MARINE-BASED MOBILE MAPPING AND SURVEY SYSTEMS

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ABSTRACT

Recent advances in Light Detection and Ranging (Lidar) sensors, inter-operability of various remote sensing systems and improved data processing capabilities have made it possible for certain laser imaging instruments, previously limited to stationary scanning platforms, to operate on mobile platforms. The practice of combining and synthesizing lidar-acquired data with dynamic motion data derived from Position and Orientation Systems (POS) to produce geo-referenced point cloud data from a marine-based mobile platform is also addressed.

Conventional airborne mapping and terrestrial-based scanning techniques faced a particular challenge when tasked to map and shoreline environments. Shorelines with very steep vertical inclinations (e.g., the face of cliffs) are obscured from aircraft-mounted sensors. Using these tools to image large marine infrastructures such as oil platforms has also presented a challenge. However, combining the existing technologies of lidar, GPS and Position Orientation Systems (POS) in novel ways shows great potential for specialized applications that meet the challenges of mapping previously inaccessible environments from marine-based mobile survey platforms. Today, scanning can be performed from moving vehicles, in-motion platforms and boats at ranges exceeding 1 km. The results achieved by using GPS-corrected point cloud data in tandem with a long-range laser imager are presented.

1. MOBILE MAPPING

Mobile mapping has been the focus of considerable research and development efforts over the past few years. The mobile mapping techniques discussed here are based upon the combined application of a pulsed time-of-flight 3D imaging instrument–in this case, Optech's Intelligent Laser Ranging and Imaging System (ILRIS-3D), and a commercial off-the-shelf (COTS) Position and Orientation System (POS) navigation instrument manufactured by Applanix. Advances in scanner and POS technologies incorporate communication between the devices, which enable the scanner output to correlate a GPS time-stamp to each laser point. This linkage of temporal and spatial data enables the output of completely geo-referenced point cloud data.

Until very recently tripod-mounted laser scanners have been just that–fixed platform scanners that operate from a stationary platform. XYZ points acquired from the stationary scanner are indexed to a reference point on the physical unit. This reference point is, in turn, related to an established ground reference point nearby, ideally a first-order GPS monument. When the scanning instrument is placed on a mobile platform however, an entirely new set of challenges is introduced. Because the scanning imager is in continuous motion, it is critical to know its exact position and orientation in all three axes at every moment throughout the scan. Determining the scanning laser's point-of-origin while the sensor is continuously moving is accomplished by a technique referred to as Motion Compensation.

When the scanner and its associated reference point move on a mobile platform such as a boat, the XYZ point cloud data must be corrected by the same degree and direction of motion that the scanner experiences. This is determined by factoring in the roll, pitch, heading and heave of the vessel. Therefore, it is essential that the scanner be mounted as close as possible to the Inertial Measurement Unit (IMU) to eliminate possible changes in the scanner-to-IMU reference points caused by mechanical deflection and platform motion.

The two most common applications where Motion Compensation is used are: (1) mobile platform vertical scanning (e.g., surveying a cliff side from a boat moving parallel to the shoreline); (2) "Stop-and-Stare" (e.g., scanning an object such as a marine oil drilling rig from a floating, anchored platform).

In the course of surveying and mapping coastal zones it was discovered that certain environments and targets present a particular challenge to airborne surveying, irrespective of the technology used (i.e., lidar, photogrammetry, IFSAR, etc.). While surveying coastal fjords in Scandinavian waters, for example, it is difficult to obtain accurate spatial data from the face of cliffs. Due to their sheer vertical angle the face of a cliff side is hidden from the aircraft surveying above. Surveying such environments is of critical importance because erosion and collapse of surface materials presents a serious hazard to the shipping and fishing industries as well as to local residents. The need to monitor cliff sides to measure movement and study stope stability is an area of growing concern in these coastal zones. Marine-based mobile mapping shows great potential for meeting the challenge of this specialized survey application.

Another specialized application for which marine-based mobile mapping is particularly well-suited is the scanning of large infrastructure such as sea-based oil rigs and drilling platforms. Terrestrial-based scanners are commonly used to image industrial physical plant inventory to create comprehensive and accurately geo-referenced spatial databases of as-built structures. Until recently, scanning a complex infrastructure such as a marine oil drilling platform has not been feasible with a terrestrial-based imager. Before the recent innovation of Motion Compensation, the continuous motion of a marine vehicle would have made scanning impossible.

2. LASER RANGING COMPONENT

The ILRIS-3D used to scan the Region of Interest (ROI) incorporates pulsed time-of-flight scanning laser imaging and digitizing technology. It is typically used in commercial survey, engineering, mining and industrial applications. It was selected because of its range, accuracy and ease of use. Smaller than a desktop computer (320 x 320 x 220 mm), and weighing around 20 kg, the ILRIS-3D's compact form factor was especially suitable for the confined spaces of the mobile marine-based survey platform. Capable of ranging up to 1,500 m and offering a scanning target registration accuracy of 7 mm, the ILRIS-3D is controlled by a wireless handheld PDA. (A laptop computer can also be used as the operator interface.)

An option available with ILRIS-3D is Enhanced Range (ER), which increases the scanner's range by up to 40%, enabling the scanning of natural features beyond 1000 meters range, and reflective surfaces (80%) beyond 1500 meters. When surveying in ER mode, the scanner operates within a Class 1M laser product rating. A push-button control switches the unit to Class 1 operation with full eye safety.

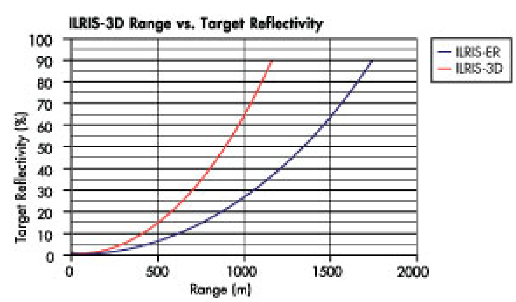


Figure 1: A comparison of range and target reflectivity, ILRIS-3D and ILRIS-ER.

3. POSITION AND ORIENTATION SYSTEM (POS) COMPONENT

The Position and Orientation Systems used in this case, POS MV and POS MV WaveMaster (for smaller survey launches), are manufactured by Applanix. These are tightly-coupled systems that offer a unique approach to Inertially-Aided Real-Time Kinematic (IARTK) technology. These systems provide accurate attitude, heading, heave, position, and velocity data. The systems maintain positioning accuracy under demanding conditions, irrespective of vessel dynamics. A high data update rate enables POS MV and POS MV WaveMaster to deliver a full six degrees-of-freedom position and orientation solution.

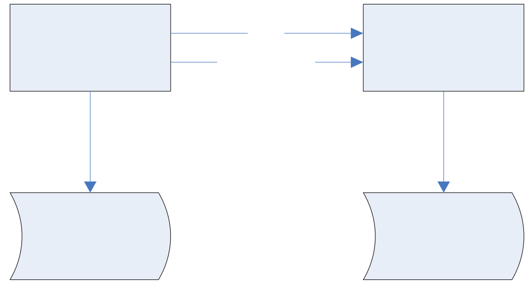
The major components of the POS system are:

1. PCS (POS Computer System) . This enables raw GPS data to be processed directly into the system, in order to compute accurate positional information.
2. IMU (Inertial Measurement Unit). This generates a true representation of vessel motion in all three axes: Roll, Pitch, Heading plus GPS time.
3. GPS receivers and antennas. Embedded GPS receivers provide heading aiding to supplement the inertial data. Two GPS antennas generate raw observable data.

4. INTER-OPERABILITY

Motion Compensation requires three levels of integration between the ILRIS-3D and an external GPS/Inertial system:

- Hardware Integration (ILRIS and POS interconnection). This involves the physical connections between the scanner and the POS, and consists of the various cables that enable the ILRIS-3D to record GPS time.
- Electrical (real-time) Integration (ILRIS and POS configuration). ILRIS-3D collects and time-stamps each XYZ data point with GPS time. The Inertial Measurement Unit (IMU) records dynamic position–continuous changes in the scanning platform's roll, pitch and heading during the scan, as well as GPS data.
- Post-Processed Data Integration (combine data sets). After the survey, three data sets must be integrated: (1) raw XYZ, laser point range information from the ILRIS-3D; (2) GPS trajectory information tracing the survey path of the scanning vehicle from the beginning to the end of data collection; (3) POS data, position information that refines the GPS trajectory data. By measuring and recording the dynamic motion of the mobile platform during the scan, all changes in vehicle pitch, roll and heading can be integrated with the GPS trajectory information, thereby refining position information from sub-meter to centimeter and even millimeter level.



5. PERFORMING A MOBILE SCAN

5.1 Selecting a Target

The ILRIS-3D utilizes an onboard high-resolution camera to facilitate highly accurate targeting. While setting up the scanner in the direction of the target, the camera actively displays the scanner's 40^{o} x 40^{o} Field-of-View (FOV) on the LCD located on the rear of the scanning unit and the handheld computer (or laptop computer). The operator may select specific target ROI by moving an adjustable pick box over the displayed image. The operator must consider the size and the approximate range of the target when selecting a ROI.

When the scanner is operating in "stop-and-stare" mode, the laser is controlled and pointed only at the targeted ROI selected by the operator in the displayed FOV. This concentrates an extremely high percentage of laser shots directed at the selected targets, ultimately resulting in a very dense point cloud acquired in minimal time.

When the scanner operates in vertical scan mode, the laser vertically sweeps a ROI selected by the operator in the displayed FOV. The result is again, a concentration of laser shots hitting the selected target area as the mobile platform moves past.

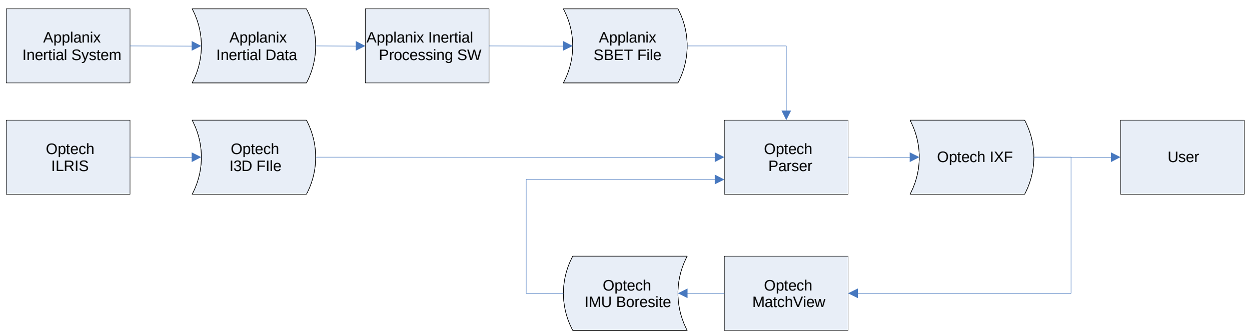
The scanner gathers 3D point cloud data based on the pulsed laser operating at a scan rate in excess of 2500 pulses per second (PPS). Each laser shot is time-stamped with GPS time for geo-referencing during post processing.

6. POST-PROCESSED DATA INTEGRATION AND WORKFLOW

The Optech Parser requires three input files to generate motion compensated data:

1. A Smoothed Best Estimate Trajectory (SBET) file. This file includes the smoothed best estimated trajectory of the scanning instrument over the duration of the survey. The sensor position, roll, pitch and heading are extracted from this file in order to determine the trajectory of the laser pulse in WGS84 coordinates.
2. Optech I3D file. This contains the ILRIS-3D laser data including range, intensity, angle and GPS time.

3. Optech IMU bore-site file. This contains parameters defining the precise misalignment between the ILRIS-3D and the IMU. These values can be derived using laboratory methods and/or Optech's MatchView utility.



The resulting Optech IXF file contains a fully geo-referenced point cloud data set in WGS84 coordinates.

7. ACCURACY

When using a terrestrial-based scanner, the scanner's reference or 0,0,0 is generally a stationary point on the physical scanner. All measurements are reported with reference to this point. This point may be the centre line of the aperture or top dead-center of the tripod supporting the scanner. Until recently, this known point has been a stationary point that can be easily be referenced or back-sighted by standard survey methods. On the ILRIS-3D, the 0,0,0 reference is the center of the bottom bolt hole for the tripod mount. Dynamic changes in the position and orientation of the scanning imager–continuous changes in roll, pitch and heading are measured and recorded by the POS. This dynamic position data is integrated in the post-processing solution to provide an accurate record of where the scanner was and how it was oriented in three planes for the duration of the survey.

Table 1 indicates the expected accuracies that a POS can achieve in both real-time and through post-processing. Errors in 3D point cloud data will include both scanner calibration errors combined with POS errors. The ILRIS-3D scanner accuracy is 7 mm at 100 meters range, and 7 mm at 100 meters angular accuracy.

Table 1: Data Based on Applanix POS MV - Marine Vehicle).

	Post Processed Data	Differential GPS Data (0 sec outage)
X, Y Position (m)	.025	.5 to 2
Z Vertical Position (m)	.05	.5 to 2
Roll and Pitch (deg)	.005	.02
True Heading (deg)	.01	.02
Heave (m)	.05	.05

Table 2 indicates the amount of angular correction being applied to each 3D point when a vessel may pitch and roll while gathering scan data. For example, at 1 km range, 1 degree of roll or pitch will create an error in X or Y of 17.455 meters. This will be corrected to less than 10 centimeters when all post-processing is completed.

Table 2: Angular corrections applied to compensate for motion of scanning imager.

Distance to Target from ILRIS (m)	10	25	50	100	250	500	1000	1500
Degrees								
1	0.175	0.436	0.873	1.746	4.364	8.728	**17.455**	26.183
2	0.349	0.873	1.746	3.492	8.730	17.460	34.921	52.381
3	0.524	1.310	2.620	5.241	13.102	26.204	52.408	78.612
4	0.699	1.748	3.496	6.993	17.482	34.963	69.927	104.890
5	0.875	2.187	4.374	8.749	21.872	43.744	87.489	131.233
6	1.051	2.628	5.255	10.510	26.276	52.552	105.104	157.656
7	1.228	3.070	6.139	12.278	30.696	61.392	122.785	184.177
8	1.405	3.514	7.027	14.054	35.135	70.270	140.541	210.811
9	1.584	3.960	7.919	15.838	39.596	79.192	158.384	237.577
10	1.763	4.408	8.816	17.633	44.082	88.163	176.327	264.490

8. CONCLUSIONS

Great strides are being made toward the advancement of marine-based mobile mapping. By combining 3D imaging techniques with GPS and POS data, it is now possible to image and map cliff sides, steep shorelines and large infrastructures that, until recently, have remained inaccessible to conventional land-based or airborne surveying techniques.