Design of Ground Surface Sensing using RADAR

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Abstract. *Ground sensing is the key task in harvesting head control system. Real time sensing of field topography under vegetation canopy is very challenging task in wild blueberry cropping system. This paper presents the design of an ultra-wide band RADAR sensing, scanning device to recognize the soil surface level under the canopy structure. Requirements for software and hardware were considered to determine the usability of the ultra-wide band RADAR system. An automated head elevation sensing system is developed and tested in wild blueberry fields. The developed system consisted of ultra wide band RADAR system customized to cover the width of the harvester head, a real-time kinematics global positioning system (RTK-GPS), custom built software for analyzing the electromagnetic waves, and a single board computer. The custom software acquired and processed the RADAR sensing data in real-time by using Fast Fourier Transform technique. Two wild blueberry fields were selected in central Nova Scotia to evaluate the performance of the developed system. One-hundred four experimental plots were randomly constructed within two fields and ground level were recorded manually and compared with RADAR sensed data to evaluate the accuracy of the developed system. Results of regression and scatter plots revealed that the proposed system was able to sense the ground level in real-time. The test results showed the potential of applying such system on working harvesters.*

Keywords. *RADAR sensing; wild blueberry; ground sensing; vegetation canopy.*

Introduction:

Sensing of vegetation structures and their condition has great economic and ecological importance in precision agriculture applications (Tian 2017). Mapping of ground level or soil level under the vegetation canopy could be used in many applications such as automating harvesting process, field leveling, and related decision making. Direct retrieval of vegetation canopy depth with respect soil level provides opportunities to model above-ground biomass and canopy volume which offers new opportunities for enhanced field monitoring, management and planning (Sinha 2015). The importance of ground level sensing is widely recognized, but measurements of soil level under the vegetation structure are challenging, time consuming, and often rely on destructive methods. There is a growing need of automating harvesting machines specially the case for wild blue berry harvesting. In Canada; more than 80% of the total wild blueberry acreage is mechanically harvested (Farooque 2014). Efficiency of Wild blueberry harvesting machines depends on the operator skills and field conditions (Chang 2017). An intelligent sensing system should be designed to improve the performance of harvesting machines.

Low bush wild blueberry suffers from the spatial variations in plant height. Maintaining the desired harvester picking head height in harvesting machine is a serious challenge for the harvesting machine operators (Farooque 2015). Harvester head adjustment is a main factor in the amount of harvestable fruit yield and affect the quality of the harvested wild blueberry (Chang 2016). Visual height estimation affect productivity and might increase losses of wild blueberry harvesting process which is considered the most important process in wild blueberry commercial production. Sensing system of the harvesting head height intended to relieve the machine operator from the manual visual height estimation of harvesting head in order to focus the operator's attention on the process control of the agricultural machine (Farooque 2014). Wild blueberry is mechanically harvested. The operator of the harvester needs to maintain the optimum height of harvester's head according to the visual estimated ground level for better yield (Chang 2014). In this study, an RADAR sensing System is developed, tested, and evaluated in a selected wild blueberry fields and compared with manual ground surface level measurement.

1. Material and Method:

2.1 Sensor Requirements & Selection Criteria

Type of ground surface sensor is selected based on: Initial Cost of sensor, Processing Time, Sensor Reliability, Sensor Accuracy, Sensor Resolution, and Power Consumption. Sensor should be designed to be waterproof and Dustproof. Design requirements of the Sensing System could be summarized in Table 1.

Table 1. Design Requirements of ground surface sensing

Sensor type	Contact less sensor
Resolution	0.01 m
Accuracy	0.02 m
Sensing dynamic range	0.1 m to 1 m
Sensor Response Time	0.05 second
Supported communication protocol	I2C; USB; serial communication
Temperature Compensated	True
Water/ Dust Proof	True
Power Consumption	< 5 W

Ground surface sensing could be done by utilizing different sensing techniques such as Mechanical contact sensors could be used for measuring the level of soil surface. Floating configuration performs better than the fixed configuration. However; this technique is not practical to be used in wild blueberry fields. Contact Based sensors require more maintenance to ensure reliable operation. However, based on the available literature review; No sensor has not been utilized by the Agriculture industry yet and there are several attempts still under development & research phase. Different types of sensing techniques evaluated for this purpose such as: Stereo imaging; Thermal imaging; ultrasonic imaging; Laser imaging LIDAR sensor; RGB-D cameras, a time of flight camera; and RADAR.

Ultrasonic sensors are not feasible for soil surface level sensing due to the high density of vegetation canopy; unless if the sensor were located behind the harvesting machine where there is less vegetation canopy after harvesting; but this solution is not effective and will not help in automating the height movement of the harvesting head. Microwave electromagnetic sensors can penetrate through most no conducting materials to differing degrees. Thus, using a microwave sensor in height control of harvesting head seems to be an attractive concept as such a device may be suitable for positioning in front of the harvesting machine. Radioactive particles in a nuclear sensor can penetrate virtually any material, making this type of sensor suitable for vegetation canopy sensing; however; nuclear sensor is a questionable choice because of health issues; price and regulations. However; due to the density of the vegetation canopy; all the above sensors except RADAR cannot be used for sensing ground surface under high density of vegetation canopy. Response Time is based on calculated speed of the harvesting machine which is around 1 mile/ hour= 0.44704 m/s; Table 2. Summarize the design requirements of Wild blueberry ground sensing system.

Table 2. Design Requirements of Wild blueberry ground sensing system

Parameter	**Required sensing range**
Average Soil Level	0 to 100 cm
Predicted Obstacle	Rocks; stumps, sticks and debris
Estimated Fruit Zone	± 10 cm
Average plant Height	0 to 50 cm

2.2 Hardware configuration of the ground level sensing

Ultra wide band RADAR ground surface level measurement system (RGSLM) was developed for low bush wild blueberry harvesting machines. The developed system consisted of a UWB RADAR sensing device covering the width of the harvester head, and custom-built ground sensing algorithm. The acquired electromagnetic received signals processed in real-time to measure the soil surface level. The overall structure of ground sensing system is presented in Figure 1.

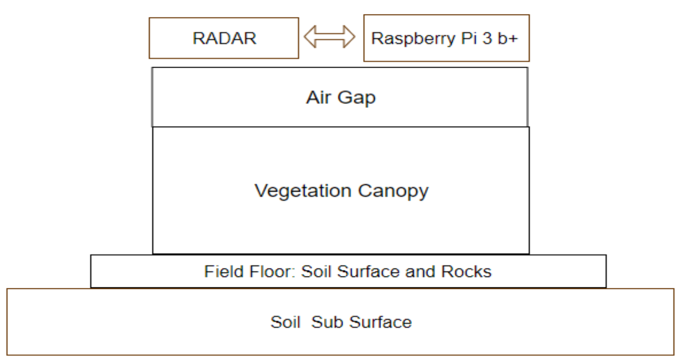

Fig. 1 Overall structure of ground sensing system

The performance of the developed system is evaluated in the lab using an experimental setup. A Walabot RADAR sensor developed by Vayyar Imaging Ltd Company (Houston, TX, USA) is adopted to capture the electromagnetic signals of the vegetation canopy. Figure 2 shows the internal layout of Walabot RADAR from both sides.

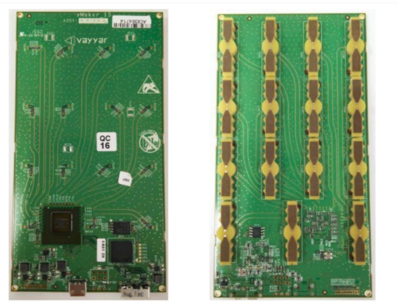

Fig. 2 Layout of Walabot Ultra Wide Band RADAR

Walabot Pro is a programmable 3D RADAR system that uses an antenna array of 18 elements to illuminate the area in front of the RADAR; and the returning signals is digitized and analysed using Fast Fourier Transform and other signal processing techniques. RADAR signals are produced by VYYR2401 A3 System-On-Chip integrated circuit.

1.3 Calibration of ground sensing system

RGSLM is installed on a tripod and connected to a laptop computer for capturing electromagnetic signal profile. In the Lab test setup; Grass is used to mimic the blueberry plants and weeds; and environment filter is configured to neglect the received signal from grass. RGSLM were calibrated and tested with solid object in the precision agriculture lab at Dalhousie University Agricultural Campus. 100 corresponding RADAR sensor readings (Electromagnetic waves) of ground level from 0 cm to 100 cm with increment of 1 cm) were recorded using RGSLM on flat ground. The manually measured ground level data and RGSLM readings were compared by linear regression using SAS 9.4 software (SAS Institute, Cary, N.C.). to evaluate sensing system performance.

Fig. 3 Field setup of RADAR sensor.

Figure 3 shows the field testing of ground level sensing using RGSLM. Field Testing and evaluation of RGSLM performed in two wild blueberry fields located in the central Nova Scotia. The fields were East Mine (45.43°N, 63.48°W; 3.88 ha) and Highland Village-II (45.24°N, 63.40°W; 2.57 ha). Walabot RADAR is connected to single board computer for processing data. Sensor range is delimited with configurable resolution and Cartesian coordinates on the x, y, z axes; The RADAR arena is calculated by converting spherical coordinates to Cartesian ones using the following formula:

$$X = R.sin\,\theta \tag{1}$$

$$Y = R.cos\,\theta.sin\,\emptyset \tag{2}$$

$$Z = R.cos\,\theta.cos\,\emptyset. \tag{3}$$

By analyzing the received RADAR signal; it can be observed that; the highest power received spot with the respect to the deepest point in the area of interest should be an indication to the soil level; while lowest power received should be an indication to the wild blueberry level. The mean value between the highest point and deepest point could be used as an indication to the fruit zone and it would be a good estimation to the suitable harvesting level. Algorithm of ground surface sensing can be summarized as following:

Ground Surface RADAR Sensing Algorithm

Inputs: Define the range of RADAR sensor
Inputs: Define the mounting angle of RADAR sensor
Inputs: Define RADAR sensor mounting Coordinates in X, Y, Z

Steps:
1- Read the received electromagnetic signal.
2- Analysis the received electromagnetic signal using FFT
3- Define the area of interest (X, Y, and Z) in the resulted FFT.
4- Extract the highest power received spot with the respect to the deepest point in the area of interest.
5- Calculate the window averaging for the deepest point in the received electromagnetic signal.
6- Repeat Steps from 1 to 5

Results and Discussion:

RGSLM is an Ultra Wide Band RADAR sensing system developed and tested for ground surface measurement under vegetation canopy. A custom program written in python language and utilized to work on an embedded computer board which is a Raspberry Pi 3 B+ connected to 7” display screen and powered with 15000 mAh battery. Table 3. Describe the specifications of Walabot RADAR.

Table 3. Walabot RADAR Specifications (Walabot 2018)

RADAR Type	Frequency Modulated Continuous Wave RADAR
Model	Walabot Pro
Number of Antennas	18
External Power supply	5V
Current Consumption	0.4-0.9 A
Average Transmitted Power	-41dBm/MHz
Frequency Range	3.3-10 GHz
Software API	C#/VB/C++/ python
Communication Protocol	USB2.0 480 Mbit
Measurement Distance	0 to 10 meter
Operating System	Windows / Linux

The received RADAR feedback data is sent to a single board computer using a USB interface. The Walabot radar is potentially a low-cost solution for 3D radar imaging. RGSLM mounted on a 4 wheel testing station. An algorithm was developed to acquire and process electromagnetic wave sensing data in real-time. Two wild blueberry fields were selected in central Nova Scotia to evaluate the performance of sensing system. Manually measured ground level values from 104 plots were compared with real-time measured values

RADAR sensing system. A linear regression model showed that height measured from the RADAR sensor to the ground level was correlated significantly with the sensor signal (R^2 = 0.9999) as shown in Figure 4.

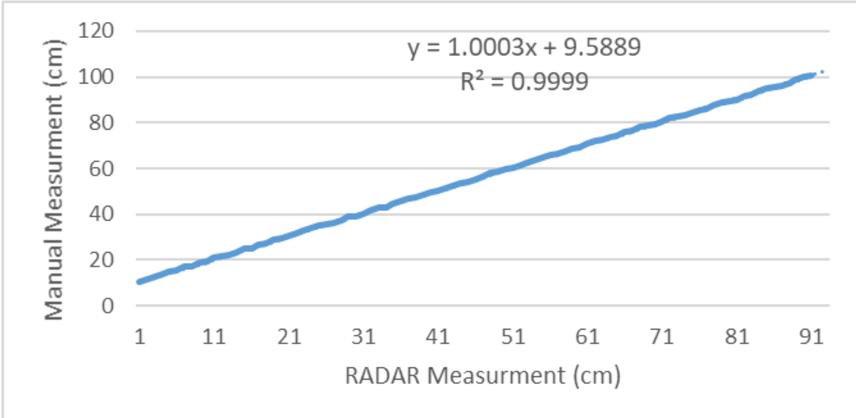

Fig. 4 Lab calibration of RADAR sensor

Field tests of RGSLM showed small fluctuations of RGSLM readings compared to the calibration in the lab tests. These fluctuations caused by uneven topography of soil and variation of vegetation coverage which acts as a noise for RADAR readings However; Overall results of linear regression revealed that RGSLM performance is accepted compared with the sensor design requirements.

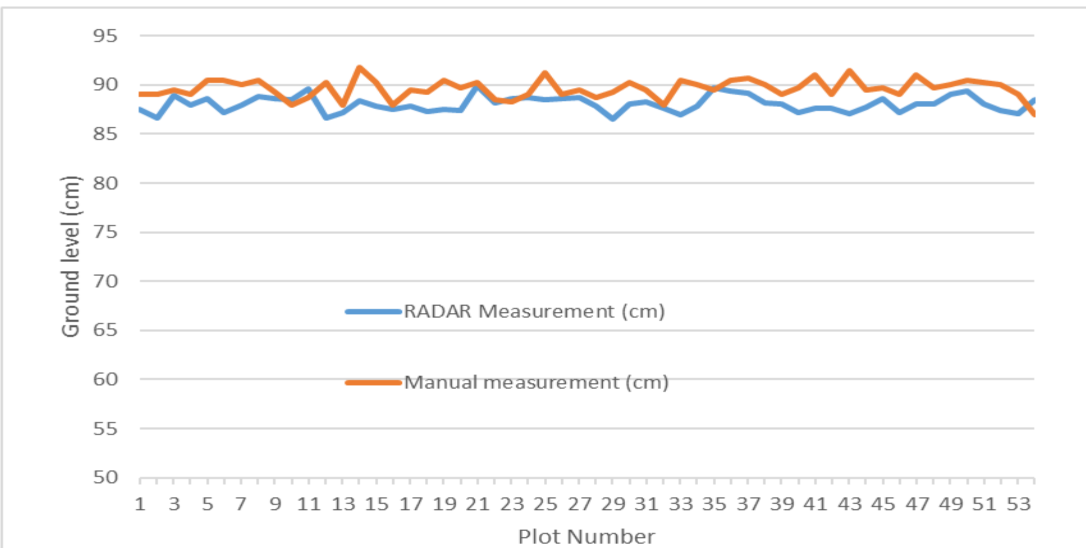

Fig. 5 Field Testing of RADAR sensor at East Mine location

Sensor was mounted on static position above ground. Sensor reading were compared with manual measurement at 56 points in a wild blueberry field East Mine location and the maximum absolute error was 0.04 meter as shown in Figure 5. To improve the sensor accuracy; a correction function is used by representing the distance between RADAR sensor and ground surface level by Isosceles triangle; where the general triangle formulas can be written as following:

$$h = \frac{1}{2}\sqrt{(4a^2 - b^2)} \tag{4}$$

Equation 4. used to improve the RADAR readings when the RADAR sensor is not perpendicular with the ground surface level. The final form of equation 4 can be written with respect to RADAR measurement as following:

$$h = \sqrt{(z^2 - \frac{1}{4}y^2)} \tag{5}$$

Where h is the corrected ground surface level; while z is the raw ground surface level; and y is the shifted distance in y direction with respect to RADAR origin. The corrected version is tested at Highland Village-II location and the maximum absolute error was 0.02 meter. Sensor reading were compared with manual measurement at 56 points in a wild blueberry field as shown in Figure 6.

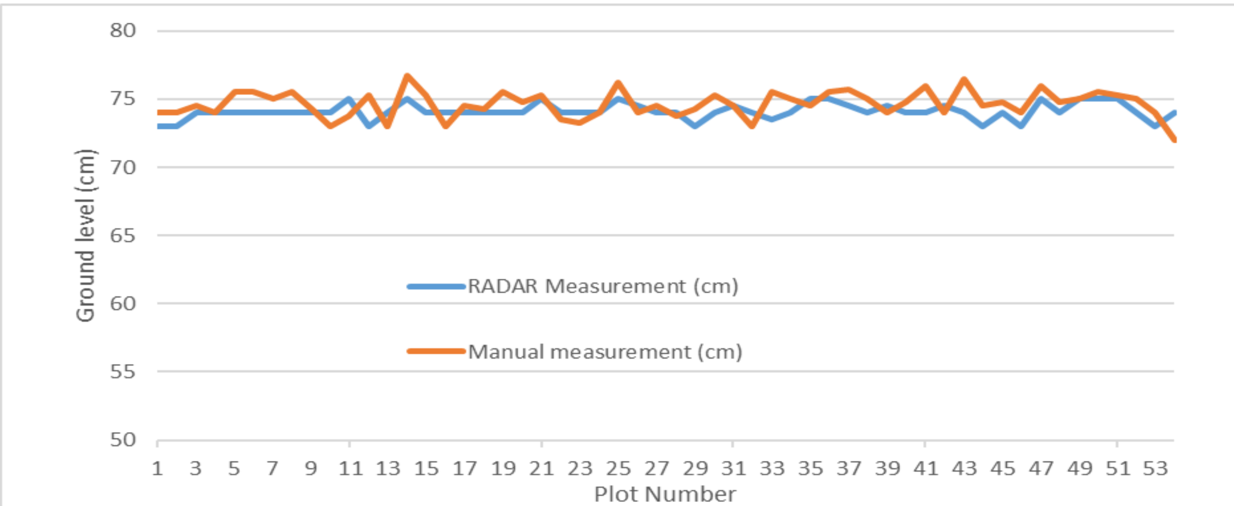

Fig. 6 Field Testing of RADAR sensor at Highland Village-II location

The above results showed a strong relationship between RADAR sensed ground surface level and manually measured height. The developed RGSLM will be an essential part of a multiple ground based sensing system for a wild blueberry harvester. RGSLM showed high potential for real-time ground sensing. RGSLM mounted on a single pivot arm to keep the height of the sensor. More accurate and advanced signal processing algorithm for the RADAR signals will be discussed on a separate paper. Ground level sensing is the key component for automatic head adjustment system that would reduce harvester operator's stress during harvesting.

Conclusion:

Ground surface measurement is a major factor for wild blueberry harvesting machines. This papers proposed a RADAR ground sensing technique for wild blueberry harvesting machines. A promising sensor technology selected and ground sensing algorithm is developed for agricultural applications. Basic tests were executed to determine the reliability and suitability of the radar sensor. Based on the lab and field tests; Ultra wide band RADAR could be used for measuring "Soil level with respect harvesting machine".

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References

Chang, Y. K., Zaman, Q. U., Rehman, T. U., Farooque, A. A., Esau, T., & Jameel, M. W. (2017). A real-time ultrasonic system to measure wild blueberry plant height during harvesting. Biosystems Engineering, 157, 35-44.

Chang, Y. K., Zaman, Q. U., Rehman, T. U., Farooque, A. A., Esau, T., & Jameel, M. W. (2017). A real-time ultrasonic system to measure wild blueberry plant height during harvesting. Biosystems Engineering, 157, 35-44.

Chang, Y. K., Zaman, Q., Farooque, A., Rehman, T., & Esau, T. (2016). An on-the-go ultrasonic plant height measurement system (UPHMS II) in the wild blueberry cropping system. In 2016 ASABE Annual International Meeting (p. 1). American Society of Agricultural and Biological Engineers.

Farooque, A. A. (2015). Performance Evaluation of a Commercial Wild Blueberry Harvester using Precision Agriculture Technologies and Mathematical Modeling.

Farooque, A. A., Zaman, Q. U., Groulx, D., Schumann, A. W., Nguyen-Quang, T., & Esau, T. J. (2015). Effect of spatial variability in crop characteristics and slope of the ground on wild blueberry fruit losses. In 2015 ASABE Annual International Meeting (p. 1). American Society of Agricultural and Biological Engineers.

Farooque, A. A., Zaman, Q. U., Groulx, D., Schumann, A. W., Yarborough, D. E., & Nguyen-Quang, T. (2014). Effect of ground speed and header revolutions on the picking efficiency ofa commercial wild blueberry harvester. Applied engineering in agriculture, 30(4), 535-546.

Farooque, A. A., Zaman, Q. U., Groulx, D., Schumann, A. W., Yarborough, D. E., & Nguyen-Quang, T. (2014). Effect of ground speed and header revolutions on the picking efficiency ofa commercial wild blueberry harvester. Applied engineering in agriculture, 30(4), 535-546.

Sinha, S., Jeganathan, C., Sharma, L. K., & Nathawat, M. S. (2015). A review of radar remote sensing for biomass estimation. International Journal of Environmental Science and Technology, 12(5), 1779-1792.

Technical specifications of Walabot Pro. RADAR; device data sheet; retrieved from. https://walabot.com/docs/walabot-tech-brief-416?type=pdf (June 2018).

Tian, F., Brandt, M., Liu, Y. Y., Rasmussen, K., & Fensholt, R. (2017). Mapping gains and losses in woody vegetation across global tropical drylands. Global change biology, 23(4), 1748-1760.