SteerVu™

RoverVu Module

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Contents

1. Description

SteerVu™ provides the GNT auto-steering logic controller with high-accuracy, high-performance GPS navigation solutions and attitude information. SteerVu™ steers vehicles such as rubber-tired gantry (RTG) cranes, cargo transport vehicles, lawn mowers and tractors using a "map and match" mode of operation. SteerVu™ is designed for use in repetitive navigation applications.

SteerVu™ consists of a Base Server (BaseVu) and a Rover Client (RoverVu). BaseVu is connected with one or more GPS Base Stations. BaseVu receives raw GPS observations from the Base Station(s) in real-time. The status of the Base Station(s) is constantly monitored. RoverVu is installed on a vehicle and is connected with BaseVu. Upon receiving a request from RoverVu, BaseVu transmits the raw GPS observations received from the Base Station(s) to RoverVu.

Map and match programming allows a human operator to map a navigation path by driving the vehicle over the path to be matched while RoverVu is in "map" mode. During map mode, RoverVu records and stores GPS positioning data which allows RoverVu to autonomously reproduce the mapped path. Multiple paths can be mapped and stored for a project site. Each path is uniquely defined by the GPS coordinates within the path. Navigation paths are stored locally in RoverVu memory and can be downloaded to a removable USB flash memory drives.

With the navigation paths stored, the vehicle is capable of retracing the mapped paths whenever necessary. When the vehicle is in the vicinity of the desired path, the operator can select the desired navigation path to be matched from a list of paths saved for the site in RoverVu memory. Once the path has been selected and connection to BaseVu has been achieved, the operator moves the vehicle near the start of the navigation path. The operator then places the vehicle in automatic operation mode and the vehicle enters the navigation path, moving to the desired locations automatically.

The GPS RTK (Real-Time Kinematic) technique allows the vehicle to know precisely where it is on the surface of the earth to a positional accuracy of better than one inch. Under purely robotic control, the vehicle will wander off course due to errors caused by wheel slippage, uneven terrain, and other mechanically-induced errors. RoverVu makes use of its GPS RTK navigation solutions and attitude information to correct for errors in the vehicle control system. In typical conditions where satellite visibility is favourable and the vehicle is well calibrated, the navigation path can be tracked to better than plus or minus two inches.

A typical field setup of SteerVu™ is illustrated in Figure 1.

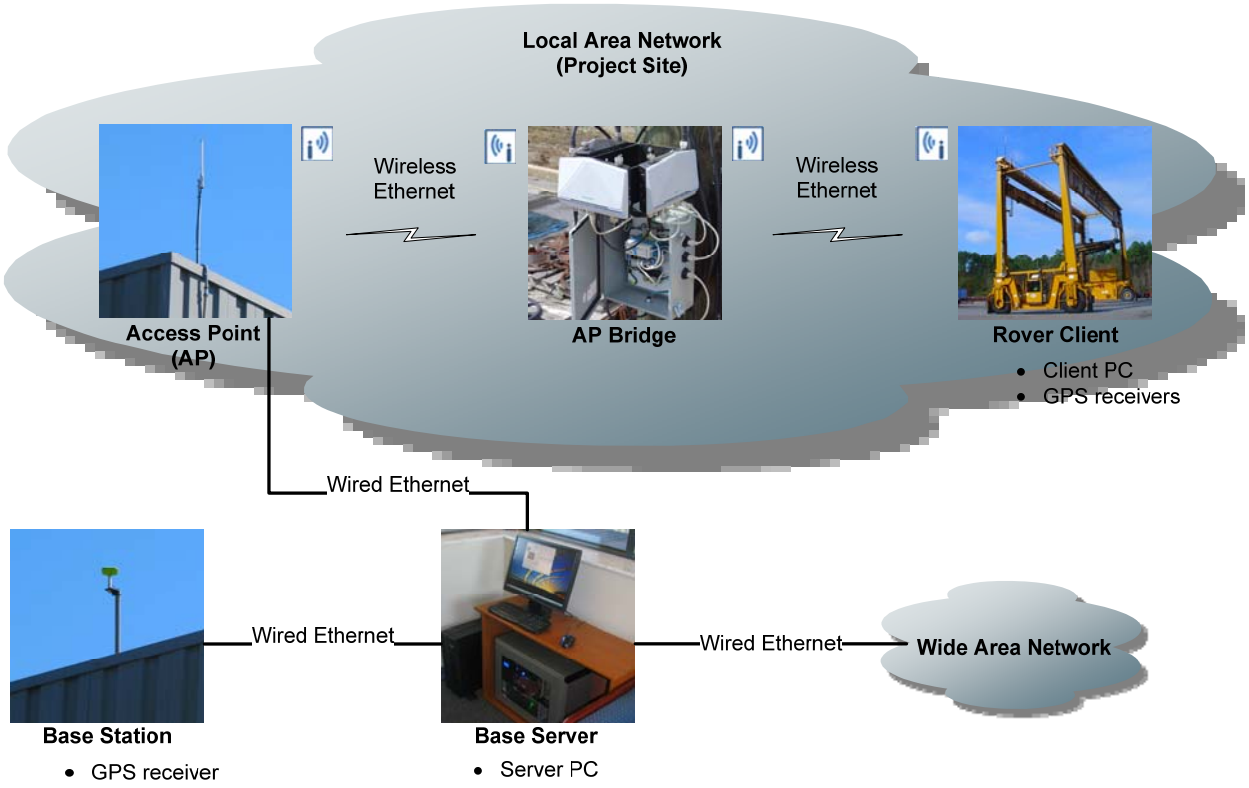

Figure 1: SteerVu™ field setup

2. RoverVu Layout

RoverVU comprises three sub-windows as illustrated in Figure 2, including Rover Client Software, GPS Status and Rover Track.

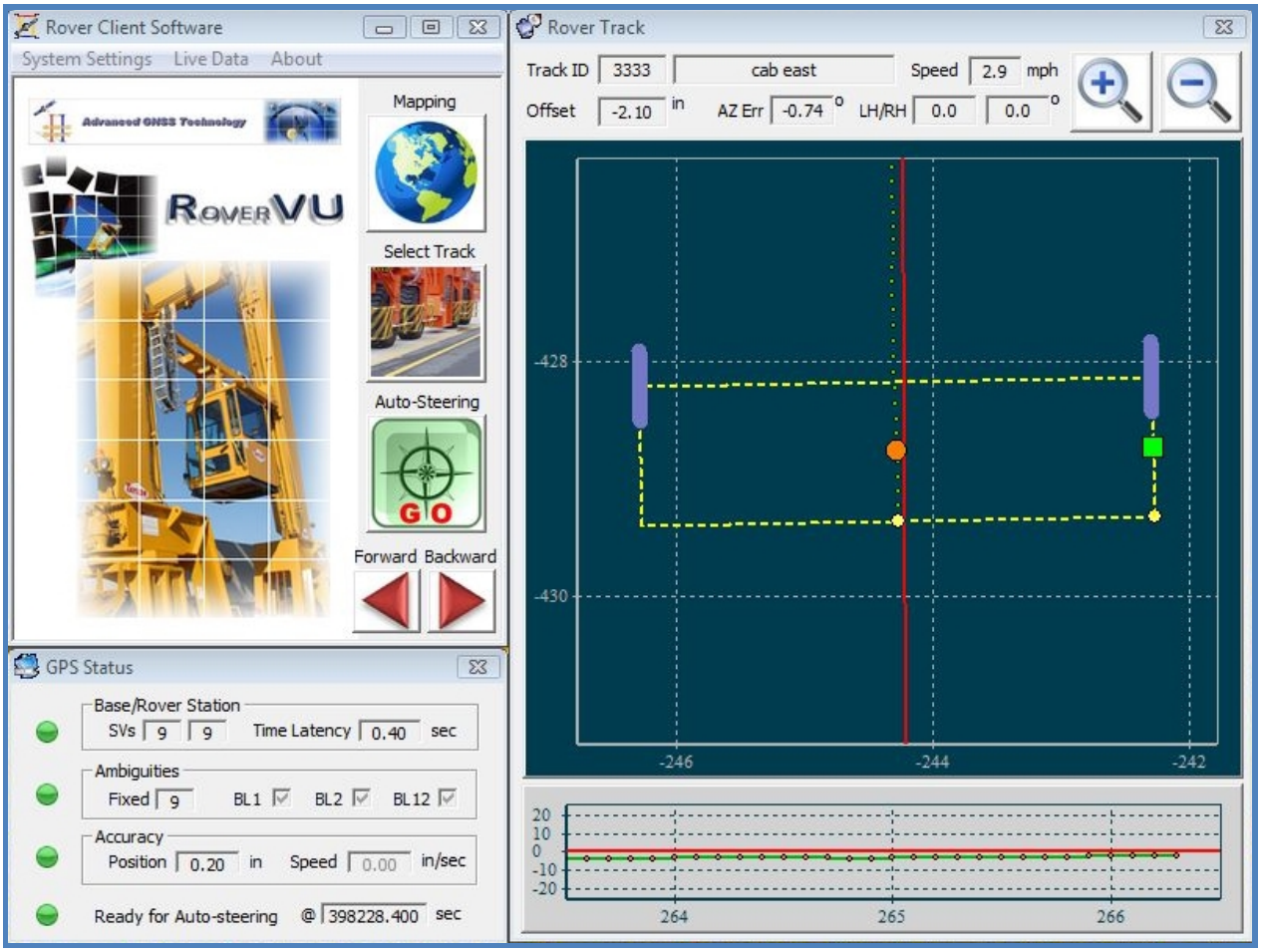

Figure 2: RoverVU layout

2.1. Rover Client Software Window

The Rover Client Software window is the main window of RoverVU (Figure 3). The menu system is used to access the utilities for auto-steering system parameters (see Section 3. Menu Descriptions). The utilities associated with user actions are activated through the button system (see Section 4. Main Interface).

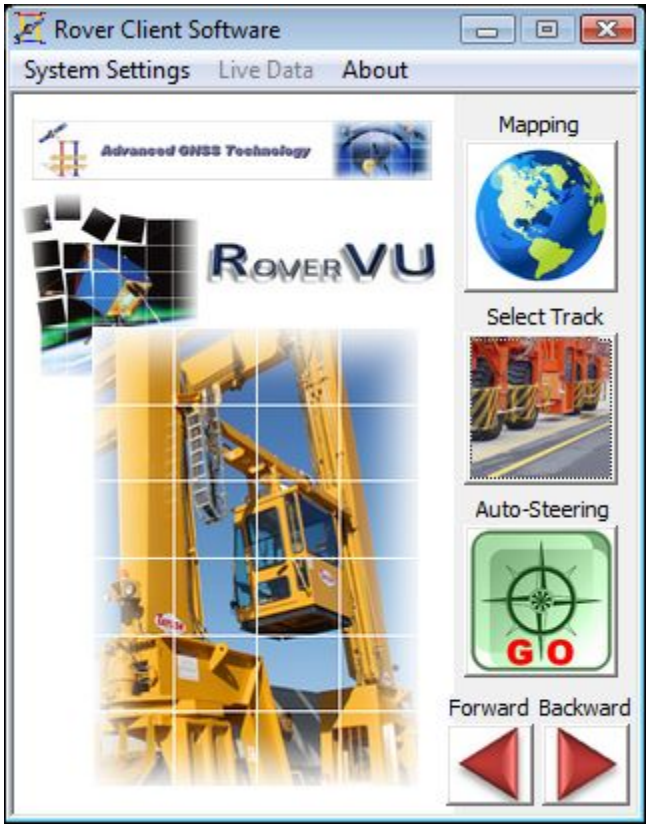

Figure 3: Rover Client Software window

2.2 GPS Status Window

The status of GPS satellites, Wi-Fi communications, and GPS solutions is displayed in real-time in the GPS Status window as illustrated in Figure 4. Users can confirm if the auto-steering function is ready to proceed through the GPS Status window. The signal lights indicate the status of individual functions, using the color scheme outlined in Table 1.

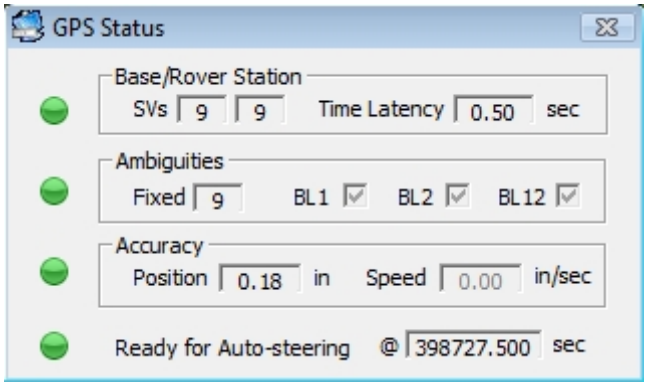

Figure 4: GPS Status window

Table 1: Color scheme for status indication

Signal	Indication
	Ready for action or healthy
	Unknown
	Not ready or unhealthy

Base/Rover Station: Indicates the status of GPS satellites and Wi-Fi communications at both the Base Station and the Rover. The green light is turned on when more than 4 satellites are being tracked and the time latency (i.e.,, the age of the Base Station data) is shorter than 10 seconds.

- **SVs**: The number of GPS satellites being tracked at the Base Station and the Rover.
- **Time Latency**: The time difference between the Base station GPS measurements received at the Rover and those of the Rover. If Wi-Fi communications experience difficulties, the Time Latency can increase from a few seconds to tens of seconds.

Ambiguities: Indicates the status of GPS solutions being used for the auto-steering logic controller. The green light is turned on when ambiguities are fixed correctly.

- **Fixed**: The number of GPS satellites for which carrier-phase integer ambiguities are resolved. It indicates the number of GPS measurements being used for providing high-precision RTK positioning solutions.
- **BL1 Checkbox**: Checked automatically if the baseline solution between the Base antenna and the Rover antenna #1 (the cab side antenna for RTG cranes) is available.
- **BL2 Checkbox**: Checked automatically if the baseline solution between the Base antenna and the Rover antenna #2 (the center antenna) is available.
- **BL12 Checkbox**: Checked automatically if the baseline solution between two Rover antennas is available.

Accuracy: Indicates the quality of GPS solutions being used for the auto-steering logic controller. The green light is turned on when position accuracy is better than ±2 inches.

- **Position**: The accuracy of GPS position coordinates.
- **Speed**: The accuracy of GPS velocity estimates.

Ready for Auto-steering: Indicates whether or not auto-steering is ready. The green light is turned on when all three signal lights (Base/Rover Station, Ambiguities and Accuracy) are turned on.

- **@___sec**: Shows the GPS Second of Week from GPS Time of the current epoch.

2.3 Rover Track Window

The Rover Track window provides a graphic interface of the machine for the machine operator. The operator can read tracking information of the selected path including response as illustrated in Figure 5. The operator can also visualize machine operation as illustrated in Figure 6 and Figure **7**.

Top Panel:

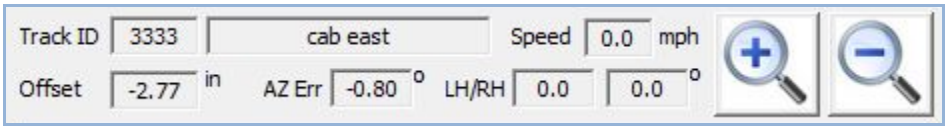

Figure 5: Top panel of the Rover Track window

- **Track ID**: Unique path identifier and name.
- **Speed**: Vehicle ground speed.
- **Offset**: Off-track distance at the vehicle Control Point.
- **AZ Err**: Vehicle heading (azimuth) error.
- **LH/RH**: Left Hand (LH) and Right Hand (RH) wheel angle reading.
- **Zoom In/Out Button**: Zoom in/out of the map display.

Map Display: Visualizes vehicle operation on the track map, as it responds to the auto-steering logic controller.

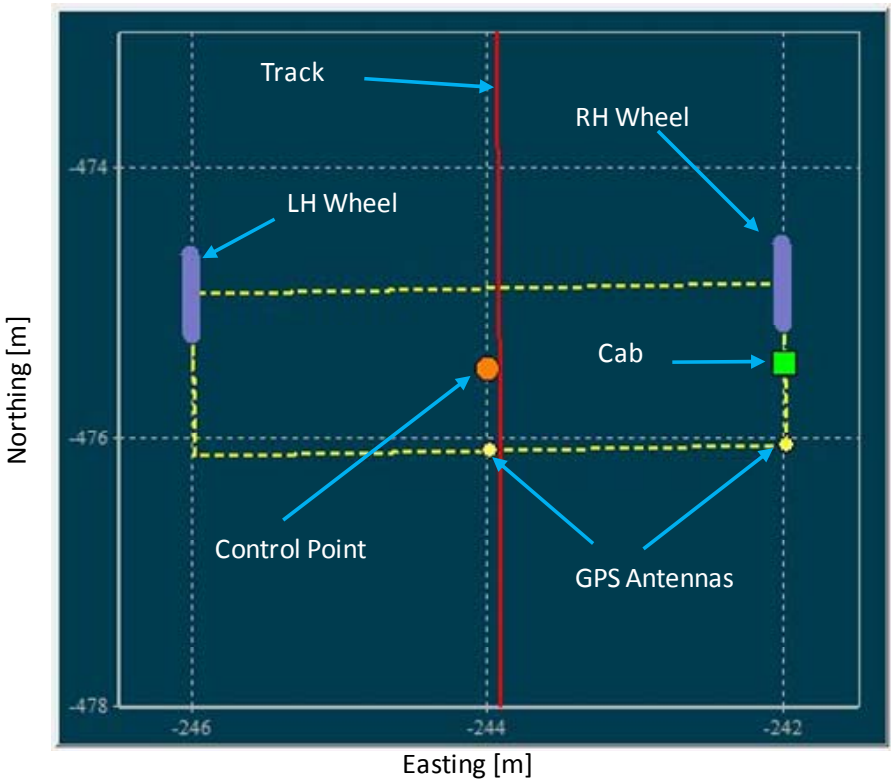

Figure 6: Map display panel for RTG Cranes

Off-Track Display: Shows the off-track trajectory of the vehicle Control Point over the operation time. The vehicle moving direction is always the right side of the display panel.

Figure 7: Off-track display panel

3. Menu Descriptions

3.1 System Settings Menu

User Inputs and Machine Calibration utilities are located in the System Settings menu as illustrated in Figure 8. As the parameters in the System Settings are critical for the performance of the auto-steering logic controller, only authorized persons are allowed to access these utilities.

Figure 8: System Settings menu utilities

3.1.1 System Settings | User Inputs

RoverVu allows users to input system parameters as illustrated in Figure 9.

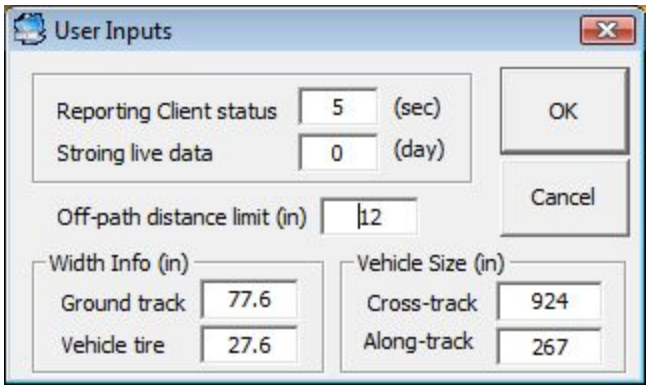

Figure 9: User Inputs Form

User Inputs:

- **Reporting Client status**: Time interval for reporting the status of Rover operation to the Base Station Server.
- **Storing live data**: Archiving period of the Rover data in the (Rover) panel PC. Any data past the due date is deleted automatically from the storage.
- **Off-path distance limit**: Threshold for the normal auto-steering operation of the machine. The auto-steering logic controller controls the machine under normal conditions within the off-path distance limit. Once the machine crosses over the limit, the auto-steering logic controller instantly stops the machine and issues an alarm.
- **Ground track**: Width of the ground track.
- **Vehicle tire**: Width of the machine's tire.
- **Cross-track**: Length of wheel centers (along machine span).
- **Along-track**: Length of wheel base (along travel direction). Both the cross-track and along-track inputs are used for the machine's kinematic model.

> As the off-path distance limit, cross-track and along-track parameters are critical for auto-steering operation, users must be extremely careful to input correct values.

3.1.2 System Settings | Machine Calibration

In order to help the auto-steering logic controller control the machine optimally, it is critical for users to calibrate the machine beforehand. Four buttons are provided for machine calibration as illustrated in Figure 10.

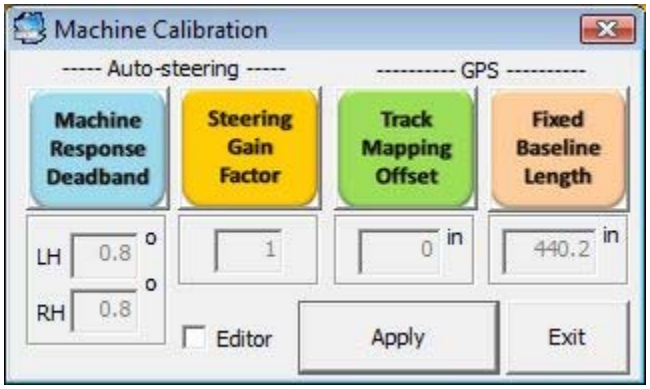

Figure 10: Machine Calibration Form

Users must calibrate the machine according to the calibration order in Table 2.

Table 2: Machine calibration order

Calibration Order	Action
1	Fixed Baseline Length
2	Machine Response Deadband
3	Track Mapping Offset
4	Steering Gain Factor

- **Fixed Baseline Length**: Click this button to determine automatically the fixed baseline length between two GPS antennas on the machine. It is recommended that users compare the captured result with known, measured baseline length if available.

  To determine an appropriate value for the Fixed Baseline Length, users must follow the procedures in Table 3.

Table 3: Fixed Baseline Length calibration procedures

Order	Action	Remark
1	Click the Fixed Baseline Length button.	Only when the signal light is green for the Ambiguities (see Section 2.2 GPS Status Window), will this calibration be enabled. A real-time calibration result is updated every second.
2	Click the Fixed Baseline	To capture the result, click the button again.

	Length button again.	
3	Click the Apply button.	The input value is not in effect unless the Apply button is clicked.

The captured calibration result is not implemented until the Apply button is clicked. Therefore, users should not proceed to the next calibration step until the Apply button is clicked. If this calibration was done previously, users can skip this step.

- **Machine Response Deadband**: The auto-steering logic controller is designed to issue a steering command every epoch, synchronized with the GPS positioning solutions at a 10 Hz update rate. Due to the mechanical hydraulic system in certain machines, the machine can experience a significant response delay to the issued steering command. This tends to overshoot the target track position. To prevent the auto-steering logic controller from overshooting, a desired wheel angle is calculated every epoch and compared with the current wheel angle. The Machine Response Deadband corresponds to a threshold for the difference between a desired wheel angle and an actual wheel angle.

  To determine an appropriate value for the Machine Response Deadband, users must follow the procedures in Table 4.

Table 4: Machine Response Deadband calibration procedures (for both LH and RH)

Order	Action	Remark
1	Click the Machine Response Deadband button.	This enables users to input a value. To disable this calibration, click the button again.
2	Input a value for LH (RH)	Acceptable value range: $0 < x < 5$. Typically a value between from 0.5 to 1.5 degrees is appropriate. It is recommended to begin with a smaller value.
3	Click the Apply button.	The input value is not implemented until the Apply button is clicked.
4	Hold the joystick.	
5	Turn the LH (RH) wheel manually.	Wide range (e.g., > 40 degrees) is recommended.
6	Release the joystick.	
7	Click the Auto-steering button.	Only when the green light (GO) is turned on for the Auto-steering button (see Section 4.3 Auto-steering), this calibration is enabled.
8	Watch how the LH (RH) wheel angle changes.	If the LH (RH) wheel angle oscillates (due to overshooting), increase the input value and

		then repeat from 3 to 7. The input value that does not make the LH (RH) wheel oscillate is what users are looking for.

As this calibration must be done in a static mode, the moving direction of the joystick is neutral. No pedal input is required. If this calibration was done previously, users can skip this step.

- **Track Mapping Offset**: To create a ground track map, the position trajectory of the center GPS antenna on a machine is used. Installation of the center GPS antenna on a machine can introduce a constant offset compared to other machine. To make the track map compatible, this offset must be calibrated on each machine. The track map being used is the reference for this calibration. If the track map has not been created, users must map the ground track first (see Section 4.1 Mapping).

  To determine an appropriate value for the Track Mapping Offset, users must follow the procedures in Table 5.

Table 5: Track Mapping Offset calibration procedures

Order	Action	Remark
1	Center the machine in the ground track.	For RTG Cranes, if the track map was mapped at the cab side, center the cab side tires between the two paint lines of the ground track.
2	Click the Track Mapping Offset button.	Only when the Ambiguities signal light is green (see Section 2.2 GPS Status Window), this calibration feature is enabled. A real-time calibration result is provided every second.
3	Click the Track Mapping Offset button again.	To capture the result, click the button again.
4	Click the Apply button.	The input value is not implemented until the Apply button is clicked.

As this calibration must be done in a static mode, the moving direction of the joystick is neutral. No pedal input is required. If this calibration was done before, users can skip this step.

- **Steering Gain Factor**: Depending on the characteristics of the machine on the test, the action of the auto-steering logic controller can be too aggressive or defensive in controlling the machine's wheel angles. The Steering Gain Factor button enables users to adjust the behaviour of the auto-steering logic controller.

  To determine an appropriate value for the Steering Gain Factor, users must follow the procedures in Table 6.

Table 6: Steering Gain Factor calibration procedures

Order	Action	Remark
1	Click the Steering Gain Factor button.	This enables users to input a value. To disable this calibration, click the button again.
2	Input a value	Acceptable value range: $0.1 < x < 10$. Typically a value between from 0.5 to 2 is appropriate. The default value is 1.
3	Click the Apply button.	The input value is not implemented until the Apply button is clicked.
4	Click the Auto-steering button.	Only when the green light (GO) is turned on for the Auto-steering button (see Section 4.3 Auto-steering), this calibration is enabled.
5	Drive the machine.	Evaluate the performance of auto-steering operation. Repeat 2 to 5 if further enhancement of the Steering Gain Factor is necessary.

- **Editor**: Check if users want to edit the values without calibration.
- **Apply**: Click to implement the input value.
- **Exit**: Close the Machine Calibration utility.

4. Main Interface

As illustrated in Figure 11, three user action utilities are enabled through the button system, including Mapping, Select Track and Auto-Steering. Click a button to activate the utility associated with it. The Forward and Backward buttons are used for indicating machine's moving directions, activated by the joystick.

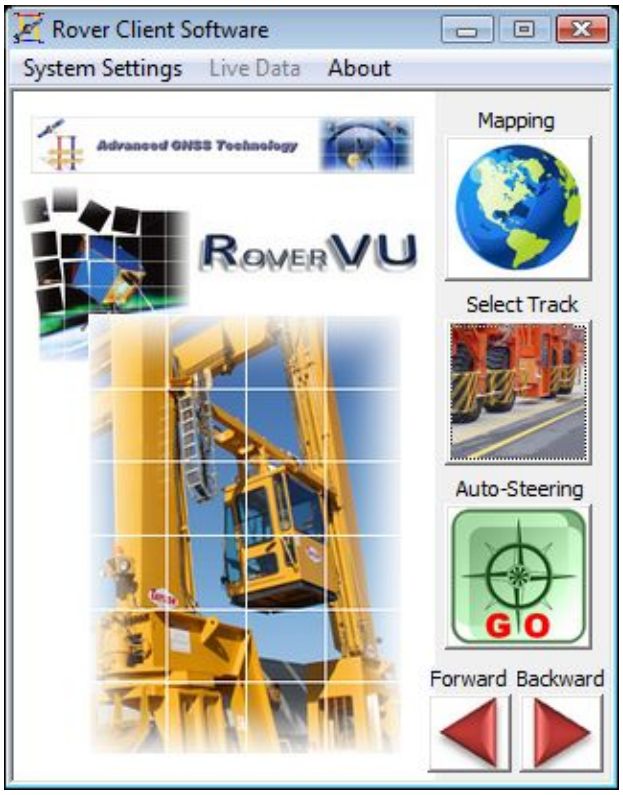

Figure 11: Button system for user actions

4.1 Mapping

The auto-steering logic controller always refers a track map and calculates the off-path distance and heading error of the machine. The track map also provides the reference for the Track Mapping Offset calibration (see Section 3.1.2 System Settings | Machine Calibration). As the accuracy of a track map is critical to the performance of the auto-steering logic controller, authorization is required to activate this utility (Figure 12). To create a ground track map, the position trajectory of the center GPS antenna on a machine is used.

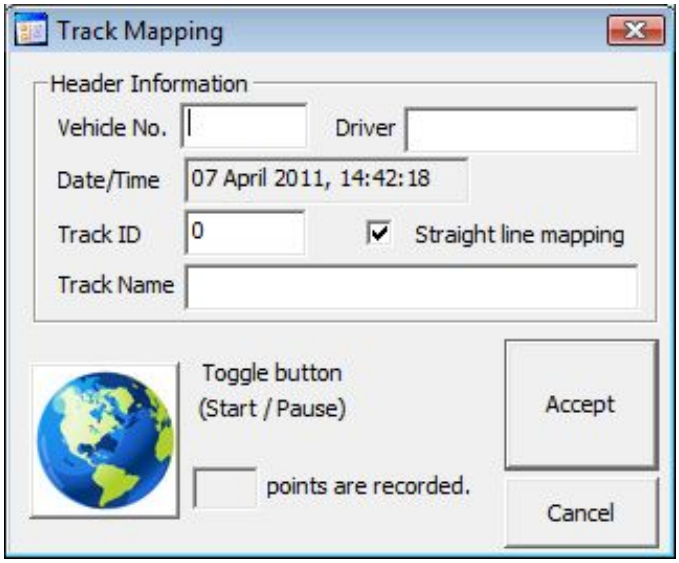

Figure 12: Track Mapping form

- **Vehicle No.**: Machine model or number (Optional)
- **Driver**: Machine operator (Optional)
- **Date/Time**: Mapping date and time (Automatic)
- **Track ID**: Unique track identifier (Valid range: 0-4095)
- **Track Name**: Track name or description
- **Straight line mapping**: Check if the track is a straight line. For mapping a straight line, the start and end points of the track are used. All other points between two end points are ignored. If unchecked, this utility allows users to map any style of lines.
- **Toggle button (Start / Pause)**: Click to Start / Pause data recording. Only when the Ambiguities signal light is green (see Section 2.2 GPS Status Window), the number of points recorded is updated every second.
- **Accept**: Generates the track using the recorded data and closes this utility.
- **Cancel**: Closes this utility without track generation.

To map a straight line, firstly move the machine to the start point, stop and then record GPS positioning solutions for at least 10 seconds. Make it sure

that the number of points being recorded increases. If not, check that the green Ambiguities light (see Section 2.2 GPS Status Window) is turned on. Secondly, click the toggle button to stop data recoding and then move the machine to the end point, stop and then record GPS positioning solutions for a few seconds for at least 10 seconds. There is no requirement for the way of driving the machine between the two points. However, users must not close this utility until data recoding is completed at the end point.

4.2 Select Track

The first action of the machine operator is to select a track where the machine is running as illustrated in Figure 13.

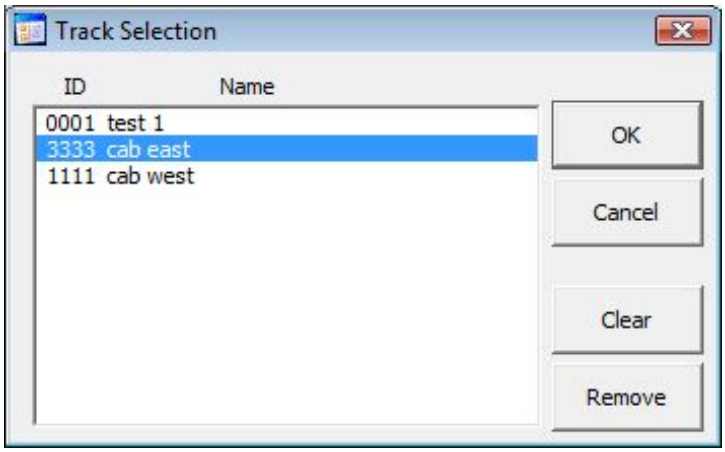

Figure 13: Track Selection window

- **ID**: Unique track identifier
- **Name**: Track name or description
- **OK**: Updates the selected track on the Rover Track window (see 2.3 Rover Track Window) and closes this utility.
- **Cancel**: Closes this utility without any update.
- **Clear**: Cleans up the track currently displayed on the Rover Track window.
- **Remove**: Delete the selected track from the track map database. As this function is critical, authorization is required.

4.3 Auto-steering

Once the track has been selected, the operator moves the machine near the start of the navigation path, and the green light is turned on for auto-steering, the machine is ready for automatic operation. Table 7 outlines the signals and actions of the Auto-steering button.

Table 7: Signal of auto-steering

Signal	Action
	Auto-steering is not ready yet. This button is signalled when any of the signal lights in the GPS Status window is not in green.
	Auto-steering is ready for action. This button is activated when the green light is on for all the signal lights in the GPS Status window. Click to kick off the auto-steering operation.
	Auto-steering is in action. Click to exit auto-steering mode.

If the joystick is activated for over 1 second, the auto-steering logic controller kicks out the auto-steering operation automatically.

4.4 Backward / Forward

The Backward and Forward buttons indicate the moving direction of the machine. The switch on the joystick controls machine's moving direction. The signals of moving direction are outlined in Table 8.

Table 8: Signal of moving direction

Signal	Action
	Neutral position. The machine does not move.
	Forward position. The machine moves towards the cab left for the RTG cranes.
	Backward position. The machine moves towards the cab right for the RTG cranes.

5. Error and Warning Messages

5.1 Error Messages

5.1.1 Auto-Steering Error Messages

Although rare, when the machine is engaged in auto-steering, fatal errors can take place. A summary of error messages is outlined in Table 9. Once these errors are detected, the auto-steering logic controller promptly interrupts the auto-steering operation and issues error messages. The machine stops by this action. Since auto-steering is disabled automatically by the system, users must activate auto-steering again once troublshooting is complete.

Table 9: Auto-steering error messages

Message	Cause and Action
▪ GPS RTK error detected	The auto-steering logic controller relies on high precision GPS RTK solutions (typically better than ±1 inch). If GPS loses the RTK mode for any reason (e.g., corrupted GPS measurements), auto-steering is disabled automatically by the system.
▪ ROVER GPS receivers are not active	The Rover GPS data has not been received at the Rover Client computer over a certain period of time (Default: 1 second). Either of the GPS receivers installed on the machine is malfunctioning or the Ethernet communication link is broken. Auto-steering is disabled automatically by the system.
▪ SERVER [ID] did not respond	The Base Station GPS data has not been received at the Rover Client computer through Ethernet wireless communications over a certain period of time (Default: 10 seconds). The Ethernet wireless communications or the Server computer is responsible for this problem. Auto-steering is disabled automatically by the system.
▪ FORWARD (or BACKWARD) Wheel crossed off-path limit	The machine's Forward or Backward wheel crosses over the off-path limit. The off-path limit is defined by users (Default: 12 inches). Auto-steering is disabled automatically by the system.
▪ Machine is located inside limit	The machine approaches one of the end points of the track. As soon as the machine gets into a certain boundary of the end points (Default: 2 ft), auto-steering is disabled automatically by the system.

▪ TMW message (PGN 65281) error	The CAN message of the machine has not been received at the Rover Client computer over a certain period of time (Default: 1 second). The CAN communication link is broken or the operator turned off the machine. Auto-steering is disabled automatically by the system. If the operator turned off the machine, RoverVU proceeds into graceful computer shutdown procedures after 5 seconds.
▪ Auto-steering is disabled by the joystick	Sometimes the operator needs to quickly exit auto-steering mode. Two options are available for the operator to do that: click the Auto-Steering button or hold the joystick. As the operator can touch the joystick by accident, the auto-steering logic controller monitors joystick signal over a certain period of time (Default: 1 second) and then disables the auto-steering mode.

5.1.2 System Error Messages

While RoverVu is being initialized, fatal errors can take place as outlined in Table 10. Once these errors are detected, RoverVu shuts down its operation.

Table 10: RoverVu system error messages

Message	Cause and Action
▪ INI file validation failure	*SERVER information not found in <StationIPList.sta>*: The registered Server information was not found in the Station Information Database. Users must copy the Station Information Database file in the Base Station Server computer to the Rover Client computer. *ROVER IP [xxx.xxx.xxx.xxx] not found in <StationIPList.sta>*: The suggested Rover IP address [xxx.xxx.xxx.xxx] was not found in the Station Information Database. The Rover IP address does not match with the registered information in the Station Information Database. Users must change the Rover IP address for the device or the registered information.
▪ Security Error	*You are not allowed to run RoverVU*:

	Either User ID or Password was not correct while users tried to authorize the software license.
▪ Station IP list not found	The Station Information Database (StationIPList.sta) was not found in the system folder (C:\Gemini Navsoft Technologies\RoverVU\Application Data).
▪ ROVER IP address undetected	This is a fatal hardware error associated with Ethernet communications in the Rover Client computer (e.g., the panel PC).
▪ Default settings error detected	The default settings file is corrupted.
▪ Wrong system INI file	The system INI file is corrupted.
▪ User settings error detected	The user setting file is corrupted.
▪ CAN connection failed	CAN device was not detected.
▪ The UDP socket was not CREATED	Errors are detected in Ethernet communications.

5.2 Warning Messages

5.2.1 Auto-Steering Warning Messages

Before the machine is engaged in auto-steering operation, initialization errors can take place as outlined in Table 11. Once these errors are detected, the auto-steering logic controller prevents the machine from getting into the auto-steering operation and issues warning messages. Users must adjust the machine manually to activate auto-steering operation.

Table 11: Auto-steering warning messages

Message	Cause and Action
▪ No track selected	Auto-steering requires a working track. Users must run the track selection utility to choose one from the Track Map Database.
▪ The selected track is out of boundary	The selected track is far away from the current location of the machine. Users can still display the track but auto-steering cannot be used.
▪ Auto-steering initialization error	The green light of the auto-steering button is on and auto-steering is ready for action but the machine is not appropriately situated for auto-steering operation because of the following reasons: *FORWARD (or BACKWARD) Wheel crossed off-path limit.* The machine's Forward or Backward wheel is located outside of the off-path limit. The off-path limit is defined by users (Default: 12 inches). To activate

	auto-steering, the operator must adjust the position of the machine wheels manually. *Machine is located inside limit.* The machine is located inside the end point boundary (Default: 2 ft). To activate auto-steering, the operator must move the machine manually.

5.2.2 System Warning Messages

System warning messages are summarized in Table 12. These warning messages are interactive to the user inputs or actions.

Table 12: RoverVu system warning messages

Message	Cause
▪ Authorization failed	*You are not allowed to use this tool*: Either User ID or Password was not correct while users tried to access the System Settings. *You are not allowed to change track database*: Either User ID or Password was not correct while users tried to remove the track database.
▪ Track Number should be 0~4095	The unique track number must be chosen from 0 to 4095.
▪ Track Number exists	The selected track number was registered before.
▪ Track Name exists	The selected track name was registered before.
▪ OnReceive nErrorCode ▪ ReceiveFrom error code ▪ No document pointer	Errors are detected in Ethernet communications.