Virtual Reference Station (VRS™) Systems for Improved Efficiencies in Port Operations

Gary Chisholm, Marine Survey Segment Manager, Trimble
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Trimble began meeting the positioning needs of the marine survey market in 1978. In that year, the company started manufacturing the Loran C receiver, and by the 1980s it had become one of the first companies to introduce GPS receivers to the marine industry.

Since these early beginnings, Trimble has become a pioneer in Differential GPS (DGPS) technology, supplying the marine industry with reference station and mobile solutions capable of round-the-clock submeter accuracy. Marine navigation and surveying is a lot more reliable and accurate as a result, and in 1993 the market welcomed Trimble’s release of the world’s first centimeter-accurate Real Time Kinematic (RTK) surveying system.

Trimble has developed its RTK infrastructure further with the Virtual Reference Station (VRSTM) system. This paper explains VRS application in the port environment.

Improving the efficiency of port operations involves several issues. These are discussed below.

Reducing Tolerances – Dredging

Port operators can optimize under-keel tolerance by dredging. However, operators considering dredging face a number of restrictions, including environmental concerns and costs.

The environmental concerns of a community can demand minimal or no dredging—usually a compromise is reached where dredging must be targeted and controlled.

In order to reduce both environmental impact and costs, port operators must dredge accurately, and the best way to achieve the accuracy they need is through a high-precision positioning system.

Safety

The standard of safety in most ports worldwide is high, and this high standard must be maintained even under the pressure of ever-increasing demands for fast turnaround times for vessels and passengers.

The safe transit of vessels covers approach channels, turning basins, and berths. Safe berth docking and piloting systems ensure that vessels and expensive infrastructure, such as wharves, are protected.

The Port Environment – The Issues

All shipping ports worldwide share one main objective: to ensure ships move into and out of port safely and without delay. An efficient port, therefore, is one where tolerances for under-keel clearance are minimized without compromising safety.

With the draft of ships increasing as post-Panamax ships capable of carrying 4100 TEU containers are now coming into service, it is now more crucial than ever that ports operate as efficiently as possible.
Long Approach Channels

Some ports cover a large area and have long approach channels (see Figure 1). For example, the Houston Ship Channel is 100 km (56 miles) long and carries 700 vessels a day.

Figure 1. Typical regional port with long approach channels

Large ports are particularly demanding of port operations and services. They require:

- precise vertical datums to centimeter accuracy over the port and port approaches
- cost control – precise dredging is required, as overdredge is seldom paid for
- precise positioning to centimeter level
- controlled piloting and berthing so minimal damage to infrastructure and ships occurs. Pilots require detailed knowledge of position, heading, and closing velocities.
- 24/7 system reliability
- The move to one-person survey and piloting parties using lightweight systems.

Positioning Systems in Use Today

The majority of positioning systems in use for waterways today are satellite based.

DGPS Systems

Since the mid-1990s many of the world’s port approaches and treacherous waterways have been covered by DGPS using International Association of Lighthouse Authorities (IALA) radio beacons. These systems have greatly improved safety at sea, as ship captains can now know with confidence their ship’s position to meter accuracy as well as its speed over ground. For commercial shipping, DGPS is required for electronic charting systems. For port operations, DGPS is used for dredging and surveying, and for services such as asset tracking (for example, containers).

WAAS (EGNOS) Systems

In the U.S.A. and Europe, the continents are covered by a satellite-based augmentation service called WAAS (in the U.S.A.) or EGNOS (in Europe). These systems are currently being trialed on waterways. They are not officially operational, nor are they optimized for coastal marine areas. In some coastal areas the required satellite is at a low elevation angle, and the correction signal can be blocked by surrounding buildings, vegetation, or vessels.

RTK GPS Systems

Real-Time Kinematic (RTK) GPS systems are used extensively for both capital and maintenance works related to ports. Typically, an RTK system is installed by a single organization such as a survey or construction company. The system consists of one reference station with a radio link operating at a 10–15 km range. This allows multiple roving applications such as those in construction, hydrographic, and land surveying. The horizontal error budget at the rover is typically 10 mm + 1 ppm. The error budget increases when the rover is further from the reference station and when there are atmospheric disturbances.
DGPS and RTK GPS Systems Compared

The table below compares the accuracy of DGPS and RTK GPS.

Table 1. DGPS vs. RTK Accuracy (RMS, 10 km baseline)

<table>
<thead>
<tr>
<th></th>
<th>Horiz. Accuracy (m)</th>
<th>Vert. Accuracy (m)</th>
<th>Speed Accuracy (ms⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DGPS</td>
<td>&lt;1</td>
<td>&lt;2</td>
<td>0.25</td>
</tr>
<tr>
<td>RTK</td>
<td>0.02</td>
<td>0.04</td>
<td>0.02</td>
</tr>
</tbody>
</table>

The table shows that RTK GPS offers ship captains significantly more accuracy than DGPS. However, the next generation in RTK implementation, the Virtual Reference Station (VRS) system, even surpasses the quality control and accuracy of RTK. At the same time it lowers operating costs for its users.

What is a VRS?

A Trimble VRS is an integrated system of GPS hardware, software, and communications links that uses data from a network of fixed reference stations to model errors throughout a region. The model generates “virtual” reference stations near a surveying location, which then provide a localized set of standard format correction messages to a roving receiver. All users in the region are provided with centimeter accuracy and improved performance and reliability.

How VRS Works

Fixed reference stations continually transmit GPS observation data to a Trimble VRS central server. The data is sent to the central server over a modem, frame relay, the Internet, or other communication link.

In the example in Figure 2, five reference stations, all spaced 50 km apart, are sending data to the central server.

At the central server the network processor performs integrity checks on all GPS observables. The processor checks the data from each station, rejecting outliers and correcting cycle slips.

Error Correction

Once the integrity of the data is checked, the central server computes ionospheric, tropospheric, and ephemeris errors by analyzing double-difference observations. The effects of these errors on any rover working within the network can be modeled, allowing the systematic errors for RTK to be significantly reduced. The effects of the errors are shown in the easting, northing, and elevation of collected points.

Figure 3 shows the effects of errors on a point that is 32 km from the nearest reference station.
VRS Generation

The central server receives the position of a rover working in the network and performs a geometric displacement to the given location. It interpolates and applies corrections for the ephemeris, tropospheric, and ionospheric errors and generates a “virtual reference station” for that specific rover. It then produces a set of standard format correction messages as if they were coming from the virtual station, and transmits those to the rover.

While a VRS is designed and installed for its centimeter-accuracy service, the correction signals can also be used by DGPS receivers for submeter accuracy. This is beneficial whenever a port does not have IALA DGPS coverage, and when lower-cost GPS receivers are used for positioning applications.

The Applications

RTK and a VRS can be used for numerous applications at port:

- Hydrographic surveying of the shipping channels, turning basins and berths.
- Precise dredging and construction – piling and coastal protection. See Figure 4.

- Use of survey equipment for both marine and land survey operations, such as land reclamation surveys.
- Under-keel clearance. Figure 5 shows the main variables acting on under-keel clearance, which are a function of time and position.

- Berth docking and piloting systems
- Precision tracking for position and speed to feed into the Vessel Tracking System (VTS)
The Efficiencies

Employing RTK and a VRS at a port lowers the cost of surveying and positioning, increases productivity, and improves the accuracy of 3D positioning.

Lower Costs and Increased Productivity

Because a VRS is an online survey infrastructure, it provides numerous cost- and timesaving benefits. By saving users time, a VRS RTK system enables them to spend more time on profitable surveying activities:

- Users save time through not setting up or moving a physical reference station.
- Because a physical receiver is not required, users are spared the expense of the purchase.
- Port operators save on staffing costs. Fewer crew are required, as some RTK systems can be operated by just one person.
- Expensive dredging rework is eliminated as the VRS enables an accurate initial dredge.

Improved Accuracy

A VRS and RTK system is a precise and accurate system for vertical measurements over a large site. For this reason it is the ideal positioning system for dredging and under-keel clearance. VRS accuracy is achieved through the following:

- In a VRS network common control is already established, so errors are not propagated from inaccurate control points. All data is quality assured.
- Because all users share the same infrastructure, the number of survey errors between users is minimized. The dredging contractor and client share the same, quality-controlled positioning network for operations.
- The whole port can use one survey datum, which is continually monitored for reliability and accuracy.

- Long-range RTK/VRS systems ensure that accuracy is not degraded by distance from the reference station.

Tide is measured at the ship’s position, not at the tide gauge some distance away.
RTK can measure heave and draft and serve as a tide gauge—separate hardware sensors are not required. GPS can also replace the gyrocompass on construction barges and survey vessels. See Figure 6.
Conclusion

A VRS and RTK system provides the following benefits to port operations:

- Ships can carry more tonnage and operate in a wider window around the tides.
- Ships can travel more safely and at higher speeds.
- Precise positioning data is available for piloting, docking, survey, and construction at critical times.
- Positioning data is provided in all weather, day and night.
- The system provides more precision for extended ranges over the port for survey and dredging (the precise vertical height is determined at the vessel’s location).
- Other equipment, such as multiple tide gauges, is not required.
- Dredging can be carried out with only minimal impact on the environment.