EE100 Report:
Sensors That Lie

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Abstract: An ultrasonic sensor deployed by the Center for Water Informatics & Technology (WIT) at LUMS measures the snow depth at Gabin Jabba, Swat. However, it does not compensate for changes in the speed of sound due to temperature. We demonstrate the error in measured and actual snow depth. We then develop a model to compensate this error using a smaller portion of data and then apply this compensation to all data available.

I. TASK 1: Calculating snow depth from reported range and confirming the anomaly in sensor readings

In this task, we use the data file `snowDataJan1-4.csv`. We first extract all relevant columns in the data into the arrays `date_time`, `range`, `temp` and `rain_data`. The height of the sensor above ground level is 310 cm, stored in the variable `height`. We can therefore subtract `range` from `height` to get the `snow_depth` array.

To visibly demonstrate the anomaly in the sensor readings, we plot two graphs with two y-axes each using the `yyaxis left`, `yyaxis right` and `figure` commands. FIG. 1 shows that as the temperature increases, the reported snow depth decreases and vice versa over the given days. FIG. 2 shows that there has been no rainfall in the time frame. This shows that the snow depth should not have fluctuated at all since there was no rainfall to increase the snow depth. Therefore, we conclude that our sensor does not have the capability to adjust for changes in the speed of sound due to changes in temperature. It is assuming that the speed of sound remains constant and that has led to marked fluctuations in the recorded snow depth.

Note: To check the output of the code, you would have to first import the relevant data file into MATLAB. Furthermore, if the MATLAB code is opened in the desktop MATLAB 2020b version, we would need to change the default date-time format to `MM/DD/YYYY`.

II. TASK 2: Determining the variation in range error against variation in temperature

From FIG. 1, we notice that as the temperature increases, the snow depth decreases. Thus, the reported range increases with a temperature increase. We can express this relationship in the following equation:

$$\Delta R = c \times \Delta T \tag{1}$$

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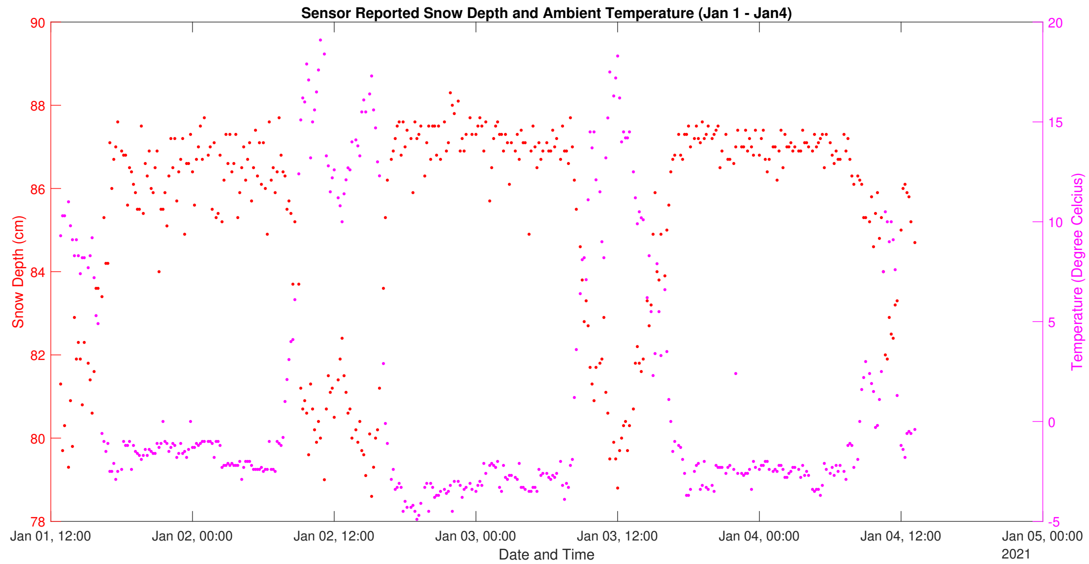

FIG. 1.

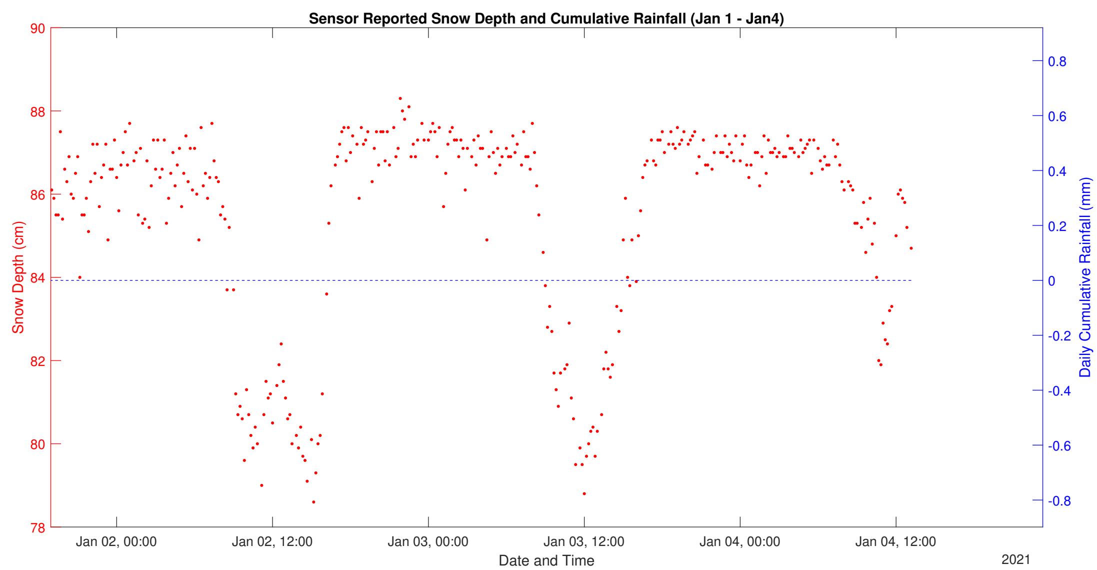

FIG. 2.

To find the constant c, we assume a certain temperature T_0 for which the range reported by the sensor $R(T_0)$ is correct. Looking at the data, we find that $3°C$ is the first temperature value with a unique range. (In hindsight, after using other T_0 values, we realize that the value of c remains the same for each T_0, but the y-intercept of the line of best fit changes. The y-intercept of $T_0 = 3$ was the smallest.)

Taking $T_0 = 3$, we plot `delta_T` (which is the difference between `temp` and `T_0`) against `delta_R` (which is the difference between `range` and `R_0`). We use the basic fitting function in MATLAB to find the line of best fit and then plot it as well. FIG. 3 shows the result. The equation of the line of best fit is:

$$y = 0.3791x + 0.5734 \tag{2}$$

We can identify $c = 0.3791$. However, we also see a y-intercept in the form of 0.5734. We ignore the y-intercept, citing that it is not significant. Note that our actions in this regard are motivated by the specificity of the task given to us, whereby we are asked to find c only and assume a direct relationship of the form (1).

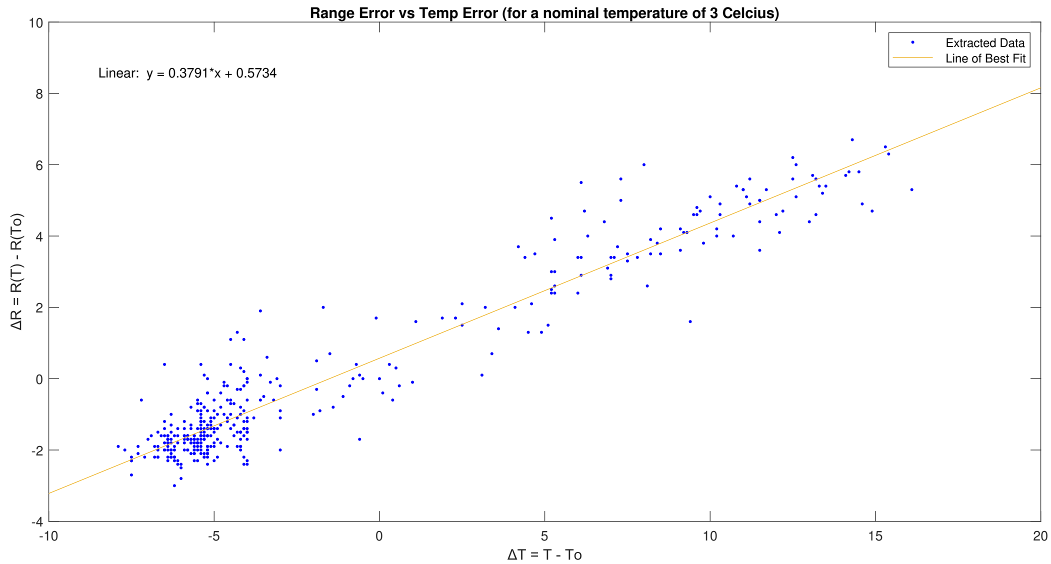

FIG. 3.

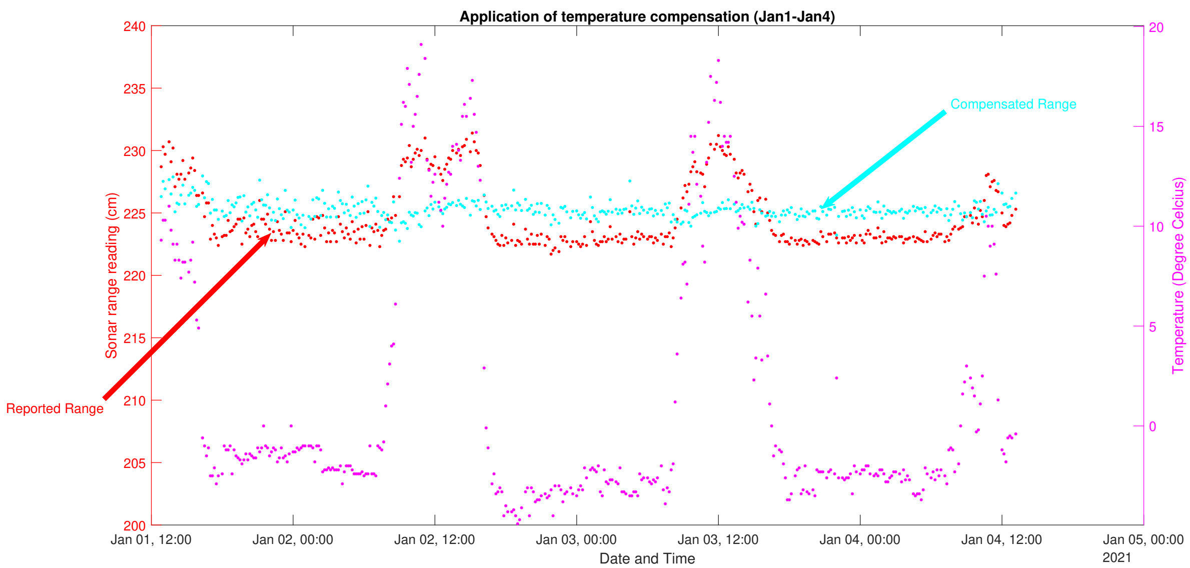

FIG. 4.

III. TASK 3: Applying the compensation

Now that we have c, we use it in equation (1) to find the compensated range. We use a `for` loop to update each element in our `R_T` array. Note that to compute ΔT, we subtract `temp` from `T_0` instead of the other way round. This is because for a temperature higher than T_0, we should get a negative value for `delta_R` because the compensated range should be lower than the reported range. Similarly, for a temperature lower than T_0, we should get a positive value for `delta_R` because the compensated range should be higher than the reported range.

To visibly demonstrate the compensation, we plot a graph of temperature, reported range and compensated range against time. FIG. 4 shows the results.

As can be clearly observed, the compensated range is fairly stable (which it should be considering the reasons outlined in **Task 1**) without the temperature-dependent fluctuations of the reported range.

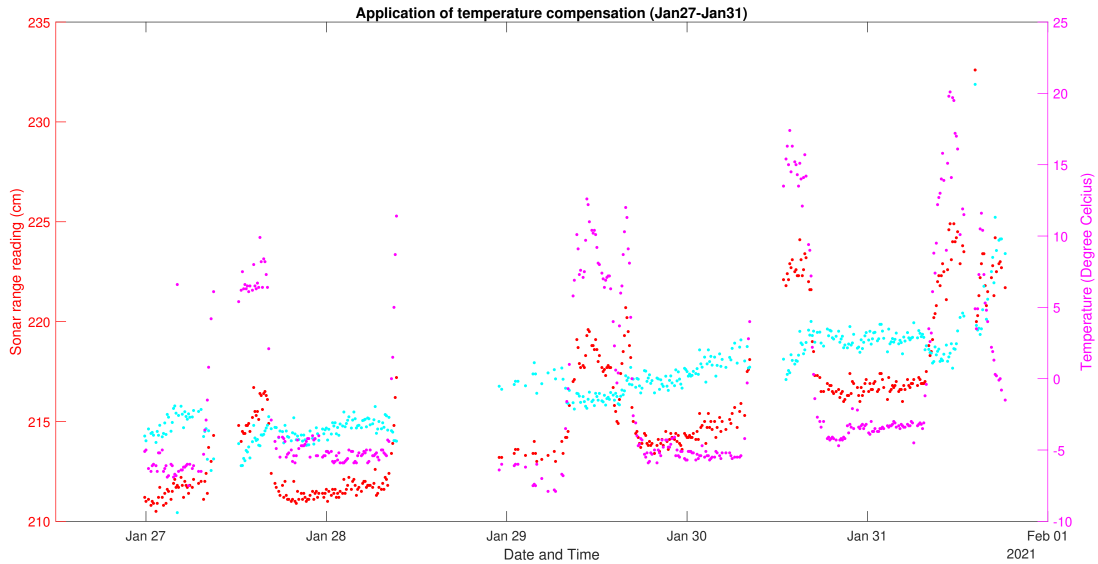

FIG. 5.

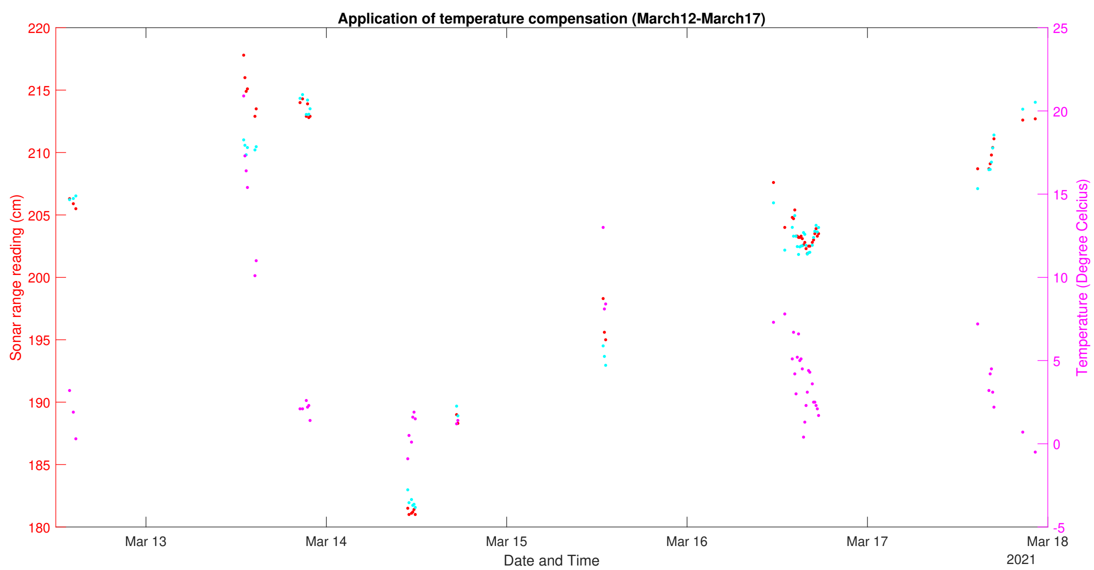

FIG. 6.

IV. TASK 4: Compensating the entire data

So far, we have worked only with the `snowDataJan1-4.csv` data file. Now, we use the `snowDataCompleteSet.csv` to compensate all the range data given. Note that we use the same constant c that we used for compensating the smaller portion of data.

First, we extract all columns from the data set (except for the rain data) into the variables `temp_task4`, `range_T0` and `date_time`. Then, we use a `for` loop to update each element in our `range_T` array which is the compensated range.

Finally, we take three portions of the data (Jan 27-31, Mar 12-17, Mar 20-23) where we can observe the compensated range clearly and obtain similar plots to FIG. 4 in **Task 3**. FIG. 5, FIG. 6 and FIG. 7 show the data. The cyan dots represent compensated range, the red dots represent reported range while the purple dots represent temperature.

In FIG. 5, observe that there has been a steady increase in actual compensated range from January 27 to 31. This

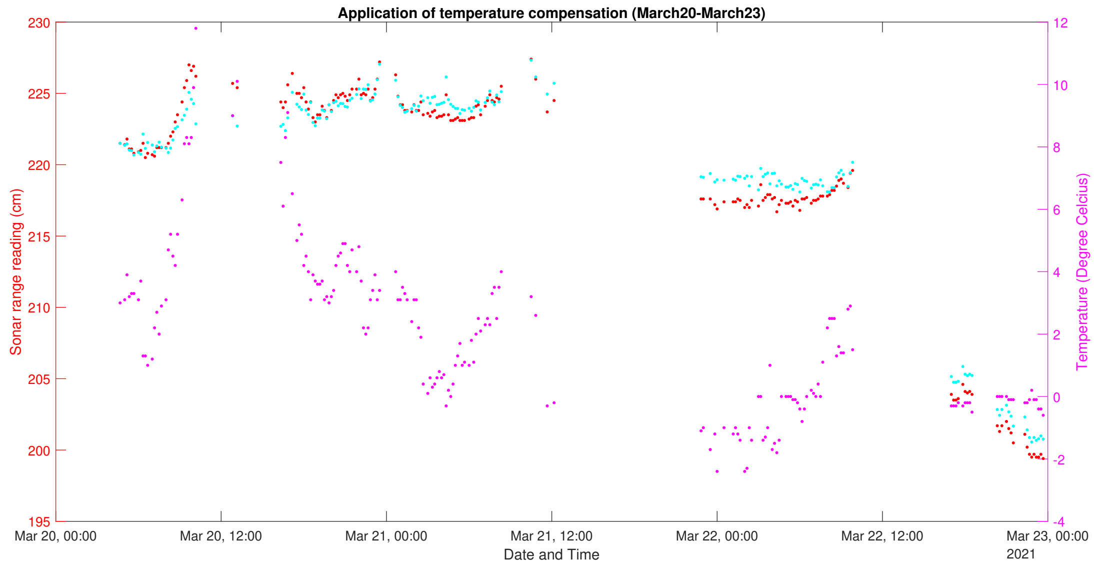

FIG. 7.

may be due to melting of snow over these days due to the high temperatures (most are greater than $5°C$). Note that when the temperature is above T_0, the compensated range is less than the reported range while the opposite happens for temperatures below T_0.

In FIG. 6, we have fewer data points to work with, but we can still clearly see that when the magenta dots are around $3°C$, the cyan dots coincide with the red dots. For temperature values above and below T_0, the aforementioned trend is observed.

Similarly, in FIG. 7, while most of the temperature values on March 20 and 21 are around $3°C$, the temperature values on March 22 are mostly below $3°C$ and the same trend is observed as before. Note that there is a sharp decrease in range from March 22 to 23, which indicates an increase in snow depth. This may be due to the precipitation being in the form of snow due to sub-zero temperatures.