Computers & Geosciences 76 (2015) 1–10

Contents lists available at ScienceDirect

Computers & Geosciences

journal homepage: www.elsevier.com/locate/cageo

Image analysis techniques to estimate river discharge using time-lapse cameras in remote locations

David S. Young [a], Jane K. Hart [b,*], Kirk Martinez [a]

[a] Electronics and Computer Science, University of Southampton, Southampton SO17 1BJ, UK
[b] Geography and Environment, University of Southampton, Southampton SO17 1BJ, UK

ARTICLE INFO

Article history:
Received 13 May 2014
Received in revised form
19 November 2014
Accepted 23 November 2014
Available online 25 November 2014

Keywords:
Remote sensing
River discharge
Glacial melt
Time-lapse camera
Image analysis
Flow rate monitoring

ABSTRACT

Cameras have the potential to provide new data streams for environmental science. Improvements in image quality, power consumption and image processing algorithms mean that it is now possible to test camera-based sensing in real-world scenarios. This paper presents an 8-month trial of a camera to monitor discharge in a glacial river, in a situation where this would be difficult to achieve using methods requiring sensors in or close to the river, or human intervention during the measurement period. The results indicate diurnal changes in discharge throughout the year, the importance of subglacial winter water storage, and rapid switching from a "distributed" winter system to a "channelised" summer drainage system in May. They show that discharge changes can be measured with an accuracy that is useful for understanding the relationship between glacier dynamics and flow rates.

1. Introduction

Recent developments in digital photography have allowed opportunities for ground-based camera monitoring of the environment. These have the potential to be part of a wireless environmental sensor network (Hart and Martinez, 2006; Kulkarni et al., 2007), a device within an Internet of Things (IoT) system (Ward et al., 2014; Zhang, 2011) or a stand-alone device. Digital cameras are generally low cost, robust, easy to install and can provide high quality environmental data. These advantages are especially important in remote areas.

Here we describe the installation, image processing and preliminary results for a pilot system to estimate discharge from a glacier-fed river at Skálafellsjökull, Iceland over a year. This camera was installed as part of the Glacsweb sensor network system (Martinez et al., 2004, 2009), whose aim is to study glacier dynamics.

Most existing work on river discharge measurement is either based on satellite/aerial images (Smith, 1997; Brakenridge et al., 2007; Marcus and Fonstad, 2010) or on detailed surface shape/flow velocity measurements, e.g. particle image velocimetry (Bradley et al., 2002; Hauet et al., 2008; Bird et al., 2010; Tsubaki et al., 2011). The latter requires markers and may involve the use of stereo cameras. By contrast we focus on results from a simple time-lapse image stream from an inexpensive fixed camera. The results indicate that this system provides a useful, low cost way to monitor discharge in remote locations.

2. Field site

The study was undertaken at Skálafellsjökull, Iceland (64°15′28.22″N, 15°50′37.44″W), an outlet glacier of the Vatnajökull ice-cap (Fig. 1). This glacier has an area of approximately 100 km^2 and is 25 km in length (Sigurðsson, 1998). An environmental sensor network was deployed, consisting of multiple heterogeneous nodes which have been developed during several years of continuous deployments (Martinez et al., 2004, 2009, 2012). Sensor nodes on and in the glacier use appropriate radio frequencies to communicate to a base station. This in turn uses a nearby Wi-Fi gateway node to communicate out to the cloud server. These gateways act as routing nodes and include dGPS receivers, a meteorological station, cameras and other diagnostic sensors.

The main study site was located on the southern side of the glacier at an elevation of 792 m a.s.l. The main portal (from which the glacier melt water drained) is located approximately 3000 m away, at an outlet of the main glacier called the Sultartungnajökull tongue, at an elevation of 400 m a.s.l. A bridge is located approximately 500 m from the glacier margin, spanning the outlet river. This river comprises a mostly single thread stream

---

* Corresponding author.
E-mail addresses: d.s.young@soton.ac.uk (D.S. Young), j.k.hart@soton.ac.uk (J.K. Hart), km@ecs.soton.ac.uk (K. Martinez).

http://dx.doi.org/10.1016/j.cageo.2014.11.008
0098-3004/

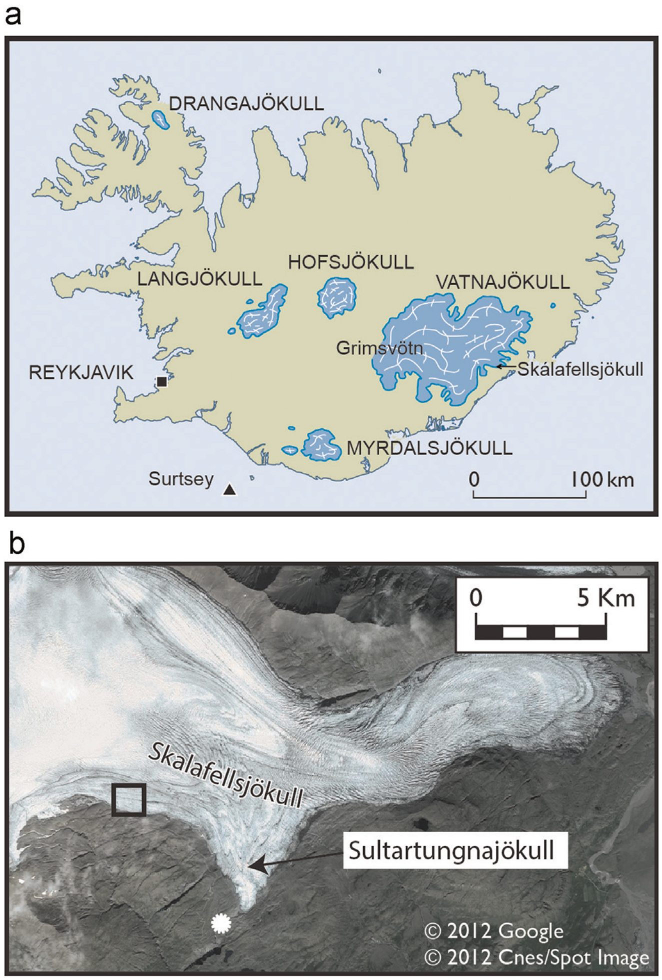

Fig. 1. (a) Location of study area at Skálafellsjökull, indicated by arrow. (b) Map of study area. Square indicates main Glacsweb study site, star indicates camera location.

approximately 1–8 m wide, depending on the state of flow, with a very coarse boulder bed. The camera, at 64°14′20.83″N, 15°48′49.33″W and altitude 344 m a.s.l., is mounted on the bridge (Fig. 2).

The camera was a Brinno TLC100, an inexpensive time-lapse camera designed for unattended outdoor battery-powered operation.[1] It can capture up to 28,000 frames of 1280 × 1024 pixels, stored on a USB flash drive as an AVI file with MJPEG compression, and has a fixed field of view of approximately 50° on the diagonal. Two main sequences were recorded: the first, at one-minute intervals, covered three days from 23 to 26 September 2012 (day of year, DOY 267–270) and was analysed at 15 min intervals; the second, at 4-h intervals, covered the period from 22 October 2012 (DOY 296) to 6 June 2013 (DOY 157). In addition we used a single hand held image from the same location (16th July 2013, DOY 197) to extend the data span. In all cases, images were missing when the light level was too low for effective capture. For a substantial part of the second sequence, the course of the river was covered with snow. Typical images for a variety of states of the river are shown in Fig. 3.

Fig. 2. Bridge where camera was installed. Circle marks camera position.

3. Image processing techniques

3.1. Overall approach

The main goal of the image processing is to make an estimate of the river discharge for each image in which water was visible. Secondary estimates were also made of fog and snow cover.

For most rivers, discharge (Q) cannot be measured directly, but is calculated from measurements of the volumetric flow rate through a cross-section:

$$Q = VA \tag{1}$$

where V is the average velocity, and A is the cross-sectional area perpendicular to the flow. Although accurate absolute values of discharge are very difficult to attain for mountain streams (Bathurst, 1985; Chen, 2013), effective relative measurements may be obtained from variations in the depth and width of the water. Our overall approach is therefore to measure the positions of the visible water margin at various points in each image, and to combine these with a simple model of the shape of the river bed and its hydraulic properties. The resulting flow estimates will have large systematic errors due to the simplifications of the model, but the random error can be kept low enough to allow temporal correlations between the flow and other events to be investigated with high confidence.

The position of the edge in the image corresponding to the water margin was measured in a number of regions of interest, each chosen so that there was a clear edge for most states of flow (Fig. 4). The water edge was either on a roughly vertical rock surface facing the camera, or on a sloping area of the bank. The edge positions, expressed in image coordinates for each frame of the sequence, formed the data for flow estimation. The image processing thus fell into two main sections: finding the image coordinates of the water margins, and combining these coordinates into a flow estimate.

3.2. Water margin image measurements

Ideally, the images would be processed fully automatically to segment the water and bank regions and hence find water margin positions. This could not be done reliably for these images for a number of reasons:

- There are strong illumination changes between frames. These result from the Sun's motion through the day and changes in meteorological conditions.
- Hue changes between the water and the banks are not strong

---

[1] http://www.brinno.com/html/TLC100.html downloaded 14 January 2014.