MFPT 2017 Paper

Health and Usage Monitoring: Critical Components analysis

Ankit Patel and Dr. John M. Lacontora

Abstract:

The following paper is centered on the premise the Intelligent Transportation Systems (ITS), the self-driving automobile and the environment in which it operates will require the automobile to have an on-board Health and Usage Monitoring Systems (HUMS) to operate safely on roadways. HUMS are in their early stages of use to monitor vehicle components and critical structures to prevent routine and catastrophic failures. Vehicle health monitoring, prognostics, diagnostics and condition-based maintenance are the central tenants of a proposed HUMS for autonomous automobiles. Over the past decade, autonomous vehicles have been studied and developed for a real-world application. It is essential to understand the critical assets that need to be monitored in those systems to conduct safe operations in ITS. This paper identifies the components that possibly would be required to monitor and some methods that would be employed to monitor those components.

Keywords: Health and Usage Monitoring Systems, Prognostics, Autonomous Systems, Automobile

Introduction:

Autonomous vehicles are going to be an essential technology of the future. An autonomous car is a vehicle that has the capability to guide itself without direct human interaction. The interest in this technology has been growing in various sectors (academia, industry and government) since 2004. According to Amnon Shashua, chief technology officer of Mobileye, sensing the road, mapping the road, and negotiate your place on road are the vital features required in building an autonomous vehicle. Under which the first feature has matured through the driver assist technology. Whereas, the other two are immensely complicated features that requires time to mature in the right way. In order to achieve these, sensors can be considered as critical assets in this vehicular technology. There are many sensors in an autonomous car, which can be categorized in the following types: Radar technology, Ultrasound technology, Cameras, Navigational aid and LiDAR. This research paper will focus on LiDAR sensor to analyze and monitor its performance through health and usage monitoring.

1.0 <u>Identification of sensors:</u>

In figure 1, a list of possible sensory location is depicted on an autonomous vehicle. This would provide a understanding of possible locations of various sensors on the vehicle. As mentioned previously, there are many sensors on an autonomous vehicle and the figure below groups them under five major groups. First, vision which would comprise of the front camera. Second, Infrared/Thermal sensors followed by third, LiDAR sensor for a 360^0 view. Fourth, Radar sensors and its combination of long and short/midrange specification and finally, fifth, ultrasonic sensors that would work in conjunction with navigation/GPS for accurate position of the vehicle.

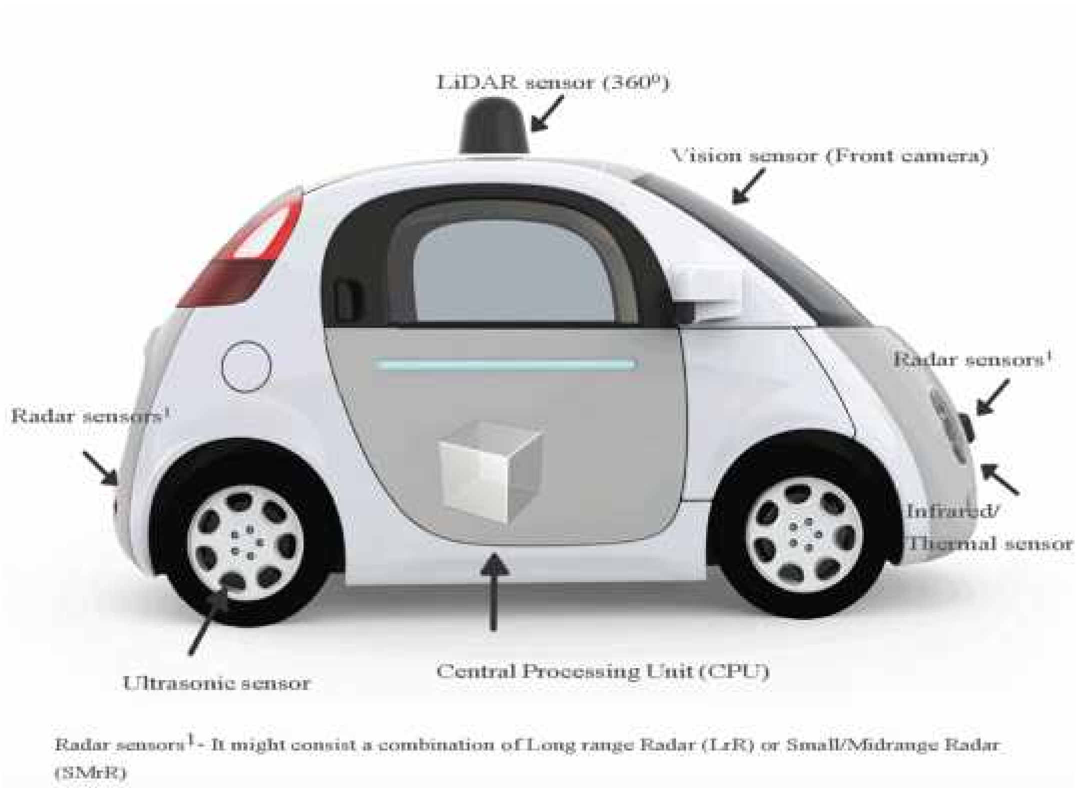


Figure 1 Sensor Identification in an autonomous vehicle

As mentioned above, there are multiple sensors coupled to a Central Processing Unit that enable an autonomous vehicle to operate efficiently. Let us identify and categorize.

1. Radar Technology:

It is primarily used for adaptive cruise control. The microwaves reflected from backside of the vehicles to the front side of the car behind it is used to adjust the speed. This type of technology does not use any satellite based information to set its control laws, it mainly uses on-board systems for processing the data. Co-operative adaptive cruise control

(CACC) on the other hand uses satellite and roadside infrastructure to make a decision about its speed and avoid the obstacle. They can be sub-categorized into Long range (78.6 MHz) and short/midrange (24.6 MHz/76.8 GHz) radars based on their applications.

2. Ultrasonic Sensor:

These sensors are basically used a position estimator for an autonomous vehicle. As mentioned before they work in conjunction with the Global Positioning System (GPS). These GPS's use real time geographical data received from several GPS satellites to calculate longitude, latitude, speed and course to help navigate a car. Eventually using this technology an auto-update feature can be created for the estimating the position of the vehicle in real-time.

3. Vision Sensor (Front cameras):

This technology is mainly used for lane-keeping and back up assistance. Image processing software can detect lane-stripes, signs, stop lights, road signs, and other objects.

4. Infrared/Thermal Sensor:

An autonomous car in the future will be traveling through the densely-populated city streets. This means they would be navigating through the stop signs and pedestrian zebra crossings. With the help of infrared/thermal sensor, there would be an added layer of detection of objects and in the case of thermal sensors for living beings.

5. LiDAR:

One of the most integral, expensive, and noticeable pieces of equipment found in an autonomous vehicle is the roof-mounted device called LiDAR, which stands for Light Detection and Ranging, is a remote-sensing technology that measures and maps the distance to targets, as well as other property characteristics of objects in its path. LiDAR essentially maps its surroundings by illuminating its targets with laser light and then analyzing that light to create a high-resolution digital image.
Google's autonomous vehicle research project uses a spinning range-finding unit, it has 64 lasers and receivers. The device creates detailed map of the car's surrounding as it moves. Software adds information from other sensors and compares the map with existing maps and notifies any differences [1].

Eventually all the data generated from these sensors would be complied in the Central Processing Unit (CPU). It would also be accountable for adjusting the vehicle dynamic functions such as steering, acceleration, braking and so on. Along with all of these various functionalities, it would also help AV in understanding the traffic laws with the help of certain control applications.

After understanding the sensor functionalities, it is vital to keep ourselves informed about how these sensors (or 5 major types in our case) would be applied or match to the new and upcoming or in some cases already existing technology (in regular cars) in comparison with the AV's. Knowing about these applications would help us evaluate the health of the sensor based on the all of the factors that could possibly work against it. Table 1, is one of many attempts towards the comparison of sensors and its applications.

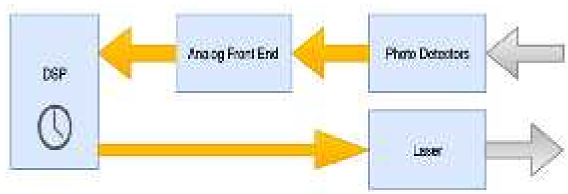
Table 1 Sensors and its relative applications

Sensors /Application	Vision sensor (Front Camera)	Infrared/Thermal sensor	Long Range Radar	Short/Midrange Radar	LiDAR sensor
Adaptive Front Lighting (AFL)	X				X
Traffic Sign Recognition	X	X			X
Night Vision	X				X
Lane Departure Warning	X				X
Adaptive Cruise Control (ACC)	X		X	X	X
Emergency Brake Assist	X			X	X
Pedestrian detection	X	X		X	X
Blind Spot Detection	X			X	X
Rear Collision Warning	X			X	X
Park Assist	X			X	X
Camera Monitor System	X				X

2.0 Reporting of sensor:

As stated earlier, we are going to focus on a few LiDAR technology sensors as they are one of the most critical components in the functioning of an AV as seen in table 1. This section will focus on what they are and how they can be monitored to understand the sensors health and overall safety of the AV from LiDAR perspective.

2.1 LiDAR sensors: LiDAR technology is a combination of various functionalities such as optics, mechanics, analog front end and digital processing. The LiDAR emits a laser light which in return enables the stop watch. The light propagates and eventually diverges with an object, some of it scatters while few photons return back to the photo detector. The analog and digital chain then sense that a pulse is received and the disable the stop watch. Simply using the Distance = speed x time, formula the range of the object can be determined. In this technology, timing accuracy to carry out this operation is essential. According to Daniel Rosenband, in the Hot Chips 2016 conference, for every millimeter of precession that you give up that is equal to 60 picoseconds. So, if you want 1 centimeter of accuracy that is 60 picoseconds that you need of the timing control. In most common cases, Time Of Flight (TOF) is used to determine the range.



Transmittance and reflectance parameters are usually imposed by the application. Design flexibility resides mainly in the selection of the laser source (power) and the receiver (sensitivity). The accuracy of TOF measurements depends on the pulse width of the laser and the speed and accuracy of the analog to digital converter (ADC) used. As seen in Figure 2, the factors affecting while finding the distance between two objects or its range gets its input from the light pulses detected by the photo detector and eventually implementing a range finding algorithm to determine the distance once the signal processing has been achieved through the combination of ADC and DSP. This range could be given by this formula as follows [2], it

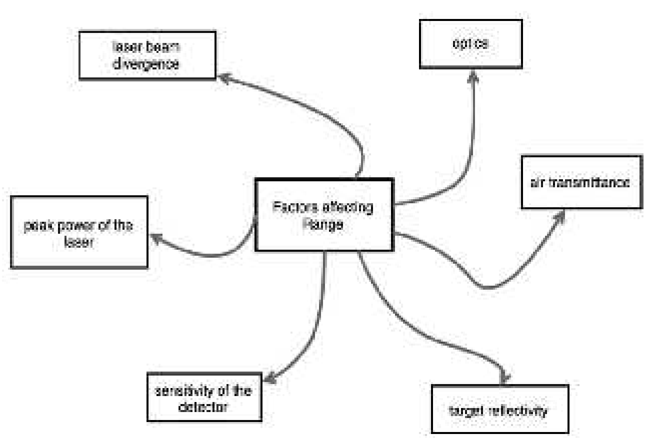


Figure 3 Mind Map for factors affecting while finding the distance between objects

presents the range of the semiconductor pulsed laser based on its power in Watts and atmospheric conditions:

$$R \quad , R_S = \sqrt{\frac{L_P * R_A * T_A * T_O}{S_D * P * B}}$$

here, $L_P = L \quad P$

$R_A = R \quad O \quad A \quad (l \quad o \quad m \quad)$

$T_A = T \quad o \ the\ at \quad he$

$T_O = T \quad o \ the\ o$

$S_D = D \quad S$

$B = B \quad d \quad in\ R$

The equation mentioned above can be used in a range identifying technique given by a flow chart below. The important things to make a note of are the use of Kalman filters and applying the on-board health and usage monitoring systems (HUMS) to understand the process efficiently.

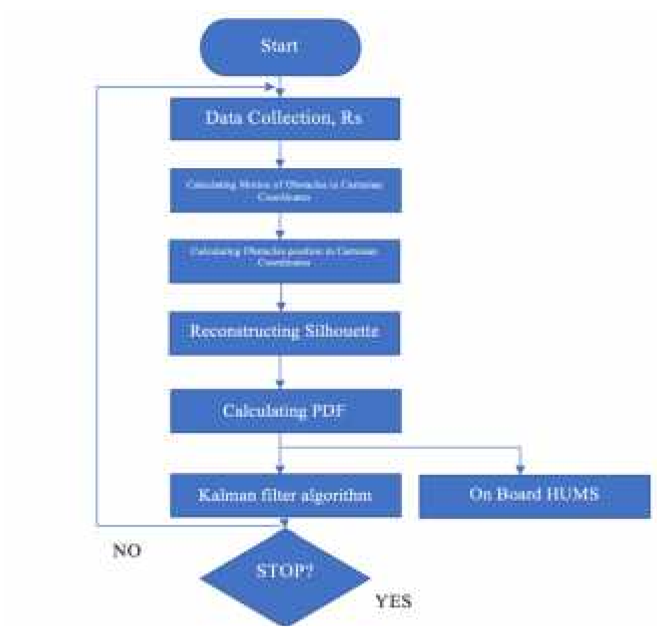


Figure 4 Flowchart for LiDAR sensor process flow and on-board HUMS application

Kalman filters algorithm is being used to transform the obstacle position from Cartesian co-ordinates to global coordinates for ease of use. Since, a Kalman filter can estimate a state of a linear system by using observation data online, this approach will not only transform the coordinates efficiently, but also enhance the accuracy of the obstacle position and motion detection. In this case, Kalman filter-based coordinates transformation algorithm consists of a system equation and an observation equation reported from the LiDAR sensor. On the other hand, the on-board HUMS system has the digital communication capability with possible options of USB, LAN, Ethernet ports [3] for data analysis and a possible sensor health management.

3.0 Sensor Fault Analysis:

The sensor groups mentioned above would be required to do certain tasks and comply with the performance standards set by their manufacturers. As we see, these sensors play an integral part in the functioning of an autonomous vehicle and monitoring them can be considered of utmost importance. Bad sensor readings can lead to catastrophic events on the roads. There are many factors/variables that would affect the sensor readings and eventually the health and operation of that specific sensor. Let us focus on LiDAR sensors and its performance criteria's. The performance of a LiDAR sensor can be judged by the following: (1) Range Specification (the maximum range at which it can see a target of a specified size). (2) Accuracy (the accuracy of its measurement of target location in range and angle). (3) Distinguishing ability (its ability of distinguish two or more target). (4) Form recognition (its ability of recognize form of the target). (5) Overall functionality (availability, reliability and maintainability).

The sensors can be evaluated on the basis of the fault modes it undergoes. There are various behavioral criteria's available for monitoring the sensor and its performance [5]. They are as follows: *Bias:* A constant offset from the nominal statistics of the sensor signal, *Drift:* A time varying offset from the nominal statistics of the sensor signal, *Scaling (or gain failure):* Magnitudes are scaled by a factor α(t) where the form of the waveform itself does not change, Noise: A random time series is observed, *Hard Fault:* The sensor output is stuck at a particular level expressed by $Y_f = C + noise$, where C is a constant, *Intermittent:* Deviations from normal readings appear and disappear several times from the sensor signal.

Based on these behavioral criteria's a decision matrix comparing the former with the specific sensors performance specifications. The purpose of this matrix would help HUMS to trigger its prognostics application to further determine sensors remaining useful life and the confidence interval of those predictions. The scoring in this matrix can be conducted through self-diagnostics capability of the system.

Table 2 Sensor performance decision matrix

Radar Sensor Performance Matrix	Range Specification *(Score 1 - 10) 10 being severe*	Accuracy *(Score 1 - 10) 10 being severe*	Distinguishing ability *(Score 1 - 10) 10 being severe*	Form Recognition *(Score 1 - 10) 10 being severe*	Overall Functionality *(Score 1 - 10) 10 being severe*
Bias					
Drift					
Scaling					
Hard Fault					
Intermittent					

Based on the scoring there would be signal generated on the severity of the fault and enable the prognostic algorithm in HUMS application for further evaluation. In order to imply these algorithm, it is of importance to understand how and what the sensor reports to the system which will be covered in the upcoming section.

4.0 Sensor Health:

Monitoring a system is certainly more than just data collection. The methodology for determining critical components, or sensors in this case, can be seen in figure 4 below [4].

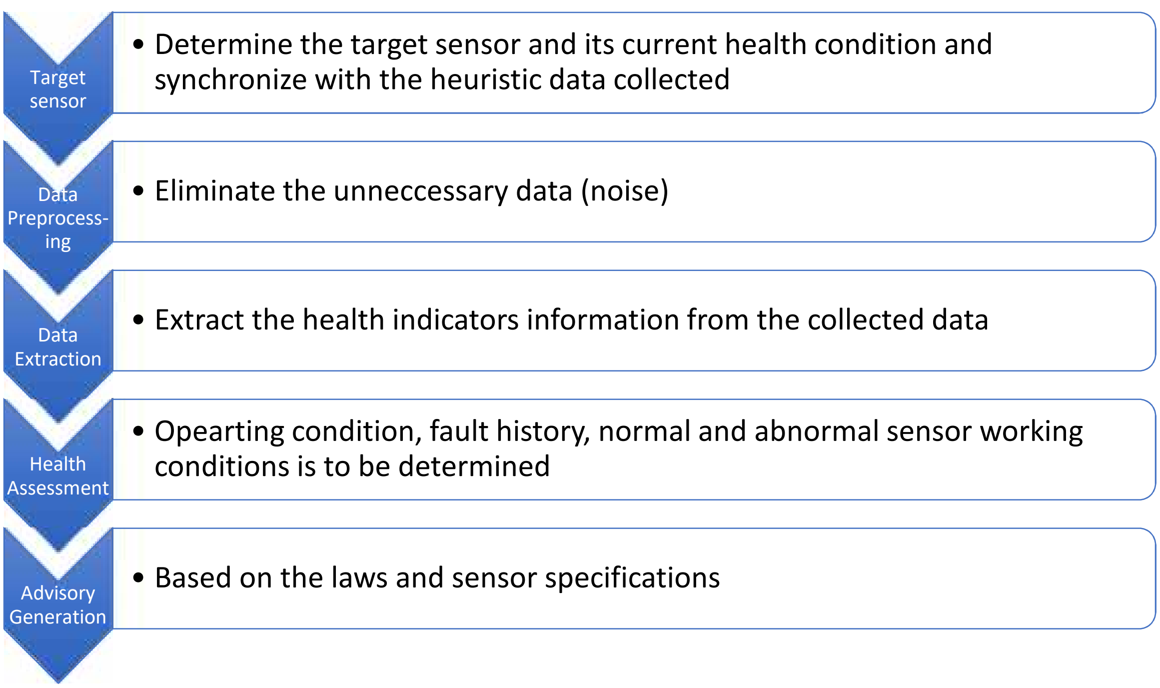


Figure 3 Health assessment for a critical sensor

As seen in the figure above, confidence intervals can be calculated. By determining the remaining useful life and trend of confidence intervals, the likelihood of failure in the near future can be estimated.

5.0 <u>Conclusion:</u>

As autonomous vehicles become more prevalent on our roadways the sensors that make them possible are at the keystone of their success or failure. The technology is expected to reach SAE level-5 by year 2021 and being promised by some automotive giants. Thus, the development of sensors and the on-board intelligence also needs to keep pace of AV implementation timelines. Understanding and maintain the sensor information and health is soon going to be a quintessential step in this process. As described in this paper, the process of determining the critical sensors, their functionalities and eventually their health will be of utmost importance in the upcoming years. This being said, it leaves us with a few questions:

1. How important is it for us to understand the health of all critical sensors in an autonomous vehicle while it is in operation?
2. How to tackle the understanding the current and future state of sensors with multiple variables for prognostics analysis?
3. How efficient are current algorithms in analyzing components and how reliable are the solutions?

6.0 <u>Future Work:</u>

To successfully create a functioning HUMS system for autonomous vehicle application, much more work is needed. As mentioned earlier, FMEA and FTA will need to be carried out for each autonomous vehicle model, and for the generic automated automobile as well, in order to pin-point the components and elements in a vehicle that require HUMS application. Following that, descriptive and precise mathematical models need to be developed that are capable of representing the founded failure mode and a mechanism will need to be developed to accurately interpret inputs from the system of sensors for autonomous vehicles in order to comply with SAE level-5. Even more mathematical models will need to be developed and tested for analyzing the data from HUMS and deriving practical insights to help predict the behavior of the components and to establish maintenance plans.

Reference:

1. "Technology and Costs." Google's Autonomous Vehicle. N.p., n.d. Web. 4 Aug. 2016.
2. McCormack, P. (2011). *LIDAR System Design for Automotive/ Industrial/Military Applications* (Literature Number: SNAA123). Texas Instruments.
3. Honeywell Aerospace. (2016). *ONBOARD VIBRATION MONITORING SYSTEM/HUMS* (N61-1549-000-000 I 04/16).
4. Advantech eAutomation. (n.d.). Smart Sensor and Prognostics for Self-Maintenance Machines.
5. D. C. Zimmerman, and T. L. Lyde, "Sensor failure detection and isolation in flexible structures using the eigensystem realization algorithm," in 33rd Structural Dynamics and Materials Conference, Dallas, TX, 1992, pp. 2156-2166.