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AN INEXPENSIVE REMOTE SNOW-DEPTH GAUGE: AN ASSESSMENT

by

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Introduction

Snow depth on the ground is routinely measured at approximately 270 principal meteorological observing stations in Canada at 1200 GMT daily. Since about 1980, 2300 Canadian climatological stations have been asked to record daily snow depth as a standard observation. Before that time, only snow depth on the last day of the month was recorded at climatological stations. Snow depth information is valuable in many hydrological, agricultural and forestry applications and is often a substitute for snow water equivalent data when such data are unavailable.

Snow depth measurements are made manually with a snow ruler. The total depth of snow on the ground at the time of the observation is determined (in whole centimetres) by making a series of measurements and taking the average. The observer must use his expertise and judgement in obtaining a representative areal measurement at the station. Presently there are over 70 automatic meteorological stations in Canada and with the trend toward increased automation, the snow depth measurement may be lost. The need exists, therefore, for a reliable, low cost automatic snow depth sensor, which can be used on future unmanned meteorological/hydrometeorological stations. One potential method for measuring snow depth is the use of ultrasonic wave reflection in air (Caillet et al, 1979; and Gubler, 1981).

The Hydrometeorology Division and the Data Acquisition Services Branch of the Atmospheric Environment Service (AES) have been co-operating on the development of such a sensor which could be used at either manned or remote stations. Development began in 1982, with a proof of principle unit being tested during the winter of 1982-83. Two additional units were built and deployed for testing during the 1983-84 winter.

System Description

A commercially available ultrasonic ranging kit from Polaroid Corp. provides an economical means of accurately measuring target distance in terms of time to target. An on-board crystal oscillator provides a time base pulse train which is activated on a measurement request command from an external device such as a data logger or data collection platform (DCP). Once the pulse train is enabled it up-counts designated registers until a target echo is received. This immediately disables the time base pulse train. The numbers memorized in the counter can now be multiplied by the precise oscillator pulse period to give an accurate round trip time from transducer to target and return. Dividing by two gives the required time to target. The target distance is determined by multiplying the time by the velocity of sound in air at a known reference temperature. The calculated target distance is then subtracted from the actual measured distance between the sensor and a reference target (i.e. the ground at the site). Since the velocity of sound in air is highly temperature dependant, a correction must be applied to adjust the velocity for ambient air temperature. Measurement data are then formatted for transmission to an appropriate peripheral for display and/or archive. Figure 1 provides an overview of the Ultrasonic Snow-Depth gauge system.

Technical Aspects

The Polaroid Ultrasonic Ranging Kits were modified to facilitate remote 'poll' or measurement requests and subsequent data transfers. The kits were also changed from battery pack power supplies to regulated DC power by the use of either an AC/DC converter at the sensor, or a remotely located raw DC supply.

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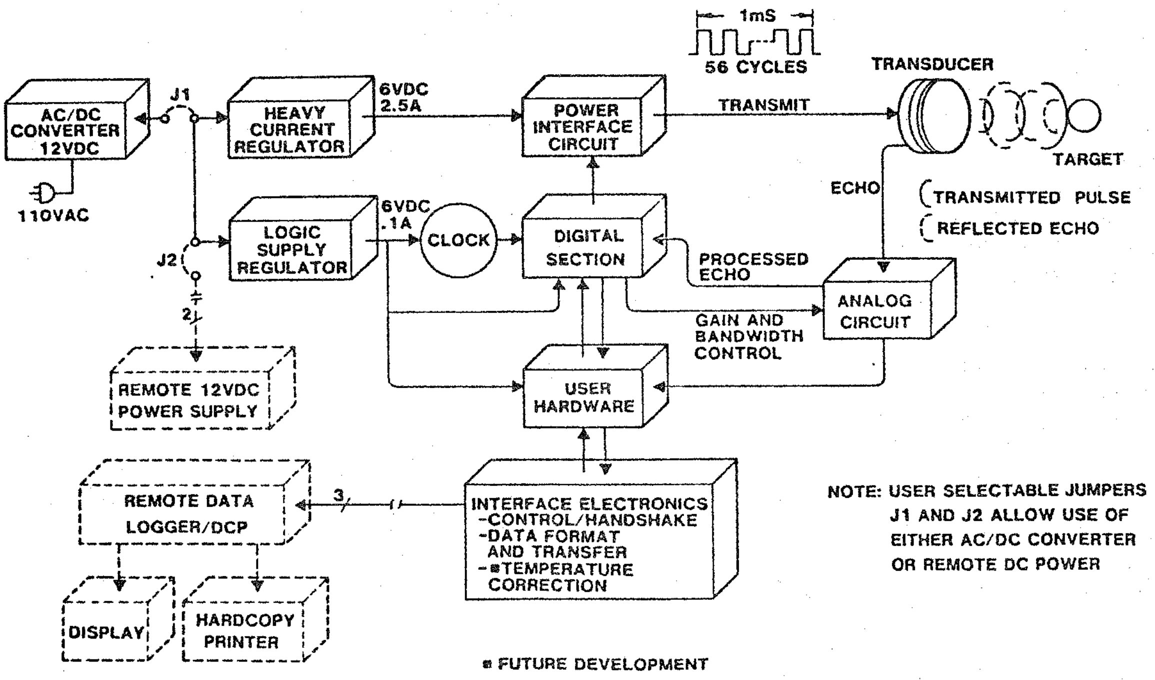
FIGURE 1- ULTRASONIC SNOW-DEPTH GAUGE



NOTE: USER SELECTABLE JUMPERS J1 AND J2 ALLOW USE OF EITHER AC/DC CONVERTER OR REMOTE DC POWER

* FUTURE DEVELOPMENT

A measurement sequence begins with the remote data logger generating a 'poll' request by raising the appropriate signal line to + 6 VDC. Internal electronics then enables the transmitter power, and synchronizes the receiver and timing logic. The transmission burst has a duration of 1 ms and is a 'chirp' of 56 cycles beginning at 60 kHz and ending at 50 kHz. Power consumption during the 1 ms transmit burst is 2.5 amperes and drops back to 100 milliamperes nominal current. At the beginning of a transmission, control logic gates the base oscillator pulse train onto the transmission line and the received 'target' echo disables the pulse train. The remote data logger counts the pulse train, converts it from binary into BCD, formats the data for transmission and sends it out for display and/or archive. Temperature corrections to the velocity of sound in air were applied to the raw data in a non-real time mode to facilitate the collection and use of temperature data from existing in-situ sensors at the sites. Calculation of actual snow depth on the ground is then determined by:

$$D = H - \frac{NtV_2}{2}\sqrt{\frac{T_1}{T_2}}$$

where: D = snow depth (cm)
H = sensor to ground baseline height (cm)
N = number of pulses counted during round trip time interval
t = oscillator period
V_2 = speed of sound in air, which is 342 m/s at 291 °K
T_1 = site temperature in °K at the time of measurement
T_2 = reference temperature, which is 291 °K

Results

A prototype snow depth measurement system was assembled and tested in the laboratory in 1982. The unit was set up to measure a fixed distance to an unobstructed solid surface every five minutes for a period of two weeks. Agreement between the sensor measurement and a ruler measurement was within ±1 cm for the entire period. The sensor was then taken to a cold chamber for testing to -40°C for a twenty-four hour period. The transducer survived this test and the sensor stability was within ±1 cm over the temperature range of +25°C to -40°C.

The sensor was deployed at AES headquarters in Toronto at the beginning of the 1982-83 winter season. The sensor was mounted 309 cm above the ground. Snowfall that year was light, providing very little data for comparison studies. Survivability of the sensor in a hostile environment, and stability of the electronics during extremes in temperature, were established during this season. During the 1983-84 season automatic data logging of sensor measurements provided a data base of approximately twenty thousand measurements. Analysis of these measurements indicates degraded sensor performance during periods of moderate to heavy snowfall. It is suspected that signal attenuation is causing problems for the echo detection circuitry during these periods. A maximum error of 12 cm was noted with most ambiguity being of the order of 6-8 cm. In no circumstance did the sensor fail to receive an echo during a measurement sequence. As well, some twenty-five comparisons of manual ruler measurements and sensor measurements were made. These results are shown in Figure 2. The sensor tended to undermeasure by approximately 2 cm.

In November 1983 another prototype system was installed at a climatological station located at Dorset, Ontario. The sensor was mounted about 1.3 m above the ground surface. A digital readout from the sensor was provided in a nearby instrument shelter. An observer took manual readings twice per day from three snow rulers fixed in the ground. The rulers were mounted in the ground around the sensor's field of view at the beginning of the season so that depth measurements could be made even if an ice layer or hard crust should form in the pack. Since the speed of sound varies with temperature, the screen temperature at the time of each observation was used to compute the corrected distance to the snowpack.

Initial results from this site (Figure 3) indicate that the ultrasonic sensor undermeasures the ruler observation by about 6 cm, with individual observations differing by up to 13 cm. Snow does build up at the ruler and this often results in an overmeasurement of up to 3 cm in snow depth by the observer. This was a sheltered site so snow scouring was not a problem. The Polaroid Ultrasonic Ranging Unit performed satisfactorily outside in ambient temperatures which ranged from +10°C to -40°C. It was also noted that rime icing or frost did not appear to build up on the sensor and had no effect on its operation. Results also indicate that the difference between the ruler and sensor measurement is not directly related to air temperature at the height of the sensor or to accumulated snow depth (maximum <1 m).

Summary

The ultrasonic snow depth sensor consistently undermeasures the actual snow depth. The causes of this bias are still under investigation. The surface of the snow and its structure (i.e. loose powder vs. hard packed crust) could have an effect. The sound wave may penetrate the surface before being reflected back toward the sensor. Signal scattering under certain atmospheric conditions is certainly a problem with most acoustic devices and could significantly reduce sensor accuracy. A strong temperature inversion near the snow surface will significantly affect the calculation of snow depth. The temperature gradient between the sensor and the snow surface could be as much as 10°C. These effects will require further evaluation.

It appears that this type of sensor offers a viable method of automatically measuring snow depth at an observing station. Planned development proposes that a microprocessor and temperature sensor be built into the gauge system to allow real-time temperature corrections for the speed of sound and also to provide some data processing capability to enhance the sensor's performance. The microprocessor could offer a high degree of flexibility in terms of formatting data and subsequent transmission to remote devices such as data loggers and DCP's. It is hoped that further refinement of the sensor/microprocessor system will ultimately produce an effective means of measuring snow depth at a remote station.

REFERENCES

Caillet, A., F. G. D'Aillon and I. Zawadzki, 1979: An ultrasound low power sonar for snow thickness measurements. Proc. Eastern Snow Conference, 36th annual meeting, Alexandria Bay, N.Y., June 7-8, 1979, p 108-116.

Gubler, H., 1981: An inexpensive remote snow depth gauge based on ultrasonic wave reflection from the snow surface. J. Glaciology, Vol. 27, No. 95, 1981, 157-163.

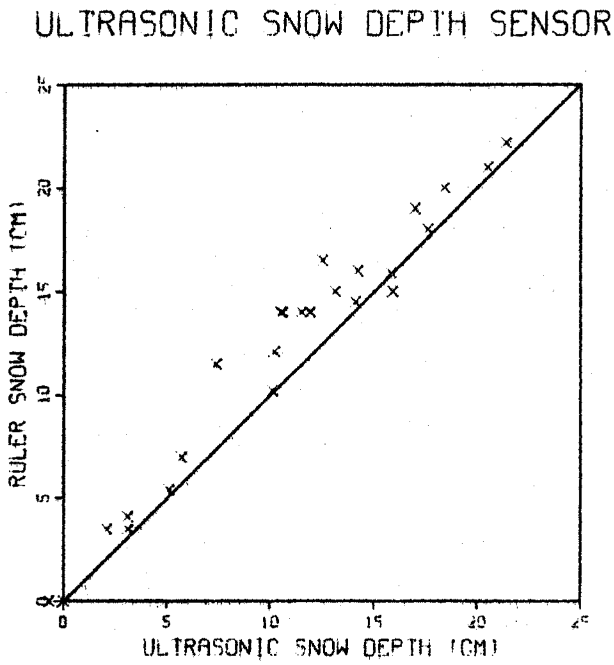


FIGURE 2: COMPARISON OF SNOW DEPTH MEASUREMENTS FROM THE ULTRASONIC SENSOR AND OBSERVED RULER MEASUREMENTS AT TORONTO, ONT.

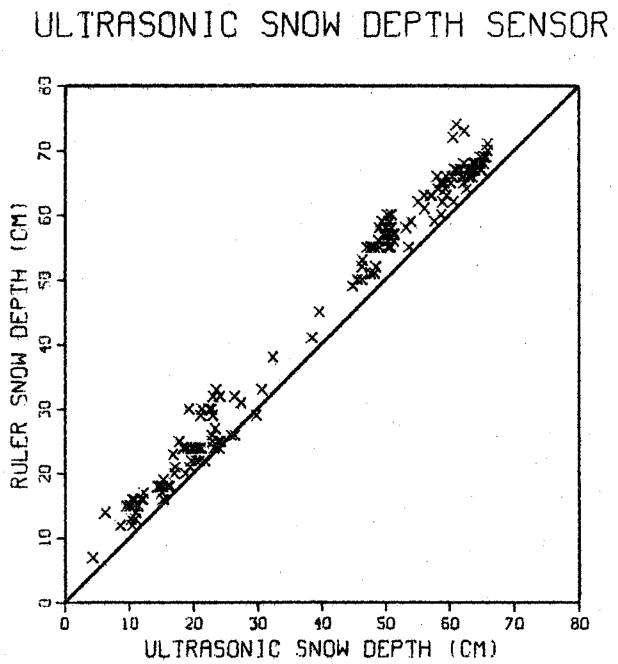


FIGURE 3: COMPARISON OF SNOW DEPTH MEASUREMENTS FROM THE ULTRASONIC SENSOR AND OBSERVED RULER MEASUREMENTS AT DORSET, ONT.