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Pseudo-random noise-continuous-wave laser radar for surface and cloud measurements

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Abstract

Laser radar (lidar) application may require an instrument with compact size, long life of the components, low consumption and eye-safety. One possibility to achieve these features is to use a continuous-wave (cw) diode laser as lidar transmitter. A practical way to perform range-resolved measurements with a cw laser diode is the pseudo-random noise (PRN) modulation. This paper presents a compact PRN-cw lidar, using a 370-mW cw diode laser and an APD as detector. Daytime measurements of cloud base and topographic surface are demonstrated with the PRN-cw lidar technique, where the range detection exceeds 2 km. The detection of the topographic surface is performed with integration time of some tens of milliseconds during daytime and some tens of microseconds during night-time.

Keywords: Cloud detection; Surface detection; Laser radar; PRN-cw lidar; Pseudo-random noise; Continuous-wave diode laser

1. Introduction

In the traditional laser radar (lidar) method for range-resolved measurement, the transmitted laser light is in short pulses (typically a few nanoseconds), with a long interval between them. The range to the target is determined by the round-trip time-of-flight of the laser pulse from the lidar to the target. This pulsed laser radar detection is successfully employed in numerous applications in atmosphere, target

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and cloud study [1,2]. The advantages of this method are in the relative simplicity of the detection and acquisition set-up.

There is a number of specific applications where either a high power efficiency, or eye-safety, or low cost of the sensor are mandatory. For this reason laser radar method is suggested, which potentially may use continuous-wave (cw) diode lasers. To be able to use the cw lasers for range-resolved measurements, a pseudo-random noise (PRN) digital code modulation has been suggested [3,4]. PRN-cw lidar method was further studied with respect to backscatter application from space platforms [5–9], DIAL measurements [10,11], wind measurements [12] and satellite ranging [13].

The previous studies have demonstrated the feasibility of the PRN-cw laser radar technique. For molecular atmosphere and aerosol layer detection, they have also pointed that the signal-to-noise ratio of the PRN-cw lidar is inferior to the one for pulsed laser radar, being more influenced by the optical background and by the backscatter signal coming from the rest of the lidar profile. This is the reason why till presently the PRN-cw lidar demonstrations have been few and limited to night-time. Consequently, the considerations for their use were confined to night-time or space applications [6,14].

On the other hand, in a number of applications where the detection of surface or cloud base is sufficient, it is advantageous to have a compact, robust and eye-safe laser radar capable for daytime detection. The use of a powerful cw diode laser makes possible to build an instrument following these requirements. The motivation in this study is to realise such PRN-cw laser radar, as well as to demonstrate its application in daytime cloud base and target detection.

2. PRN lidar principles and signal-to-noise ratio

The application of the PRN digital sequences in various communication and microwave radar techniques is well known [15–17]. The description of the PRN-cw lidar principle with an amplitude modulation of the transmitted cw laser radiation, presented here, follows the guidelines in [3].

In the case of atmosphere and surface lidar probing, the backscattered light depends linearly on the incident radiation. The received signal $y(t)$ can be presented as a convolution of the probing signal $x(t)$ and the response function $g(t)$ of the probed medium

$$y(t) = \int_{-\infty}^{+\infty} x(t - t')g(t')\mathrm{d}t' + b(t) \tag{1}$$

In this equation, t is the response time of the probed medium which in the case of lidar is the double-trip time from the lidar to the probed medium; $x(t)$ is the power of the probing laser pulse, $y(t)$ the received optical power and $b(t)$ the background noise power at time t. The response function $g(t)$ is expressed differently in the lidar equation depending on atmosphere probing or target and surface probing [1,2]. The modulation of the transmitted optical power P_0 in the PRN-cw lidar is assumed in