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An Improved Dual-axis Mirror Control Scheme for Imaging LIDAR Application

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Abstract: An improved dual-axis mirror control scheme for the imaging LIDAR (LIght Detection And Ranging) is proposed in this paper. The scheme features that a direct drive mechanism is developed utilizing PMSMs (Permanent Magnet Synchronous Motor) and rotary resolvers to control the angular positions of *x-y* mirrors. The controller is composed of the standard *d-q* current loops and a specifically designed position loop. Thus, the capabilities of accurate scanning and high accuracy pointing and tracking are enabled, together with the enhanced laser generator, resulting in the extension of the range measurement to be as far as 25 kilometres, as well as the near-zone imaging capability. In addition, a safety mode is developed to prevent the LIDAR from interior damage. Then, the implementation of the mirror subsystem is introduced and the experimental results have validated the agreement with the requirement.

Keywords: mirror, pointing, scanning, transition, PMSM, motor, FOC, accuracy

1. INTRODUCTION

Being a key guidance instrument, the imaging LIDAR provides the range and image information to the GN&C system and plays unique role in missions like moon and mars exploration (J. P. Carmo, 2011), the rendezvous and docking with the cooperative targets like the International Space Station (A. C. M. Allen, 2008) and the track and identification of the targets like the near-earth asteroids (T. D. Cole, 1996). As well known, two types of laser imaging schemes are currently being explored and utilized. The first scheme is to utilize the concentrated laser beams and scanning mechanisms to implement the functions of range measurement and image acquirement. The mirrors commonly move about fixed central positions with alterable amplitude and frequency. The high repetitive rate of the laser beams along with the high sampling frequency of the mirror angular positions makes the desired functions possible by the accurate operation of time measurement unit, beam generator and processing unit of LIDARs. This scheme is technically mature and has been widely employed in many applications. The shortcoming is that the fast imaging is difficult because of the limited scanning rate of motor mechanisms. The second scheme is the flash LIDAR (F. Amzajerdian, 2014) that having the advantage of greatly improved frame rate. However, the operational range of the current products is commonly limited.

A new type imaging LIDAR is now under development and is required to have an operational range from 25 kilometres to 10 meters. For the range from 25 kilometres to 2 kilometres, the LIDAR shall provide the range information with the error being less than 1 meter. For the range from 2 kilometres to 10 meters, the accurate scanning capability is needed to acquire the 3-D range image of the target. The proposed requirement has established considerable challenge in the design of the laser generator subsystem and the mirror subsystem. It is because that the power level and repetitive frequency of available types of laser generators cannot meet the demanded long range measurement requirement if LIDAR operates in the usual scanning mode. The newly developed LIDAR product utilizes two laser generators and orthogonally gimballed mirror pair to overcome this problem. A solid state laser generator can produce the beam pulses shorter than 15 nanoseconds and with the peak power about 4 megawatts, but with a low repetitive frequency of less than 5 Hz, is utilized in the long range measurement circumstance in order to have acceptable energy level of incoming beams rebounded from the target. Thus, the high accuracy pointing and tracking capability of the mirror subsystem is obligatory. In the near region of less than 2 kilometres, a fibre laser generator with the peak power about 5 kilowatts and a high repetitive frequency of 50 kHz is used, along with the scanning movement of the mirrors, to implement the 3-D range imaging function. As a conclusion, the functionality improvement of the new LIDARs requests the mirror subsystem to have the twofold functions of high accuracy pointing and tracking as well as accurate scanning, while the former one is commonly absent for the currently wide-used LIDAR products. As a matter of fact, the expected mirror subsystem shall: 1) have the capability of pointing the beams to a target over 25 kilometres away with the angular error of each mirror being less than 0.006 degrees, and the transition time being restricted in 0.1 seconds for angular step without exceeding 0.3 degrees. 2) in the scanning mode, the largest scanning amplitude reaches 5.0 degrees and the highest scanning frequency reaches 50 Hz for both mirrors, and the two requirements are unnecessary implemented simultaneously. On the other hand, the smallest value of the scanning amplitude is 0.25 degrees and the lowest frequency is 15 Hz. Another restriction is, both errors of amplitude and frequency in the scanning mode shall be lower than 10%. Furthermore, with the proceeding of the development, the central position, amplitude and frequency of the scanning movement is demanded to be alterable in the real time.

A comprehensive evaluation is thus conducted concerning the most suited mechanism to implement the established mirror

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control purpose. Among the candidate solutions under consideration, the one that each mirror being controlled by a separated direct PMSM mechanism is the most appropriate in our comprehension. The rotor Field-Oriented-Control (FOC) method, which has been widely employed in industrial applications, may be employed to realize the high-performance steering of the mirror assemblies. In the latter chapters of this article, the design issues of the mirror control subsystem are addressed concerning: 1) the selection of the sensing unit for angular position. 2) the combined controller that including standard *d-q* current loops and a specifically designed angular position loop. 3) the operational aspect of the mirror control subsystem. Whereafter, experimental results are presented and the agreement with the requirement is testified.

2. ANGULAR POSITION SENSING UNIT

The angular position sensing unit is used to feed the instantly sampled position data to the mirror control loops, and meanwhile, these data are transferred to the processing subsystem of LIDAR for the purpose of image producing by combining with the synchronized time-of-flight data of the laser beams. Considering the functionality importance of angular position sensing unit, focus is placed on the two aspects: high resolving capability, which guarantees the position accuracy of the pointing and scanning movement, and the significant tolerance capability in severe space environment.

Currently, two types of position sensing device are available: the encoder and the rotary resolver. The resolving capabilities of the two are similar under the same restriction imposed by weight and volume. On the other side, the rotary resolvers with the associated electronics are evaluated as superior to the available encoders in mechanical stiffness, while a series of thermal vacuum test and radiation test have been done and both devices show the equivalent competence. Fig. 1 shows the disassembled scanning mirror mechanism of the two axes.

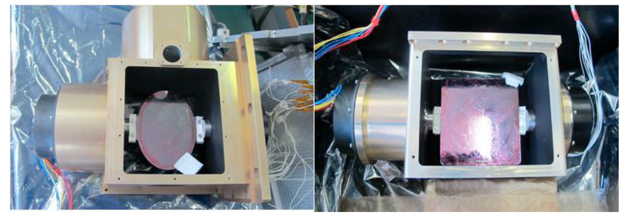

Fig.1. Disassembled mirror mechanism. Left: *x*, right: *y*

It is observed that the PMSM and the rotary resolver are installed at either side of the mirror. The rotary resolver and the associated electronics have the resolving capability as high as 0.000172 degrees per LSB bit. A mechanical frame with high enough stiffness is designed so as to maintain the high pointing accuracy of the laser beams. The rotating inertia of the elliptical and rectangular mirror, including respective mechanical assembly, ranges between $4 \sim 6 \times 10^{-4} \mathrm{kg \cdot m^2}$.

3. DESIGN OF THE CONTROLLER

Fig. 2 shows the functional diagram of the developed scheme for controlling the movement of one piece of mirror, which includes the standard *d-q* current loops and a specifically designed angular position loop.

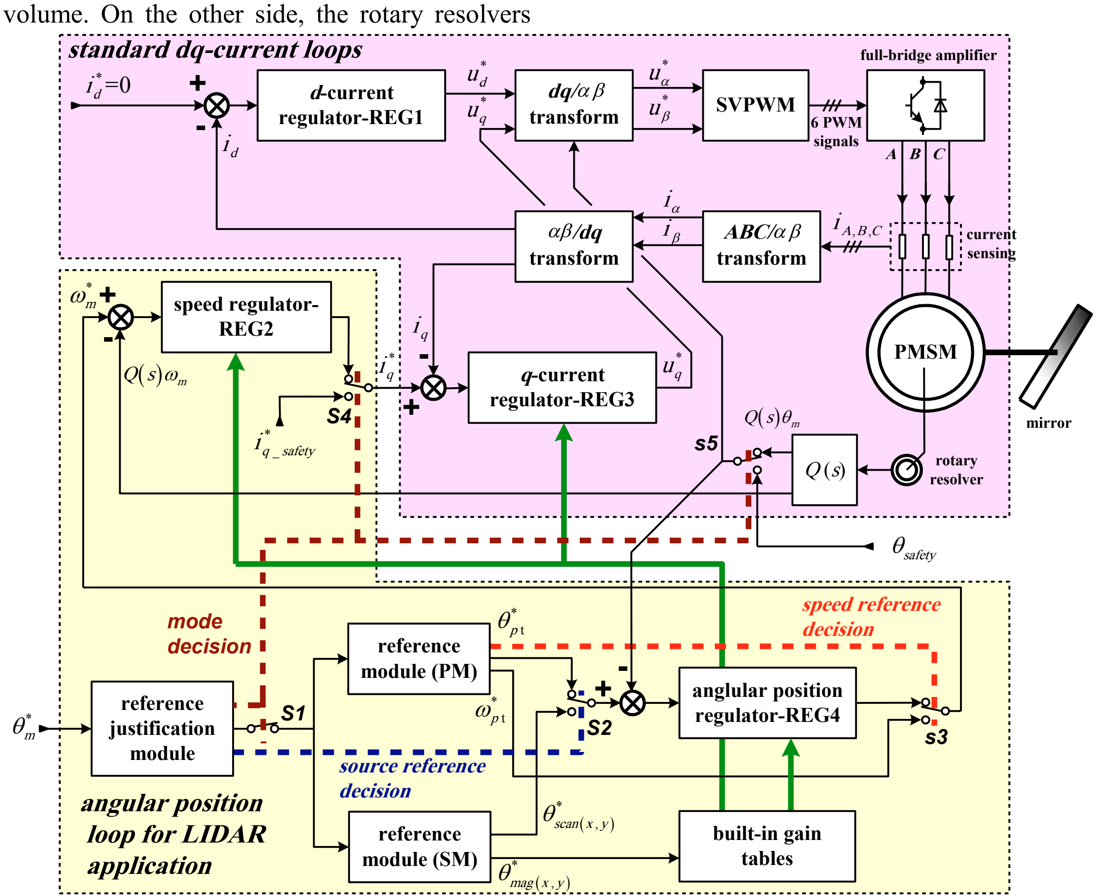

Fig.2. Functional diagram of the mirror control scheme