Measurement of Snow-Depth Using Frequency Modulated Continuous Wave Radar Sensors

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***Abstract*—In this paper, we present our preliminary research work on the measurement of snow depth using frequency modulated continuous wave radar sensors. An experiment using silicon radar kit that consists of two radar front-ends, an evaluation baseband board, and Nucleo64 microcontroller board was conducted and built a prototype to measure the snow depth. The measurement was carried out and can be displayed in real-time on a self-made GUI interface using the SAMI cloud system. The built measurement device has been attached with the Unmanned Ariel Vehicle (UAV) is capable of transmitting reliable data from the sensors in real time environment from the selected site of snow depth measurement.**

***Index Terms*—silicon radar, SaMi cloud system, snow depth measurement, frequency modulated continuous wave**

I. INTRODUCTION

Knowledge of spatial snow depth either on the roof of your house or on the frozen lake is always beneficial for the people who are living in the northern side of the globe where snowfall is more prominent. The manual measurement of snow depth is not only dangerous but also it is time-consuming and tedious.

II. RELATED WORKS

We have reviewed some similar research in the area of snow-depth measurement and illustrates our novel approach by deploying a frequency modulated continuous wave radar sensor and a UAV. In [1], Jeffrey *et al.* present a study on Lidar that directly measures the three-dimensional distribution of plant canopies, can accurately estimate vegetation structural attributes and should be of particular interest to the forest, landscape, and global ecologists. Similarly, Philip Harder *et al.* in [2] emphasizes the accuracy of snow depth estimation in mountain and prairie environments by an unmanned aerial vehicle where their findings on the accuracy of digital surface models and orthomosaics, generated through application of structure from motion techniques to imaginary captured by a small fixed-wing UAV, was evaluated in two different environments to verify its ability to quantify snow depth as its spatial variability over the ablation period. We have also studied a similar work by Avanzi *et al.* in [3] where they perform centimeter accuracy in snow depth using unmanned aerial system photogrammetry and finally compared a data sample plot of 6700 m^2 with the multi-station measured data. In a similar way, Griessinger *et al.* in [4] demonstrate that ground penetrating radar is capable of accurately measuring snow ablation rates in complex alpine terrain, and their setup was optimized for efficient measurements and consisted of a common-mid-point assembly with four pairs of antennas mounted to a plastic sled, which was small enough to permit safe and convenient operations.

III. PRINCIPLES OF FMCW RADAR

Frequency Modulated Continuous Wave radar (FMCW radar) is a particular type of radar sensor which radiates continuous transmission power like a simple continuous wave radar (CW-Radar). In contrast to this CW radar, FMCW radar can change its operating frequency during the measurement: that is, the transmission signal is modulated in frequency (or in phase). Possibilities of Radar measurements through runtime measurements are only technically possible with these changes in the frequency (or phase). [5]

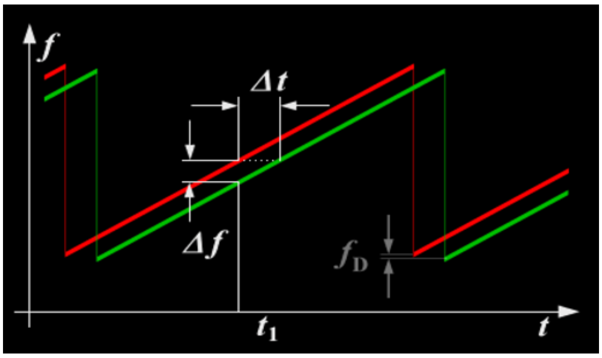

Figure 1. Ranging with an FMCW system

Fig. 1 illustrates the range of FMCW radar and its characteristics is as follows:

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- The distance measurement is accomplished by comparing the frequency of the received signal to a reference (usually directly the transmission signal).
- The duration of the transmitted waveform T is substantially higher than the required receiving time for the installed distance measuring range.

The following relations can determine the distance R to the reflecting object:

$$R = \frac{c_0|\Delta t|}{2} = \frac{c_0|\Delta f|}{2(\frac{df}{dt})} \qquad (1)$$

where c_0 is the speed of light, Δt is delay time in second, Δf is the measured frequency difference in Hertz, and *df/dt* is the frequency shift per unit of time. [6]

IV. EXPERIMENT

In this section, first of all, we are going to discuss the equipment that is needed for carrying out the research. Secondly, we present our work on an experimental setup where the microcontroller is attached with UAV such that the composite device will be able to be successful in capturing the measurement. Lastly, measurement testing procedure has been described, where a connection with built-in Wi-Fi hotspot with the computer was deployed.

1) *Used equipment*

The SiRad Easy Evaluation Kit consists of two radar front ends (24 GHz and 122 GHz), an evaluation baseband board, and an STMicroelectronics Nucleo64 microcontroller board–all stackable as shown in Fig. 2. The SiRad Easy Evaluation Kit comes with a free graphical user interface for user-friendly parametrization of the baseband board and multiple visualization modes for radar data. [7]

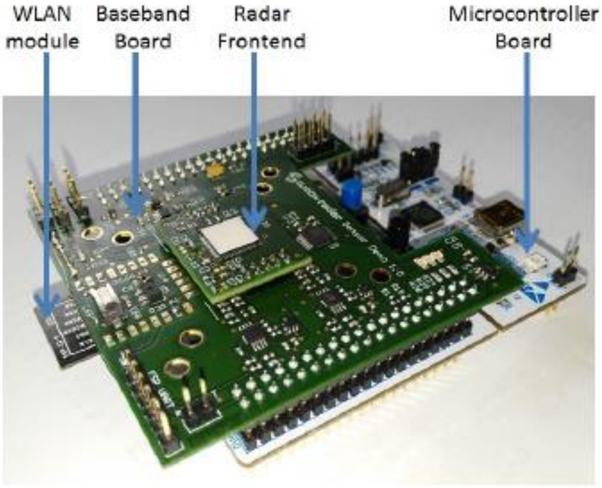


Figure 2. ST microelectronics Nucleo64 microcontroller

2) *Experimental setup*

We have decided on using the 122 GHz front end due to its superior accuracy in low range measurement as shown in the following Fig. 3. Within this experiment, we have also utilized a UAV (DJI-Phantom 4 Pro) whose function is to lift the measurement device on the air.

Figure 3. FMCW 122 GHz front end sensor

3) *Measurement test*

To begin the measurements, a connection is required to sensors built-in Wi-Fi-hotspot with a computer, using either web GUI provided by the manufacturer as shown in Fig. 4 or our self-developed web GUI as shown in Fig. 5. After connecting, settings need to be adjusted according to test conditions, depending on the software of choice. The in-built Wi-Fi module has a limited transfer rate, and the maximum possible frame update rate is about 10 Hz when using the Wi-Fi connection.

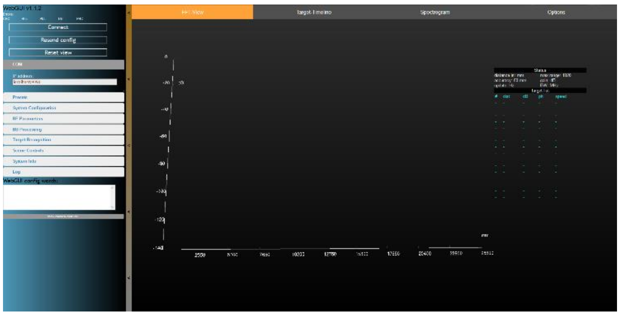


Figure 4. Manufacturer’s in-built web GUI

Figure 5. Self-developed web GUI

We have started testing our own web GUI developed as shown in Fig. 5 and the next step is to analyze captured data that was received from Real Term Serial Capture Program 2.0.0.70 as shown in Fig. 6. After running the data through our own parse program, which is written with C#, it starts finding the target frames from the captured data based on Fig. 7 and converts the distance data from hexadecimal to decimal and saves them to a separate text file. In the text file as shown in Fig. 8, each line represents one measurement being 64 characters long, and each target is four characters in mm, meaning there are 16 targets in total. On the other hand, if we use the manufacturer's web GUI the IP-address must be changed to 192.168.4.1: 9090, which is default as a “*localhost: 9090*” and then press “Connect button” as shown in Fig. 9.

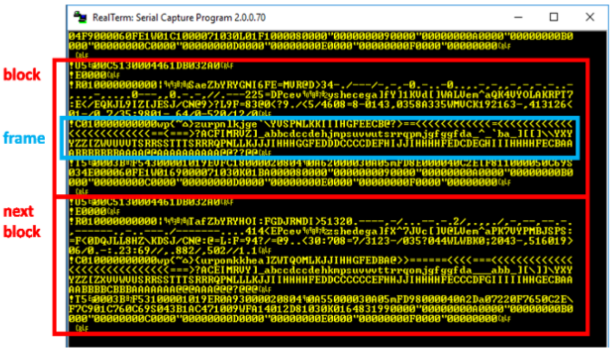
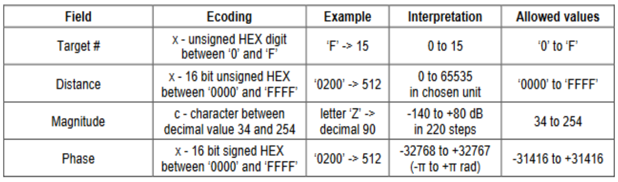


Figure 6. Captured data viewed in RealTerm



Field	Ecoding	Example	Interpretation	Allowed values
Target #	x - unsigned HEX digit between ‘0’ and ‘F’	‘F’ -> 15	0 to 15	‘0’ to ‘F’
Distance	x - 16 bit unsigned HEX between ‘0000’ and ‘FFFF’	‘0200’ -> 512	0 to 65535 in chosen unit	‘0000’ to ‘FFFF’
Magnitude	c - character between decimal value 34 and 254	letter ‘Z’ -> decimal 90	-140 to +80 dB in 220 steps	34 to 254
Phase	x - 16 bit signed HEX between ‘0000’ and ‘FFFF’	‘0200’ -> 512	-32768 to +32767 (-π to +π rad)	-31416 to +31416

Figure 7. Target list frame format and data encoding and interpretation of target list fields

```
[
  {
    "Tag": "Measurement 0",
    "Data": [
      {
        "Tag": 0,
        "Value": "2289"
      },
      {
        "Tag": 1,
        "Value": "2716"
      },
      {
        "Tag": 2,
        "Value": "4579"
      }
    ],
    "Object": "LumenSyvyys",
    "TimestampISO8601": "2019-02-21T15:45:00.00Z"
  },
  {
    "Tag": "Measurement 1",
    "Data": [
      {
        "Tag": 0,
        "Value": "2289"
      },
      {
        "Tag": 1,
        "Value": "2716"
      },
      {
        "Tag": 2,
        "Value": "4579"
      }
    ],
    "Object": "LumenSyvyys",
    "TimestampISO8601": "2019-02-21T15:45:00.00Z"
  },
```

Figure 8. Updated parsed data format

IP address: 192.168.4.1:9090

Figure 9. IP address and connect button

4) *Connecting to university’s own cloud (SaMi)*

Our web GUI also includes functionality to send data to Savonia’s cloud service “SaMi” (Savonia measurements). After the captured data have been parsed with the parse program, the text file generated can be read by webGUI’s page “Send data to SaMi” which transfers the read data to SaMi database for later use.

Another aspect of the web GUI is reading the data from SaMi through “Read data from SaMi” page. The page is configured by default to read the data sent to SaMi with our web GUI, but it can also be used to read other measurements too, provided that the required parameters are known.

V. RESULTS AND DISCUSSIONS

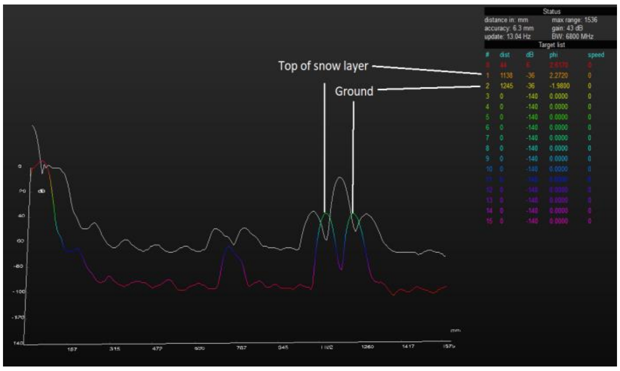
One of the problematic parts of this research work was to get reliable measurement data from the sensor. The sensor has so many different adjustable settings that will influence measuring accuracy and distance. We achieved to set the right parameters and placed our sensor on top of the snow layer. In the end, we were able to get correct measurement data, but it took so much time to set up all the equipment in the right order and especially finding the right settings for our sensor, which would be something to work on further. The prototype measurement using the ST microcontroller attached on the UAV along with a bucket of snow is shown in Fig. 10. The final result of the snow-depth is shown in Fig. 11. As shown in Fig. 10, we have also measured the depth of the snow kept in the bucket using measuring tape manually and found that the experimental result using FMCW radar sensor measured data was highly identical.

In this work, we have also developed a novel GUI for the measurement of snow depth in the real-time environment. The starting kit, that we used have already a GUI which has limited facilities such as connect and disconnect to the sensors, also is able to adjust the settings available for the sensor and can provide real-time visualizations and target distance data from the sensor. The self-developed GUI has the following features.

- Connects to and disconnects from the sensor
- Captures and saves data from the sensor
- Hosts self-developed parsing program for the captured data that can be downloaded

- Parsing program extracts target distance data from the captured data and converts it from hexadecimal format to decimal format.
- The program takes the converted decimals and saves them in the new text file in which each line corresponds 1 measurement (sensor has been set to make four measurements per second)
- The lines being 64 characters long, and each target being 4 characters long (for example "0010" being 10 mm) making up for a total of 16 targets per measurement
- Has an additional page for sending the parsed data to Savonia Measurements (SaMi) service
- Also for reading the sent data with required parameters set by default
- The reason for developing the GUI was so the data could be saved and being able to connect to SaMi service

Figure 10. Prototype measurement setup for snow depth



Status

distance in: mm max range: 1536
accuracy: 6.3 mm gain: 43 dB
update: 13.04 Hz BW: 6800 MHz

Target list

#	dist	dB	phi	speed
0	44	[illegible]	[illegible]	0
1	1138	-36	2.2720	0
2	1245	-36	-1.9800	0
3	0	-140	0.0000	0
4	0	-140	0.0000	0
5	0	-140	0.0000	0
6	0	-140	0.0000	0
7	0	-140	0.0000	0
8	0	-140	0.0000	0
9	0	-140	0.0000	0
10	0	-140	0.0000	0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	0	-140	0.0000	0
13	0	-140	0.0000	0
14	0	-140	0.0000	0
15	0	-140	0.0000	0

Figure 11. Final result of snow depth in real-time

In Fig. 12, the vertical axis is amplitude in dB and the horizontal axis is the target distance from the sensor Status box on the right shows these values for each target. In this case, the first circled target is the table that's under the sensor, the measured distance was 470mm and the sensor measures 490mm. The second circled target is the floor under the table at 1000mm, a sensor measuring 966mm. The ideal scenario with measuring snow depth would be to have the top of the snow be this demonstrations tabletop, and the ground under it as the floor, the space in the middle of the targets being the actual snow layer.

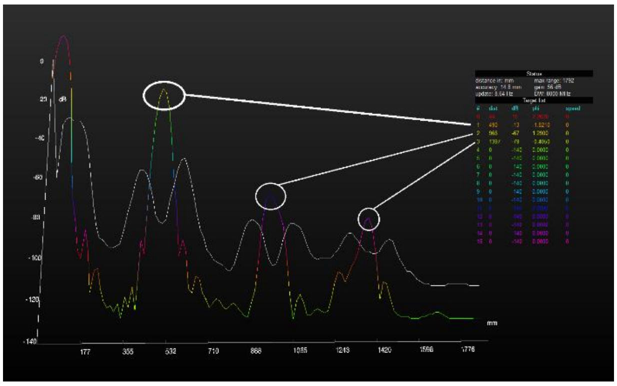


Figure 12. Measurement result showing target distance

VI. CONCLUSIONS AND RECOMMENDATIONS

The overall analysis was successful in achieving accurate results. We have managed to develop a device that can measure snow depth using FMCW technology and it is possible to obtain reliable data. The advantage of the developed scheme is to provide an instant measurement result. To improve our research work, we are still working on how to get reliable data immediately when the sensor is active, regardless of the circumstances.

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