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CMOS 單光子雪崩二極體陣列抑制環境雜訊抗干擾之主動式光達系統

CMOS SPADs Array Ambient Light Suppression and Anti-interference Active LiDAR System

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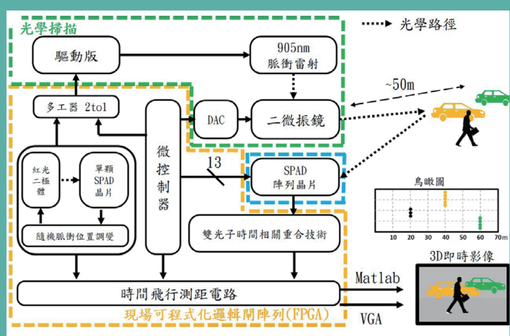
作品摘要

自駕車近年的蓬勃發展，讓各家廠商爭相搶進自駕車市場，而當中的技術核心之一的感測器，各家製造商不外乎著重於攝影相機、雷達與光學雷達。攝影相機目前暫居自駕車系統感測器的領先地位，在強大的影像分析技術下，可以在適當的情境下得到相當準確的判斷，但相較於攝影鏡頭，光達可以較不受限環境因素影響，在夜晚等複雜的情境下，能可以提供足夠清晰的畫面給後端的電腦判斷，且可直接提供距離畫面，對於安全係數要求高的自駕車系統，是一個精準且可靠的技術。過往的光學雷達使用雪崩光電二極體，感測器無法整合與CMOS電路整合，使用單光子雪崩二極體（SPAD）作為感測器，擁有CMOS製程整合的優點，且SPAD有非常高的時間解析度，可以準確到皮秒、奈秒等級，有機會發展出低成本的光學雷達模組。

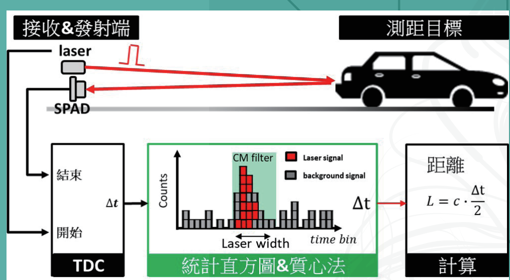
本團隊的光學雷達搭載自行開發的CMOS SPAD 64x128陣列晶片作為接收端，且使用自行設計的905nm短脈衝高功率雷射作為發射源。光學雷達測距的方式採用主動式掃描陣列來成像，其速度可達一秒10張以上的更新率，其總像素達8192個像素點，具有9.6°x5.8°的視角。面對如此巨量的資訊，本實驗室用硬體實現TDC與統計直方圖來運算，進而達到短時間內完成資料處理即時成像的目標，如圖一。在單點量測下，100us的積分時間且40klux的背景光的條件下，於50m的測距誤差可以控制在15cm以下。

光學雷達採用直接飛行時間法（D-TOF）來實現距離量測，如圖二，D-TOF透過脈衝雷射發射數顆光子，在行徑過程被物體漫射，則有機率會被感測器偵測。這段時間差表示光子行徑所花的時間，透過距離公式，則可以計算出距離，此方式可以透過TDC電路來實現，且從多筆的資料中透過統計直方圖的方式找出真正的光子事件，而得到正確的距離。

本作品完成三項突破的重點技術，其一，雙光子時間相關重合技術可以抑制背景光量，使訊雜比提升，且降低後端電路的負荷，其二，隨機脈衝位置調變技術解決車道上相同頻率關係的光達系統會有干擾的問題，其三，使用互相關演算法可以突破DTOF在測距上的物理限制，使得雷射可以在高頻操作（>1MHz）下縮短測距所需時間，同時維持150公尺的測距範圍，如圖三。



▲圖一 單光子光學雷達系統示意圖



▲圖二 直接時間飛行測距法（DTOF）示意圖

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研究領域

MOS 單光子雪崩式二極體光學雷達、分子束磊晶技術、超薄金屬薄膜、三五族半導體光電元件

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研究領域

CMOS 單光子雪崩式二極體光學雷達、高速類比 IC 設計、光纖通訊系統類比前端 IC 設計、微機電感測器之類比前端 IC 設計、半導體光電元件設計

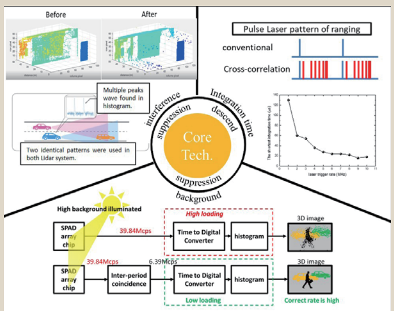
Abstract

With the technological development in recent years, various manufacturers rush into the autonomous car market. For one of the core technologies: sensors, various manufacturers focus on photographic cameras, radars and LIDAR. Photographic cameras currently lead in autonomous car sensors. With high image resolution and powerful image processing technique, they can obtain fairly accurate judgments in certain situations. However, compared with mature camera, LiDAR can work in various scenarios. It can provide a clear picture for the back-end computer in the night, heavy rain and other situations, and can directly provide distance information. It is an accurate and trustworthy technology for autonomous car systems that require high safety index. In the past, LiDAR used avalanche photodiodes, the sensor could not be integrated with CMOS circuits on chip. By using single-photon avalanche diodes with the advantages of CMOS process integration, and a very high timing resolution, they can reach the time resolution of picoseconds to nanoseconds so it could enable the development of low-cost LiDAR modules.

Our LiDAR is equipped with a self-developed CMOS SPAD 64x128 array chip as the receiver, and uses a self-designed 905-nm short-pulsed high-power laser as the transmitting source. The LiDAR ranging method deploys an active scanning array to produce images. Its can reach over 10 frames per second with a total of 8192 pixels and a viewing angle of 9.6°x5.8°. Facing huge amount data generated by the array, our team have developed the hardware embedding TDC and statistical histogram calculations and thus achieved the goal of fast data processing the for real-time demonstration, as shown in Figure 1. For single-point ranging, under the integration time of 100us and the background light of 40klux, the accuracy of the distance measurement at 50m is within 15cm error.

LiDAR uses the time-of-flight method (D-TOF) to achieve distance measurement, as shown in Figure 2. DTOF emits photons through a pulsed laser, which travel and are scattered back by the objects and a very small amount of them can be detected by the sensor. This time difference represents the travel time taken by the photon. Accordingly, the distance can be calculated. This method can be achieved through the TDC circuit, and the true target signal can be found from multiple data through statistical histograms to get the correct distance.

This work provides three key breakthrough technologies. First, the two-photon time-correlative coincidence (TPTCC) technology can largely suppress the amount of background light counts, increase the signal-to-noise ratio, and reduce the load on the back-end circuit. Second, stochastic pulse-position modulation (SPPM) tackles the problem of inter-LiDAR interference. Third, the use of cross-correlation algorithms can overcome the physical limitations of D-TOF in ranging so the laser can be operated at high frequencies (>1MHz) while the distance measurement range is still up to 150 meters. as shown in Figure 3.



◀ Fig. 3 Our LiDAR core technolgies