2-D Scanning LiDAR with MEMS Mirror and STM32

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Abstract. In this paper, the 2-D scanning rangefinding LiDAR based on MEMS mirror and STM32 is proposed, in terms of time-of-flight (TOF) measurement, employing a APD as photodetector in order to steer nanosecond pulsed beam. The aim, centimeter-level measurement accuracy with low power consumption and a scanning angle of $+/-30^\circ$, were achieved using application-specific integrated circuits, optical system, TDC-GP21 chip and MEMS mirror. Compared to the traditional system, the volume of this model is much smaller. The basic function of the scanning system of receiver optics is already checked experimentally.

1. Introduction
A Time of Flight (TOF) LiDAR (Light Detection and Ranging) system is used in distance measurement by calculating the flight time between the emission of a light pulse and its return to the sensor, after being reflected diffusely by the object we want to measure. The main deference between LiDAR and RADAR is the operation frequency: hundreds of THz for LiDAR, tens of GHz for RADAR. This is important since it affects the angular resolution of the device, in the order of some degrees for the latter, down to $0.1^\circ$ for the first [1]. Since the advent of the laser in the 1960s, after more than 50 years of development, with the continuous advancement of detection technology, laser technology and technology, the significant progress has been achieved for laser radar, and its unique technological advantages gradually emerged.

The interest in LiDAR technology has grown significantly in recent years considering the numerous civilian and military application, including indoor positioning, mapping and cartography of planets, forestry management and planning, flood modeling, pollution, urban planning, transport planning[2], target identification, precision tracking, Scorpion, Missile guidance, cellular network planning terrain mapping, autonomous driving[3]. Especially, the Advanced Driver Assistance Systems (ADAS) application has been given great attention.

One of main application of LiDAR is ranging. The traditional LiDAR is a single-point LiDAR, which has the characteristics of long ranging rang and ranging accuracy. However, it can only capture the distance information of a single point, and its application is limited. In order to obtain an overall three-dimensional image, a 2-D Scanning LiDAR has emerged. At present, there are two main implementation of 2-D Scanning LiDAR, single-point two-dimensional scanning and non-scanning area array. However, the single-point scanning device has complicated structure, a slow spatial sampling rate, and the scanning-free area array technology is immature, and the measurement distance and measurement accuracy are not easy to be improved simultaneously. In recent years, due to the booming development of micro electromechanical mechanical systems (MEMS), especially the emergence of MEMS scanning mirrors, it has become possible to reduce the size, speed and cost
single-point scanning. Xiaobao completed 2-D Scanning LiDAR by a 2-axis tilt MEMS scanning mirror and proposed an optical system, expanding the scan angles from 8° to 40° theoretically [4].

In this report, the 2-D Scanning LiDAR system which used MEMS technology, APD and TDC-GP21 chip is proposed.

2. HARDWARE
This system configuration of the 2-D Scanning LiDAR is showing in Fig 1, which composed of a pulsed laser diode, an avalanche photodiode (APD), a MEMS mirror, optics, STM32 microcontroller and electronics. The STM32 microcontroller generates the pulses to trigger the LiDAR, the maximum average power of the generated pulse is 2W and can be adjusted.

Figure 1. System architecture of the proposed LiDAR system.

The APD was selected for its high performances (high speed, low light detection) at 1550nm, the emission wavelength of our LiDAR. Among the different components of a LiDAR receiver system, the optical detector directly affects the instrument sensitivity performance, the APD specifically designed for LiDAR application is the ideal echo backscattered form target receiving component [5]. The signal amplified by the APD is output to a fast comparator to distinguish the backscattered light from the noise.

It considers using for the 2-D scan of transmitting laser the micro mirror which is a commercial product. The mirror has two axes, the fast axis and the slow axis, both of which are driven by current. It has a maximum deviation angle of ±3° in each axis and is controlled by a MEMS driver. If the repetition cycle of a pulse is set up near the natural frequency of a mirror, the scanning angle of the mirror will become large, ±10° optical scans are possible for this mirror by the pulse driver with resonance frequency. The diameter of the mirror is 6mm, and the X-axis resonance frequency and Y-axis resonance frequency of mirror are 507Hz and 431Hz, respectively.

The core of our system is to measure the distance between the transmitting point and the target point by measuring the round-trip time interval between the transmitting point and the measured target point by the time measuring module. Therefore, the accuracy of time measurement determines the accuracy of pulsed laser ranging. TDC-GP21, high integration and low price used in the system is a new generation of time digital conversion devices, launched by ACAM in Germany after TDC-GP2. At the same time, it has received great attention in the field of measurement in industry due to low power consumption characteristics as work, as well as high precision characteristics. Digital TDC uses internal logic gate delay to acquire high precision measurement time interval. The measurement principle of the time TDC is illustrated in Fig 2.
Figure 2. TDC-GP21 internal logic gate architecture.

The intelligent circuit structure, the guarantee circuit and the special measurement method ensure that the time of the signal passing through the logic gate can be guaranteed accurately. The maximum measurement accuracy depends entirely on the propagation time of the internal signal through the logic gate. The measurement unit is triggered by a start signal, and cut off by the stop signal. The time interval between the START signal and the STOP signal can be calculated from the position of the ring oscillator and the count value of the coarse value counter, and the measurement range can be up to 20 bits. Temperature and Voltage have a large effect on the propagation delay time of the gate, calibration to compensate for errors caused by temperature and Voltage changes. TDC-GP21 has two measurement ranges, of which time measurement range 1 is from 3.5ns to 2.5us, and the measurement range 2 is from 500ns to 4ms. The actual measurement range is lower than the theoretical value due to the inevitable attenuation characteristics of laser pulse transmitted in the atmosphere and the interference of external noise. Our LiDAR prototype is exhibited in the Fig.3.

3. SOFTWARE

The firmware has been written in C, and a flow chart of the workflow executed during a scan is depicted in Fig.4. At start, after the initialization of the system, 2-D scanning mirrors start scanning and the LiDAR start transmitting pulse, at the same time, Laser sync signals are sent to the TDC-GP21 as the start signal which has a fixed delay with the pulse. The measurement range 1 is selected. When an interrupt is generated, the STM32 will determine the cause of the interrupt, timeout or measurement result and decide whether to output the result. The control of the LiDAR via PC was performed through the software. This software allows the user to decide the frequency of the laser pulses, output power of LiDAR and the width of pulse.
4. EXPERIMENTAL RESULTS
Two sets of TOF measurement experiments were performed. These tests are hereafter described.

4.1. Distance Measurement
To verify the accuracy of the time interval between systems, a distance measurement has been performed. We placed a baffle at a distance of 1m from the laser, and measured it many times. Fig.5 shows the result of measurement. The variance was used to analyze the accuracy of the system, due to the fluctuation value of actual result of the measurement. By analyzing the result of measurement, the variance of data is 0.2ns, system requirements achieved.
4.2. 2D TOF Measurement
The maximum TOF distance and imaging quality are two important factors of laser imaging radar performance. The outdoor TOF measurement has not been done and the experimental distance is far from the maximum working distance. Fig.6a shows the vertical view of three whiteboards in which, in the left, a whiteboard is placed 2m away from the LiDAR, the middle is placed 2.2m and the another is placed 3.41m. The LiDAR scan result image, a quasi-uniform scanning dot matrix with a pixel of 128 x 128, is depicted in Fig.6b. In order to highlight the border of the whiteboard, we stretch pixels to 0-255. As the Fig.6b shows, the whiteboards and the boundaries between whiteboards were detected.

Fig.7a depicts a cylindrical obstacles placed in the front of the whiteboard placed 5m away from the LiDAR, 4.2m away from the LiDAR, the scan image is showed in Fig.7b. As the picture shows, the cylindrical obstacle was detected accurately.
5. Conclusion

By this report, the optical system which used MEMS technology as a 2-D scanning optical system and APD as optical receiver of LiDAR was proposed. Thanks to the employment of the MEMS mirror, the size of LiDAR system has been reduced greatly respect to those systems equipped with motors to rotate the whole system. There is no doubtful that the TOF LiDAR based on MEMS mirror is an important area in distance measurement. Of course, our prototype is far from the state of art but the smaller size of system would be easily integrated in the design of a vehicle.

A significant improvement is expected for the better prototype in terms of measuring distance, FOV and the robustness substituting the MEMS mirror. The use of MEMS mirror allows to simplify hardware but, on the other hand, could limit the scan angle and robustness. The best MEMS mirrors actually on the domestic market exhibit a FOV of $\pm 30^\circ$ without beam expander system but not all those mirrors could be used for autonomous driving, the hottest area for the research of LiDAR.

The maximum impact on robustness is the accuracy to obtain the laser echoes from spatial noise, which is difficult in designing LiDAR system. Optical pulse coding techniques will be employed to obtain a more solid detection needed to distinguish the signal from the noise, however, which will imply harsh requirements in terms of pulse duration. Currently the concept studies have done and the practical development is on-going.

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