Università del Salento
Laurea Magistrale in
Ingegneria Meccanica

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RADAR – Based Perception for Autonomous Outdoor Vehicles

Tesi in Meccanica del Veicolo

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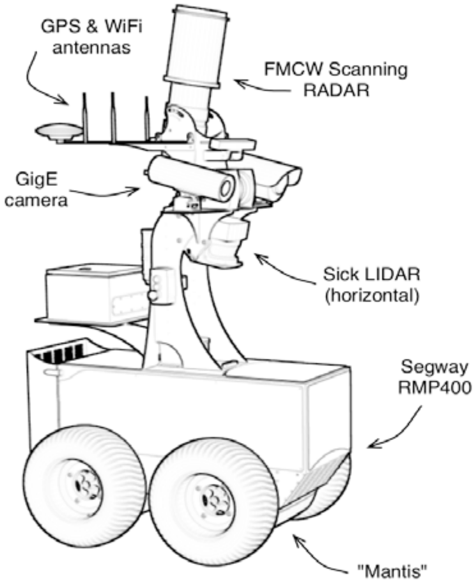
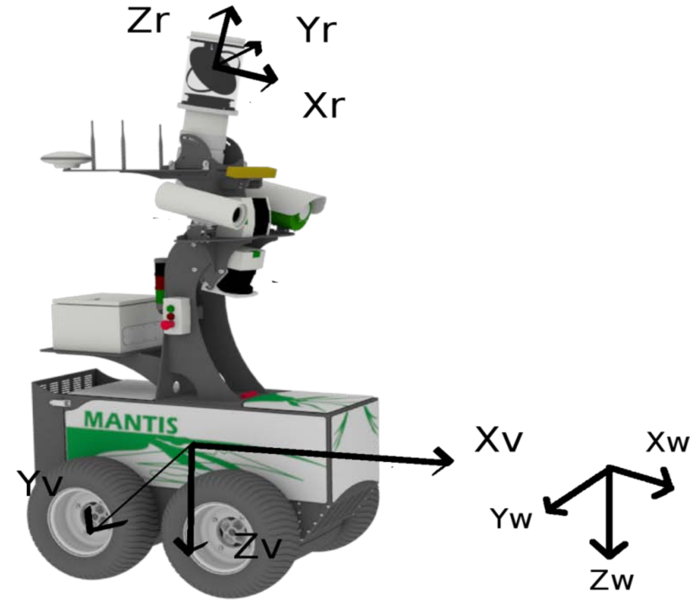
Purpose of the Thesis

- Autonomous driving is a challenging problem in outdoor environments.
- In addition, field scenarios are often characterized by low visibility conditions (presence of dust, fog, rain, changing illumination conditions).
- In this thesis, we propose the use of ***millimeter-wave radar*** for scene understanding and autonomous navigation.
    - Radar operates at a wavelength that penetrates dust and other visual obscurants and it can be successfully employed for persistent perception.
    - Radar has shortcomings as well including large footprint, specularity effects, and limited range resolution, all of which may result in poor environment survey or difficulty in interpretation.

Radar

Custom built at the ACFR, 95-GHz (3 mm) frequency-modulated continuous wave radar



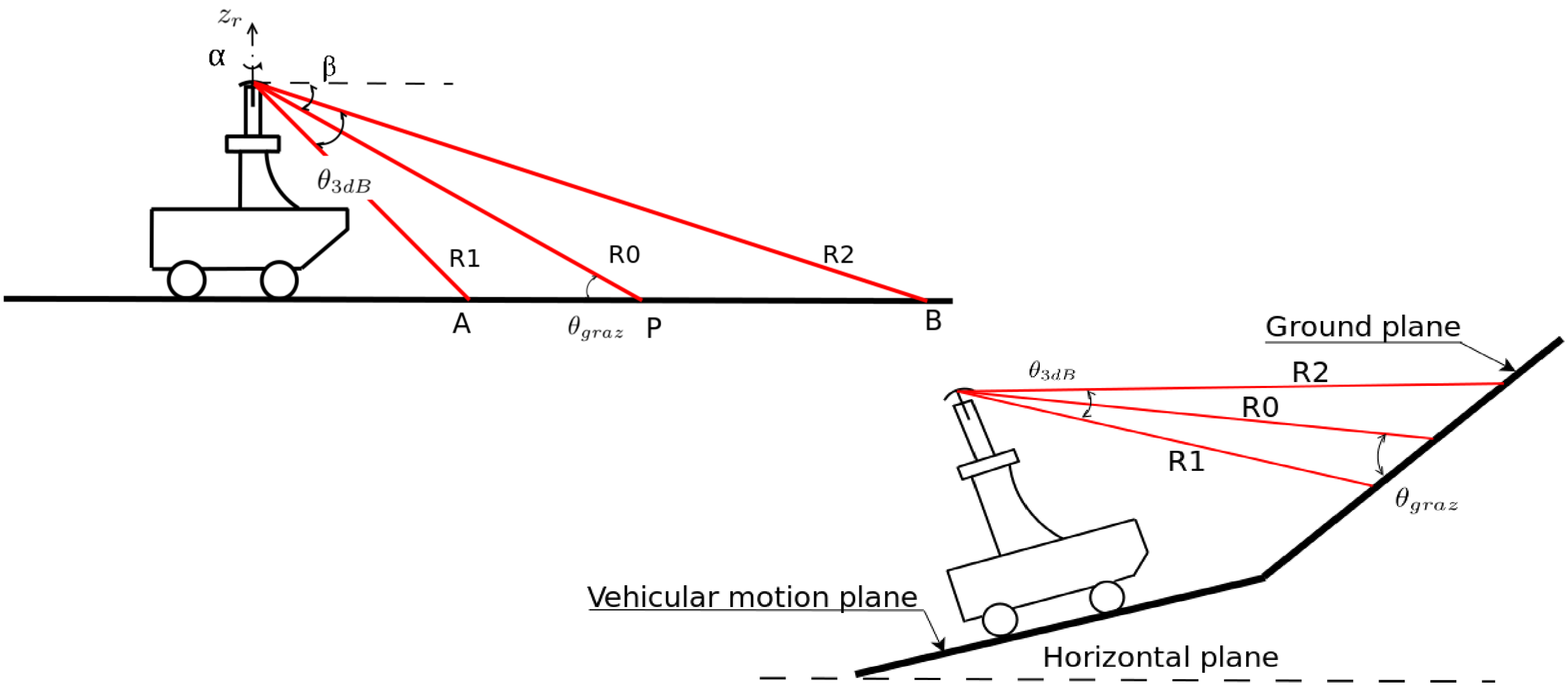


Technical properties

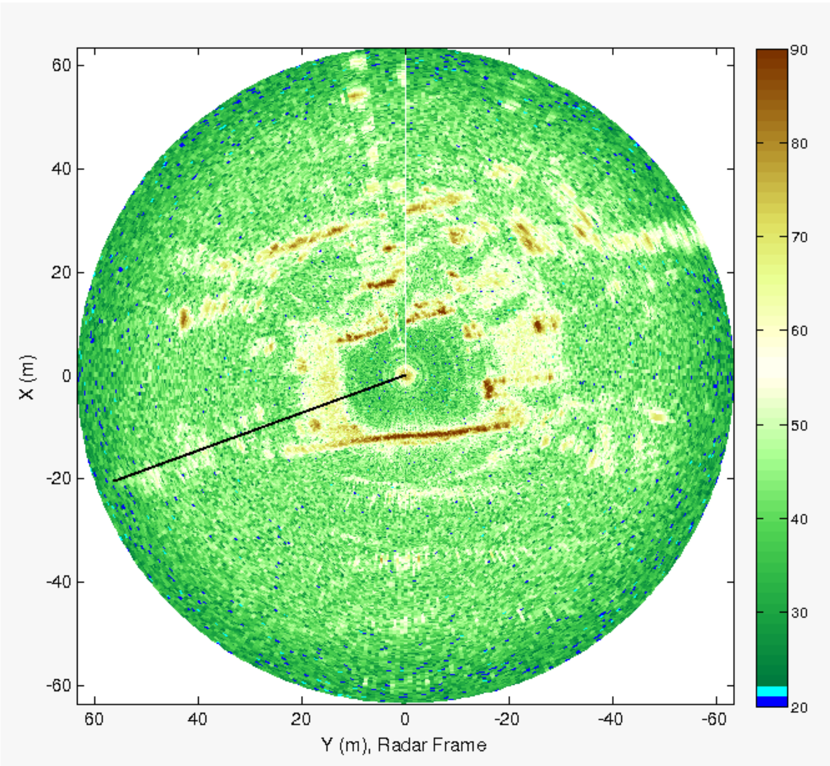
Property	Value
Model	ACFR – Custom built
Max Range(m)	60
Wave-length(mm)	3.16
Half-power Beam-width (deg)	3
Range Resolution (m)	0.03
Angular Resolution (deg)	0.77
Chirps per sec	4000
Frequency (GHz)	95

Radar

- The radar is directed at the front of the vehicle with a constant nodding angle (β =11 deg).
- The center of the beam intersects the ground at a look-ahead distance of 14 m when the ground is horizontal.



Radar



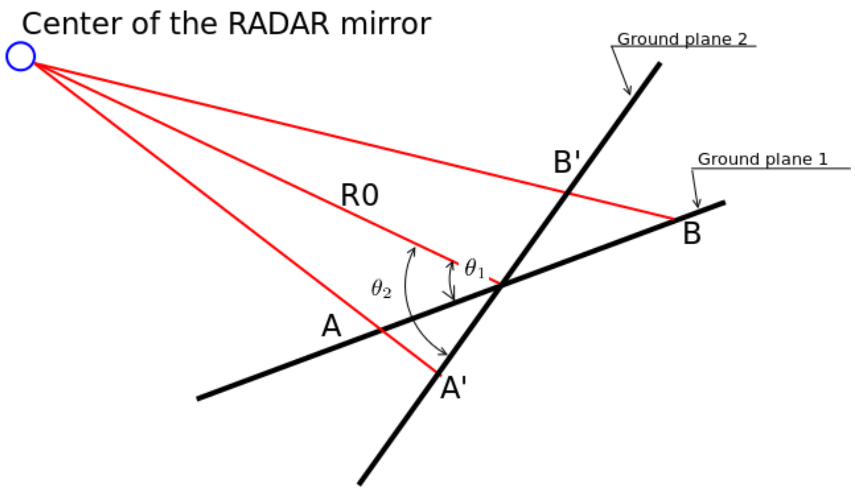
Sample Radar Image

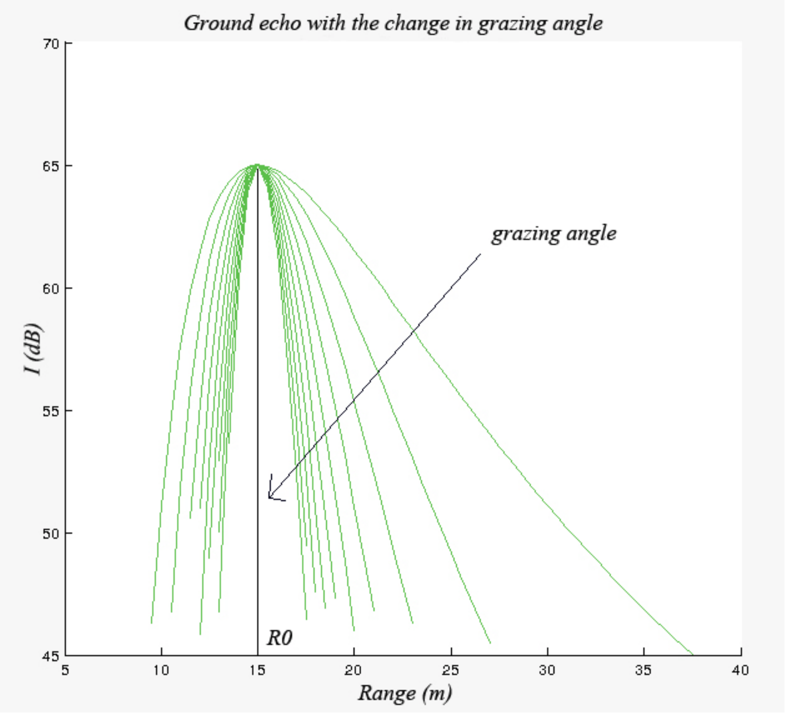
Camera image approximately co-located with the radar

The Radar Centric Ground Detection Algorithm (RCGD)

- It aims to classify each radar given observations as ground and non-ground.
- It is based on a physical model of the ground echo that is compared against a given radar return to assess the membership confidence to the ground class.
- The RCGD algorithm is performed by two loops in order to calculate the couple $(R0, \theta_{graz})$ describing the Ground-Echo model which fits the given RADAR observation best.

Ground echo model

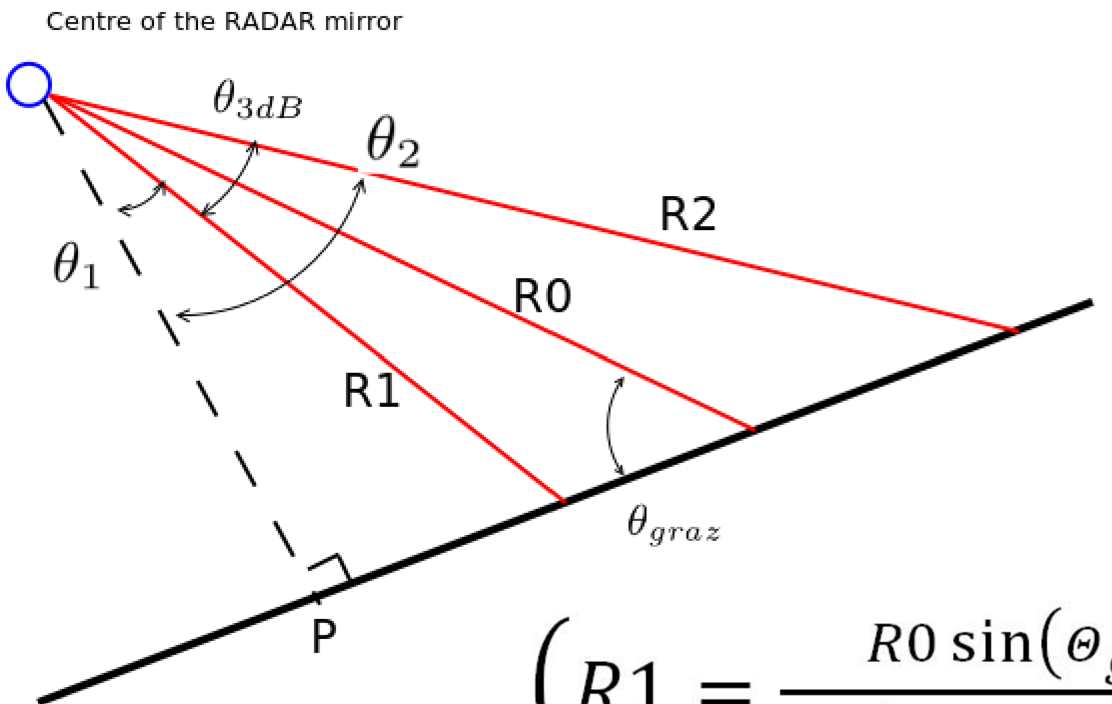




Simulated power return of the ground echo for a given scan angle

- The range spread and the power return represent two pieces of information defining the theoretical ground echo in the radar image.
- Any deviation in the spread or intensity shape suggests low likelihood of ground return in a given radar observation.

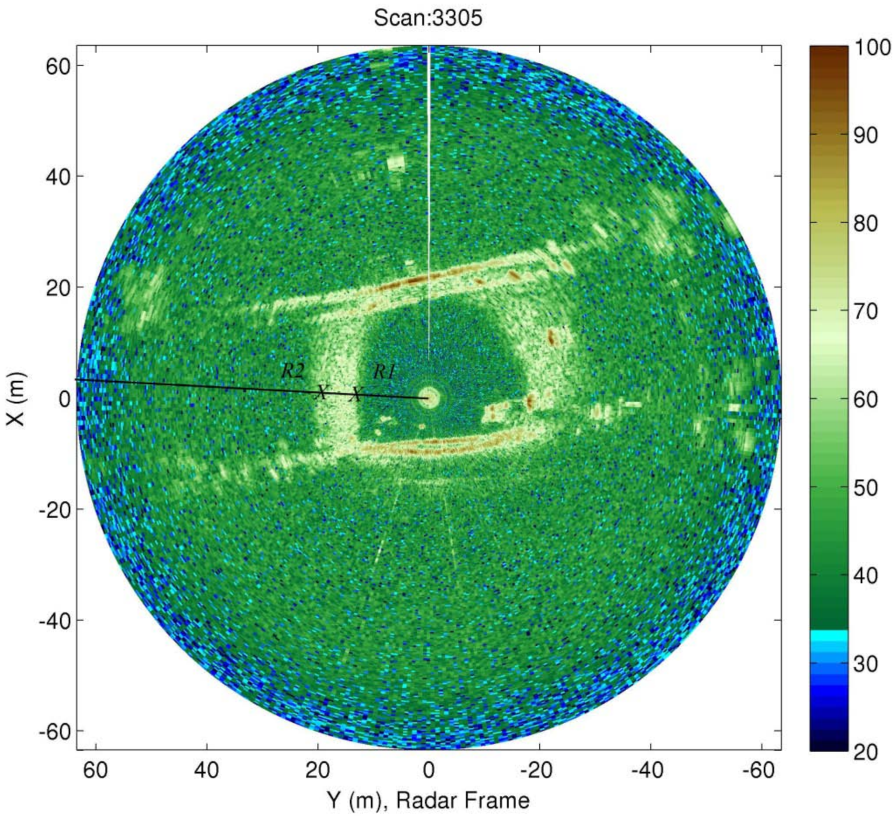
Definition of the window of interest

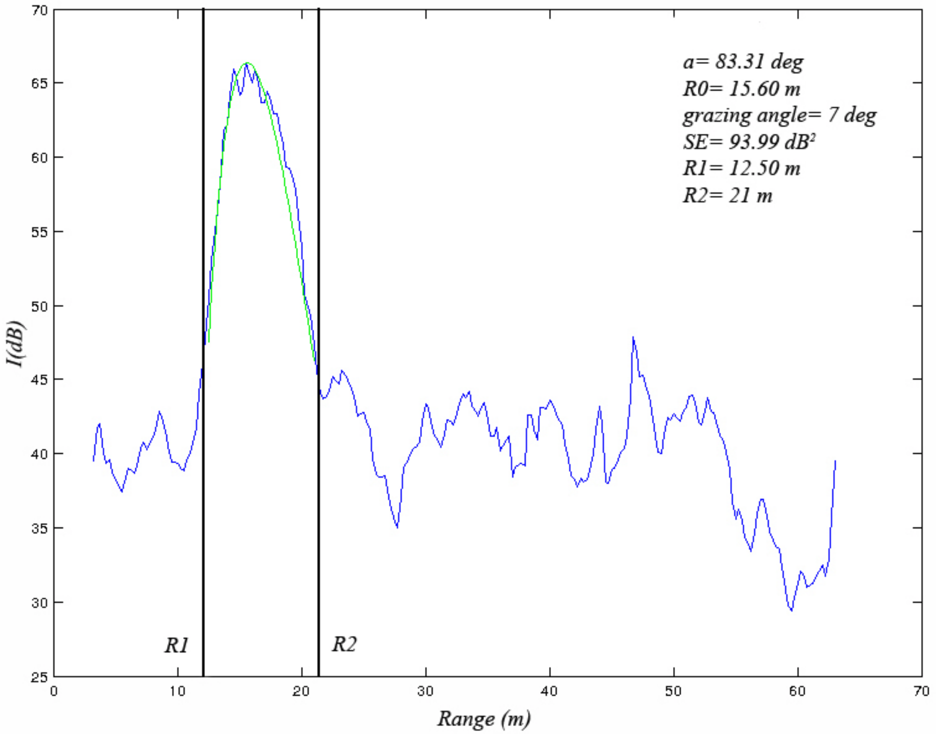


$$\begin{cases} \Theta_1 = \pi/2 - \Theta_{graz} - \Theta_{3dB}/2 \\ \Theta_2 = \pi/2 - \Theta_{graz} + \Theta_{3dB}/2 \\ R1 = \dfrac{\overline{OP}}{\cos(\Theta_1)} \\ R2 = \dfrac{\overline{OP}}{\cos(\Theta_2)} \\ \overline{OP} = R0 \sin(\Theta_{graz}) \end{cases}$$

$$\begin{cases} R1 = \dfrac{R0 \sin(\Theta_{graz})}{\sin(\Theta_{graz} + \Theta_{3dB}/2)} \\ R2 = \dfrac{R0 \sin(\Theta_{graz})}{\sin(\Theta_{graz} - \Theta_{3dB}/2)} \end{cases}$$

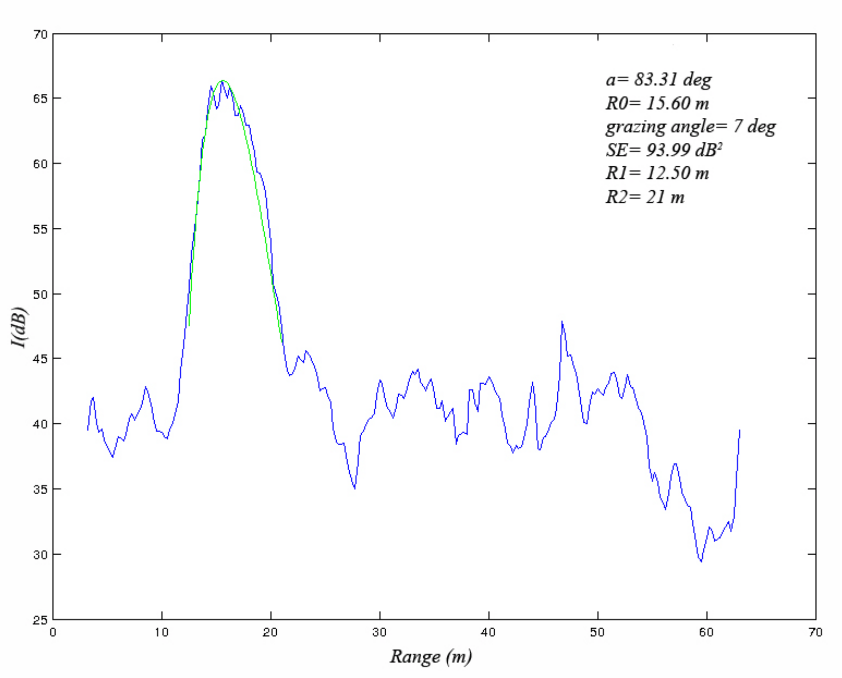
Definition of the window of interest



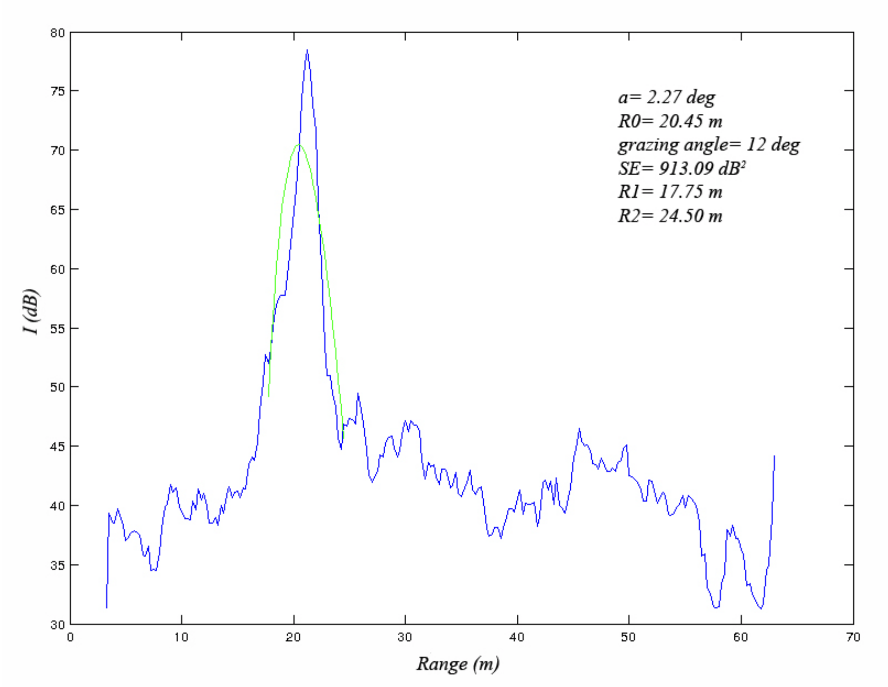


Ground Segmentation

- The power return model can be fitted to a given radar observation.
  - o A good match attests to a high likelihood of ground.
  - o A poor goodness of fit suggests low likelihood (i.e., obstacle or irregular terrain).

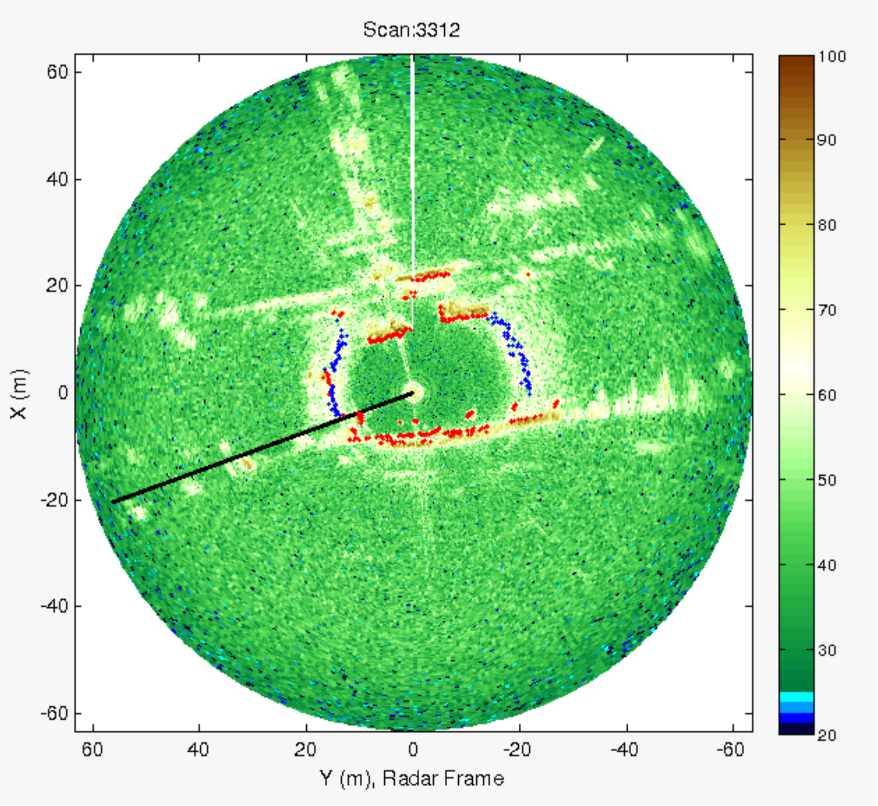


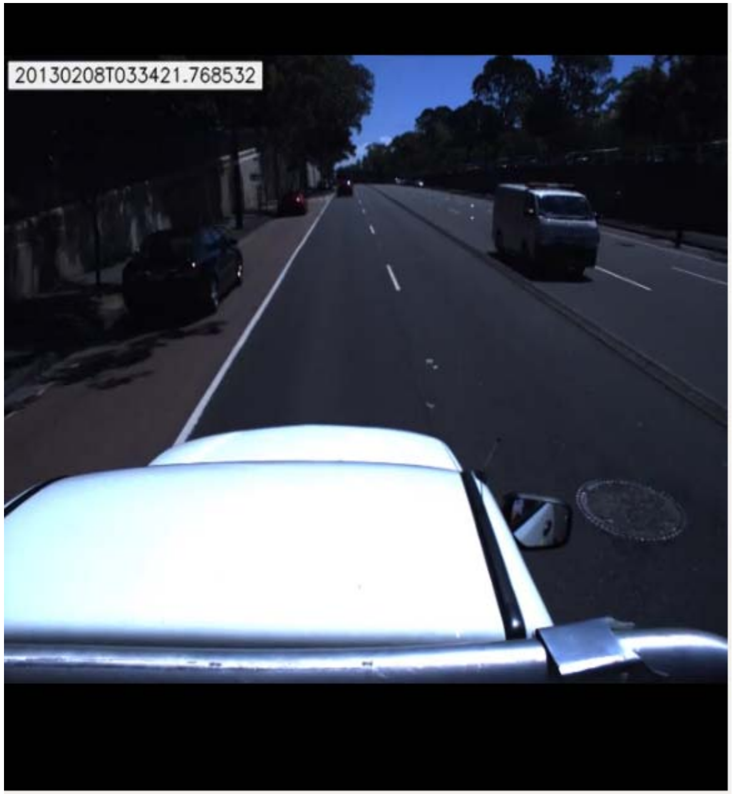
Ground-labeled observation



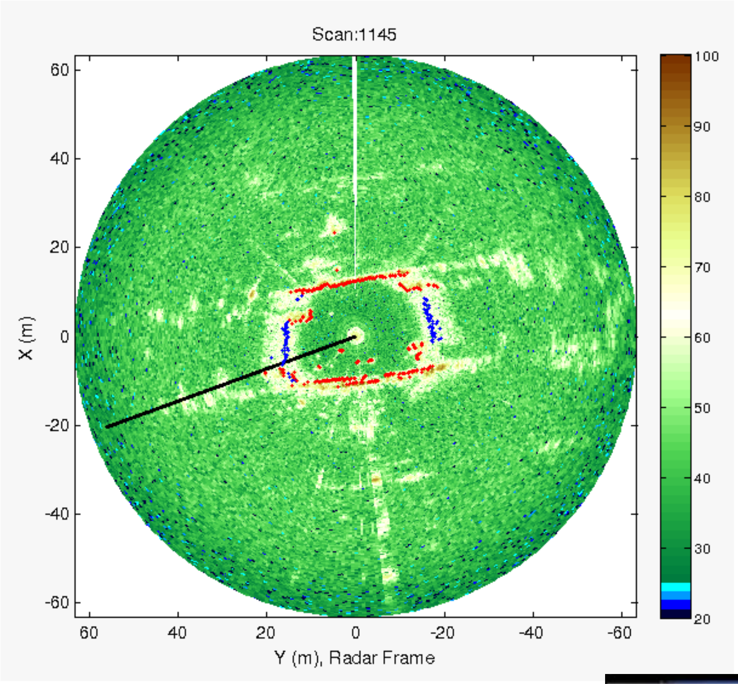
Nonground-labeled observation

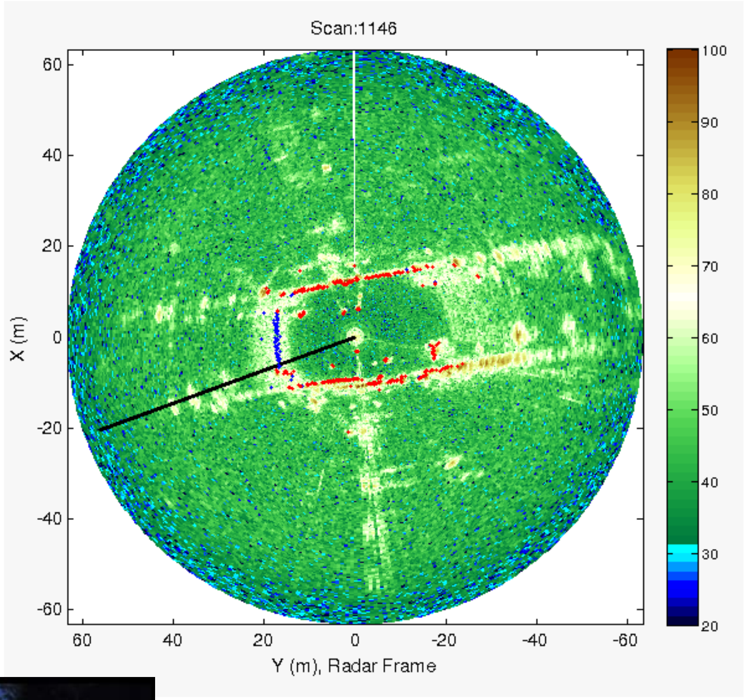
Experimental results





Experimental results





Conclusions

- A novel method for ground segmentation was presented using a MMW radar mounted on a off-road vehicle.
- It is based on the development of a physical model of the ground echo that is compared against a given radar observation to assess the membership confidence to the ground class.
- In addition, the RCGD system provided improved range estimation of the ground-labeled data for more accurate environment mapping, when compared to the standard highest intensity-based approach.
- The RCGD algorithm was proved effective with an accuracy of

  0.035 m by the comparison with laser data.


Classified Ground
Classified Non-Ground