Improving Traffic Safety through Better Snow Fences: Image-Based Methods to Measure Trapped Snow Volume and the Snow Relocation Coefficient

tech transfer summary

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MTC RESEARCH PROJECT TITLE
Improving Traffic Safety through Better Snow Fences: Image-Based Methods to Measure Trapped Snow Volume and the Snow Relocation Coefficient

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The Midwest Transportation Center (MTC) is a regional University Transportation Center (UTC). Iowa State University, through its Institute for Transportation (InTrans), is the MTC lead institution.

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Image-based techniques such as particle tracking velocimetry, large-scale particle image velocimetry, and photogrammetry can help improve snow fence design and evaluation by efficiently measuring snowfall, snow drift, and snow accumulation.

Problem Statement

The current protocols used to quantify snowfall, snow drift fluxes, and snow volumes accumulated at fences are costly, intrusive, and of questionable accuracy. Instrumentation and personnel must be deployed at proposed fence sites for extended periods of time in harsh winter conditions. Direct, non-intrusive methods are needed to measure actual conditions at proposed snow fence locations so that effective fences can be designed and those fences can be evaluated without reliance on empirical relationships that may not be applicable.

Background

Blowing and drifting snow on roadways leads to ice formation on the roads, decreased visibility and increased safety risks for drivers, and ultimately more accidents. Snow fences are commonly used to mitigate snow drift on roadways by slowing the speed of drifting snow and promoting snow deposition downwind of the fence.

East view of in situ snow fence site in Shueyville, Iowa, looking upwind

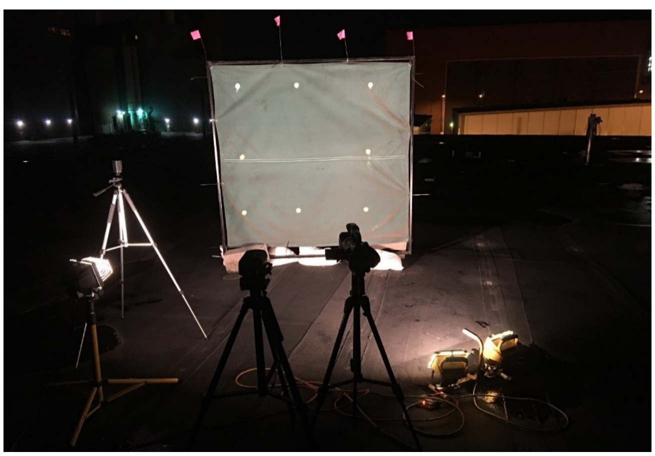
A primary variable in snow fence design is the snow relocation coefficient (SRC), the percentage of fallen snow relocated from the upwind fetch area through drifting. SRC relies on empirical relationships that are strongly correlated with the meteorological, topological, and ground surface conditions at specific snow fence sites.

Moreover, estimating SRC requires the snowfall and snow drift fluxes at the fence site to be quantified. If the value of SRC at a site cannot be estimated, designing an effective snow fence for that site is nearly impossible because snow drift varies greatly from location to location and over time.

Objectives

The primary objective of this research was to test a set of new, non-intrusive, image-based technologies that support the design and evaluation of snow fences by quantifying snowfall and snow drift fluxes. Technologies included particle tracking velocimetry (PTV) and large-scale particle image velocimetry (LSPIV) coupled with three-dimensional (3D) photogrammetry.

This research also aimed to refine the use of close-range photogrammetry to provide a general methodology for non-intrusive remote estimation of snow deposit volumes using automated data acquisition protocols.



LSPIV test setup on a flat rooftop (top) and sample image (bottom)

Research Description

PTV and LSPIV imaging techniques were used to quantify snowfall and determine the horizontal transport of snow particles in the form of snow drift, respectively. Close-range photogrammetry was used to measure snow volume at snow fences.

Three experimental sites were chosen to validate the methodologies used to quantify the snowfall and snow drift velocities. The sites were located near Iowa City, Iowa, to allow instrumentation to be deployed as soon as a storm event occurred.

1. The snowfall measurement site was located on the rooftop of the IIHR – Hydroscience & Engineering building at the University of Iowa. The experiment was conducted using PTV. A snowboard (white board) was used to measure snow depth, a Vaisala anemometer was used to measure local wind velocity, a Sony 4K video camera was used to record snowflake movement continuously during the snowfall event, and a Rigidhorse LED light was used to illuminate nighttime events. Evaluation software for digital particle image velocimetry (EDPIV) developed by IIHR – Hydroscience & Engineering, was used to analyze the images.

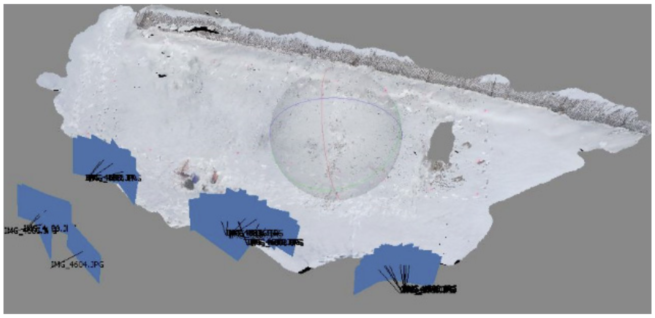
2. The snow drift measurement site was located along a railroad track near the Iowa River. LSPIV was used for this analysis. Six experimental arrangements were tested using different configurations of camera angles and LED lighting, one of which was tested in the laboratory due to insufficient snowfall during the 2016–2017 winter season.

   For the laboratory test, snowflake and snow bedform movements were simulated with melamine plastic particles. Agisoft Photoscan software was used to construct a 3D model of the drift through photogrammetry. This technique was used in conjunction with LSPIV to quantify snow drift velocity.

   Sample in situ snow drift measurements were obtained using PTV and LSPIV during a snow drift event on December 16, 2016.

3. The in situ snow drift site was located in Shueyville, Iowa, as suggested by the Johnson County Secondary Roads Maintenance Superintendent. This site was used to evaluate snow drifting and map the volume of snow deposited at two snow fences during the 2016–2017 winter season.

   Close-range photogrammetry using Agisoft PhotoScan software was also used to construct a 3D model of the snow deposit at the site after a March 14, 2017 snow storm.



Photogrammetry results of snow deposit mapping near snow fence

Key Findings

- The snowflake velocities measured using non-intrusive PTV protocols were found to agree with the wind velocities measured directly using a standard anemometer. The results essentially validate the proposed image-based method to measure particle velocity, though the PTV velocities were slightly smaller than those obtained using the anemometer.

- For the snow drift analysis, the movement of the snow dunes as they migrate over the layer of compacted snow is more accurately quantified by LSPIV than PTV. This is because LSPIV is based on gray-level pattern recognition, while PTV is more accurate for capturing the movement of individual particles.

- The snowflake velocities obtained from PTV measurements were approximately one order of magnitude higher than the velocity of the snow bedforms migrating over the fixed layer of snow.

- Agisoft PhotoScan was found to be highly capable of reconstructing a 3D model of the in situ snow drift site and its relevant details using only six images. The photogrammetry maps could be used as standalone 3D representations of the snow deposited at any location in situ, including snow volumes upwind and downwind of the snow fence.

- Using successively generated photogrammetry maps, the rate of volume change can be tracked and used to characterize the dynamics of the bedform movement, an essential factor in documenting snow drift dynamics.

Future Research Recommendations

- Use the proposed methodologies to measure snowfall above the ground and to measure snow drift up to 1 m above the ground during strong snow storm events in areas where the wind is not obstructed

- Repeat measurements at several sites to confirm the robustness of the proposed techniques and produce a set of data that can be compared with available reference results

- Use image-based techniques to perform the whole series of measurements needed to generate the data required by snow fence design software

- Compare the results of snow fence performance measurement using the proposed methodologies to those obtained using current methodologies

- Develop standardized protocols for implementing the proposed methodologies in practice

- Reevaluate the available design standards and provide specific corrections that account for site characteristics and meteorological conditions

Implementation Readiness and Benefits

Directly measuring snowfall and snowdrift to calculate SRC can improve the accuracy of estimated SRC values, more accurately predict the volume of snow retained by the fence, and more accurately estimate the risk that a snow fence will be overtopped during a storm event.

The proposed image-based measurement methods do not require permanent equipment installation, are mobile, can obtain continuous data, and can be quickly performed to produce information readily usable in snow fence design. Their non-intrusive characteristics preclude interfering with the natural process of snow blowing near the ground and exposing personnel to frigid, windy conditions.

The methods developed for mapping snow deposition at snow fences can not only efficiently support design decisions regarding the type, size, and position of the snow fence, but can also be used to evaluate the design efficiency of the snow fence.

The proof-of concept technologies and methods used in this research have not been fully evaluated due to the lack of snow drift conditions at the monitored sites over the two winter seasons covered by this study. However, the preliminary results for estimating snowfall and snow drift flux and mapping snow deposits are promising.