Speed-Up of MEMS Mirror's Transient Start-Up Procedure

Andreas Strasser†, Philipp Stelzer†, Christian Steger† and Norbert Druml*

†Graz University of Technology, Graz, Austria

email:{strasser, stelzer, steger}@tugraz.at

*Infineon Technologies Austria AG, Graz, Austria

email:{norbert.druml}@infineon.com

***Abstract*—Light Detection and Ranging (LiDAR) sensors are the next generation of Advanced Driver-Assistance Systems (ADAS). This device will be a key enabler for automated driving. As a consequence these devices must be highly robust, fail-operational and safe. In this paper we introduce a novel concept to speed-up the start-up procedure of 1D MEMS Micro-Scanning LiDAR systems to enable quick recovery after unexpected fatal shocks to ensure safe driving for passengers and other road participants.**

***Index Terms*—MEMS Mirror, LiDAR, LiDAR Safety , Start-Up Phase, LiDAR Optimization**

I. Introduction

In the next few years, autonomous driving will disruptively change the automotive industry as well as our society [1]. Autonomous driving is one of the key enablers for smart mobility. Smart mobility will change the urban environment by connecting vehicles, infrastructures and citizens together and enables resource-efficient short-distance traffic [2]. In Europe several partners founded "PRYSTINE" (Programmable Systems for Intelligenze in Automobiles), a research project that focus on the development of next-generation Advanced Driver-Assistance Systems (ADAS). PRYSTINE's focus is on the development of a fail-operational urban surround pereception system, containing robust RADAR and LiDAR (Light Detection and Ranging) systems [1]. RADAR is already a proven technology in the automotive industry and can already been found in middle-class vehicles. The RADARs are used in ADAS such as the Adaptive Cruise Control (ACC) to avoid collissions. [3]. The LiDAR technology instead can not been found in middle-class vehicles yet, but there are feasbility studies such as Google's Waymo project [4]. The LiDAR system of Google's research car contains a mechanical rotating LiDAR system [5], this device has the big disadvantage that it is mounted on top of the car and influences the aerodynamic negative and is rather expensive [6], [7]. A smarter approach is the novel LiDAR concept of Druml et al. with their 1D MEMS Micro-Scanning LiDAR system as seen in Figure 2 [8]. Their approach integrates the rotating mirror into a Micro-Electro-Mechanical system (MEMS). This will decrease the overall costs and enables an integration inside the driver cabin without any negative influence on vehicle's aerodynamics [8].

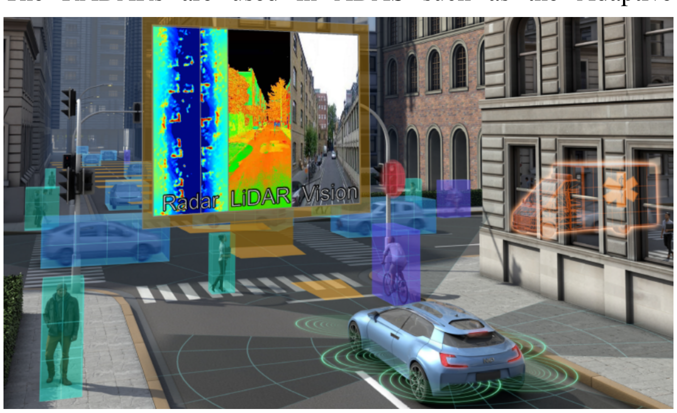

Fig. 1. PRYSTINE's concept view of a fail-operational urban surround perception system [1].

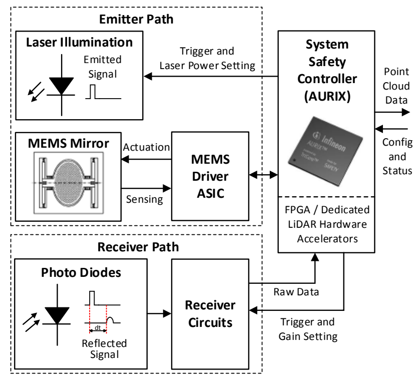

Fig. 2. Overview of a LiDAR system for automonomous driving [8].

LiDAR systems will be a major key enabler for autonomous driving for Level 3 driving automation of the SAE's automation levels [1]. On Level 3 the drivers can move their eyes off the street and enjoy a movie during their trip. For this driving automation level the provided systems needs to have a high level of safety, reliability and must be fail-operational [1]. One of the most critical situation of the 1D MEMS Micro-Scanning LiDAR system is the long duration of the transient start-up procedure of the MEMS mirror until it can operate. In general the long duration would be no problem, if the mirror is starting at engine start and turned off when the engine stops. Unfortunately, the MEMS mirror is sensitive to fatal shocks. In this situation, the shock influences the MEMS mirror and could disrupt the functionality of the whole LiDAR system. In such a situation, there is only the possibility to restart the transient start-up procedure of the MEMS mirror. The problem in that case is, that during the start-up phase the LiDAR system is not able to recognize any deviations on the street and could cause an accident. Consequently this start-up procedure needs to be as fast as possible to recover safely after a shock in a specific time to mitigate possible accidents.

II. Related Work

MEMS mirrors are already used as optical scanners in different fields to enable a two dimensional movement of a laser [7], [9], [10]. In most applications, the occurance of strong vibrations and their consequences on the MEMS mirrors are neglected because mostly these systems are deployed for non-moving applications such as terahertz wave generators or coherent light sources [10]. In the last years the MEMS mirror technology has been introduced in the automotive domain to enable cheap and robust LiDAR systems for supporting automated driving [8], [11], [12].

A. 1D MEMS Micro-Scanning LiDAR

Druml et al. have introduced a novel 1D MEMS LiDAR concept, as seen in Figure 3. This concept offers a high measurement range, represents a low-cost design is highly robust against shocks and vibrations and provides ASIL-C safety level [8].

The LiDAR system can be operated in open and closed control-loop. Both loops are used to guarantee a robust scan shape. In Figure 4 the direction of the mirror and the related signal states are displayed. The phased-locked loop (PLL) follows the oscillating MEMS mirror and adapts the values of the internal control registers to ensure a correct continous operation [8].

Druml et al. describes that, because of the high Q factor of the mirror, the design is highly robust against external perturbations such as shocks or vibrations [8]. Consequently shocks and vibrations needs to be considered for LiDAR systems in the automotive domain.

B. Vibration Effects on LiDAR systems

The effects of exposed vibrations on LiDAR systems have already been examined for airborne LIDAR systems. Hongchao et al. [13] presented in their results that vibrations could cause positioning errors.

Both paper clearly shows that the effects of vibrations on LiDAR systems should not be neglected in the automotive domain. Automotive vehicles and their components are strongly exposed to vibrations during lifetime through different road conditions. MEMS mirrors are minimized mechanical structures and could be affected by these vibrations.

The automotive domain already considers vibration exposures

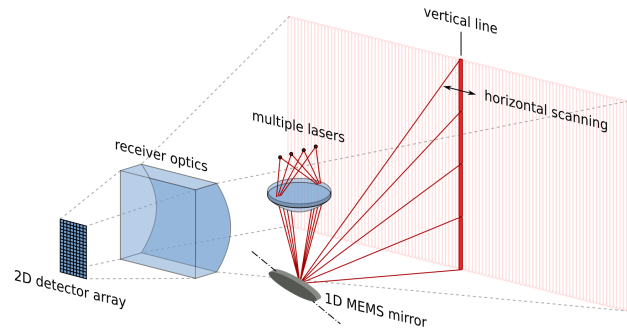

Fig. 3. Concept overview of the 1D MEMS Micro-Scanning LiDAR system of Druml [8].

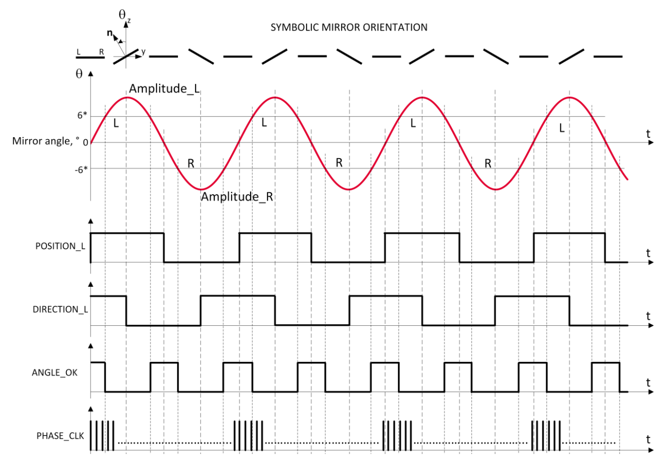

Fig. 4. Signal overview of the 1D MEMS Micro-Scanning LiDAR system of Druml [8].

on mechanical components such as mechanical connectors. For mechanical connectors the automotive domain has developed industrial standards such as “USCAR-2” [14] or “LV 214” [15] that specify certain requirements that must be fullfilled to guarantee safety along appalling road conditions. For MEMS based LiDAR systems, these vibrations could result in an fatal shock that could trigger an immediate stop of the whole LiDAR system. The usual recover-procedure in this case is to restart the whole MEMS mirror.

These circumstances arises several research questions that we are focussing in this paper:

- Is it possible to disrupt the LiDAR MEMS mirror through a fatal shock?
- How long does the state-of-the-art transiert start-up procedure take to recover the MEMS mirror to a certain frequency?
- Could the start-up procedure be accelerated to minimize the recovery time?

III. Speed-Up MEMS Mirror's Start-Up Procedure

In this section we provide system architecture information about the state-of-the-art start-up procedure and our novel approach to speed-up the common start-up procedure. To

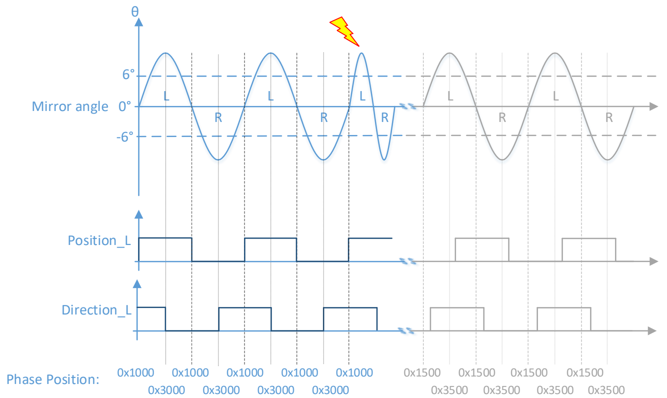

Fig. 5. Concept overview of the impacts of an unintended shock on the LiDAR signals.

clarify the needs of this improvement we firstly describe a case, where the novel 1D MEMS Micro-Scanning LiDAR system by Druml et al. could fail [8].

A. Shock Injection

In Figure 5 the mirror's angle and the related position and direction signal can be seen. The first two cycles are equivalent to the signals of Figure 4. At the beginning of the third cycle a fatal shock occurs and negatively affects the MEMS mirror. This could be seen in a rapidly frequence change of the mirror's angle. First of all, the mirror is possible to recover himself to the previous settled frequency, but the position and the direction signals do not match anymore. In Figure 6 the described worst-case is depicted: a fatal shock causes the PLL to loose its lock. The shock was triggered by a hardware module that simulates the impacts of a fatal shock. The consequences of the shock could be seen through the rapidly increase of the PLL error. The PLL fails and with the PLL the settlement of the control register values. The MEMS mirror is sliding down to a lower frequency due to the PLL that lost its lock. At this state the LiDAR system could not

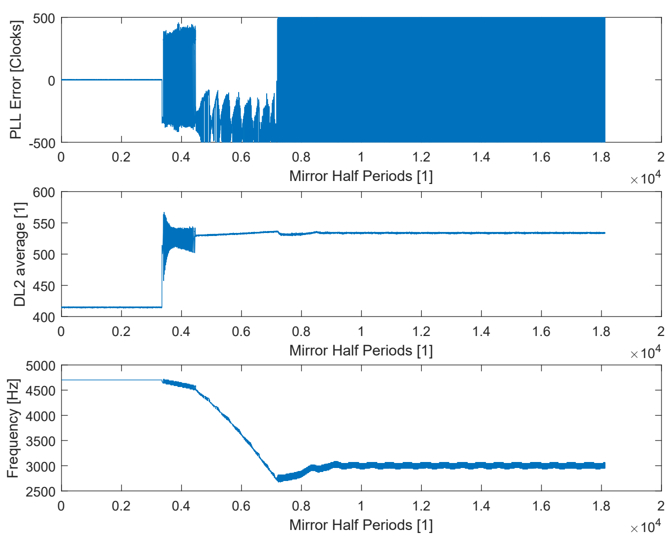

Fig. 6. Measurments and effects of a PLL lock loose, possible triggered by a fatal shock to the LiDAR system.

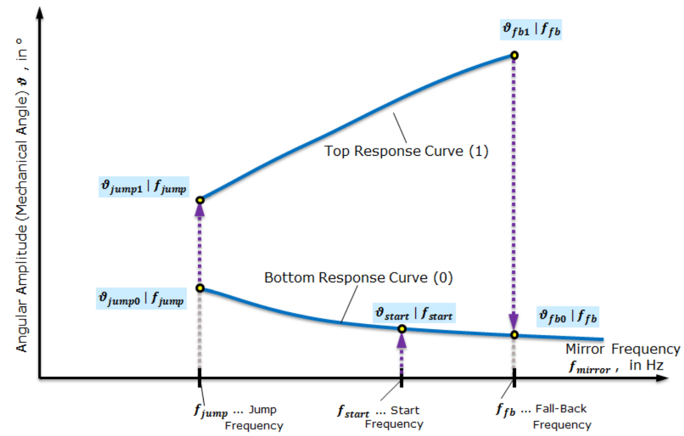

Fig. 7. Overview of both resonance curves of the MEMS mirror [8].

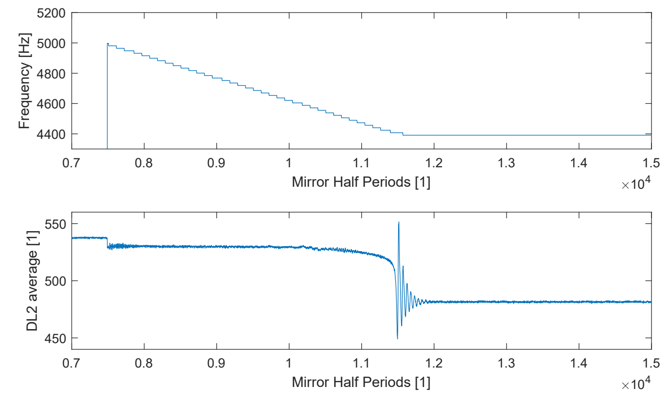

Fig. 8. State-of-the-Art start-up procedure of the 1D MEMS Micro-Scanning LiDAR system.

find back to the previous operating point and recovery is only possible through a MEMS mirror restart.

B. State-of-the-Art Start-Up Procedure

In Figure 8 the transient response of the state-of-the-art start-up procedure can be seen. The mirror provides a top and a bottom resonance curve. The mirror is starting on the lower curve and needs to be driven to the jump frequency. At this jump frequency, the MEMS mirror is jumping on the top response curve [8]. Consequently the start-up routine starts at 5000 Hz and decreases the frequency until the MEMS mirror is jumping onto the top response curve. The response of the top curve can bee seen in Figure 8 at the average mirror current DL2 signal. The conservative start-up procedure needs about 430 ms until the mirror can be used for signal processing. Consequently during this time the LiDAR system has no possibility to send any data to the automated driving signal processing units.

This amount of time would be no problem, if the MEMS mirror would start at engine start and stop at engine off. But there is always the possibility of a fatal shock during run-time, as we have shown in Figure 5 and Figure 6. As a consequence, to ensure safe behavior during run-time this start-up procedure needs to speed-up.

C. *Novel Start-Up Procedure*

To speed-up the start-up procedure it is necessary to set the specific jump frequency. But the jump frequency needs different additional settings such as counter settings of the PLL. These values are MEMS mirror related and vary for each device. In Figure 9 a functional overview of our novel start-up procedure can be seen. At first start-up of the mirror device the specific jump frequency and all related signals need to be found with the help of a calibration procedure. If these values are already saved in the specific registers the MEMS mirror can immediately be forced to this specific frequency. This frequency point will trigger the jump onto the top response curve. The novel start-up procedure can be divided into two logical branches:

1) **Initial Start-Up**
   Jump frequency and related signals are not known and the device is started for the first time.
2) **Continuous Start-Up**
   Jump frequency and related signals are known and saved in the specific registers.

Firstly the MEMS mirror driver is checking if the jump frequency and all related counter signals are set in the specific registers. If not, the "Initial Startup" path will be executed. In this path the state-of-the-art start-up procedure will be executed. When the jump occurs the MEMS mirror driver is saving all related counter parameters into registers. In the next start-ups these values could be used for speeding-up the start-up procedure.

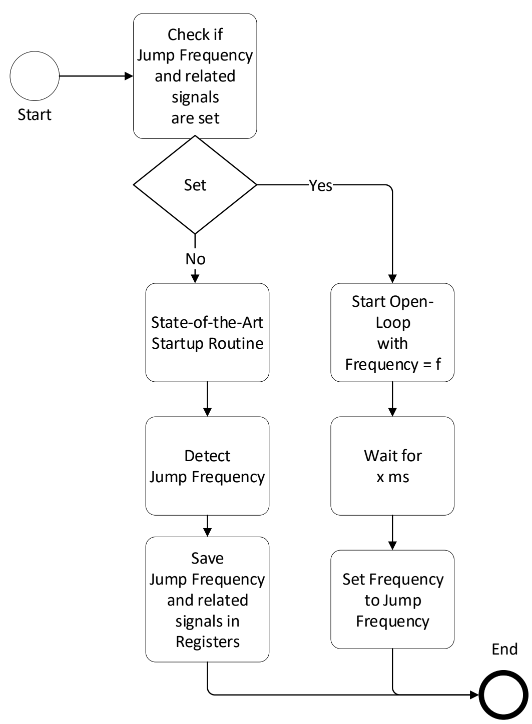

Fig. 9. Functional overview of our novel start-up procedure for speeding up the recovery time.

IV. Results

In this section we provide measurement results of our novel start-up procedure that was introduced in Section III-C.

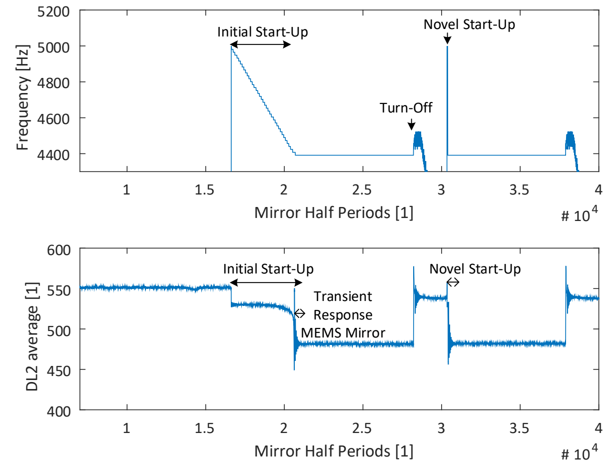

Fig. 10. Initial start-Up measurement of the novel start-up procedure.

In Figure 10 the whole start-up process of our novel start-up procedure can be seen. In the Initial start-up phase the jump frequency and the related signals are not saved in the specific registers. Therefore the MEMS mirror driver triggers the Initial start-up phase. The measurements clearly shows the state-of-the-art start-up procedure. In the next phase the MEMS mirror firstly gets stopped. At the next start-up the MEMS mirror jump frequency and related signals are known and set and the MEMS mirror can immediately jump onto the top resonance curve.

In Figure 11 the magnified Continous start-up phase can be seen. The Continous start-up phase needs about 5.2 ms until the MEMS mirror is ready to proceed.

Figure 12 clearly shows that our novel methodology also works with pre-saved values into the specific registers.

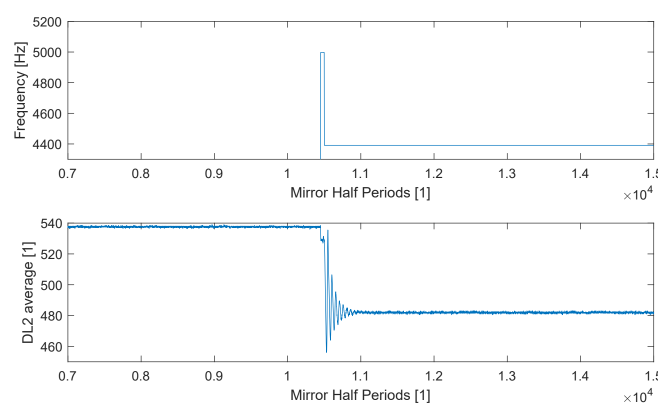

Fig. 11. Magnification of the Continous start-up phase of the novel start-up procedure.

TABLE I
MEASUREMENT RESULTS OF THE STATE-OF-THE-ART START-UP PROCEDURE AND THE NOVEL START-UP PROCEDURE.

	Begin	End	Time in ms
State-of-the-Art Start-Up	11590	7491	426.97
Novel Start-up	25610	25560	5.20

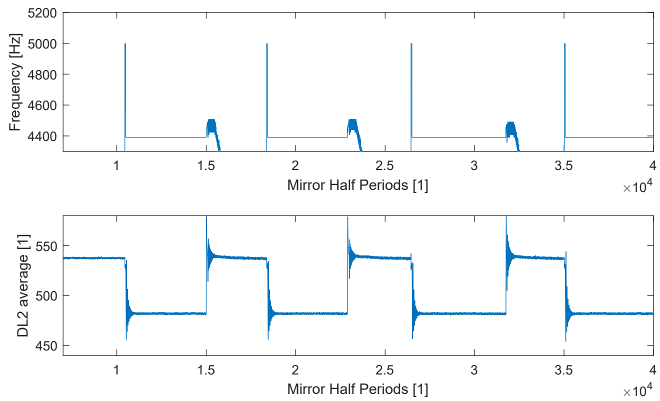

Fig. 12. Novel start-up procedure with pre-saved jump frequency and related signals, including frequent start-stop procedures.

Furthermore Figure 12 proves that it also works for frequent start-stops phases.

V. SUMMARY

In our paper we have introduced a novel start-up procedure for 1D MEMS Micro-Scanning LiDAR systems. The state-of-the-art procedure requires about 430ms until the MEMS mirror is ready to proceed and this is too long for automated driving.

In Section II we have discussed the need of a small recovery time after a fatal shock, probably triggered by appalling road conditions. In Section III-A we have introduced a concept and measurement results, how these shocks will affect the MEMS mirror until the LiDAR system stops working. This result clearly shows that fatal shocks have an impact on the LiDAR system and needs to be mitigated. For this purpose we have designed a novel Start-Up procedure.

In Section III-C we have introduced our novel start-up procedure that is able to shorten the start-up time of the MEMS mirror. In Section IV we have provided measurement results that proves the efficiency of the procedure as well as showing that the start-up phase can be reduced from 430ms to 5.2ms. Furthermore, we have shown that by pre-saving specific signal values into registers this start-up could be speeded up at every start and can also be used for frequent start-stop procedures.

Our novel start-up procedure can be used to quickly recover the MEMS mirror after a fatal shock. With this procedure, the LiDAR system can be recovered in a short time that still ensures safe driving for passangers and road participants.

VI. ACKNOWLEDGMENTS

The authors would like to thank all national funding authorities and the ECSEL Joint Undertaking, which funded the PRYSTINE project under the grant agreement number 783190.

PRYSTINE is funded by the Austrian Federal Ministry of Transport, Innovation and Technology (BMVIT) under the program ”ICT of the Future” between May 2018 and April 2021 (grant number 865310). More information: https://iktderzukunft.at/en/.

REFERENCES

[1] N. Druml, G. Macher, M. Stolz, E. Armengaud, D. Watzenig, C. Steger, T. Herndl, A. Eckel, A. Ryabokon, A. Hoess, S. Kumar, G. Dimitrakopoulos, and H. Roedig, “Prystine - programmable systems for intelligence in automobiles,” 08 2018.

[2] R. Faria, L. Brito, K. Baras, and J. Silva, “Smart mobility: A survey,” in *2017 International Conference on Internet of Things for the Global Community (IoTGC)*, July 2017, pp. 1–8.

[3] W. Pananurak, S. Thanok, and M. Parnichkun, “Adaptive cruise control for an intelligent vehicle,” in *2008 IEEE International Conference on Robotics and Biomimetics*, Feb 2009, pp. 1794–1799.

[4] S. Verghese, “Self-driving cars and lidar,” in *Conference on Lasers and Electro-Optics*. Optical Society of America, 2017, p. AM3A.1.

[5] G. Pennecot, P.-Y. Droz, D. E. Ulrich, D. Gruver, Z. Morriss, and A. Levandowski, “Devices and methods for a rotating lidar platform with a shared transmit/receive path,” Sep. 16 2014, uS Patent 8,836,922.

[6] Muoiod, “Google just made a big move to bring down the cost of self-driving cars,” Jan 2017. [Online]. Available: https://www.businessinsider.de/googles-waymo-reduces-lidar-cost-90-in-effort-to-scale-self-driving-\cars-2017-1?r=US&IR=T

[7] B. Yang, L. Zhou, X. Zhang, S. Koppal, and H. Xie, “A compact mems-based wide-angle optical scanner,” in *2017 International Conference on Optical MEMS and Nanophotonics (OMN)*, Aug 2017, pp. 1–2.

[8] N. Druml, I. Maksymova, T. Thurner, D. Van Lierop, M. Hennecke, and A. Foroutan, “1D MEMS Micro-Scanning LiDAR,” in *Conference on Sensor Device Technologies and Applications (SENSORDEVICES)*, 09 2018.

[9] X. Zhang, L. Zhou, C. Duan, D. Zheng, S. Koppal, Q. Tanguy, and H. Xie, “A wide-angle immersed mems mirror and its application in optical coherence tomography,” in *2016 International Conference on Optical MEMS and Nanophotonics (OMN)*, July 2016, pp. 1–2.

[10] W. M. Zhu, W. Zhang, H. Cai, J. Tamil, B. Liu, T. Bourouina, and A. Q. Liu, “A mems digital mirror for tunable laser wavelength selection,” in *TRANSDUCERS 2009 - 2009 International Solid-State Sensors, Actuators and Microsystems Conference*, June 2009, pp. 2206–2209.

[11] L. Ye, G. Zhang, Z. You, and C. Zhang, “A 2d resonant mems scanner with an ultra-compact wedge-like multiplied angle amplification for miniature lidar application,” in *2016 IEEE SENSORS*, Oct 2016, pp. 1–3.

[12] U. Hofmann, F. Senger, F. Soerensen, V. Stenchly, B. Jensen, and J. Janes, “Biaxial resonant 7mm-mems mirror for automotive lidar application,” in *2012 International Conference on Optical MEMS and Nanophotonics*, Aug 2012, pp. 150–151.

[13] H. Ma and J. Wu, “Analysis of positioning errors caused by platform vibration of airborne lidar system,” in *2012 8th IEEE International Symposium on Instrumentation and Control Technology (ISICT) Proceedings*, July 2012, pp. 257–261.

[14] “Performance specification for automotive electrical connector systems uscar2-4.” [Online]. Available: https://www.sae.org/standards/content/uscar2-4/

[15] “The impact of lv 214-4, the german automotive oem connector test specification.” [Online]. Available: https://www.automationmag.com/education/features/6499-the-impact-of-lv-214-4-the-german-automotive-oem-connector-\test-specification