates; the total number of mates can range from 30 to 50 depending on how efficiently you mated the components. Mates are responsible for the description of the relative motion between the mated parts, i.e. hinge mates only allow two connected parts to rotate relative to each other about the hinge axis. If solving the current model, SolidWorks Motion must consider all mates as locations where motion may occur (even if you know that the only resulting motion of the robot is rotation about the wheel axle). We can effectively use rigid groups to simplify the calculation.

A rigid group combines parts and subassemblies in a group and treats them as one mass, significantly reducing the number of mates that need to be considered by SolidWorks Motion. Three rigid groups can be created in our case:

- Entire body of the robot, excluding the rider's head subassembly,
- Left wheel and axle subassembly and the corresponding Rotor,
- Right wheel and axle subassembly, corresponding Rotor, and the CrossTemplate part.