Train Trax: Train Monitor for Positive Train Control Test Beds

System Test Plan

Document

Version 1.3

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# Revision History

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| Version | Date | Description | Author |
| 1.0 | 10/22/2015 | Initial Version. | Stephen Jalbert  Rashad Madyun  Corey Sanders |
| 1.1 | 11/9/2015 | Updated the excluded software list. Clarified description of testing procedures. | Stephen Jalbert |
| 1.2 | 12/01/2015 | Updated the cover page to make clearer versioning information.  Fixed formatting of document.  Replaced “Train Navigation Engine” with “Train Navigation Service”.  Add overview figures and scope.  Updated Glossary  Included more details on how video will be used for testing.  Updated the requirements traceability matrix. | Corey Sanders |
| 1.3 | 12/08/2015 | Updated the glossary with the latest information.  Updated section describing the scope of the project. | Corey Sanders |
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# Introduction

In a real-word train environment, trains often carry very valuable assets: people, oil, merchandise, etc. It is important for rail system to be able to track the location of each train in order to prevent collisions and to monitor the state of trains in the event of attack.   
The computer engineering department owns a Positive Train Control Test Bed that is intended to mirror a typical train environment. The purpose of the train track is to be a teaching tool for instructing students on creating safety critical software. It is desired for the department Positive Train Control Test Bed to be able to track the location in for each train for this reason. Like subway trains, the department Positive Train Control Test Bed is completely indoors, so a Global Position System (GPS) is not possible.   
The purpose of this document is to describe how to test that the Train Trax Train Monitor correctly assists the department with tracking trains as they move along the Positive Train Control Test Bed. It describes how testing will be conducted to ensure measure the quality of the system in both meeting the requirements discussed in the software requirements specification as well as its construction.

## Scope



Figure 1 Train Trax Communication Diagram

Train Trax's primary purpose is to estimate the position of each train operating along the Positive Train Control Test Bed accurately enough to allow Train Operators schedule trains to run close enough to operation on the same section of track with minimal risk of collision. Additionally, Train Trax provides a means for Train Operators to easily control switches on the train track without the need to using any additional train control software. Train Trax is only a monitor for trains, not train control software. Furthermore, the development team is to assist the department with any modifications necessary to the Positive Train Control Test Bed to support proper operation of Train Trax, including the placement of markers on the track at pre-designated locations.

Train Trax consists of hardware that is equipped on either the train engine or rail cars to measure train movement. It also consists of software that will run on existing equipment within the department to graphically display train positions and to control movement.

As shown in Figure 1, a unit is attached to a rail car that is equipped with an Inertial Motion Unit (IMU) that measures the acceleration and angular velocity (rotational vectors) of the rail car as it is tugged by the train along the track. This unit, called a Motion Detection Unit, will send its collected measurements over WIFI to a train monitor terminal (i.e. computer) that will estimate the train’s position using numerical integration to solve for displacement kinematic equations. The resulting position is then displayed on the terminal as well as the layout of the track itself. RFID tags, whose position is already recorded in a database, will be used as the track markers and placed strategically throughout the track so that they can correct the position calculated from IMU measurements. Lastly, the monitor terminal displays representations of all of the switches on the track and allows the user to control them through a GUI that sends LOCONET messages to the track's switch controllers, which then control relays to change a switch’s state. Train control software, such as JMRI, is expected to be used to control/throttle the movement of the train via LOCONET messages to the Train Command Station.

# Glossary

**Digital Command Control (DCC)**

Digital Command Control protocol which is a electric signaling protocol used to control train engines on a train track through the rails.

**Java Model Railroad Interface (JMRI)**

Popular open-source software suite for controlling model trains.

**Inertial Motion Unit (IMU)**

A hardware device often composed of an accelerometer and a gyroscope used to perform dead-reckoning of the position of objects based on measurements of effects of forces acting on an object in space.

**LocoNet**

An Ethernet-link proprietary communication protocol created by DigiTrax for full train and track layout control of model train sets.

**Position**

A description of where a given object is located on the Position Train Control Test Bed. It uses a relative coordinate system based on the distance from a fixed point on the table.

**Positive Train Control Test Bed**

A model train system designed to scale to represent actual railway systems. Its purpose is to facilitate the testing, design, and training of train control systems without the risk of associated performing these activities on live trains, such as bodily injury and costs for scheduling and operating full scale trains.

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**Rail Car**  
Simple wheeled container that is attached to the train to carry cargo.

**Railway System Owner**

The entity that owns Positive Test Control Test Bed.

**Radio Frequency Identification (RFID)**

Data exchange method that relies on the properties of induction to read information imprinted on a device when in close proximity.

**Track**  
The track is a pair of metal rails that the train runs on top of to move. It provides both power and control signals to the train. It is divided into different physical pieces called sections to simplify its assembly.

**Track Block**

A segment of the entire track of the test bed, which has been divided and identified into segments by the Train Technician and Train Operator, which is used to highlight areas of interest by these individuals and to divide the track into regions from which trains can go in different directions on the track. In practice, a block is Track Circuit Block. It is a single element where the Positive Train Control Test Bed Can Detect whether one or more trains is on it or not.

**Track Marker**  
Special hardware placed at different spots on the track to highlight places of interest on the track. Examples of train markers include RFID tags that are read by the train as it moves along the track, and track sections that signal when one or more trains are present.

**Track Switch**Devices on the track to control the direction of train engine movement by changing the sections of track that are connected together.

**Track Switch Controller**

A hardware device that is the bridge between hardware that physically controls switches of the test bed and software being used to remotely control the test bed. It is attached to the track that translates requests from operators to control track switches on the test bed into signals to switch relays that move the switches into different positions.

**Train**

A to-scale model of a commercial train engine. It is the primary vehicle used to move along the test bed

**Train Command Station**

A hardware device that is the bridge between hardware that physically controls trains of the test bed and software being used to remotely control the test bed. It is attached to the track that translates requests from operators to control the train into control signals that the train understands.

**Train Control Terminal**

The equipment, such as a laptop, used by the system to allow operators to control trains that belong to the test bed.

**Train Monitor Development Team**

A group of people who have been commissioned by the Railway System Owner to create a system for tracking the movement of trains along the railways system real time.

**Train Monitor Terminal**

The display equipment, such as a laptop, used by the system visually display to operators information about the test bed.

**Train Occupancy Detector**

A hardware device that is the bridge between hardware that physically detects when one or more trains are on a section of track and software being used to report train locations. It is attached to the track and uses changes in current draw that occur when one or more trains are being powered by a track block in order to detect train occupancy in that block. Lastly, it can issue messages for when a train is entering or exiting a track block.

**Train Operator**

A person or machine that controls one or more of the trains on the Positive Train Control Test Bed.

**Train Technician**

A train technician is a person who maintains the Positive Train Control Test Bed.

# Tested Features

* Report the current position of each train on the rail system.
* Report the history of each train’s movements along the rail system.
* Predict the direction that a given train will go when it crosses the next switch in its path.
* Control switches on the rail system.
* Collect information to describe the shape and geometry of the track.
* Collect raw measurements used to estimate each train’s position.
* Alert when trains are too close together.
* Alert when there is a system failure.

# Features Not Tested (Per Cycle)

N/A

# Test Items

|  |  |
| --- | --- |
| **Test Case** | **Associated Requirements** |
| Test Acceleration Measurement | MDU-1010, MDU-1030, MDU-2000, MDU-2010 |
| Test Rotation Measurement | MDU-1020, MDU-1050, MDU-2000, MDU-2020 |
| Test Train Marker Detection | MDU-1040, MDU-1060 |
| Test Report of Train Position | TNE-1000, TNE-1010, TNE-1020, TNE-1021, TNE-1022, TNE-1030, TNE-1031, TNE-1032, TNE-1033, TNE-2000, TNE-9000, TND-5000, GUI-1000, GUI-3000 , GUI-9000 |
| Test Track Switch Control | TNE-4000, GUI-4000, GUI-6000 |
| Test Train Travel Path Display | TNE-1000, TND-1000, TND-2000, TND-5000, GUI-5000 , GUI-5010 |
| Test Persistence of Positive Train Control Test Bed Information | TND-1000, TND-1010, TND-1020, TND-2000, TND-2020, TND-2030, TND-2031, TND-2032, TND-2040, TND-3000, TND-3010, TND-3020, TND-3030, TND-3060, TND-4000, TND-4011, TND-5000 |
| Test Reporting of Track Geometry | TNE-3000, TND-3000, GUI-2000 , GUI-2020, GUI-2030 |

Table 1 Requirements Traceability Matrix

# Testing Strategy and Approach

## System Testing

The purpose of system testing is to verify that the system's functions correctly to meet requirements. It involves running the system along on the customer's Positive Train Control Test Bed or replaying collected data from operating the system on the test bed. It is important that the primary use cases for the system be reflected also in these tests.

Test Report of Train Position:

* Compare estimated train position against observed train position from video using visible markers of know position as reference points.
  + Stickers are placed under each RFID tag on the track. The stickers below the RFID tags are to be big and reflective enough to easily appear in the video.
  + A camera is placed above the track to record movements of the train across the track.
  + The initial position of the train is on top of a RFID tag before recording of the video starts. The initial RFID tag is recorded in addition to the video. It also will be recorded in the name of the video.
  + Since the RFID tags are to be evenly spaced apart (presently 6 inches), the distance travelled by the train can be determined by the tester visually counting the number of RFID tags that the train passes by.
  + Each frame of the video has a unique time stamp. The time between the first frame that has the train crossing a given RFID tag/sticker and the first frame that had the train crossing the next RFID tag/sticker can be used to approximate the change in time between RFID tags. This time can be used to calculate the average speed of the train during this period.
  + In order to synchronize timestamps from recorded video and motion detection unit measurements, the RFID reader on the test rail car is painted so that one can visually identify in the video when the RFID reader crosses RFID tags.

Test Switch Control:

* Verify that switches change state after request for change from monitor
* Verify that LocoNet traffic is generated correctly when controlling switches from the terminal.

Test Acceleration Measurement:

* Rotate the unit along each axis of the device and verify that it reports correctly gravity along the expected axis.

Test Rotation Measurement:

* Place the device in a fixed position. Rotate the device a fixed amount of degrees along each device axis. Verify that the measured change in rotation matches the actual rotation of the device.

Test Train Marker Detection:

* Position the rail car on the track. Move the rail car along a known train marker. Verify that the device announces that the car crossed the marker.

Test Persistence of Positive Train Control Test Bed Information:

* Verify that saved items can be read after restarting the system.

Test Train Travel Path (Position History) Display / Test Reporting of Track Geometry

* Run train along a loop of track where the shape and sequence of train markers is already known
* Verify that sequence of markers read by Motion Detection Unit matches expected sequence.
* Have Tester verify that path of train shown by the Train Monitor GUI matched the shape of the test track loop.

## Integration Testing

The purpose of integration testing is to identify errors with how the main components of the system interact with each of other and the Positive Train Control Test Bed. The plan for testing each main component is described below.

### Boundary Testing

One cross-cutting concern for testing is checking how the system handles the range of values that are input into the system. It is important to test how Train Trax responds specifically to input that is provided either directly from or from observing its environment. For this purpose, the following type of boundary testing will be conducted where necessary:

* negative values
* zero
* positive values
* maximum value
* maximum value +1
* minimum value
* minimum value-1

### Motion Detection Unit

Create a listener program that will record all of the radio messages sent by the motion detection unit, save them, and decode them. Compare the decoded output against expected test values.

Test cases include:

* Test Bounds of Gyroscope Measurements
* Test Bounds of Accelerometer Measurements
* Test when Gyroscope is unresponsive.
* Test when Accelerometer is unresponsive.
* Test when RFID Reader is unresponsive.
* Test when Optical Sensor is unresponsive.

### Train Navigation Service

Feed in previously recorded measurements from the track and synthetic data generated from ideal calculation of the track to simulate input from the Motion Detection Unit. Compare messages output to LocoNet to confirm control behavior of the service. Compare return values from service calls to against expected values from recorded measurements based on observations of test rail car from video recorded when each recorded test sample was collected.

Test cases include:

* Test when Motion Detection is unresponsive.
* Test when Motion Detection Unit reports an error.
* Test reporting of an unknown track marker ID
* Test reporting of an unknown train ID
* Test when Train Navigation Database is unresponsive.
* Test when Train Controller is unresponsive.
* Test when Train Controller reports an error.
* Test Bounds of Track Marker (RFID tag) positions.

### Train Terminal Display UI

Have Tester confirm that expected visual behavior of the display is what is observed. Use a Train Navigation Service Driver and Train Database Driver to feed input to the display and confirm output. Each Driver emulates the behavior and functions of the system component it represents.

Test cases include:

* Test when Train Navigation Database is unresponsive.
* Test when Train Navigation Database reports an error.
* Test when Train Navigation Service reports an error.
* Test when the Train Navigation Service cannot be located.
* Test Bounds of Train Position Estimates
* Test Bounds of Track Marker (RFID tag) positions.
* Test Bounds of Track Layout

### Train Navigation Database

Write test values to the database. Restart the system. Confirm that values written to the database can be read back. Remove values from the database. Restart the system. Confirm that values no longer exist in the database.

Test cases include:

* Test when cannot connect to backend Database.
* Test when cannot read from backend Database.
* Test when cannot write to backend Database.

## Unit Testing

The purpose of unit tests is to identify as many errors as possible with the implementation of system. Unit Tests should be created to test all of the operations performed by each object in the software. They will also be created to verify that each component of the software behaves according to its responsibilities described in the software design document. Automated unit testing frameworks, such as JUnit and Arduino Unit will be used perform all of the unit tests created. EclEmma will be used to verify the amount of code coverage performed by the tests. 100% structural and branch Code Coverage is required for the product to ensure that all code in the software of the system is being exercised.

# Description of Functionality

## Features

* Report the current position of each train on the rail system.
* Report the history of each train’s movements along the rail system.
* Predict the direction that a given train will go when it crosses the next switch in its path.
* Control switches on the rail system.
* Collect information to describe the shape and geometry of the track.
* Collect raw measurements used to estimate each train’s position.
* Alert when trains are too close together.
* Alert when there is a system failure.

## Use cases

* Monitor train
* Control track switches

# Arguments for Tests

* Simulated IMU messaging
* Recorded sensor measurements
* Simulated RFID tag detection
* Video of train movement
* Simulated Train Navigation Service messages
* Measured position of objects on train track /test track
* User control of system

# Expected Output

* Train Position Estimates
* LocoNet message traffic
* Visual display from UI
* Radio traffic from motion detection unit
* Content of train database.

# Specific Exclusions

Any third party source code or libraries with a sufficiently large user base (e.g. millions of users) are exempted from unit testing. This is because it is assumed that the authors of the third party have independently conducted testing for them and the user base of sufficient size that significant errors have been detected and resolved.

Excluded source code and libraries:

* Arduino Development Environment
* Junit
* Java Development Environment
* Eclipse
* Eclemma
* Octave
* Android Development Environment
* Standard Arduino Libraries
* Standard GNU C Libraries

# Dependencies

* Camera
* Video Software
* Motion Detection Unit Test Driver
* Navigation Service Test Driver
* Train Monitor GUI Test Driver
* Train Database Driver
* Train Database Client Software
* Wireshark
* JMRI Train Control Software
* Positive Train Control Test Bed
* JUnit
* EclEmma code coverage tool
* Arduino Unit (https://github.com/mmurdoch/arduinounit)
* Test Computer
  + Windows or Linux

# Success/Failure Criteria for Test Cases

* Test Acceleration Measurement
  + All reported acceleration measurements match expected acceleration measurements.
* Test Rotation Measurement
  + All reported rotation measurements match performed rotations.
* Test Train Marker Detection
  + The train marker is reported matches the test the train marker that the tester was instructed to move the rail car across.
* Test Report of Train Position
  + The final position reported matches within a tolerance the final position that the rail car is moved.
* Test Track Switch Control
  + The track switch that is changed matches the switch that changes on the Positive Train Control Test Bed.
* Test Train Travel Path Display
  + Verify that the path rendered by the Train Monitor Terminal GUI matches the shape of the track configured for the train to move across.
* Test Persistence of Positive Train Control Test Bed Information
  + Verify that the information reported by the Train Monitor GUI when the train is moving is the same information reported when reviewing the travel history after restarting the GUI.
* Test Reporting of Track Geometry
  + Verify that the path rendered by the Train Monitor Terminal GUI matches the shape of the track configured for the train to move across.

Pass/Fail Criteria for the Complete Test Cycle:

* A test cycle is considered complete when all of the system tests and unit tests have been completed and all have passed. Anything else is considered a failure

# Entrance and Exit Criteria

System testing must be conducted before any release or when changes to the tests have been made. System testing is considered complete when the Test Manager verifies that all tests passed. If testing is being done because of changes to the tests, the Moderator must also verify that all tests passed. All System tests must pass before a release can be completed.

Unit Test and Integration Testing must be conducted before any change to the code can be approved. Testing is considered complete when the Moderator verifies that all tests passed.

# Test Suspension Criteria and Resumption Requirements

When conducting any of the types of testing, the tester must execute all of the test cases available. A tester may stop execution of a test case on the first step that fails. After all of the test cases have been executed, the tester must suspend testing until notified by a member of the team that corrections have been made. Once notified, testing will be performed for all test cases again starting with all of the test cases that failed.

# Test Deliverable and Status Communication Vehicles

The state outcome of testing should be communicated to the team with a test report. For system tests, this will be a copy of the Test Description Document that reports the purpose for the test and the target release version and the version control ID for the specific version of code tested. The test description versions should be associated with the target release both in the version control system and any associated change request that prompted the testing.

For unit tests and integration tests, this should be an automated test report created by the code coverage tool. The automated report should be attached to the change request associated with the features or fixes implemented and saved in the version control system.

# Testing Tasks

* Conducting unit testing of software
* Conducting integration testing of software
* Conducting system testing of software
* Updating unit tests of software
* Updating integration tests of software
* Updating system tests
* Verifying unit tests
* Verifying integration tests
* Verifying that system tests
* Verifying system test traceability to requirements

# Hardware and Software Requirements Problem Determination and Correction Responsibilities

Every time that a change to the code base is completed, the unit tests and integration tests for the code base must be updated and reviewed. The change cannot be considered complete until all unit tests passed. The Test Manager must be included with each review and must make changes to the system tests if necessary and place those tests under review.

# Staffing and Training Needs/Assignments

* Developers are responsible for conducting and updating unit and integration tests before checking in changes.
* The Moderator is responsible for running unit tests and integration tests before declaring an issue complete. He also is responsible for verifying that unit test and integration tests are correctly updated as part of the review process.
* The Test Manager is responsible for running complete test cycles for releases and as needed for testing changes as part of the review process. He also maintains system tests and verifies that system tests trace back to requirements.

# Test Schedules

* Release 2/1/2016
  + Report the current position of each train on the rail system.
  + Collect raw measurements used to estimate each train’s position.
* Release 3/1/2016
  + Control switches on the rail system.
  + Report the history of each train’s movements along the rail system.
  + Collect information to describe the shape and geometry of the track.
* Release 4/1/2016
  + Alert when trains are too close together.
  + Alert when there is a system failure.
  + Predict the direction that a given train will go when it crosses the next switch in its path.
* Release 4/22/2016
  + Final Release Testing
  + Customer Acceptance Testing

# Risks and Contingencies

Risks are addressed according to the procedure described in the Software Development Process and Configuration Management Plan Document.

# References

* Carnegie Mellon University System Test Plan Template. <http://www.sei.cmu.edu/productlines/ppl/system_test_plan_template.html>
* Train Trax Software Development Process and Configuration Management Plan Document
* Train Trax Software Requirements Specification Document
* Train Trax Software Design Document