1.55-µm LiDAR system implemented with Optical Access Network for automated-driving support services

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Abstract: For automated-driving support services around the intersection, we have proposed a novel LiDAR system configuration implemented with deployed Passive Optical Network (PON). The LiDAR head is set on the traffic signal, for example, and can detect the people walking in the intersection. To cost-effectively distribute each LiDAR system the optical short pulse, the centralized optical pulse generator is located with OLT in the central office. The optical pulse utilizes 1.55-µm wavelength light because it can overlay the existing broadband optical services and utilize widely used optical components such as optical amplifiers and WDM filters and so on. We have estimated the scalability of this distributed LiDAR system on the PON as a function of the splitting ratio, and detectable distance of LiDAR as a function of the reflectance of the object. We have experimentally checked the reflection properties of various the detected objects as a function of the angle of the perpendicular to the detected object and the incident light. As a result, we have clarified LiDAR can detect reflected light with a wide range of angle from the perpendicular of the object surface, if the object is a no-glossy metal.

Key words: ITS, LiDAR, Automated driving, Optical Network, Passive Optical Nwtwork

1. INTRODUCTION

Recently, various sensing technologies for automated driving have been aggressively investigated [1]. LiDAR (Laser Imaging Detection and Ranging) is one of the most promising techniques because it has high ranging detection accuracy. Another trend is ITS（Intelligent Transport System）utilizing ICT (Information and Communication Technology). Its goal “smart mobility” will be realized by transport and communication network integration [2]. On the contrary, optical broadband access network systems have been widely deployed in the last decade, especially Passive Optical Network (PON). In this paper, we propose a novel LiDAR sensing architecture implemented with PON (Passive Optical Network) for automated driving support services.

2. PROPOSED LIDAR SYSTEM ARCHITECTURE

Figure 1 shows the proposed LiDAR system. It consists of the centralized part (LiDAR light source and controller in the central office) and the distributed part (LiDAR head in the edge box) via the optical distribution network based on the PON architecture. These LiDAR heads are set on the traffic signal, for example, and can detect the people walking in the intersection. To cost-effectively distribute each LiDAR system the optical short pulse, the centralized optical pulse generator is located with OLT in the central office. The optical pulse utilizes the wavelength light of 1.55µm because it can overlay the existing broadband optical services. 1.55µm as the wavelength of the LiDAR light source is equal to that of the video distribution service on the access fiber cable. It can therefore utilize the light source of the telecommunication transport equipment such as optical amplifiers and WDM filters and so on. This leads to cost effectiveness of the total system. Moreover, 1.55µm is generally less risk for retinal damage than the visible light source widely used. Therefore, we can develop the detectable distance by using higher-power light source. This LiDAR system can be constructed on the existing optical fiber distribution network and can reuse OLT and ONU of GE-PON system widely deployed in Japan. The wavelength of LiDAR light source and control signals (1.3/1.49μm) can be multiplexed using WDM coupler.

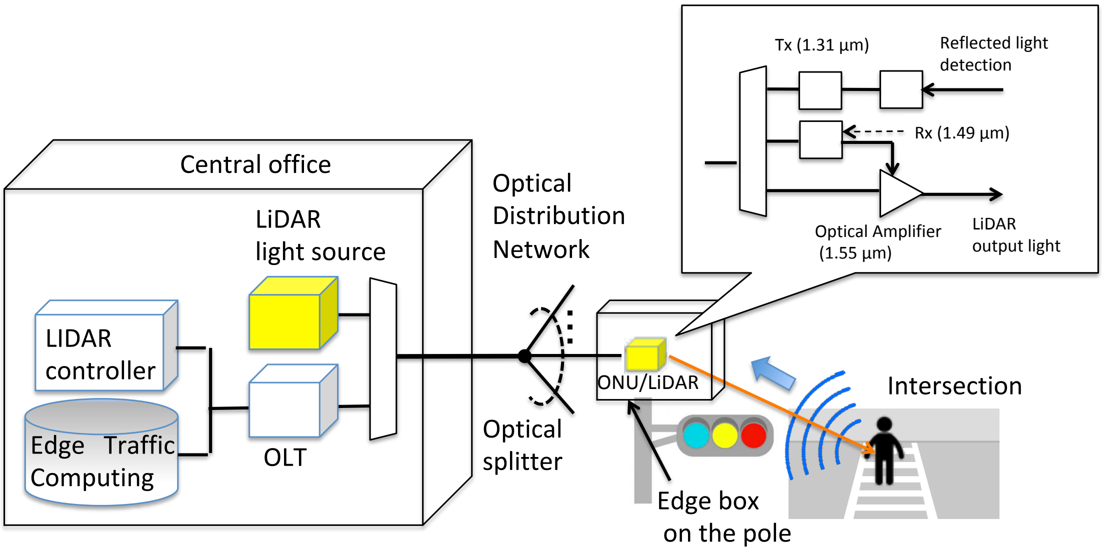

Figure 1. Proposed LiDAR system architecture implemented passive optical network

3. SYSTEM DESIGN

(1) Scalability of distributed LiDAR head in the edge box

The LiDAR light source located at the central office supplies each distributed LiDAR head via the optical distribution network with an optical splitter. In this system configuration, its scalability can be determined by optical budget between the LiDAR light source and the received power at the optical network unit (ONU), and the number of the optical splitter. Figure 2 shows the received power versus the splitting ratio of the optical splitter as a function of LiDAR light source power.

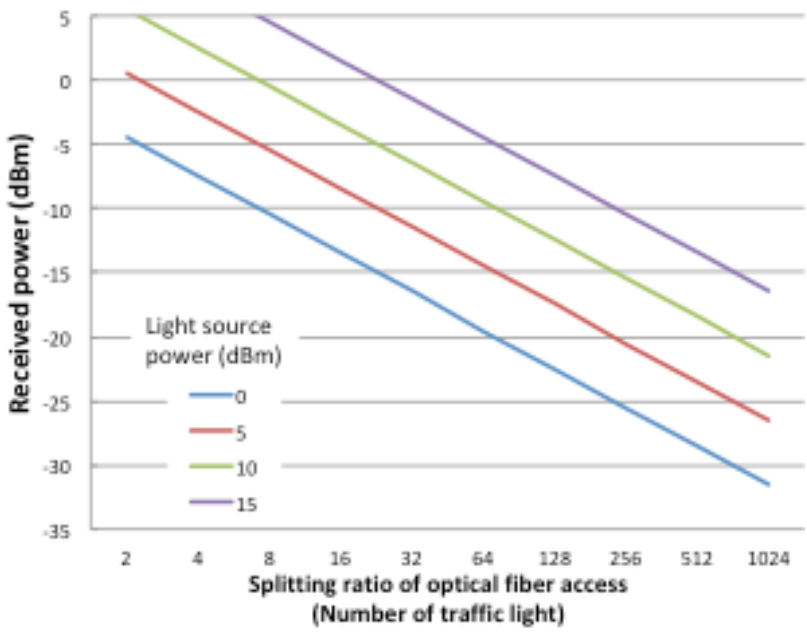

Figure 2. Received power versus Splitting ratio as a function light source power

Here, the optical fiber was a normal single mode fiber (SMF) and transmission distance between the light source and the ONU was 10 km. When the light source power is +0 dBm as equal to the typical launching power of OLT and the received power (the incident power into optical amplifier) was -24 dBm, the allowable splitting ratio (the loss of optical splitter) was about 128. When the light source power will upgrades to be +10 dBm, the splitting ratio becomes over 512, it means the light source can cover over 512 traffic lights.

(2) Detectable distance to object

The launched optical pulse from the LiDAR head is reflected at the surface of the object. The reflected light from the object is detected by InGaAs PIN-PD/TIA. The detectable distance is determined by the launch power, the sensitivity of the receiver, and the reflectance of the object. Figure 3 shows the output voltage of PIN-PD/TIA versus the distance between the LiDAR head and the object as a function of the reflectance of the object.

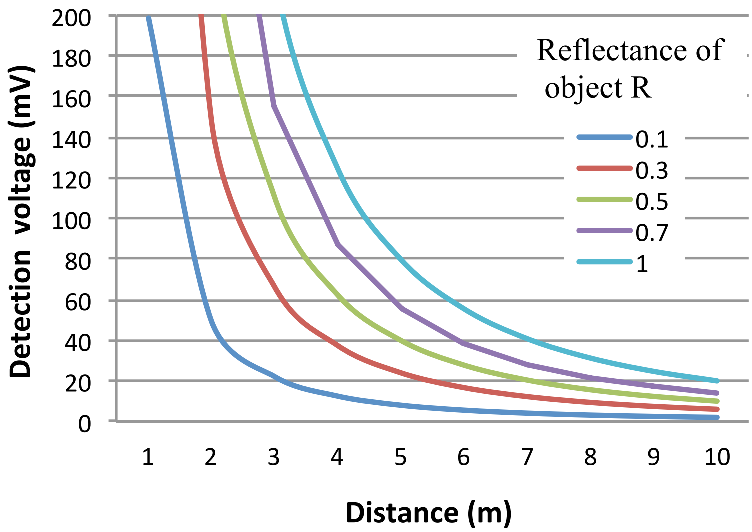

Figure 3. Output voltage of TIA versus distance as a function of reflectance of object

Here, the angle of the optical launched beam was 2 $\times 10^{-3}$radian and the beam waist was 1 mm. The pulse width was 40 ns and its duty was 0.02. On the other receiver side, the received efficiency was 0.8 A/W, and the gain of TIA was 1 x 10^{9}. The load resistance was set to 50 Ω. If the limit of detectable voltage is 20 mV, all objects with any reflectance can be detected within 10 m. Even the reflectance is around 0.5, the object within 5m which is as large as the size of middle-scale intersection, can be detected.

4. EXPERIMENTAL SETUP

Figure 4 shows the experimental setup. The wavelength and the optical output power were 1556.53 nm and 1.35 dBm, respectively. The optical pulse of LiDAR light source was generated by Flex Pulser (TriMATIZ). The pulse width and the duty cycle of the optical pulse were 40 nsec and 2 %, respectively. The optical Generated optical pulse was divided into the launched light of LiDAR head toward the object and reference light. The launched light was amplified by Er-doped fiber amplifier (EDFA) with 20 dB gain. The launched light was shaped to collimated beam by an optical collimator. The mirror worked as a beam scanner, which can change the incident angle to the object. The reflected light from the object was focused by objective lens and was detected InGaAs PD/TIA. The oscilloscope can observe the time difference between the reflected light and the reference light, which corresponds to the distance to the object.

5. EXPERIMENTAL RESULTS

Figure 5 shows the reflection properties of various the detected objects as a function of the angle of the perpendicular to the detected object and the incident light. The distance to the object was set to 3m.

From the result, the received optical power strongly depends on the surface condition of the detected object.

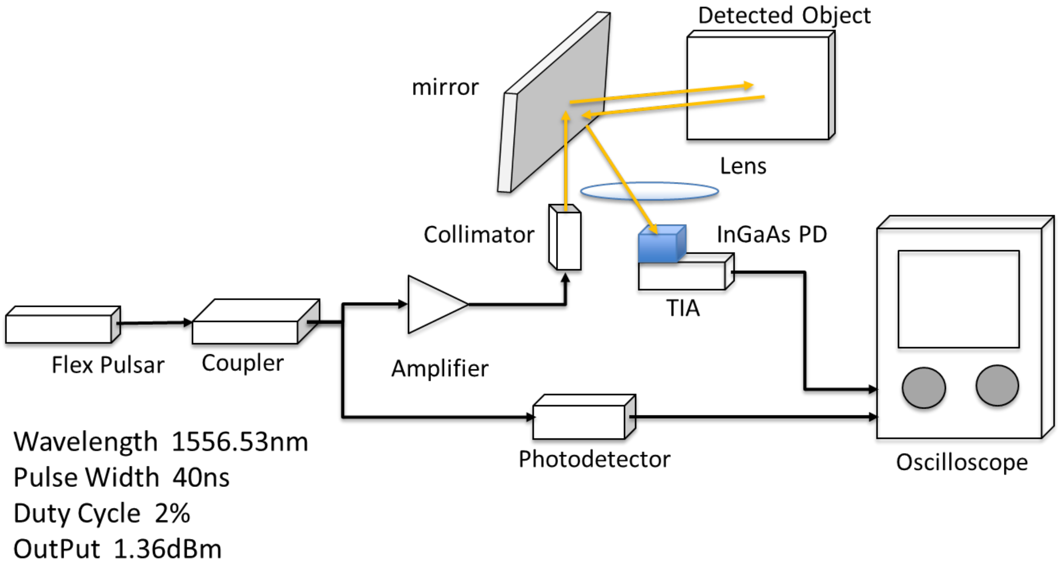

Figure 4 Experimental Setup

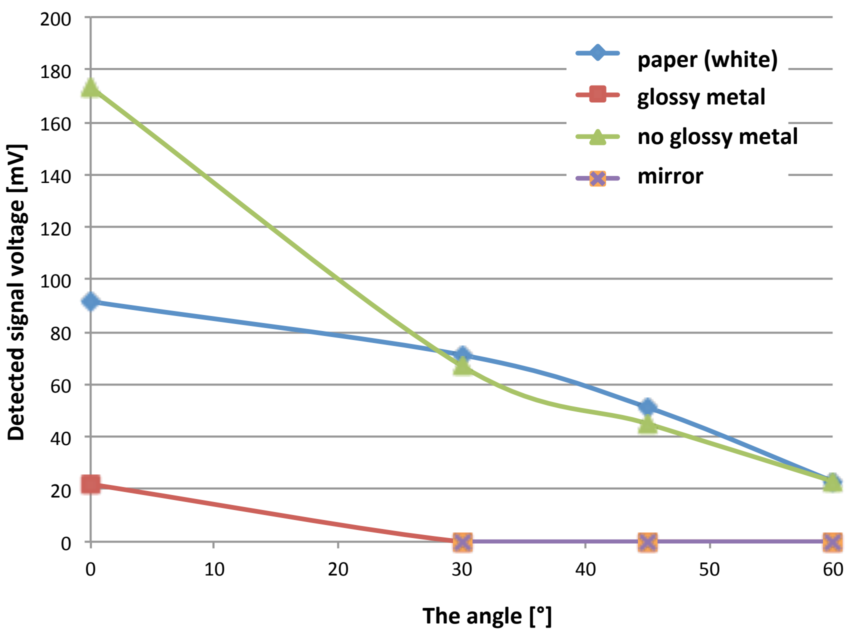

Figure 5. Reflection properties of various the detected objects as a function of the angle of the perpendicular to the detected object and the incident light

In case of a mirror (R= 100 %), the range of detectable angle was very small. On the other hand, in case of the object with rough surface (like papers) or no glossy surface, even a large angle from the normal, reflected signal can be detected. These results are caused by well-known Lambertian reflex. The power of the reflected light decreases in inverse proportion to the squire of the angle, which agrees well with the theory.

Figure 6 shows the detected signal voltage as a function of the distance to the object. In this case, the used object was a paper with the reflectance of about 30 %. As shown in the measurement result, the detected signal voltage decreases in inverse proportion to the squire of the distance, which agrees well with the calculation result. If the limit of detectable voltage is 20 mV, this type of the object with rough surface can be detected around 8 m.

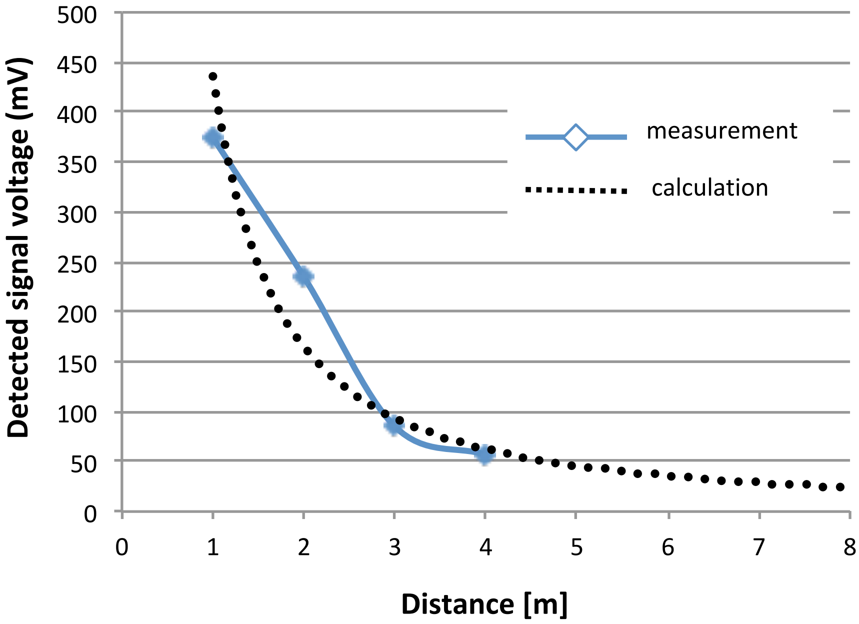

Figure 6. Detected signal voltage as a function of distance

6. SUMMARY

We proposed a new LiDAR system integrated with PON architecture and estimated the scalability of this system, and showed feasibility of proposed LiDAR system configuration for detecting walkers in the intersection

References

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