Design and Implementation of a Novel Automated Snow Depth Sensing System

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Abstract

Accurate and automated snowfall measurement is a major challenge in different environmental conditions. Minimization of environmental effects is essential for accurate measurement of snowfall. It is required to get reliable information about the snow depth for true weather report and better forecasting of snowfall. Automation of snowfall measurement is also necessary to remove the human error, to get repeated information about the snow depth, continuous measurement of snow depth and instantaneously storage of measured data. The first phase of this paper addresses design and implementation of an encoder based electromechanical snow depth sensor to enhance accuracy and resolution of snow depth measurement. It works as a standalone-embedded device with intelligent functions. Additionally, a dedicated virtual instrument for the sensing device is developed to provide easy connectivity with PC for online snow depth measurement. The second phase grapples with measurement of snowfall in the different climate conditions in which ultrasonic snow depth sensor faces large variability. The results of measured snow depth with prototype of proposed sensor are presented which are comparable with direct and standard measurement method of snow depth and indicate higher level of accuracy.

Keywords: Snowfall measurement; Snow depth; Electromechanical sensor; Virtual instrument; Weather report

1. Introduction

On our planet, precipitation occurs in both forms as liquid and solid. Five percent of precipitation occurs in the form of snow annually. The process of precipitating snow is called snowfall. The development of snow began in subfreezing cloud where water exists in each of the three conditions of matter: solid, liquid, and vapour. There are different types of crystals like dendrites, needle, columns, plates, freezing rain etc precipitate during snowfall. Types of precipitating snow depend upon the temperature & pressure of atmosphere near earth surface (Aiguo Dai, 2008). Snowfall

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brings lot of happiness and joyfulness for local people. On the other hand, it also brings sorrow in form of avalanche and flood. Snow avalanche occurs due to sliding of accumulated snow on highly sloped mountain. Flood occurs when snow melts at end of winter session. Avalanche could become a disaster during heavy snowfall and destroy buildings structure, block roads, affect country economy etc (Doesken et al., 1997). To prevent from these damages it is required to measure snowfall accurately and provide weather forecasting for local administrative or people. Accurate and continuous measured snow data is used by many users like climate change researchers, airport manager, winter resort manager, farmers, construction engineer, water resource manager etc. There are many parameters used to estimate the quantity of snow precipitated during snowfall such as snow depth measurement, snowfall rate, snow density, snow water equivalent (SWE). Now a day, many manual and automated methods are used to measure these parameters. In manual method (like SWE, direct method) observer have to take care about interval of collecting snow data or beginning and end of snowfall event. Inaccuracy in measured snow data occur due to involvement of human in manual measurement. For highly accurate and continuous measurement, automated methods are preferred. Automated measurement of snow is based on property of ultrasonic wave, radar signal, gamma radiation, satellite-imaging system. These methods face different challenges during measurement.

Microwave radiation emitted by earth is used to quantify spatial distribution of SWE (Pulliainen and Hallikainen, 2001). Grain size and sort, mountains, forest area affects the accuracy in this type of measurement (Foster et al., 2005). A dual radar method is used to measure average size of snowflake. It provides a relationship among snowfall rate, radar reflectivity and snowflake size at constant snowflake density. Accuracy of this method affects when different density of snowflake precipitates (Sergey, 1998). Since snow depth, age, and temperature affect the albedo of pure unaltered snow, the reflectivity constant for fresh snow and old snow is 0.80 and 0.50-0.60 respectively for visible and UV radiation and strongly depend upon wavelength of radiation (Wiscombe and Warren, 1980; Grenfell et al., 1994; Feister and Grewe, 1995). Image of snow surface taken by satellite is utilized for evaluating snow distribution precisely. This method works only in cloud free sky and light snowfall (Arola et al., 2003). As compare to distributive method, field measurement methods (like ultrasonic method, snow pillows) measure accurate SWE and unaffected by grain size, forest, mountain etc. It also measures snow data accurately in cloudy sky. Ultrasonic snow depth method is used to measure the accumulated snow on ground in a fixed time interval. In this method, time of flight of ultrasonic signal is utilized to measure the depth of snow by sending the wave towards snow surface and detection of reflected wave (Goodison et al., 1984). Therefore, the precision and accuracy of measurement completely rely on reflected sound wave and the accuracy of measurement is constrained by intensity of reflected sound signal. Snow depth measured by ultrasonic sensors of different companies at different sites in USA provides two results. First, snow depth values measured by both Judd and Campbell sensors have error ±1.0 cm over the full scope of conditions and sites. Second, snow depth value is affected by the following environmental conditions such as snow crystal type, presence of blowing snow, intense snow, wind speed, uneven snow surface (RYAN et al., 2008). These factors lead to some inaccuracy and large variability in measurement. So a technique is required that can quantify the depth of snow accurately and precisely in these conditions. This paper presents an encoder based electromechanical sensor to enhance the accuracy and resolution of snow depth measurement and it is able to overcome the drawbacks confronted by the ultrasonic snow depth sensors in different environmental conditions.
2. Encoder based Electromechanical Snow Depth Sensing System: Proposed Technique

The basic principle behind the snowfall measurement is to measure the accumulated snow on ground by detecting the surface of snow in a prescribed time interval. To measure the depth of accumulated snow, a design of novel automated snow depth sensing system using an encoder based electromechanical technique is proposed. This system is a combination of electrical and mechanical hardware components and dedicated software. Fig. 1 shows the block diagram of the proposed encoder based electromechanical snow depth sensing system. The section below explains the five major functional components of the sensing system.

2.1 Encoder based electro-mechanical snow depth sensor: This is the main part of the device. Its main function is to sense the surface of snow on ground to calculate depth of snow. Fig. 2 shows the schematics of proposed sensor. A tactile snow surface detector is used to measure the accumulated snow by an electromechanical course of action. It measures the value of ‘F’ i.e. the distance of the sensor from snow level by sense of touch of snow surface and calculates the depth of snow, knowing the distance of the sensor from the ground. The important elements of sensor are: snow surface detector, DC motor driven circuit, DC motor and thread assembly, digital encoder and pulley assembly and limit switch. The elements are explained in brief below.
Fig. 2. Schematics of automated encoder based electromechanical Snow Depth Sensor

(a) Snow surface detector: It is the most useful part of this device. A tactile type infrared transmitter-receiver (Rebman, 1984) arrangement is used to detect the snow surface under the device. The detected signal is sent to the microcontroller. Fig. 3 depicts the snow surface detection process. Biasing circuit of detector is shown in Fig. 4 (a), it requires 5V DC supply. Fig. 4 (b) shows the structural arrangement of IR source, detector and float. The snow surface detector consists of a float that moves freely in upward direction. In position ‘a’ detector is above the snow surface and float position is extremely down, as a result IR transmission from the source and detector is uninterrupted. In position ‘b’, when float touches the snow surface, it slightly moves upward, this interrupts IR transmission. As the signal between IR source and detector is interrupted by movement of float in upward direction, output voltage changes its state from LOW to HIGH. The change of state of detected signal is sensed by the microcontroller to initiate action of moving the snow surface detector upward.

Since the device works on touch type mechanism, it is called tactile type detector. Advantage of this tactile type detector is that the detected signal is not affected by environmental conditions. To perform snow depth measurement in a location detector is installed at specific height ‘L’ above the earth surface. It is able to move either in the upward and downward direction by the thread that rolls/unrolls on an encoder based pulley
arrangement attached to the shaft of a DC motor. During downward movement the distance covered by the detector depends upon the depth of the snow under the device. More the snow depth less the distance will be covered by snow surface detector and vice versa. If the distance covered by detector in downward direction ‘F’ is measured, accumulation of snow depth under the device is given by equation (1)

\[ D = L - F. \]  

Where,

D - Depth of snow under the device.
L - Distance of the sensor unit from ground.

![Fig. 3 Working of snow surface detector](image)

![Fig. 4. (a) Biasing circuit of snow surface detector. (b) Arrangement of IR transmitter-detector](image)

(b) **DC Motor & Thread Assembly**: A geared DC Motor is used to roll and unroll the thread. One of the ends of the thread is rolled in large diameter encoder, connected to the motor shaft and other end is tied with snow surface detector that passes through encoder pulley. Operating voltage of motor is 5 V DC. To roll and unroll the thread, it is required to rotate the motor in both anticlockwise & clockwise direction and to accomplish this task a bidirectional DC motor driver circuit is used.
(c) **DC Motor Drive circuit**: It uses L293D, a simple 16 pin dual H-bridge IC, to control the direction of rotation (anticlockwise and clockwise) of DC motor by providing the controlling signal from microcontroller.

(d) **Digital Encoder & Pulley Assembly**: This component is used to measure the length of thread passing during downward movement of snow surface detector. It consists of a pulley, placed on the shaft of incremental encoder. Since thread is passing through the pulley, the linear displacement in thread during downward movement of snow surface detector provides angular displacement in pulley. The angular displacement in pulley is measured by an incremental type digital encoder (Osann, 1978). Fig. 5 shows the encoder, a disc with 32 holes that provides 32 counts in one rotation. It provides angular resolution of 11.25° (360°/32). An infra-red transmitter-receiver is used to sense the number of counts during rotation of encoder disc. Since the angular rotation of encoder disc depends upon the length of thread passing through pulley so there is a proportional relation between angular displacement of encoder disc and linear displacement of the thread. For angular step size, θ = 11.25° and pulley of radius, \( r = 1.38\) cm, corresponding linear displacement of the thread (\( x \)) in downward direction is given by the equation (2).

\[
x = r \times \theta = 1.38 \times 11.25 \times (\pi/180).
\]

\[
x = 0.271 \text{ cm}
\]

\[
x = 2.71 \text{ mm}
\]

Hence, resolution of this prototype in measuring the linear displacement or the depth of snow is 2.71 mm. If the total number of encoder counts in downward direction is given by 'N', the value of 'F' is calculated using equation (3).

\[
F = N \times x
\]

Substituting value of F in equation (1), value of D, snow depth is calculated using equation (4)

\[
D = L - N \times x
\]

Equation 2 describes that linear step size of device depends upon the radius of pulley (r) and angular step size (θ) of incremental encoder. So the resolution of device can enhance by decreasing the both quantity r and θ.
Fig. 5. Encoder and pulley assembly

(e) Limit Switch: An electromechanical type of limit switch (Fig. 6) is used to abort the operation of motor during upward movement of snow surface detector when the snow depth sensor comes to its initial position after taking measurement. Limit switch is excited by 5V DC supply.

Fig. 6 Prototype of limit switch

2.2 Microcontroller: It is a low-power embedded computing device and is interfaced to different sensing, actuating and display elements. The device is programmed to control the functioning of each component and maintain their sequencing, process the input data and display the measured value of snow depth on display unit. ATmega328 based Arduino UNO, a microcontroller board is used here to interface the components and control the operations like driving the motor, detection of number of counts from digital encoder, snow surface signal detection, limit switch signal detection etc. Arduino board is also interfaced to the USB port of the host PC and acts as data acquisition device for virtual instrument.

2.3 Human interface: It provides external intervention to the user and consists of different switches and LCD display unit. These elements are interfaced to the microcontroller. Switches allow the user to select operational mode auto or manual, calibration or measurement and select acquisition time rate of 30s, 60s or 5 min during auto operation. Result of measurement indicating snow depth in mm is displayed on LCD display unit.
2.4 Virtual Instrumentation: The technology of virtual instrumentation is used to control the device by personal computer using the dedicated virtual instrument and display the results on user interface on computer screen. A dedicated virtual instrument program with graphical user interface is developed to acquire (read/write) data serially (to/from microcontroller) and perform calibration or measurement tasks as explained in section IV and V.

2.5 On Board Power supply: This component is AC to DC converter that provides stabilized 5V and 9V DC supply to different components of the sensing system according to their power requirement. The device is given power using the single-phase AC power the device is given power and then it works independently.

3. Prototype Model of Sensing System

Fig. 7 shows the fabricated prototype model of the proposed snow depth sensing system. Thread is rolled on motor shaft and passes through the pulley, attached on shaft of encoder. Other end of thread is connected to snow surface detector. Initial position of snow surface detector is just below the limit switch.

When operator gives measurement command from input switch, program downloaded in microcontroller executes to operate each component. Motor starts rotating in clockwise direction to unroll the thread, as a result snow surface detector moves downward. Since thread passes through pulley attached on digital encoder, it starts rotating. Angular displacement in encoder is directly proportional to linear displacement in thread (equation 2) and total linear displacement of thread is equal to the downward distance covered by snow surface detector. Microcontroller measures angular displacement in encoder by counting the total number of counts ‘N’. The program code using equations (3) and (4) then calculates total linear displacement and depth of snow respectively. When snow surface detector touches the snow surface, phototransistor output voltage
changes state. The microcontroller at its digital input pin detects this change of state and issues appropriate signals to motor driver unit to rotate motor in anticlockwise direction to roll the thread on motor shaft. Snow surface detector moves in upward direction and motor stops rotating when snow surface detector touches the limit switch. LCD display unit displays the measured value of snow depth.

4. Sensing System: Software

For automatic operation of the device two types of programming platforms are used (i) embedded programming platform using microcontroller (ii) PC based virtual instrument. For standalone operation of the device, microcontroller is programmed using Arduino programming platform based upon C programming language style with use of build-in header files, MACRO statements and functions. Arduino programming is used to program the control logic for the device and interfacing logic so that microcontroller communicates with LabVIEW using Virtual Instruments Software Architecture (VISA) & Universal Asynchronous Receiver Transmitter (UART).

Fig. 8 shows the flow chart of embedded program that controls the operation of the snow depth sensing system. At the start of operation all variables representing system parameters are initialized. \( L \) that represents the initial distance between ground and snow surface detector is set to constant for all measurement, \( N \) - Represents number of counts of encoder detected by microcontroller, \( D \) - Represents depth of snow below the sensor.
Fig. 8. Flow diagram of snow depth sensing device

For continuous PC based operation of the sensing system, dedicated virtual instrument is programmed on the platform of NI LabVIEW (Jovitha J.). LabVIEW program, in general, consists of two windows: front panel and block diagram. Front panel is the user interface that has certain controls to input data /issue command to the program and indicators to display results in text or graphically on charts and graphs. Block diagram is the coding window. The program code is implemented by logically connecting the different input/output terminals of functional blocks through wires that allow the flow of data on the block diagram.

The virtual instrument for proposed sensing system is multi-functional and interactively. Fig. 9 shows the snapshot of front panel of virtual instrument for snow depth measurement. CALIBRATION and MEASUREMENT tab controls on the front panel allows the user to perform initial calibration of the device or take a new measurement. The user performs initial calibration procedure during initial installation of the device to calculate automatically the height of the sensor from the ground in terms of digital counts (Fig. 9(a)). The latest value of this data is saved in the file to be used to calculate snow depth during measurement. In the case of measurement (Fig. 9(b)),

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the front panel allows the user to select auto/manual mode of operation and select the acquisition time interval. At the click of the START button the snow depth sensing system operates automatically and displays the depth of the snow in mm. In the case of auto selection mode, snow depth measurement is updated continuously panel at the rate selected by the user. In the case of manual mode, snow depth measurement is done once on user demand.

Fig. 9. Front panel of dedicated virtual instrument for snow depth sensing system  (a) Calibration (b) Measurement

5. Device Installation and Working

The snow depth sensing system is installed at a prescribed height from the ground level. The height depends upon the average annual precipitation in that area. It is important that nothing like trees, installation hardware, wires etc. should come below the sensor. In this experiment, the maximum height of sensor is taken as 1.5 meters. Vertical and horizontal poles are required to support the sensor. Initially the distance between snow surface detector and ground (i.e. L) must be known. The value is manually fed or is automatically taken by the device during calibration of the device and is fed in the program for further calculation of snow depth during measurement. All the commands to operate and set certain parameters of the device are provided through the device front panel control switches or virtual instrument soft controls. Sections below explain in brief the working of the device.

5.1 Calibration

After installation of the device, the device is calibrated to measure and store the initial height (L) of snow surface detector from earth surface as a reference value to perform snow depth calculation. Device front panel/virtual instrument front panel provides automatic calibration procedure for initial height.

5.2 Measurement
In order to take measurement of snow depth, acquisition rate, auto/manual mode is selected and start command is issued through the switch on instrument human interface or from the front panel of virtual instrument. This initiates the measurement procedure and power on the microcontroller board. Arduino transmits the signal to motor driven circuit to unroll the thread and snow surface detector starts moving in downward direction to detect the snow surface. Since thread is connected through encoder's pulley, encoder also starts rotating. At the same time, microcontroller starts detecting the number of counts, which depends upon the length of thread going downward. When snow surface detector touches the snow surface, it sends the signal to microcontroller which provides signal to motor driven circuit to rotate the motor in opposite direction to roll the thread on motor shaft. This in turn moves the float (tactile snow sensor) in upward direction. After reaching its starting position, the limit switch operates and sends a signal to the microcontroller, which in turn sends a signal to motor driven circuit to stop the motor and abort the movement of the detector in the upward direction. Based upon the number of counts obtained during downward movement of the thread and initial height of the sensor from the ground, snow depth is calculated using equation (1). The calculated value of snow depth is then displayed on LCD display unit interfaced to the device's microcontroller and is displayed on the front panel of virtual instrument.

6. Results and Discussion

To test the working performance of the prototype model of snow depth sensing system, many experiments were performed in the laboratory. Ice slabs of different depths were used to infer snow depth measurement using the sensing system. The snow depth measurement was displayed on LCD panel and on virtual instrument. To validate the results, the height of ice slab was measured with the standard meter scale. Displayed results of snow depth on front panel are comparable with high level of accuracy with manual direct measurement method. Once the sensing system was installed, initially the sensor was calibrated. The initial height of the snow surface detector from ground level as measured was $322 \times 2.71 \text{ mm} = 876.62 \text{ mm}$. This height indicated the value of 'L' that was stored in the device memory to further use during the measurement mode. Snow depth measurement was performed under different test conditions with equally/unequally distributed snow of different depths. A few of the experiment results are discussed below:

(a) No snow condition: In this experiment, no snow was present below the snow depth sensor. This is called the initial or zero depth of snow. Fig. 10(a) shows that the absence of snow below the snow surface detector. Fig. 10(b) shows that measured snow depth in no snow condition on the virtual instrument of the proposed device. Snow depth indicator displayed the result of measured snow depth i.e. 0 mm that justified the measurement.

(b) Hard ice slabs of variable depths: In this experiment, ice slabs of different depths were palced consecutively to measure snow depth in each case. Fig. 11(a) represents the depth of ice slab (snow) measured by measuring scale (direct method) in all the three cases when ice slabs were added consecutively. Fig. 11(b) shows the corresponding measured depth with snow depth sensing system. Initially ice slab of 110 mm depth was placed on the floor below the snow depth device and measurement was taken that indicated value of 111.27 mm on the virtual intrument. In the second and third cases, the snow depth was increased to 153 mm and 362 mm by adding another slabs and measurements were made that indicated the value of
151.98mm and 363.98mm respectively. In all the cases, it was found that measured depth was accurate and highly correlated with the depth measured by the measuring scale that indicated the true value of snow depth.

(c) Soft snow of uneven depth: In this experiment, soft snow crystals with uneven surface was taken instead of ice slab and placed on the floor under the sensing system. Under such conditions, in the case of ultrasonic snow depth sensor, as reported in literature (Ryan et al., 2008) there would be scattering of ultrasonic signal due to uneven and soft structure of snow and measurement might not be reliable. But, the measurement done using the proposed sensing system proved to be accurate. Fig. 12 (a) indicates depth measurement of soft snow with measuring scale (b) Snow depth measurement on the virtual instrument of the proposed sensing system.

Fig. 10. (a) No snow below the detector (b) Snow depth measurement on the virtual instrument of the proposed device
Fig. 11. (a) Represents the depth of ice slab (snow) as measured by measuring scale (direct method) in all the three cases when hard ice slabs with even surface were added consecutively (b) Corresponding snow depth measurement on virtual instrument of the proposed device.

Fig. 12. (a) Measurement of snow depth of soft snow with measuring scale (b) Snow depth measurement on virtual instrument of the proposed device.

Results of the above experiments are tabulated in Table 1 that also indicates the measurement error, the difference between the measured and true value of snow depth. Fig. 13 shows the error curve of measured snow depth readings under different experiments performed using prototype model of snow depth sensing system. Based upon the design characteristics and overall performance analysis of proposed snow depth sensing system, the section below describes the salient parameters of the device.
(i) **Accuracy:** The accuracy of the instrument is very high. Limiting error of measurement is within the resolution limit of the device and varies as ±2.71mm. Maximum percentage accuracy with respect to true value is 0.46% and is highly acceptable.

(ii) **Resolution:** The resolution of the sensing system is dependent on many design factors and is very high. The change in snow depth by 2.71mm is measured with certainty with this instrument. Device resolution depends on step size of linear displacement that in turn depends upon angular resolution of encoder and diameter of pulley. The linear displacement is proportional to the angular displacement of the encoder so higher the angular resolution of the encoder, higher is the total resolution of snow depth device. But practically there is limit to the maximum resolution of the encoder. Encoder with angular resolution of 11.25° is conveniently designed for the sensing device. Diameter of the pulley that rolls/unrolls the thread attached to float based snow surface detector affects device resolution. Lesser the diameter of pulley, lesser thread will pass in one rotation thus providing less step size and increase in resolution but this will increase the measurement time also.

**Table I** Experimental results of snow depth measurements using prototype model of snow depth sensing system

<table>
<thead>
<tr>
<th>Exp. No.</th>
<th>Condition</th>
<th>Direct measured depth (mm)</th>
<th>Device measured depth (mm)</th>
<th>Error (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No snow</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Hard Snow (slab1)</td>
<td>110</td>
<td>111.27</td>
<td>1.27</td>
</tr>
<tr>
<td></td>
<td>Hard Snow (slab2)</td>
<td>153</td>
<td>151.98</td>
<td>-1.02</td>
</tr>
<tr>
<td></td>
<td>Hard Snow (slab3)</td>
<td>362</td>
<td>363.68</td>
<td>1.68</td>
</tr>
<tr>
<td>3</td>
<td>Soft snow</td>
<td>50</td>
<td>48.85</td>
<td>-1.15</td>
</tr>
</tbody>
</table>
Fig. 13. Error curve of measured snow depth readings under different experiments performed using prototype model of snow depth sensing system

(iii) Insensitive to environmental conditions: This device is able to overcome the effect of different climate condition those affect the ultrasonic snow depth sensor (Ryan et al., 2008) as described below:

- Snow crystal effect: A tactile type sensor is used to sense the surface of snow instead of ultrasonic wave so scattering and absorption of sent signal by different snow crystal will not affect the measured value of snow depth.
- Effect of blowing snow: In ultrasonic snow depth detector, sound wave is reflected from blowing snow rather than reflecting from snow surface, thus providing inaccurate snow depth value. By proper arrangement of tactile sensor on float, the effect of blowing snow is totally removed.
- Intense snowfall effect: This is also removed by the same arrangement as for blowing snow.
- Wind speed effect: In ultrasonic snow depth sensor, the path of sound wave is diverted by high speed wind that leads to large variability in snow depth measurement. On the other hand by providing the proper weight to the float, this effect can be removed.
- Uneven snow surface: In ultrasonic depth sensor, sound wave may divert or scatter from uneven snow surface and reflected sound wave may not able to reach the receiver, hence the snow depth measurement is not reliable. The proposed sensing device is not affected by uneven snow surface because it uses electromechanical arrangement of sensing instead of sound wave sensing method.

7. Conclusion

Measurement of snow depth to estimate the snowfall is essential for forecasting of avalanche in any snowy region and accurate snow data reporting for weather stations. This can be done by using a reliable, accurate and high-resolution snow depth sensing system, the one proposed in this paper. The conclusion of the work is as follows:

i. The proposed work has presented a schematic of encoder based snow depth sensor, which is electromechanical sensor. This novel method of sensing snow depth is not affected by many environmental factors to which the established ultrasonic sensors.

ii. To test the design feasibility, a prototype model of proposed design of sensing system is fabricated with intelligent functions and easy to use interface. In this design, an incremental encoder of 32 counts with the appropriate pulley arrangement is successfully implemented to give step size of 2.71 mm for linear displacement of thread that enhances the resolution of snow depth measurement from 1cm to 2.71mm.

iii. The snow depth sensing system is an embedded device that provides stand-alone measurement at a fast rate. The device is multi-functional, has many important functions and can easily be connected to any weather stations. The user interface of the instrument allows the user to select different parameters to operate the instrument such as auto/manual mode of operation, acquisition rate, automatic data saving, device calibration and measurement mode through appropriate switches. Reading of snow depth measurement is indicated on the LCD display panel. Additionally, a dedicated virtual instrument is implemented for online operation of the proposed snow depth-sensing device. The virtual instrument, allows easy interfacing of the device to any host PC/server. It operates the snow sensing system, acquires, analyses and displays the result of snow depth measurement on interactive front panel. It also provides
facility to calibrate the device and intimate the user about the communication/device connectivity problem.

iv. To test the working performance of the proposed snow-sensing system, experimental tests were conducted in the laboratory using ice slabs of different depths and results were validated against the manual and direct measurement of snow depth using standard meter scale. Experimental results presented indicate high accuracy of measured value of snow depth with maximum error to be within the resolution of the device i.e. ±2.71 mm. The error reported is very less as compared to error of ±1 cm for the ultrasonic snow depth sensor.

v. Not only the accuracy and resolution of the proposed sensing system is better than the established methods but is insensitive to many environment and snow factors. Comparison of proposed model with ultrasonic snow depth sensor in different environmental conditions like snow crystal type, presence of blowing snow, intense snow, uneven snow surface, wind speed etc. indicate the positive improvement in snow depth measurement value. Needless to say, that the proposed snow depth sensing system is in fact a good alternative to other existing methods of snow depth measurement.

The future scope of the work is to modify the design of snow depth sensing system by using commercially available components, weather resistant casing and robust housing structure so that it is easy and effective to install the instrument in actual snow environment. However, the device resolution is sufficient but it can be enhanced by using commercially available digital encoder with more counts per revolution and appropriately decreasing the pulley diameter that overall reduce the step size of linear displacement of the thread attached to tactile snow depth sensor. Looking into the present-day scenario of sensor networks, the idea is also to integrate the proposed snow sensing system with wireless nodes to form snow depth weather reporting network.

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