LiDAR FUSION for Impervious Surface Mapping

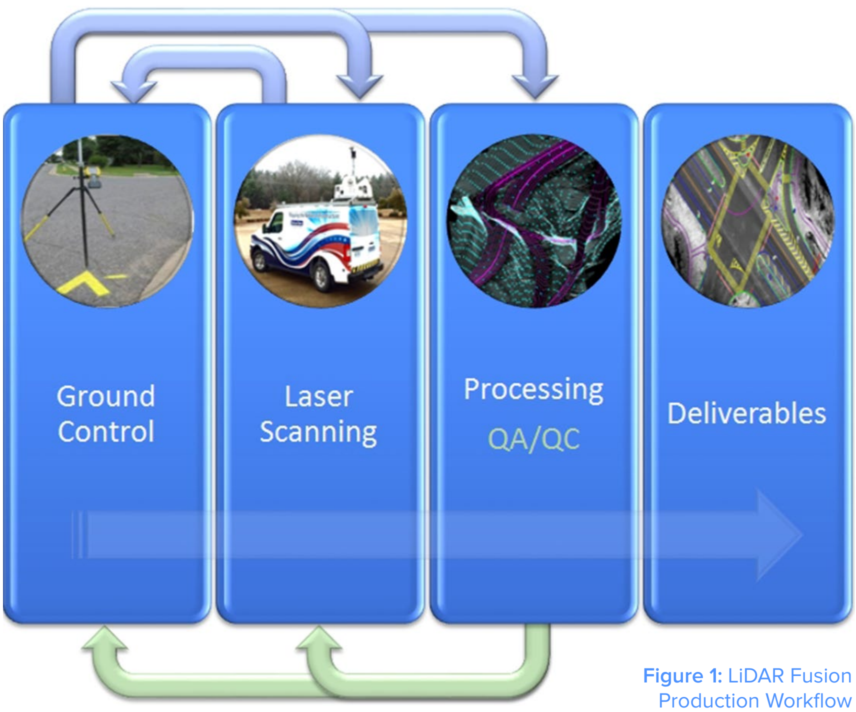

Figure 1: LiDAR Fusion Production Workflow

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An impervious surface, as a result of urbanization or natural features and phenomena, increases water runoff and reduces water infiltration. Roads, buildings, driveways and other types of manmade and natural surfaces prohibit aqueous infiltration into the soil. The practice of utilizing impervious surface coverage as an indicator for determining the overall environmental health of an area has been well documented. Practitioners however, now have access to emerging technologies and techniques to address measurability.

Pervious/impervious pattern mapping at the land-parcel scale can play a significant role when local government authorities are coping with sustainability and containment of urban development. Local authorities and other stakeholders of critical infrastructure are charged with managing and monitoring water conservation and urban stormwater run-off from the catchments. The most current methods for precise mapping of impervious surfaces should be employed to help address environmental concerns, climatic effects, such as the urban heat island, and to promote fairness on land-parcel assessments. Implementation of information-age data handling offers local government administrators the option of imposing an annual levy upon property owners based on the amount of impervious surface on their property ("pavement tax"), as they wrestle with the challenge of impervious/pervious surface balancing when reviewing planning permit applications.

Technology Integration

Aerial photographs have been an important source of land use/land cover information for many years, and have historically been the primary mechanism for identifying and mapping impervious surfaces. With the increase in the spatial resolution, efforts have been made to use satellite data, and in recent years some organizations have used a blended approach of aerial imagery combined with aerial LiDAR (Light Detection and Ranging). While marrying both aerial platforms yields a more refined delineation and more accurate measurement of impervious areas, aerial capture alone does not easily allow identification of small features within aerially-obscured areas (primarily due to tree canopy). A broad overview of the LiDAR fusion workflow is given in **Figure 1**.

The advent of terrestrial mobile LiDAR, along with new techniques for the integration (fusion) of data from aerial and mobile platforms, creates additional data processing possibilities and product generation for the 2D, 3D, and 4D environment. In particular, the fusion of aerial and mobile LiDAR datasets offers opportunity to leverage similar technologies, captured from differing vantage points, to create a single comprehensive LiDAR dataset that provides widespread coverage over a large area, but also yields high resolution detail where it's needed.

Data fusion is an effective way to optimize utilization of large volumes of data from multiple sensors/sources/technologies. Multi-sensor data fusion seeks to combine information from disparate sources to achieve inferences that are often not feasible from a single sensor or source. Exploiting the synergy between the two LiDAR technologies has provided data fusion opportunities. When used together, the resulting dataset(s) provide comprehensiveness for analysis that is perhaps greater than the "sum of the parts." Aerial LiDAR provides a foundation for the topographic information, while the mobile LiDAR provides high-resolution, high density, unambiguous terrestrially observed information of topography and infrastructure.

Although both LiDAR sources can generate identically-formatted data, there are several issues and parameters that need to be carefully addressed to properly facilitate their fusion into a single common model: point density, nadir or oblique views, positional accuracy, among others. The relative strengths and weakness of each data collection method should be directly understood and evaluated to gauge its relevance, use and application.

LiDAR Data Processing

The basic LiDAR dataset consists of large data files containing (at a minimum) x, y, and z values for each measurement. Contained within the basic raw data are combinations of points measuring the earth's surface, as well as, natural and as-built features. LiDAR data processing has been reported in great detail in academic, scientific, government and trade publications, but for simplicity we can categorize processing into four primary areas: 1) Point Cloud creation; 2) Spatial Adjustment; 3) Point Cloud classification (automated and manual); and 4) Product Deliverables (DEM, DTM, TIN, contours, planimetric features, visualizations, etc.).

The processing of mobile LiDAR data is similar in nature to that of aerial LiDAR processing by employing the same primary processing areas as listed above. However, due to high point densities, terrestrial capture, and close proximity to targets, processing routines are more robust and complex. Unlike aerial LiDAR, the high-resolution data generated from mobile LiDAR

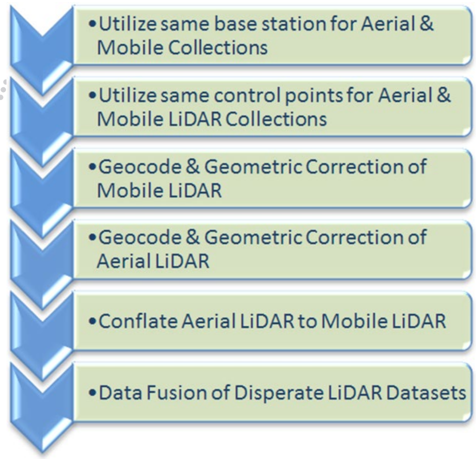

Figure 2: LiDAR Fusion Methodology

scanning operations present the ability to continually refine spatial accuracies by performing additional ground control surveys at "LiDAR-identifiable" locations days or weeks later.

Processing routines are also further expanded to include additional workflows for extraction of real-world features that were obscured or unidentifiable in aerial datasets. Available products extend far beyond the typical bare-earth and topographic elements produced from aerial LiDAR. These include detailed planimetrics directly suitable for engineering or design work, as well as terrestrially captured imagery for use in QA/QC and feature identification.

Data Fusion

Historically, data fusion has been the topic of interest in imagery-based remote sensing. Wherein two datasets with different spatial and spectral resolution are merged to produce a product which is more useful for image interpretation. Leveraging these concepts, LiDAR fusion capitalizes on the "top-down" viewing perspective of aerial LiDAR, and the "ground-up" perspective of mobile LiDAR. This results in better overall scene comprehension, and a more comprehensive inventory of the real world. The LiDAR fusion methodology is shown in **Figure 2**.

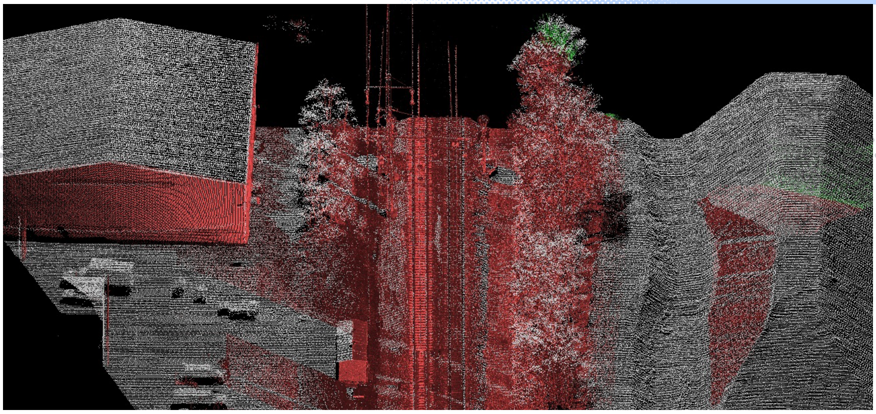

Figure 3: Fused LiDAR Point Cloud of an urban railway corridor. Red points captured by Mobile LiDAR, and white points via Aerial LiDAR.

The data fusion workflow employed by Baker begins with spatial constraint. To speed processing and reduce anomalies (which ultimately reduces effort and cost), ideally both datasets utilize the same control solution framework. Spatial constraint is typically performed on the mobile LiDAR data first. Typically requiring a higher number of targets, some of which may not be identifiable within the aerial data (concrete joints, corner of drop-inlets, etc.), constraining the mobile LiDAR first yields a new dataset that can be further used to constrain the aerial LiDAR. This ultimately results in an aerial LiDAR dataset that is more accurate and more easily ingested during fusion. A fused product is shown in **Figure 3**.

Once both datasets are constrained, they are fused to generate a single point cloud. Fusion creates incredibly rich data with information about the canopy and topography. Viewable from top-down and ground-up perspectives, detailed as-built features (walkways, medians, outbuildings, light poles, signage, utilities, etc.) are in a single cloud, along with complete building roofs and crown of the vegetation canopy. Various techniques and methodologies are used to fuse the datasets. Each technique ultimately uses project parameters, unique topography, and available data. Seldom is a single method used for every project. More aptly, various techniques are used throughout a single project. For single-use impervious surface mapping projects, it is more common (for efficiency) to block-replace aerial LiDAR data in areas where mobile LiDAR is present. However, multi-use projects may require more complex processing efforts. Consider splicing datasets along various horizontal and vertical planes in relation to relative ground levels.

Impervious mapping:

The multiple laser returns (1st, 2nd, 3rd, and Last) and intensity values available from the fused LiDAR dataset enables automated processes for rapidly identifying impervious surface features (buildings, edges of pavement, sidewalks, driveways, etc.), and alleviates the significant limitations of imagery-only analysis. The overall process can be enhanced by utilizing photography as a primary mechanism for review and quality control. Robust QA/QC routines correct for: misclassifications; irregular geometric shapes; and apply topological conventions. All of which ultimately result in a cost-efficient and sustainable solution that enables local authorities to base their decisions on accurate measurements. An impervious map produced is shown in **Figure 4**.

Conclusion:

The proper application of LiDAR fusion techniques to combine aerial and mobile LiDAR facilitates the creation of cost-effective impervious mapping to unprecedented detail.

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Figure 4: Fused LiDAR Point Cloud of a suburban jurisdiction with extracted and classified impervious features.