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An Analysis of Airborne Data Collection Methods for Updating Highway Feature Inventory

Yi He

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AN ANALYSIS OF AIRBORNE DATA COLLECTION METHODS
FOR UPDATING HIGHWAY FEATURE INVENTORY

by

Yi He

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Civil and Environmental Engineering

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UTAH STATE UNIVERSITY
Logan, Utah
2016
ABSTRACT

An Analysis of Airborne Data Collection Methods
for Updating Highway Feature Inventory

by

Yi He, Master of Science
Utah State University, 2016

Major Professor: Dr. Ziqi Song
Department: Civil and Environmental Engineering

Highway assets, including traffic signs, traffic signals, light poles, and guardrails, are important components of transportation networks. They guide, warn and protect drivers, and regulate traffic. To manage and maintain the regular operation of the highway system, state departments of transportation (DOTs) need reliable and up-to-date information about the location and condition of highway assets. Different methodologies have been employed to collect road inventory data.

Currently, ground-based technologies are widely used to help DOTs to continually update their road database, while air-based methods are not commonly used. One possible reason is that the initial investment for air-based methods is relatively high; another is the lack of a systematic and effective approach to extract road features from raw airborne light detection and ranging (LiDAR) data and aerial image data. However,
for large-area inventories (e.g., a whole state highway inventory), the total cost of using aerial mapping is actually much lower than other methods considering the time and personnel needed. Moreover, unmanned aerial vehicles (UAVs) are easily accessible and inexpensive, which makes it possible to reduce costs for aerial mapping. The focus of this project is to analyze the capability and strengths of airborne data collection system in highway inventory data collection.

In this research, a field experiment was conducted by the Remote Sensing Service Laboratory (RSSL), Utah State University (USU), to collect airborne data. Two kinds of methodologies were proposed for data processing, namely ArcGIS-based algorithm for airborne LiDAR data, and MATLAB-based procedure for aerial photography. The results proved the feasibility and high efficiency of airborne data collection method for updating highway inventory database.

(101 pages)
PUBLIC ABSTRACT

An Analysis of Airborne Data Collection Methods for Updating Highway Feature Inventory

Yi He

Highway inventory plays an important role in highway management. Governments and agencies have been employing different kinds of methodologies for highway inventory. Existing methodologies include field inventory, photo/video log, integrated global positioning system (GPS)/global information system (GIS) mapping, aerial/satellite photography, terrestrial light detection and ranging (LiDAR), mobile LiDAR, and airborne LiDAR. Each has advantages and disadvantages as well as limitations in collecting road inventory data. This paper mainly focused on the application of airborne data collection method.

Four highway sections in Utah were mapped in this experiment: one section on Interstate 84 (I-84), two sections on Interstate 15 (I-15 north and I-15 south), and one section on US-191. Both LiDAR point cloud data and high-resolution aerial imagery data were obtained. This project mainly focused on processing and analyzing the LiDAR point cloud data by using ArcGIS, but also provided an automatic road sign detection algorithm based on MATLAB for the aerial images.

A comprehensive introduction to highway inventory methodologies, especially airborne LiDAR technology, was provided to relevant departments and personal to promote their understanding of the pros and cons of different inventory techniques. An
ArcGIS-based algorithm was developed to analyze and process LiDAR data and to extract desirable features from raw LiDAR point clouds. In addition, a MATLAB-based feature extraction algorithm was also proposed to demonstrate the effectiveness and economic efficiency of the airborne data collection system.

The results showed that although small signs (e.g., speed limit signs) along highways cannot be identified successfully because of the low point density of airborne LiDAR data, other features, such as guardrails, median strips, light poles, and large signs, are very easy to detect. Also, from airborne LiDAR data, one can detect features like culverts and bridges, which cannot be detected by mobile mapping or other inventory techniques. Furthermore, airborne LiDAR data provide accurate coordinate information for the detected highway features. And for aerial images, we can also extract some kind of assets based on the assets’ color, shape or other characteristics.

The findings of this research can be used as a reference for the Utah Department of Transportation (UDOT) and other state DOTs before they choose a methodology to collect highway inventory data. Also, the LiDAR-data-based, and image-based road sign extraction methods, may provide inspiration for future researchers to develop more effective and efficient methods for road sign detection.
DEDICATION

This research is based on the airborne LiDAR data and aerial imagery data collected by the Remote Sensing Service Laboratory (RSSL), Utah State University (USU). I would like to thank Dr. Hatim Geli at the Civel and Environmental Engineering Department for his help in data collection and raw data processing. Also thank Dr. Xiaojun Qi from Computer Science Department for teaching me how to do image analysis using MATLAB and giving me effective recommendations for my research. Special thanks to Dr. Ziqi Song for giving me the opportunity to study in USU and to do this research, while also providing support for me both academically and mentally. And particularly thank Dr. Anthony Chen and Dr. Joseph A Caliendo, my committee members, for their support and guidance in this research. Finally, I would like to thank my husband, Zhaocai Liu, for always encouraging me, inspiring me and providing me a wonderful family atmosphere so that I can concentrate on my research.

Yi He
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CHAPTER 1

INTRODUCTION

1.1 Problem Definition

The main focus of this research project is to evaluate the application of the airborne light detection and ranging (LiDAR) system when updating the highway inventory database. Highway assets, like traffic signs and signals, directional signs, mile markers, streetlights, guardrails, and culverts, play a leading role in regulating traffic and guiding and warning drivers as well as pedestrians. Therefore, it is helpful for state departments of transportation (DOTs) to have up-to-date inventory data to establish the condition of the road networks within their states, prioritize reconstruction and repair work, and value their highway assets. DOTs also use road inventory data for traffic engineering studies, planning, and meeting federal data reporting requirements. Because of the importance of collecting highway inventory data, many methodologies have been proposed to gather the data. The techniques range from the simplest manual inventory method to methods that involve advanced technology, such as aerial photography and LiDAR. In the past few years, various state DOTs have conducted inventory data collection using a number of methods. Among these methods, photo/video log and integrated global positioning system (GPS)/global information system (GIS) mapping are popular because of their low initial cost and ease of operation. For example, the Washington DOT has adopted photo log and integrated GPS/GIS mapping for roadway data collection, the Michigan DOT has used the integrated GPS/GIS mapping method
and field inventory, and the Idaho DOT utilizes video log. Mobile LiDAR and airborne LiDAR, even though they involve higher equipment cost and are relatively new, are being employed by more and more state DOTs and transportation agencies.

A lot of work has been done to analyze different methodologies for road inventory. For example, Khattak et al. (2000) conducted four experiments to compare the traditional manual method with the integrated GIS/GIS mapping systems. Jeyapalan (2004) developed a method to obtain the three-dimensional locations of road features with data captured from a video logging system. Landa and Prochazka (2014) compared RGB (red, green, blue) image-based road inventory and LiDAR-based road inventory, founding that road sign detection from RGB data is much cheaper and can include color information, while more precise position and height information can be obtained from LiDAR data. They also provided a traffic sign detection method based on point clouds obtained by a mobile laser scanning system, and tested their method on a road section in Brno, Czech Republic. The results showed relatively high precision in their proposed LiDAR-based method. Jalayer et al. (2015) evaluated the capability of the photo/video log to collect geospatial highway inventory data required by the Highway Safety Manual (HSM). The authors conducted a Web-based nationwide survey to analyze the advantages and disadvantages of photo and video logs as well as a field trial that recorded the data collected time and data reduction time for three different types of roadway segments (rural two-lane highway, rural multilane highway, and urban and suburban arterial segments) using the photo and video logging method. Based on the survey and the trial, the authors concluded that geo-tagged photo and video log technology is one of the most
economical and efficient methods for DOTs.

Despite LiDAR becoming increasingly popular across the United States and state DOTs and transportation agencies adopting LiDAR technology to deal with transportation-related applications, to date, airborne LiDAR is still not as popular as other inventory techniques because of its expensive initial investment and limitations in identifying small objects. The main purpose of this research is to analyze the advantages and disadvantages of airborne LiDAR technology in collecting and recording highway assets. Because aerial imagery data are very easy to acquire when the aircraft is flying, the imagery data were collected together with the LiDAR data for a joint analysis.

1.2 Research Objectives

To achieve the goal of this research project, the following objectives were identified:

• Conduct literature review covering the existing road inventory technologies, especially for airborne LiDAR technology.

• Carry out a field trial to collect both airborne LiDAR data and high-resolution aerial images of four highway sections in Utah: two on Interstate 15 (I-15), one on Interstate 84 (I-84), and one on US-191.

• Develop a GIS-based algorithm to process the raw LiDAR point clouds to extract candidate highway assets, and then apply the manual recording method to assess the location and structure information of the assets.
• Propose a MATLAB-based method to process the imagery data. Cylindrical road features include light poles, and traffic sign poles, and drainage grates being detected with high accuracy.

1.3 Expected Contributions

Highway inventory data collection should be conducted periodically to check the completeness of road infrastructures and assets to ensure safety. This is a very costly project for most transportation agencies; not only are a large number of crews sent out for a long time, but the crews are also exposed to traffic, which is not safe. The airborne mapping technique is often more cost-effective than conventional surveying methods and has other additional values, such as no disruption to traffic and improved safety. Thus, proving that data collected through airborne mapping can also provide effective information about road assets will help state DOTs and transportation agencies save large amounts of resources on road inventory in the future. Our research project assessed aerial mapping technology in highway assets detection, showing that airborne mapping is a promising technique for relevant agencies to collect road inventory data in the future.

1.4 Framework of the Article

Chapter 1 has given a brief introduction to the research. Chapter 2 introduces different kinds of existing technologies for road surveying. Chapter 3 focuses primarily on the introduction of LiDAR, especially the advantages and applications of airborne
LiDAR. In Chapter 4, the field experiment and data collection will be presented. Chapter 5 develops an ArcGIS-based algorithm to analyze LiDAR data and provides the data analysis results. Chapter 6 proposes an image processing method based on MATLAB to detect traffic signs and highway drainage grates. Finally, Chapter 7 concludes the thesis.
CHAPTER 2

INTRODUCTION OF ROAD SURVEYING METHODOLOGIES

Road surveying/inventory is a compilation of components and conditions of a road system. Collecting and storing roadside assets data such as lane width, traffic sign height, location, and condition help the government make future safety and maintenance investment decisions and provide program managers with better information for program prioritization. For example, the recently published Highway Safety Manual (HSM) (2010) has assisted many state DOTs to evaluate the highway safety performance at different construction stages and operation stages. However, some state DOTs are still in the awkward position of lacking HSM-required highway inventory data (HID). Given the importance of the information of roadside features to the management of roadways, finding effective and economic methods to enrich the inventory data system is fairly urgent.

State DOTs and local agencies have employed different types of HID collection techniques, such as field inventory, photo/video log, integrated global positioning system (GPS)/global information system (GIS) mapping systems, aerial/satellite photography, terrestrial light detection and ranging (LiDAR), mobile LiDAR, and airborne LiDAR. These techniques vary in time consumption, costs, effectiveness and accuracy. In this section, we provide a brief introduction to each of these techniques and focus mainly on their advantages and disadvantages in the application of road inventory data collection.

Existing roadway inventory data collection methods can be roughly divided into
two categories: ground-based and air- or space-based methods. Based on the equipment of these systems, they can also be divided into three parts: based on GPS; based on GPS and image; and based on GPS, image, and LiDAR. The classification of existing road inventory data collection methods is given in Table 2.1.

Table 2.1
Classification of existing road inventory data collection methods.

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<th>GPS, Image and LiDAR</th>
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<td>• Field Inventory</td>
<td>• Photo/Video log</td>
<td>• Terrestrial LiDAR</td>
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<td></td>
<td>• Integrated GPS/GIS Mapping Systems</td>
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<td>• Mobile LiDAR</td>
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<tr>
<td><strong>Air- or Space-based</strong></td>
<td>• Aerial/Satellite Photography</td>
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<td>• Airborne LiDAR</td>
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2.1 Manual/Field Inventory

The first proposal and implementation of collecting roadway inventory data dates back to the mid 1890s (Degray and Hancock, 2002). At that time, road inventory mainly relied on manual collection, which is also known as field inventory. Typically, manual inventory needs data collectors, a vehicle, a distance measuring instrument (DMI), and paper and pencils or a laptop for collecting and recording georeference (i.e., latitude, longitude, and altitude) and descriptive (i.e., length, width, height, and condition) data (Khattak et al., 2000). Although this method is time consuming, loosely organized and unsafe because crews need to be exposed to traffic and field, its capability of collecting rich and accurate data and its low initial cost still make it quite a competitive method.
As the nation’s road network rapidly and continuously grew, manual collection could no longer satisfy the big and sophisticated needs for roadway data. New technologies emerged, allowing for more efficient data collection and recording. However, field inventory is still required and cannot be completely replaced by later technologies, as new technologies may not be able to collect data on all kinds of assets.

The advantages and disadvantages of manual inventory are summarized as follows:

**Advantages**

- Low equipment cost
- Minimal training requirements for personal
- Low data reduction efforts
- Capable of collecting rich road inventory data
Disadvantages

- Personnel exposed to dangerous traffic environment
- Hider the traffic to some extent
- Long collection time
- Labor intensive
- Less accuracy

2.2 Photo / Video Log

In recent years, advances in technologies have assisted researchers to collect data using images and video records in transportation studies (see Sharifi et al., 2015a,b,c; Sharifi et al., 2016). Image inventory, also known as a photo log, is based on cameras taking images of a roadway at constant intervals along the road. The primary difference between a photo log and video log is that they use different recording mediums. A photo log is obtained by automatically recording pictures while the vehicle is moving along the roadway. Whereas a video log records continuous images.

Employing a high-resolution digital camera, GPS, and INS, the mobile photo/video logging system has been widely used for capturing roadway features in recent years. For example, approximately 27000 miles of roadway in Tennessee were mapped by photo log (Tao, 2000). Jeyapalan and Bhagawati (2000) used the video logging method to collect roadside assets at a scale of 25 feet or less in order to create a GIS. Then in 2002, Jeyapalan and Jaselskis used a video log for their study (Jeyapalan
and Jaselskis, 2002), testing three sites with video logging van-captured images: Grand Avenue, EDM baseline, and US-30. A few years later, the video logging technique was once again used by Jeyapalan, who developed a method for determining the three-dimensional (3D) locations of road features by using images obtained from a video logging system (Jeyapalan, 2004).

Compared with field inventory, most of the work of a photo/video log can be done indoors, thereby reducing potential hazards to data collection personnel. Only one or two personnel are required, and they ride inside the vehicle, without direct exposure to traffic. Therefore, a photo log is more efficient and safer. In addition, the data collected by a photo log is more accurate and uniformly recorded, because field inventory is generally conducted by several different crews whose operating levels toward measurement equipments and degree of carefulness may be remarkably diverse. Thus, there tends to be more errors in field inventory.

![Videologging](image)

*Fig. 2.2 Videologging (Jeyapalan and Bhagawati, 2000).*
But this method collects lots of useless information, so it needs large data reduction efforts. It is also not able to measure feature dimensions. Another disadvantage of photo log or video log is that the collected data quality is subject to weather conditions.

2.3 Integrated GPS/GIS Mapping System

An integrated GPS/GIS mapping system is commonly used technology among DOTs and transportation agencies for roadside inventory. Most integrated GPS/GIS mapping systems are also equipped with an inertial navigation system (INS). INS is the backup system when GPS loses its lock due to signal obstruction so that the mapping system can obtain continuous position information (Fig. 2.3).

![Fig. 2.3 The GPS/INS integration procedure (Source: http://www.lambdatech.com).](http://www.lambdatech.com)

The advantages of the integrated GPS/GIS method are that it needs relatively low initial cost and low data reduction efforts, and it improves data accuracy. But crews have
to be exposed to the traffic and field during long data collection periods.

Fig. 2.4 Integrated GPS/GIS mapping

2.4 Aerial/Satellite Photography

High-resolution images taken from an aircraft or satellite can be used for analyzing road networks. Hallmark et al. (2001) tested the use of remotely sensed images with different resolution levels (2-inch resolution, 6-inch resolution, 24-inch resolution, and 1-meter resolution) on road inventory feature detection. They found that most features could be successfully identified in the 2-inch and 6-inch datasets, while only
large features such as intersections and railroad crossings had relatively higher identification rate in the 24-inch or 1-meter datasets.

Fig. 2.5 Aerial photography No.1.

Fig. 2.6 Aerial photography No.2.
Because photos are obtained from the air with a panoramic view, they can display the entire road network. Such a display can provide researchers with a better understanding of how the transportation network interacts with the environment around it. The aerial/satellite photography method can collect inventory data efficiently, and there is no traffic exposure so collection personnel do not need to face dangerous traffic, and the collection process will not distract motorists on the road. However, this method requires crews with professional skills and the latter data processing part could be quite complicated. In addition, the quality of the collected data is greatly affected by the weather conditions during the collection period.

2.5 LiDAR

LiDAR or 3D laser scanning is a remote sensing technology that uses laser light to densely sample the surface of the earth. Three types of LiDAR can be used to collect road inventory data, namely, terrestrial LiDAR, mobile LiDAR, and airborne LiDAR. Recent dramatic advances in LiDAR technology have made it quite competitive in science and engineering applications. A detailed description of LiDAR will be presented in Chapter 3.

2.6 Chapter Summary

In conclusion, many methods are available to perform road inventory. These methods include field inventory, photo/video logs, integrated GPS/GIS mapping,
aerial/satellite photography, terrestrial LiDAR, mobile LiDAR and airborne LiDAR. Each method has its advantages and disadvantages as well as the scope of application. Road inventory is a costly and laborious project, and should be conducted periodically. Therefore, choosing an appropriate method to survey the road in order to get accurate statistics on road features is critical for enabling state DOTs and transportation agencies to save costs.

This chapter has mainly introduced different road inventory methodologies, except for the LiDAR technology, which will be discussed in Chapter 3. The equipment needed for each technique is described, as well as the strengths and weaknesses.
CHAPTER 3

LIDAR

3.1 What Is LiDAR

LiDAR is a remote sensing technology that collects geometric and geographic information from targets on the earth’s surface in the form of point clouds (Fig. 3.1). A LiDAR system principally consists of a laser scanner, a specialized GPS receiver, and an IMU system. It uses a similar principle as radar, a better-known technology. The main difference is that instead of using radio waves or microwaves, LiDAR sends out intense, focused beams of light to measure the distances to the objects. Depending on the wavelength laser used, LiDAR can map a wide range of objects, such as rocks, vegetation, chemical compounds, clouds, and even single molecules. Recent advancements in the LiDAR mapping technique have enabled researchers and mapping professionals to efficiently map large scale areas with improved accuracy and flexibility.

The history of LiDAR dates back to the early 1960s, shortly after the invention of laser. LiDAR was first used in meteorology by the National Center for Atmospheric Research (Goyer and Watson, 1963). In the early 1970s, early models of LiDAR were successfully used in the United States, Australia and Canada. The Ohio Department of Transportation was one of the earliest agencies to employ LiDAR systems in engineering operations (Grejner-Brzezinska et al., 2005). By the end of the 1990s, this technology was occupying a leading position in high-precision spatial data. Compared with other
remote sensing technology, LiDAR is more automatic, efficient, and accurate; and it can work both during the daytime and at night because laser scanning is relatively independent of sunlight. Since the introduction of LiDAR, this technology has been used for a wide range of applications, including high-resolution topographic mapping (Hill et al., 2000), archaeological sites detecting (Doneus et al., 2013), 3D surface modeling (Zhao et al., 2008), and infrastructure and biomass studies (Chen et al., 2012).

![Fig. 3.1 LiDAR point.](image)

### 3.2 How LiDAR Works

There are two methods to estimate the distance between the LiDAR unit and the
target objects: time-of-travel and phase-shift. Time-of-travel scanners transmit pulses and record the time interval between an initial transmission of individual laser pulses and the returning detection of reflected signals to calculate distance values.

\[
\text{Distance} = \frac{(\text{Speed of Light} \times \text{Time Interval})}{2}
\]

While phase-shift scanners calculate distance using the phase shift principle. A sinusoidally modulated laser pulse is sent out; as the laser beam reaches a surface, a shift in the signal is detected and registered as a point in the space.

Compared with phase-shift scanners, time-of-travel scanners are rated at much longer ranges, so they are usually used for long-range applications. Phase-shift scanners, however, are limited in range and are generally utilized for indoor or short-range applications, despite being faster and more accurate.

The measured distance is then combined with the position and orientation information obtained from integrated GPS and IMU systems to generate the 3D (i.e., latitude, longitude, and altitude, which are also known as the x, y, z coordinates) information about the targeted objects. The x, y, z coordinates of the objects are computed based on:

1. the distance between the object and the scanning LiDAR sensor,
2. the angle at which the laser pulse was “fired”; and
3. the absolute location of the sensor.
3.3 LiDAR Classification

Generally speaking, there are three types of LiDAR systems: (1) airborne laser scanning (ALS), (2) mobile laser scanning (MLS), and (3) terrestrial laser scanning (TLS). Each system varies in application, data collection time, cost, and accuracy.

3.3.1 Airborne Laser Scanning (ALS)

ALS is an aerial mapping technology that uses reflected laser returns from the earth’s surface with on-board GPS and IMU sensors to generate precise 3D information about terrestrial objects.

Airborne LiDAR is the most commonly available LiDAR, and most airborne LiDAR systems can cover more than 50 square kilometers per hour while the collected data still meet the requirements for high-accuracy data.

![Airborne LiDAR system schematic](http://gmv.cast.uark.edu/scanning-2/airborne-laser-scanning/)

**Fig. 3.2** Airborne LiDAR system schematic (Source: http://gmv.cast.uark.edu/scanning-2/airborne-laser-scanning/)
As shown in Fig. 3.2, airborne systems are capable of scanning perpendicularly to the airplane’s flight direction to capture segments of the earth’s surface. The laser ranging device sends out millions of pulses to determine the distance between the aircraft and the targets. The GPS provides the location of the instrument holding the LiDAR sensor, and the IMU is used to measure the pitch, roll and heading of the aircraft, which are important for accurate elevation measurements.

### 3.3.2 Mobile Laser Scanning (MLS)

MLS is essentially the same as ALS, except that the LiDAR set up is integrated on a ground-based vehicle. Depending on the range requirement, MLS can use either the time-of-travel or phase-shift method. Current MLS systems are capable of collecting up to one million points per second while driving at highway speeds, including digital imagery and other geospatial data (Williams et al., 2013). This enables MLS systems to provide a dense, geospatial dataset as a 3D virtual world. MLS is efficient in collecting data, also, and it can minimize traffic disruption as well as safety hazards. Fig. 3.3 presents a MLS system.

### 3.3.3 Terrestrial Laser Scanning (TLS)

The fundamentals of laser distance measurement and scanning of TLS are similar to ALS and MLS. TLS is usually operated on a tripod (Fig. 3.4). Because it generally has a relatively smaller range requirement, a TLS system mainly uses phase-shift measurement systems. An ALS system needs only one scanning direction (the other one
is accomplished by the moving aircraft), while a terrestrial laser scanner needs a 2D scanning device (Vosselman and Maas, 2010). Because TLS refers to tripod-based measurements, it is stationary and does not need a GPS or INS for direct georeferencing; furthermore, it is able to achieve the highest accuracy among the three types of LiDAR systems.

Fig. 3.3 Mobile LiDAR system (Topcon IP-S2 HD system operated by Oregon DOT).

Fig. 3.4 Terrestrial LiDAR system (Source: http://www.bu.edu/tech/support/research/visualization/gallery/lidar/).
### 3.4 Comparison of LiDAR

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Airborne LiDAR</th>
<th>Mobile LiDAR</th>
<th>Terrestrial LiDAR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High degree of automation</td>
<td>Safe</td>
<td>Higher flexibility</td>
</tr>
<tr>
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<td>Safe operation</td>
<td>Good view of pavement</td>
<td>Higher resolution</td>
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<tr>
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<td>Less affected by atmospheric conditions</td>
<td>Direct view of vertical features</td>
<td>Higher accuracy</td>
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<td>Efficient</td>
<td>Higher density</td>
<td>Easy to use</td>
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<tr>
<td></td>
<td>Direct view of pavement and building tops</td>
<td>Cost effective</td>
<td>Highest level of detail</td>
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<tr>
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<td>Faster coverage</td>
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<td></td>
<td>Larger footprint</td>
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<tr>
<td></td>
<td>Point density is more uniform</td>
<td></td>
<td></td>
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<td></td>
<td>High post-processing efficiency</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disadvantages</td>
<td>Poor view of vertical features</td>
<td>Cannot capture building tops</td>
<td>Inefficient</td>
</tr>
<tr>
<td></td>
<td>Lower point density</td>
<td>Slower coverage</td>
<td>Lowest cost efficiency</td>
</tr>
<tr>
<td></td>
<td>More horizontal positioning uncertainty</td>
<td>Small footprint</td>
<td>Limited to project size</td>
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</table>

#### 3.5 Airborne LiDAR

3.5.1 Background and History

As early as the beginning of the 1970s, airborne LiDAR systems could reach the precision of less than one meter when measuring distances between aircraft and the
earth’s surface. However, they were not widely used at that time for their limited accuracy and measurement range. With the introduction of differential GPS at the end of the 1980s, the position of the scanners could be determined in the range of a sub-decimeter. After that, airborne LiDAR developed very rapidly and became widely used (Vosselman and Maas, 2010).

Many studies and applications have been conducted since the introduction of airborne LiDAR. Baltsavis (1999) provided us with quite a complete overview of existing systems, firms, and resources of airborne laser scanning through extensive research. Vosselman and Maas (2010) introduced the principles of airborne and terrestrial laser scanning technology as well as the applications of 3D point clouds collected by laser scanners. This technology is being used for a wide range of applications, including high-resolution topographic mapping and 3D surface modeling as well as infrastructure and biomass studies. Airborne LiDAR data were successfully used by Bernardini et al. (2013) in the mapping of Karstic areas (northeastern Italy), which demonstrates the value of airborne LiDAR technology in landscape archaeology and archaeology. Swetnam and Falk (2014) used airborne LiDAR to identify individual trees across large forested landscapes. Doneus et al. (2013) demonstrated the potential of this novel technique to map submerged archaeological structures over large areas in high detail in 3D, providing unique means for underwater heritage management.

3.5.2 Components

The basic components of the airborne laser scanners include the following five
parts:

1. Flight management system
2. Airborne platform
3. Laser scanner
4. Position and orientation system
5. Control and data recording unit (computer)

*Flight Management System*

The flight management system serves as a means for mission planning, and various stages of processing. For example, the pilot can display the preplanned lines through this system, which will give support in completing the mission *(Vosselman and Maas, 2010)*.

*Airborne Platform*

An airborne platform is a platform for mounting all of the data collection hardware. Airplanes and helicopters are the most commonly used platforms for acquiring LiDAR data over broad areas. Helicopters are typically used in the following applications: (1) small width, elongated areas (e.g., power lines, corridor mapping, and topographic and bathymetric mapping along coastlines), (2) small areas (e.g., airports, open pit mines), (3) conditions at very low altitudes (for higher accuracy and denser point measurements) or low flying speeds are needed (flood mapping), (4) conditions when high maneuverability and many high-curvature turns (e.g., following roads in 3D city modeling) are required, and (5) difficult terrain with abrupt height discontinuities
Laser Scanner

The airplane uses a laser to scan the earth from side to side as the plane flies. As shown in Fig. 3.5, a typical laser scanner can be subdivided into the following key units: laser ranging unit, opto-mechanical scanner, and control and processing unit (Wehr and Lohr, 1999). A medium-sized digital camera that provides image data often works together with laser scanners because it is difficult to recognize objects using only the range data provided by laser scanners (Vosselman and Maas, 2010). Powerfully pulsed lasers are needed for the measurement of the range because of the relatively large distance between the aircraft and the objectives.

![Laser scanner schematic unit](image)

Fig. 3.5 Laser scanner schematic unit (Wehr and Lohr, 1999).

Position and Orientation System

The laser scanner measures only the line-of-site vector from the laser scanner
aperture to a point on the earth’s surface (Wehr and Lohr, 1999). In order to obtain a 3D position of the target point, the laser scanner system should be supported by a position and orientation system. GPS and IMU are usually used together as the position and orientation system. The GPS antenna is always installed on top of the aircraft to provide an undisturbed view for the GPS satellites, and the IMU is either fixed directly on the laser scanner or close to it (Vosselman and Maas, 2010).

**Control and Data Recording Unit**

A computer equipped with a display and an operator should be included to provide the control and processing functions for the overall system. The onboard computer also records and stores all of the important information that the LiDAR collects as it scans the earth’s surface. By technically using this unit, the operator can set up mission parameters and monitor the performance of the system (Vosselman and Maas, 2010).

Airborne LiDAR systems are always completed by a GPS ground station, serving as a reference station for achieving decimeter accuracy. During the data collecting process, two GPS ground stations are usually operated—one as the base station and the other as a back up. In recent years, several countries have installed permanent GPS ground stations; thus, normally there is no need to operate their own GPS stations.

3.5.3 Applications of ALS in Transportation

**Traffic Flow Estimation**

Grejner-Brzezinska et al. (2005) conducted a project using Airborne LiDAR data
for traffic flow estimates. The study presented theoretical and practical studies on the feasibility of using LiDAR data and airborne imagery collected over the transportation corridors for the estimation of traffic flow parameters. They proved that high-point density airborne LiDAR can effectively support traffic monitoring and management by delivering a variety of traffic flow data.

**Highway Corridor Mapping**

Uddin and Al-Truk (2001) presented the application of airborne LiDAR technologies for the cost-effective management of highway corridors, airports, and related transportation infrastructure assets. They produced digital terrain models, generated digital mapping databases, and linked various data sources through user-friendly GIS software. In their study, they introduced a real case study of the Raleigh bypass highway alignment project. The study also carried out a high resolution and accurate digital terrain mapping for Oxford and surrounding areas in northern Mississippi by applying the airborne LiDAR technology to illustrate the data accuracy, efficiency, and cost-effectiveness of the airborne laser technology.

**Integrated Uncertainties of Traffic Islands Modeling**

Affecting traffic behavior safety, air pollution, and transport decision support, traffic islands play a major role in transport studies. Zhou and Stein (2013) used airborne laser scanning data to develop a random set approach to determine the locations of traffic islands. The study showed that point spacing makes the largest contribution to the positional accuracy of a traffic island.
Collecting and Recording Highway Inventory

Zhou et al. (2013) compared various technologies of collecting highway inventory data to determine the most cost-effective method. These technologies include field inventory, photo/video logs, integrated GPS/GIS mapping systems, aerial photography, satellite imagery, virtual photo tourism, terrestrial laser scanners, and mobile mapping systems (i.e., vehicle-based LiDAR, and airborne LiDAR). They concluded that mobile LiDAR can collect all required feature data in a short period, but it requires an extensive data reduction effort and has the ability to collect data valuable for multiple DOT programs.

Expanding Highway Projects

The application of airborne laser technology in Uddin’s paper demonstrated that ALS is an efficient and economical way of collecting data (Uddin, 2008). In this paper, the author compared the elevation data accuracy, efficiency, and cost-effectiveness with the traditional aerial photogrammetry and ground-based total station survey methods. This research recommended that traditional methods should be combined with low-altitude airborne laser technology to save money and time for highway projects.

3.6 Chapter Summary

This chapter provides a detailed description of LiDAR technology, and places more emphasis on airborne LiDAR. LiDAR is a remote sensing technology that can generate accurate 3D information of target objects. It is widely used in road inventory data collection in recent years. Based on different carrying platforms, there are three
kinds of LiDAR: terrestrial LiDAR mounted on a tripod, mobile LiDAR in a mobile vehicle, and airborne LiDAR in a plane or aircraft.

Compared with terrestrial LiDAR and mobile LiDAR, airborne LiDAR has significantly high mapping efficiency; it can also map a wide range of highways without affecting highway traffic. Although airborne LiDAR produces data with lower point density, the data resolution is sufficient for us to identify the location of many features on highways. The attractive advantages of airborne LiDAR make it a very promising technology in transportation.
CHAPTER 4

FIELD EXPERIMENT AND DATA COLLECTION

4.1 Methodology

The object of this project is to evaluate the pros and cons of the airborne LiDAR system when gathering road inventory data. Remote Sensing Service Laboratory (RSSL) at Utah State University (USU) carried out the data collection.

Fig. 4.1 The USU Cessna TP206 research aircraft.

The USU airborne LiDAR system is mounted in a single engine Cessna TP206 aircraft (Fig. 4.1). The system consists of a LiDAR scanner, IMU, and flight navigation unit (Fig. 4.2). This LiDAR instrument consists of a Riegl Q560 transceiver and Novatel SPAN LN-200 GPS/IMU positioning and orientations system. Depending on the flight
height, the LiDAR scanner is able to collect data at a pulse rate of 250,000 shots/seconds. Together with the LiDAR system, the USU airborne system is also equipped with multispectral and thermal infrared cameras, which can be used for aerial photos. The camera system is composed of four ImperX 4820 Monochrome cameras with 4872 x 3248 pixels per camera. They are also equipped with interface filters in the blue, green, red, and near-infrared (NIR) centered at 0.472 μm, 0.562 μm, 0.655 μm, and 0.80 μm, respectively.

![Image](image.png)

**Fig. 4.2** The onboard integrated remote sensing system.

### 4.2 Data Collection

This part of the study summarizes the field experiments conducted by the RSSL at USU. The flight campaign was conducted on June 4, 2015, and can be divided into two separate parts. The first part was from 11:20 am to 12:45 pm and covered three road
sections, namely I-84, I-15 North and I-15 South. The second part was from 3:20 pm to 4:20 pm and mapped section I-191. The weather conditions were a partially cloudy sky and a clear sky during the first and second parts of the flight, respectively. LiDAR data and high-resolution color image data were captured simultaneously during the flight.

![Map of Utah with sections I-84, I-15 North, I-15 South, and US-191 marked]

Fig. 4.3 Layout of the mapping.
Both airborne LiDAR data and aerial images were obtained for highway road
features inventory. This study covers four road sections in Utah, one on Interstate 84 (I-84), two on Interstate 15 (I-15), and one on US-191 (Fig. 4.3, Sites 1-2). The exact location of these sites can be described by the distance between two mile posts (MP) as:

1. I-84 from Mountain Green to Morgan County/Summit County (MP 97 to 113)
2. I-15 North from Payson to Springville (MP 284 to 307)
3. I-15 South for Region 2 (MP 240 to 260)
4. US-191 from MP 84 to 112 (MP 84 to 112)

Table 4.1
Raw LiDAR data files for I-84, I-15 North, and I-15 South.

<table>
<thead>
<tr>
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</table>

The data were acquired at an average flight height of approximately 500 m agl or lower. The LiDAR scan rate was about 125 Hz, the pulse rate was 200,000 shots/second, and average flight speed was about 180 km/h. In these settings, the point density can be
up to 6.2 points/m². In total, four bands of multispectral data were acquired by the thermal infrared cameras; red, green, blue, and NIR. The lists of raw LiDAR data for I-84, I-15 North, I-15 South, and US-191 are given in the following two tables. Because there are a large number of imagery data files, we decided not to list them here.

<table>
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<tr>
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### 4.3 Data Preprocessing

The raw airborne LiDAR data and imagery data were preliminarily processed and evaluated by the RSS at USU using the Waypoint Inertial Explorer software (www.novatel.com) to process the raw GPS/IMU data and the GPS data, which were obtained from the onboard navigation system and the international Global Navigation Satellite System (GNSS) (https://igscb.jpl.nasa.gov/) service (IGS) base stations, respectively. From these data sets, they could get the position and the altitude of the aircraft. Four IGS base stations were chosen based on their proximity to the four highway intersections. The coordinates of the IGS base stations established a geo-position relative to the WGS84 datum during the data collection process, and generated the navigation
The flight trajectory data were transformed to the WGS84 datum. Fig. 4.5 presents the whole flight trajectory for the entire data collection. Fig. 4.6 presents the separate flight trajectories for each intersection.

![Fig. 4.5 The whole flight trajectory for the entire data collection.](image)

The aircraft trajectories were also processed in time. The separations of the aircraft trajectories are shown in Fig. 4.7, where the east, north, and up directions (x, y, and z coordinates) were presented by red, green, and blue colors, respectively, and the peak/high separation values respected the direction changes or turns.
Fig. 4.6 The separate flight trajectories for four intersections.
Site 1. I-84
Site 2. I-15 North
Site 3. I-15 South
The RiAnalyze software was used to analyze the collected LiDAR data and transform the LiDAR full waveform data to point cloud data. Then the RiProcess software was used to add the x, y, z coordinates to the point cloud data. They also used the RiProcess software to perform data calibration and strip (single scan line) adjustment to improve data accuracy. Because each flight line was processed individually, it was possible for the data analyst to ensure quality control (QC) for the overlap between lines.

4.4 Accuracy of LiDAR Data

Here we used the U.S. Geological Survey (USGS) National Geospatial Program (NGP) standard to evaluate the LiDAR data accuracy. This standard places unprecedented emphasis on LiDAR point cloud data. The basic requirements for LiDAR point cloud data according to the USGS NGP standard are shown in Table 4.3.
Table 4.3
Summary of USGS NGP guidelines v.13 for LiDAR data quality.

<table>
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<tr>
<th>RMSE</th>
<th>Condition</th>
<th>Source</th>
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<td>12.5 cm</td>
<td>Fundamental vertical accuracy (in the clear)</td>
<td>USGS</td>
</tr>
<tr>
<td>10.0 cm</td>
<td>Within swath overlap regions</td>
<td>USGS</td>
</tr>
<tr>
<td>7.0 cm</td>
<td>Relative accuracy within individual swaths</td>
<td>USGS</td>
</tr>
</tbody>
</table>

Two methods are used to evaluate the accuracy of the LiDAR data. One evaluates the differences between the flight trajectory obtained from the onboard GPS/IMU system and the flight trajectory obtained from the ground-based IGS station. The other evaluates the elevation differences of different flight strips within their overlapping areas. However, during the data acquisition process, no ground control point information was collected. Hence, we cannot use the flight trajectory solution to estimate data accuracy. But according to Fig. 4.7, the average forward/reverse or combined separation is less than 5 cm, which generally means that the fundamental vertical accuracy (in the clear) of 12.5 cm can be achieved.

The error within swath overlap regions can be calculated by comparing the differences between flight lines in their overlapping areas. Figs. 4.8-4.11 show the flight lines for one highway section and use one overlapping area for error evaluation; the evaluation result is provided in a histogram.

The associated RMSE for each of the road sections (i.e., I-84, I-15 North, I-15 South, and US-191) was calculated to be 8.3, 7.6, 8.2, and 6.2 cm, respectively. The average RMSE was 7.6 cm, which is smaller than 10 cm as required by the USGS standard. Thus, the accuracy standard within the swath overlap regions was achieved.

Generally speaking, the relative accuracy within individual swaths will not be
greater than the overlap regions’ accuracy. Hence, the relative accuracy within the swath can be estimated to be less than the RMSE of 7.6 cm on average.

Fig. 4.8 Site 1. I-84.
Fig. 4.9 Site 2. I-15 North.
Fig. 4.10 Site 3. I-15 South.
Fig. 4.11 Site 4. US-191.
A summary of the LiDAR data accuracy assessment is shown in Table 4.4.

Table 4.4
Summary of LiDAR data accuracy assessment.

<table>
<thead>
<tr>
<th>RMSE Requirement</th>
<th>Condition</th>
<th>Estimated RMSE Achieved</th>
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</thead>
<tbody>
<tr>
<td>7.0 cm</td>
<td>Relative accuracy within individual swaths</td>
<td>Less than 7.6 cm estimated</td>
</tr>
<tr>
<td>10.0 cm</td>
<td>Within swath overlap regions</td>
<td>7.6 cm average measured</td>
</tr>
<tr>
<td>12.5 cm</td>
<td>Fundamental vertical accuracy (in the clear)</td>
<td>Not assessed, but was likely achieved</td>
</tr>
</tbody>
</table>

4.5 Chapter Summary

In this chapter, the data collection process as well as the airborne LiDAR data preprocessing were introduced. Both LiDAR data and aerial imagery data were collected by the RSSL at USU. Totally four highway sections in UTAH were mapped, including one section on Interstate 84 (I-84), two on Interstate 15 (I-15), and one on US-191. The collected raw LiDAR data were preprocessed through specific software, and accuracy was evaluated according to the USGS NDP standard. The results showed that the collected data generally met the accuracy requirement.
CHAPTER 5

AIRBORNE LIDAR DATA PROCESSING USING ARCGIS

5.1 Introduction

After preprocessing, LiDAR data can be used to extract information such as the height and location of various highway assets. Several kinds of software can process LiDAR data, including ArcGIS and FugroViewer. FugroViewer is a 3D geodata viewer; it can read LiDAR data and provide some basic tools to extract information from the data. ArcGIS is powerful software developed by Esri for working with maps and geographic information. Once the data have been acquired as a vector file, a raster file, or a LAS file, they can be viewed and operated in ArcGIS. In this chapter, we developed an ArcGIS-based algorithm to detect highway assets from the obtained LiDAR data.

Highway assets include traffic signs, traffic signals, billboards, road lamps, guardrails, bridges, culverts, and more. As previously mentioned, LiDAR is a remote sensing technology that collects geometric and geographic information of targets on the earth’s surface in the form of point clouds. In LiDAR data, an object can only be identified based on its corresponding points. Thus, if an object has no or very few corresponding points, we cannot identify it. The point density of the obtained LAS files is around 6 points/m². For small traffic signs such as speed limit signs and instruction signs (Figs. 5.1-5.2), their areas are usually less than 1 m². Moreover, there is an angle (less than 90 degrees) between the laser beams and the signs during scanning. Therefore, there
may be only one or two points representing a sign. We can hardly identify an object based on one or two points; thus, it is impossible for us to detect those small signs simply by using airborne LiDAR data. However, large traffic signs, especially those with large assemblies, are fairly conspicuous in LiDAR data. Fig. 5.3 shows a picture of an overhead traffic sign, and Fig. 5.4 shows its corresponding LiDAR data. We can see that, although the sign’s face cannot be clearly seen in LiDAR data, the large sign assembly represented by a series of points and can be easily identified. Similarly, small traffic signals are not clear in LiDAR data (as shown in Fig. 5.5 and Fig. 5.6), while traffic signals with large assemblies can be identified in LiDAR data (as shown in Fig. 5.7 and Fig. 5.8). In addition, road lamps usually have long light poles; they can also be identified in LiDAR data (as shown in Fig. 5.9 and Fig. 5.10). Billboards usually have large faces and assemblies, making them very conspicuous in LiDAR data (as shown in Fig. 5.11 and Fig. 5.12). Since airborne LiDAR technology maps target objects from the air, highway structures including bridges and culverts can also be seen in airborne LiDAR data. Fig. 5.13 and Fig. 5.14 show a picture of a bridge and its profile in LiDAR data, respectively. Fig. 5.15 and Fig. 5.16 show a culvert and its profile in LiDAR data respectively. Barriers are also very important subsidiary facilities for highways. Different types of barriers exist, such as cable barriers, box beam barriers, and constant slope concrete barriers. In the collected airborne LiDAR data, all kinds of barriers can be easily identified, except for cable barriers with a small surface. Fig. 5.17 shows a section of cable barriers and Fig. 5.18 shows its profile in collected LiDAR data. Cable barriers can
hardly be seen in LiDAR data, as shown in Fig. 5.19 and Fig. 5.20, where a segment of W-beam barriers correspond to a long string of points above ground in LiDAR data.

Fig. 5.1 Speed limitation board.  
Fig. 5.2 Instruction sign.

Fig. 5.3 Overhead traffic sign.  
Fig. 5.4 Overhead traffic sign in LiDAR data.

Fig. 5.5 Small traffic signal.  
Fig. 5.6 Small traffic signal in LiDAR data.
Fig. 5.7 Large Traffic signal.

Fig. 5.8 Large traffic signal in LiDAR data.

Fig. 5.9 Road lamp.

Fig. 5.10 Road lamp in LiDAR data.

Fig. 5.11 Billboard.

Fig. 5.12 Billboard in LiDAR data.
For all the above-mentioned road assets that can be identified in airborne LiDAR data, their specific location information and structure characteristics can be manually measured and recorded in the LiDAR data. However, manually identifying all the road features will require a great deal of time and effort; meanwhile, it may lead to some omission due to human error. Therefore, we developed an ArcGIS-based algorithm to extract certain types of road features from airborne LiDAR data. Based on the algorithm,
we first used ArcGIS to automatically find all specific road assets, and then measured and recorded their location and structure information.

### 5.2 ArcGIS-based Feature Extraction Algorithm

The algorithm we developed for extracting road assets is based on the elevation difference between the assets and the bare ground. Fig. 5.21 shows the flowchart of this algorithm.

![Flowchart of ArcGIS-based algorithm](image)

**Fig. 5.21** Flowchart of ArcGIS-based algorithm.

The algorithm consists of the following steps:

1) Load LAS files (airborne LiDAR data) to ArcGIS. Divide the LAS data into many small square cells of a certain size. For each small cell, calculate the elevation difference between the highest point and the lowest point within that cell. This procedure can be done using the LAS Point Statistics as Raster tool in ArcGIS. The result will be raster data, within which each cell has a
particular value: the elevation difference.

2) Evaluate the range of elevation difference between a certain type of road asset and the bare ground. Delete all the cells that are out of the range from the obtained raster data.

3) Determine a road boundary and clip the raster data from step (2) according to the boundary to remove the cells beyond the road.

4) Further convert the raster data from step (3) into feature data.

In this paper, we used a large traffic sign as an example to show the effectiveness of the proposed algorithm. Fig. 5.22 shows a section of the original LAS data in ArcGIS. We can hardly see anything from the raw data, so we transformed the LAS data into raster data using the LAS Point Statistics as Raster tool (step 1). The obtained raster data are shown in Fig. 5.23. Then we can use the raster-based tools in ArcGIS to deal with the raster data. In this research, we chose 1 as the cell size of the raster data (i.e., each cell of the raster data has an area of 1 m²). It can be seen from Fig. 5.23 that most cells have values near zero. As previously mentioned, the value of a cell represents the elevation difference between the highest point and the lowest point within that cell; thus, a cell with a value near zero means all the LAS points within that cell have a similar elevation. For the cells that contain points representing a large traffic sign, the values should be near the height of the traffic sign. The height of traffic signs can be directly measured from LAS data, or can be estimated based on highway design specifications. If we remove all the cells whose values fall into a certain range (e.g., smaller than the height value of the traffic sign), the remaining cells should be the candidate cells that may contain points
representing the traffic sign (Fig. 5.24). We then clipped out all the cells that were within
the range of the road surface; as traffic signs should be in the range of the road surface
(Fig. 5.25). From Fig. 5.25, we can easily detect the traffic sign and then record the
location and structure information of the traffic sign.

![Fig. 5.22 LAS data.](image1)

![Fig. 5.23 Raster data.](image2)

![Fig. 5.24 Filtered raster data.](image3)

![Fig. 5.25 Clipped raster data.](image4)

5.3 Road Assets Inventory

With the proposed ArcGIS-based algorithm, we can easily identify different kinds
of road assets. However, this algorithm can only help us find road assets. The specific
location and structure information of the road assets still need to be collected manually.
In this section, we provided our collected information of all the assets that can be identified from airborne LiDAR data and compared them with the Mandli dataset.

5.3.1 I-84

In total, 10 raw airborne LiDAR data files were obtained for the mapping section on I-84: No.1-No.10 (Chapter 4, Table 4.1). Among them, No. 8 was a duplication of No. 7, and both No. 9 and No. 10 missed some part of the highway. Therefore, in our project, only the first 7 files were used to extract highway features. The total length of the mapping section was around 17.5 miles, crossing Peterson and Morgan.

With the proposed feature extraction algorithm, we found 2 overhead traffic signs, 1 traffic signal, 19 street lamps, 5 billboards, and 27 bridges on the mapping section of I-84. In addition, barriers (excluding cable barriers) were identified. Fig. 5.26 shows all road assets detected on I-84.

5.3.2 US-191

Fourteen raw LiDAR data files were collected for US-191: No. 1-No. 14 (Chapter 4, Table 4.2). Only 11 files were valid. Files No. 3, No. 7, and No. 14 could not be used because they either missed some parts of the highway, or duplicated other files. The total effectively mapped highway length was about 14 miles.

On the mapping section of US-191, we did not find any recognizable traffic signs, signals, or road lamps. We identified just 1 billboard, 1 bridge, 4 culverts, and all barriers. All road assets we detected on US-191 are shown in Fig. 5.27.
5.3.3 I-15 North

As introduced in Chapter 4, I-15 North refers the section from Payson to Springville (MP 250 to 260) on I-15. In total, 14 raw airborne LiDAR data files were obtained for the mapping section on I-15 North: No.11-No.24 (Chapter 4, Table 4.1). Among them, No. 17 and No. 23 were redundant because their mapping section were also covered by other LAS data. The total length of the mapping section is around 8 miles.

On I-15 North, we found 192 overhead traffic signs, 178 street lamps, 124 billboards, 54 bridges and 1 culvert on the mapping section of I-15 North. In addition, barriers (excluding cable barriers) were identified using the ArcGIS-based algorithm. Fig. 5.28 shows all the road assets we identified on I-15 North.

5.3.4 I-15 South

On I-15, we also collected airborne LiDAR data from MP 284 to 307, which is referred to as I-15 south. In total, 7 raw airborne LiDAR data files were obtained for the mapping section on I-15 South: No.25-No.31 (Chapter 4, Table 4.1). These LiDAR data are all valid and were used to extract information from the road assets. The total length of the mapping section was around 23 miles.

On I-15 south, 34 overhead traffic signs, 103 street lamps, 56 billboards, 33 bridges and 4 culverts were detected. We also identified all barriers (excluding cable barriers) using the proposed ArcGIS-based algorithm. Fig. 5.29 shows all road assets identified on I-15 South.
Fig. 5.26 Detected road assets on I-84.
Fig. 5.27 Detected road assets on US-191.
Fig. 5.28 Detected road assets on I-15 north.
Fig. 5.29 Detected road assets on I-15 south.
5.4 Comparison with Mandli Data

Fig. 5.30 Comparison of the billboards detected by Mandli and our study.
To verify the collected information from road assets, we compared it with a Mandli dataset. The latest Mandli dataset was collected via LiDAR and photolog imagery. Traffic signs, including small signs and large overhead signs, traffic signals, billboards, and barriers, were all included in the Mandli dataset. Because of the sparseness of the airborne LiDAR points, we could not extract small signs in this research. However, all other assets included in the Mandli dataset were successfully explored. Moreover, we detected bridges and culverts that cannot be mapped from mobile platform thanks to the broad view of the aircraft. We also explored the road lamps that may be useful to state DOTs but were not detected by Mandli. However, we only collected the location and size information of those assets; the specific contents (e.g., the advertisement details of the billboards, the instruction information of the signs) of the assets could not be identified, although this kind of information can be easily obtained if we combine it with imagery data in the future.

Fig. 5.30 shows the comparison between the billboards detected in our research and by Mandli.

5.5 Chapter Summary

In summary, we developed an ArcGIS-based algorithm to semi-automatically detect and record highway assets from the collected LiDAR data. According to the point density of the airborne LiDAR data and the characteristics of different highway features, we successfully extracted large overhead traffic signs, traffic signals, billboards, barriers, bridges and culverts. For these highway features, their height above the ground was the
main characteristic distinguishing them. Therefore, we used the elevation difference within a certain area of the point cloud as a criterion for determining whether an object was the target feature or not. And then manually recorded the location and structure information of those assets. The detection results showed that the ArcGIS-based algorithm proposed in this report is effective and efficient, and airborne LiDAR technology is applicable for highway inventory.
CHAPTER 6

IMAGE PROCESSING

6.1 Introduction

In this section, I developed a method for automatic sign and drainage detection based on high-resolution RGB aerial images. Traffic signs (i.e., traffic signals, traffic signs and light poles, (for simplicity, I will use ‘signs’ to represent all the traffic signs, traffic signs and light poles hereinafter)) are significant components of a traffic system, they help guide and regulate traffic. Drainage system, a system that helps remove water from streets and highways, is extremely important for the safety of roadway system. Water that remains on the roadway surface may cause serious traffic accidents, especially in winter when the temperature is low. Also, without a good drainage system, pavement edge deterioration will accelerate, which can result in additional safety hazards. Therefore, traffic signs, light poles and drainage grates are all important objects of roadway inventory.

Normally, the detection of road signs is based on the shape or color of the signs, with pictures or videos taken from the ground. It is very easy to recognize the traffic signs or other signs from those pictures because the signs usually have distinctive color and shape. For example, the ‘STOP’ sign is a standard octagon with red color, the warning signs are always triangles with yellow color. To date, tons of methods have been developed to extract road signs from color images. Garcia et al. (2003) proposed a
MATLAB-based method to detect traffic signs from RGB images obtained from ground. Sallah et al. (2010) utilized shape feature to detect road signs. In Sallah’s paper, Hough Transform method was firstly used to detect the number of peaks and lines that can indicate the shape of the road sign, then the ratio of the area and the ratio of the perimeter were determined. They preliminarily stored the ratio values of all kinds of road signs in MATLAB. After comparing the ratios of area and perimeter with the stored values in MATLAB, the road sign can be recognized. They tested 49 randomly chosen road sign images and got a 83.67% success rate, which means that their methodology worked well in detecting and recognizing road signs from images. Balali and Golparvar-Fard (2015) proposed a recognition and classification method to automatically detect traffic signs based on video images. Both color and shape features were used in their method. Color feature helped them to extract a set of bounding boxes that potentially contained a traffic sign, and shape feature was then utilized to further refine and categorize those potential bounding boxes.

However, for aerial images, we can hardly recognize the shape or the color of the signs along roadway (Fig. 6.1). Because the pictures were taken from the aircraft, the lamp posts, traffic signs and traffic signals became thin lines that were perpendicular to the road direction to some degree. So the traditional shaped-based or color-based detection methods are not applicable under this circumstance. We need to find another way to detect the signs according to their characteristics in aerial images. As for drainage grates detection, I will also develop an algorithm based on the characteristics of drainage grates in aerial images.
6.2 Sign Detection

The proposed approach was mainly composed of the following two steps: 1) get the color features, segment the image into two parts: road and non-road, by using Fuzzy-C-means (FCM), 2) based on the road features, find the position of the lamps and the road signs on the road, mark the position of the streetlights and the traffic signs on the original image.

Fig. 6.2 shows the framework of the road sign recognition algorithm that presented in this paper.
6.2.1 Road Segmentation Using FCM

Fuzzy-C-means (FCM) clustering method was used to find the region of interest (ROI), e.g., the road part of the images. Clustering is the task of classifying a set of objects into different groups based on their features. Fuzzy-C-means (FCM) algorithm is one of the most popular and useful fuzzy clustering methods. It is widely used in various fields such as medical image segmentation, data mining and so on.

The CIELab color space was selected as the color features of the image pixels. Because CIELab space has metric color difference sensitivity to a good approximation and is very convenient to measure small color difference, while the RGB does not. Thus, our first step was to transform the RGB aerial images that obtained by the airborne system to LAB images. The FCM algorithm of MATLAB was then used to cluster the image pixels into two clusters, road and non-road, according to their color features. And
the membership values $u_k(i)(k=1,2, i=1,2,...,n)$ can be obtained, where $k$ is the number of clusters, and $n$ is the number of image pixels ($n=M*N$ for an image with size $M*N*3$). If $u_1(i) > u_2(i)$, the image pixel $i$ belongs to the first cluster, otherwise the pixel belongs to the second cluster. We labeled the pixels in the first cluster 0, and the pixels in the second cluster 1. When showing an image in MATLAB, the image pixels with intensity 1 appears to be white, and those with intensity 0 appears to be black. Thus, we can decide which cluster belongs to the road part (Fig. 6.4).

![Fig. 6.3 Original image.](image1) ![Fig. 6.4 Image after clustering.](image2)

As we can see, the image was roughly divided into two parts, road (white) and non-road (black). However, some other objects such as rooftop of buildings and cars in parking lots were misclassified as road surface. Therefore, we utilized the connected component analysis and morphological opening and closing algorithms to remove these misclassified features. The result is shown in Fig. 6.5. After that, we reflected the
segmentation result to the original image (Fig. 6.6).

![Fig. 6.5 After morphological.](image1)
![Fig. 6.6 Segmentation result.](image2)

6.2.2 Locate the Signs on the Road

The streetlight and the traffic sign on the road have similar color feature with the road surface, so it is difficult to extract them by using their color features. I used the edge detection to isolate them in this project. The edge of Fig. 6.6 was detected according to the local homogeneity model as proposed by Sakthivel, K. et al (2014).

First, a 5*5 local image window as in Fig. 6.7 was constructed for the computation.

Second, compute the standard deviation of each pixel.

The standard deviation is:
\[ v_{i,j}^k = \sqrt{\sum_{m=i-2}^{i+2} \sum_{n=j-2}^{j+2} \left( p_{m,n}^k - \mu_{i,j}^k \right)^2 / 25} \]  \hspace{1cm} (1)

where \( k = 1,2,3, \ 1 \leq i, m \leq M, \ 1 \leq j, n \leq N, \ \mu_{i,j}^k \) is the mean intensity of the pixels within the local image window and calculated as:

\[ \mu_{i,j}^k = \left( \sum_{m=i-2}^{i+2} \sum_{n=j-2}^{j+2} p_{m,n}^k \right) / 25 \]  \hspace{1cm} (2)

Third, employ Sobel operator to calculate the discontinuity and use the magnitude \( e_{i,j}^k \) \((k = 1,2,3)\) of the gradient at location \((i,j)\) as the measurement:

\[ e_{i,j}^k = \sqrt{\left( G_x^k \right)^2 + \left( G_y^k \right)^2} \]  \hspace{1cm} (3)

where \( G_x^k \) and \( G_y^k \) are the components of the gradient of pixel \((i,j)\) in the horizontal and vertical directions, respectively.

The standard deviation and discontinuity values are normalized in order to

**Fig. 6.7** Local image window.
achieve computational consistence:

\[ V_{i,j}^k = \frac{v_{i,j}^k}{v_{max}^k} \]  \hspace{1cm} (4)

\[ E_{i,j}^k = \frac{e_{i,j}^k}{e_{max}^k} \]  \hspace{1cm} (5)

where \( v_{max}^k = \max\{v_{i,j}^k\}, e_{max}^k = \max\{e_{i,j}^k\}, 1 \leq i \leq M, 1 \leq j \leq N, k = 1,2,3 \)

The local homogeneity is represented as:

\[ LH^k = 1 - E_{i,j}^k \times V_{i,j}^k \]  \hspace{1cm} (6)

where \( 1 \leq i \leq M, 1 \leq j \leq N, k = 1,2,3. \)

The local homogeneity result is shown as follows:

![Edge detection result](image)

**Fig. 6.8** Edge detection result.

Use the Canny edge detector to further detect the edge of **Fig. 6.8**, and then extract the horizontal edge. Deleting the short horizontal edges (the edge of the cars), we
got the edge of the lamp and the traffic sign as in Fig. 6.9.

Based on Fig. 6.9, mark the locations of the lamp and the traffic sign on the original image (Fig. 6.10).

6.2.3 Results and Conclusion

We tested our method on 10 aerial images, which totally contain 23 sings (traffic signs, traffic signals and light poles). Table 6.1 shows the testing results.

From the results, we can see that most of the signs can be detected successfully. But some other objects were also misclassified as the road signs. Therefore, the future research should focus on reducing the misclassification rate and maximizing the detection accuracy.
### Table 6.1
Traffic Sign Detection Results and Accuracy Evaluations.

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<th>Right Object</th>
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<th>Wrong Object</th>
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</table>

### 6.3 Highway Drainage Grates Detection

Unlike light poles or erected signs, the shape and color of the drainage grates are identical in aerial images. The drainage grates have predefined size (length and width) and conspicuous color: dark (Fig. 6.11). From the aerial images, we can observe that the color of the road surface is distinct from the roadside shrubs, and the color and shape of the drainage grates is also very special. In this part, we decide to use color and shape characteristics to detect drainage grates from RGB images.

Red-Green-Blue (RGB) model is one of the most commonly used models for representing images. In the RGB model, a color is defined as the mixture of red, green and blue light which have certain intensity level. Each of the red, green, and blue have intensity values from 0 to 255, which means there are total $256 \times 256 \times 256$ different colors.
0 indicates the lowest intensity level (black), and 255 represents the highest intensity level (white).

**Fig. 6.11** Drainage grates from aerial image.

**Fig. 6.12** Drainage grates detection flowchart.
The algorithm used to detect drainage grates is similar to the algorithm used for traffic sign detection shown in part 6.2. Fig. 6.12 shows the flowchart of the algorithm for drainage grates detection.

Fig. 6.13 Road surface color characteristic analysis.
6.3.1 Road Segmentation

For the drainage grates on the highway, the main features that can distinguish them are their dark color and rectangular shape. However, other objects in the image also have either a similar color or shape. Within the highway surface, the main objects similar to the drainage grates are the windshields of white cars. Outside the highway surface, the shrubs or other objects may have a similar dark color as the drainage grates. In order to eliminate the interference of the bare ground and shrubs, we first extract the highway surface from the aerial images. As we can see in Fig. 6.11, the highway surface has a relatively light color, compared to the color of the bare ground or shrubs. Based on this characteristic, we can roughly divide the image into two parts, where the light-colored part should be the highway surface and the dark-colored part will be the bare ground and shrubs.

In order to get an appropriate demarcation, we first analyzed the color distribution within the image. As shown in Fig. 6.13, we chose several profiles of the highway and analyzed the color composition of each pixel along the profile. We can see that, approximately, the intensity values of red, green and blue of pixels representing highway surface are all larger than for pixels representing bare ground or shrubs.

Obviously, for each pixel, the intensity values for R, G, and B colors have the same trend. If the intensity level of red for one pixel is high, the intensity level of green and blue for that pixel will also be high, and vice versa. From Fig. 6.13, we can see that the intensity value of pixels that represent ground or shrubs falls into the 0-100 range, while road surface falls into the 80-180 range. In order to make the difference (between
highway surface and round) more significant, we sum up the intensity values of red, green and blue for each pixel and assign the value to the corresponding pixel, and resulting a new matrix I (Fig. 6.14).

\[
I(i,j) = R(i,j) + G(i,j) + B(i,j) \quad \forall \ i \in [1,M], j \in [1,N] \\
I(i,j) = 1 \quad \forall I(i,j) \geq T_1 \\
I(i,j) = 0 \quad \forall I(i,j) \leq T_1 
\]

where \( I \) is the summation value, \( M \) is the number of columns in the image, \( N \) is the number of rows in the image, and \( T_1 \) is the threshold value that determines the boundary of the road and non-road. In this project, we use \( T_1 = 300 \).

![Diagram of summation of R, G, B color band](image)

**Fig. 6.14** Summation of R, G, B color band.

We assigned 0 to pixels whose values are smaller than 300 and 1 to pixels whose values are larger than 300. After using the thresholding method, the resulting image is shown in **Fig. 6.16**, where white pixels have a value of 1 and black pixels have a value of 0. Note that, within the range of highway surface, pixels representing dark-colored objects were assigned a value of 0, whereas outside the range of the highway surface, some objects, such as parking lots and light-colored roofs, are misclassified as highway.
Thus, the morphological opening and closing, as well as BoundingBox methodologies were used to eliminate the misclassified data. Fig. 6.17 shows the resulting image. Finally, the non-highway part was deleted from the original image.

![Fig. 6.15 Original image.](image1) ![Fig. 6.16 After thresholding.](image2) ![Fig. 6.17 Road surface.](image3)

6.3.2 Drainage Grates Detection

*Color Thresholding*

After segmenting the highway surface from the image, our next step was to extract the drainage grates. As with the road extraction, we also used color characteristics to detect the drainage grates because their color is quite different from the highway surface color. We still used the profile analysis method to evaluate the intensity value of
the drainage grates. Fig. 6.18 shows the results of three profiles displaying the contradistinction between the intensity values of drainage grates and highway surface. It is fairly clear that the intensity values for all R, G, and B bands for the drainage grates were no greater than 80 in most cases. Similarly, we summed up the intensity values of red, green, and blue colors for each pixel and assigned the value to the corresponding pixel, then used the threshold value of $240 = 3 \times 80$ to classify the image.

$$I(i, j) = 1 \quad \forall I(i, j) \leq T_2$$

$$I(i, j) = 0 \quad \forall I(i, j) \geq T_2$$

where $T_2 = 240$.

**Shape Analysis**

We can see from the original aerial image that black car or the windshields of white cars have a similar color as the drainage grates. Thus, using only color thresholding is not enough to get the ideal extraction results. We thus used shape characteristics for further analysis. The previously discussed results of color thresholding will be the image with a series of connected components that represent the drainage grates, black cars, windshields, or some other objects. Each connected component has its own shape and area. The shape of the connected components that represent the drainage grates is nearly rectangular, and size is also relatively unified. For the purpose of evaluating the property of the drainage grates, we measured the length, width and area of 31 connected components that we preliminarily determined to be drainage grates. Table 6.2 shows the statistical values of the 31 connected components.
Based on the data in Table 6.1, length ranged from 5 to 16, width ranged from 5 to 15, and area ranged from 52 to 110. We set the lower and upper limits of length and width to 5 and 20, respectively, and the threshold values of area were set to 30 and 150, to cover more cases. The connected components that satisfy the following constraints were regarded as candidate drainage grates.

**Fig. 6.18** Drainage grate color characteristic analysis.
\begin{align*}
T_2 & \leq L(k) \leq T_3 \\
T_2 & \leq W(k) \leq T_3 \\
L(k) + W(k) & \leq T_4 \\
|L(k) - W(k)| & \geq T_5 \\
T_6 & \leq A(k) \leq T_7
\end{align*}

where \( L(k) \), \( W(k) \), and \( A(k) \) are the length, width, and area of the \( k \)th connected component, respectively, and \( T_2 = 5, T_3 = 20, T_4 = 30, T_5 = 5, T_6 = 3 \), and \( T_7 = 150 \).

For each connected component, constraints (14) and (15) restricted the range of length and width while constraint (16) limited the area. Constraints (17) and (18) further restricted the shape of the connected components to be approximately rectangular.

Table 6.2
Statistics of the chosen samples.

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</table>

Filtration

Shape analysis can help us eliminate the interference of dark-colored cars, while the windshield of white cars, whose color and shape are both similar with the drainage grates, cannot be completely removed. Hence, we used the following procedure to further filtrate the drainage grates.

a. Use color thresholding to identify white cars, excluding the windshield.
b. Use morphological operation to get the entire range of cars.

c. Remove all candidate connected components that fall into the range of cars.

Fig. 6.20 shows an example of the detection results, the drainage grates are marked by blue crosses.
6.3.3 Results and Conclusion

The algorithm was tested on 20 images, and the results are given in Table 6.3.

Table 6.3
Drainage Grate Detection Results and Accuracy Evaluation.

<table>
<thead>
<tr>
<th>Image Number</th>
<th>Detection Results</th>
<th>Accuracy Evaluations</th>
</tr>
</thead>
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<tr>
<td></td>
<td>Right Object</td>
<td>Missed Object</td>
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</table>

According to the data in the table, the completeness of the algorithm on the 20 testing images is 89.3% while correctness is 77.9%. For some images, we can see that both completeness and correctness are high; for other images, the algorithm does not work well. The quality of images and road segmentation are the main factors influencing
the performance of our algorithm. To improve the image quality, we should collect data on fair-weather days and fly the plane at reasonable heights. In addition, in our algorithm, the parameters used to filtrate drainage grates are adjustable. If we choose those parameters that can eliminate more interference objects similar to drainage grates, some drainage grates that are less legible may also be eliminated; if we try to detect all the drainage grates, even those that are irregular or illegible, more interference objects will be misidentified as drainage grates. In the future, we should focus on the improvement of the road segmentation method and the refinement of our algorithm to make it more robust.

6.4 Chapter Summary

In this chapter, we discussed how to detect highway features from aerial images, which are obtained together with LiDAR data as auxiliary data. According to the characteristics of different features on the highway, two MATLAB-based methods were developed to extract certain objects. The first method is suitable for the detection of columnar features erected along the highway, such as traffic signs and light poles. In the aerial images, these features are approximately perpendicular to the lengthwise direction of the road, so that we can use horizontal edge detection to locate them. The second method, which is based on the legible color and regular shape of the objects, was specifically designed to detect drainage grates on highways. The special color and size of the drainage grates make it quite easy for detection.

Although the testing results showed that the proposed methods worked well, they
have some limitations because they are very strict in terms of image quality. In future work, we need to improve the methods to increase their accuracy rate and make them more applicable.
CHAPTER 7

CONCLUSION AND FUTURE WORK

The work presented in this thesis investigated the applicability of airborne data collection methods, including the airborne LiDAR technique and aerial photography method, for collecting highway inventory data. Highway inventory data collection is a complicated and repetitive work that requires a lot of manpower and resources. State DOTs and transportation agencies are always looking for better techniques to reduce costs. Currently, the commonly used techniques include field inventory, photo/video log, integrated GPS/GIS mapping systems, aerial/satellite photography, terrestrial LiDAR, mobile LiDAR, and airborne LiDAR. Among them, the air-based methods—namely, aerial/satellite photography and airborne LiDAR—are less popular. The main reason is the lack of technology to detect features from airborne LiDAR data and aerial images. In fact, the airborne LiDAR technique and aerial photography method are much more efficient in data collection. Therefore, if we have effective methods to process LiDAR data and aerial imagery data, these methods will become more promising for updating highway inventory in the future.

The main contribution of this thesis is the proposed ArcGIS-based and MATLAB-based algorithms that extract highway features from airborne LiDAR data and aerial imagery data, respectively. To get the data, field data collection was conducted to map highways in Utah. Four highway sections were chosen: I-15 North, I-15 South, I-84, and US-191, covering approximately 80 miles of highway in total. For the data processing
part, we processed all the valid LiDAR data and some of the high-quality images using our algorithms. The experimental results demonstrated the feasibility of our proposed algorithms in detecting certain types of highway features (e.g., guardrails, median barriers, traffic signs and drainage grates).

A number of research extensions can be considered in future studies. First, the ArcGIS-based algorithm we proposed is semi-automatic; we plan to develop a program to make it fully automatic. Second, we will combine the LiDAR data with aerial images to improve detection accuracy and develop new methods to detect some additional features.
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