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Autonomous Driving Sensor Technology LiDAR Data Processing System: Patent Document Analysis

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ABSTRACT

The Internet of Things (IoT) is the upcoming game changer of the coming decade. Each and every objects will go smart and autonomous with the development of IoT technologies. The adoption of IoT in almost every industries is happening in a fast pace with the help of smart sensors, highly sophisticated software/ algorithms with or without artificial intelligence (AI). Examining the various industries, automotive industry can be considered one of the early adopters of internet of things (IoT). Incorporating smart features to vehicles to making them fully autonomous has been the research motive of the automotive industry for years. Patent protection, being one of the strong factors in innovation cycle of technologies, is one main element to be considered. How far patent system affects innovation is a major question of the era, which can only be answered by analysing the patent applications of respective technologies and tracking their patent status.

In this paper, we shall examine one of the main component of autonomous vehicle, the light detection and ranging (LiDAR) systems, which is crucial for autonomous vehicles in the environment understanding and decision making. Analysis of patent applications of LiDAR systems and their statuses can be helpful in the analysis of whether the development of that technology is enhanced with the patent protection or whether it leads to hindering of research and development in that area.

Keywords: *Patent, Patent Analysis, Internet of Things (IoT), Autonomous vehicles, Light Detection and Ranging, LiDAR.*

I. INTRODUCTION

Light detection and ranging (LiDAR) sensors have become one of the crucial enabler of internet of automotive (IoA) with its very unique capability to produce accurate three-dimensional scanning of the environment of the vehicle. As the smooth working of an

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autonomous vehicle need real- time scanning of the environment of the vehicle, the innovations taking place in the LiDAR technology to make it compatible for roads has grown in a steady rate. This is evident from the huge number of patent applications piling up in patent offices all over the world.

Innovations in hardware as well as software relating to it are taking place in a rapid pace. Since the implementation of internet of things needs connectivity of a number of objects and parameters, software innovations play a key role in this realm. Data processing, decision making, communication etc requires a strong software support. This varies from application to application and situation to situation. Since the technology is very much dependent of software and we could say the development of technologies happening now a day is software driven, patenting of such technologies have become hot topic for discussion. How far the hardware-software innovations are to be dealt under the patent regime is an important question to be looked into.

In case of autonomous cars, LiDAR being the major environment scanning sensor that plays a crucial role in real- time imaging of the environment, how far software driven innovation is helping the technology is a major aspect to look into.

In this paper we shall look into patent documents dealing with LiDAR optical analysing system for data processing, which is the LiDAR computer. We shall look into certain granted patents from different jurisdictions to study the nature of patenting and an analysis of such patents can be done. Then, we shall study some recent patent applications in this category filed in various jurisdictions to understand the recent technology and trends of patenting.

II. PATENT DOCUMENTS

(A) Improvements in LiDARS

This is a patent application filed through PCT[2] in 17/04/2009 and has priority date 18/04/2008. It was published in 2009. It was filed by BAE Systems PLC. It was granted in EU in 29/11/2013.[3]

This falls under one of the first types of automotive LiDARs which are kind of primitive types of lidar. This patent covers apparatus and method of operation of a lidar device having a rotatable light source. Here a light source capable to emit partially rotatable light at certain angular intervals; reflection means with clear indication of focal point angles; reception means

[2] WO2009136184
[3] IPC- G01S 17/42, G01S 7/481, G01S 13/93.
CPC- G08G 1/16, G01C 3/08, G01S 7/4814, G01S 17/42, G01S 2013/9375

for receiving the reflected light and analysis means for calculating the position based on angles and time delay of reception are the major claims involved. The invention covers use of single and array of mirrors for reflection. The shape of the beams according to this and reflection which is parabolic is also claimed. Analysis is calculation in Cartesian coordinate system and includes intercept point calculation, with respect to the transmitted and reflected axes.[4]

In the patent application filed in the European Union[5], much more clear claims can be seen. Here a parabolic mirror having a focal point, its position, angular range of the light falling is clearly given in claim. Also apart from using the Cartesian coordinate system for calculation means, the condition at which Polar coordinate system based calculation possible is also clearly specified in the major claim.[6]

Looking into the prior art cited, it points to a patent document filed in 1989 which is a three dimensional image analyzing device which makes use of X, Y and Z axes for the analysis of an object using laser irradiation and a camera is mentioned.[7] Another patent application filed in 1992, a collision avoidance system used in a vehicle is mentioned.[8] It comprises of range finder scanner means mounted on a vehicle. It has a processor for tracking the range and angle of the target inorder to find the velocity and acceleration of the target, to predict the separation distance of the target. This may be considered as the closest prior art. The calculation means for the patent document under consideration has a clear inventive step and shows better

[4] 1. A Light Detection and Ranging (LIDAR) apparatus comprising: a light source means enabled to emit a light ray and arranged such that the light ray is at least partially rotatable about a rotational centre, the light ray being emitted at a plurality of angular intervals; reflection means having a focal point, the reflection means positioned such that the rotational centre of the light ray is substantionally located at the focal point and between a first angle and a second angle, reception means for receiving reflected light from one or more features in the path of the light ray; and analysis means for calculating a position at which one or more features are present based on the angle that the light ray was emitted and the time delay associated with the received reflected light, wherein, when the light ray is emitted between the first and second angles, the analysis means takes into account the reflection of the light ray from the reflection means.

[5] EP2291677

[6] 1. A Light Detection and Ranging (LIDAR) apparatus (10) comprising:
a light source means (12) enabled to emit a light ray (C_1 to C_8 and P_1 to P_{15}) and arranged such that the light ray is rotatable through 360° about a rotational centre, the light ray being emitted at a plurality of angular intervals;
a parabolic mirror (14) having a focal point, the parabolic mirror being positioned such that the rotational centre of the light ray is substantially located at the focal point and the parabolic mirror falls within an angular range of less than 180°, and the successive emitted light rays (C_1 to C_8) once reflected from the parabolic mirror (14) follow a substantially parallel path,
reception means (12) for receiving reflected light from one or more features in the path of the light ray; and
analysis means (16) for calculating a position at which one or more features are present based on the angle at which the light ray was emitted and the time delay associated with the received reflected light, wherein, when the light ray is reflected by the parabolic mirror, the analysis means takes into account the parabolic mirror reflection and the position of the or each feature is calculated using a Cartesian coordinate system having a reference point at the focal point and wherein when the light ray is emitted at an angle such that the light ray is not reflected by the parabolic mirror the analysis means is capable of calculating a polar coordinate position for any feature which reflects light from the light ray.

[7] JPH01161107- Three-dimensional image analyzing device

[8] EP0473866-Collision avoidance system

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improvement in calculation than its prior art.

(B) System and method for multipurpose traffic detection and characterization

This is a patent application filed through PCT[9] in 01/03/2013 by Leddartech Inc.[10] This was published in 06/09/2013. In US it was granted in 12/01/2016 and in EU in 13/04/2017.

It consists of a method for tracking and characterizing a plurality of vehicles simultaneously in a traffic control environment. The major claims include providing an optical emitter, optical receiver, receiving the backscattered reflection in the 3D detection zone acquiring a digital full waveform for each detection channel. It is with this digital waveform the presence of plurality of vehicles is detected. The major claim also includes assigning a unique identifier to each vehicle detected. The process of finding this is repeated at certain predetermined frequency, updated position of each vehicle is tracked and recorded.

In the corresponding US patent application[11], apart from the above claims some software aspects like extracting observations in the individual digital full-waveform LIDAR trace; using the location for the observations to remove observations coming from a surrounding environment; extracting lines using an estimate line and a covariance matrix using polar coordinates; removing observations located on lines parallel to the x axis are also claimed as major claims. This purely comes under the algorithms or instructions.

In the patent filed in EU[12], the claims have become more specific and narrow. Here the optical receiver's orientation is clearly specified. Also emitted light waves characteristics are mentioned in the major claim. Also the polar coordinates and underlying equation or situation of extraction is also clearly mentioned.

The closest prior art refer to a patent document filed in 2010 which contains a method for detecting the presence of an object in a detection zone.[13] Here also an emitting module emits pulses and a receiving module receives part of pulses and an image sensing module provides an image of the object by detecting a signal echo in digital waveforms obtained. Here detection location of object is only possible. Updates of position of a moving object cannot be found, which is possible in the principal invention.

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[9] WO2013128427

[10] IPC- *G08G 1/04* (2006.01) ,*G01S 17/88* (2006.01) ,*G08G 1/017* (2006.01) ,*G08G 1/052* (2006.01) ,*G01S 17/06* (2006.01) ,*G01S 7/484*(2006.01)

[11] US20140159925
Grant Number- 09235988
IPC- G08G 1/01, G08G 1/065, G01S 17/58, G01S 17/66, G01S 17/88, G01S 17/89, G01S 7/48, G01S 7/484,, G08G 1/04, G06K 9/00, G08G 1/015, G08G 1/017, G08G 1/054, G06K 9/32, G06T 7/20, G01S 17/02

[12] EP2820632

[13] WO2011077400- Active 3D monitoring system for traffic detection

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(C) Method for localizing a vehicle equipped with two LiDAR systems

This patent application was filed through PCT in 02/04/2013 by Oxford University Innovation Limited and published in 10/10/2013.[14] In US it was granted in 17/04/2018 and in EU in 12/10/2018.

Here a method for localising transportable apparatus within an environment using data obtained from two ranging devices being patented. Here method of receiving data from a first ranging sensor which collects information relating to a 2D representation of environment; and receiving data from a second ranging sensor which collects surface over which the transportable apparatus is moving and use this data to estimate the linear and rotational velocities of the transportable apparatus which is the vehicle itself. Using these data a 3D point cloud of the environment is generated. This is compared with existing 3D point cloud to determine the environment of the vehicle. These are included in the major claims.[15] Here computing method is claimed as minor claims they mostly include equations, instructions or algorithms. This includes, generating a probability distribution representing the new point cloud; generating a probability distribution representing the existing point cloud; comparing the new point cloud probability distribution with the existing point cloud probability distribution. Here the comparing step involves computing a Kullback-Leibler divergence value between the new point cloud probability distribution and the existing point cloud probability distribution.

[14] WO2013150286
!PC- *G01S 17/87* (2006.01) ,*G01S 17/58* (2006.01) ,*G01S 7/48* (2006.01) ,*G01S 17/89* (2006.01) ,*G06T 7/00* (2006.01) ,*G01C 21/00*(2006.01)

[15]1. A method of localising transportable apparatus within an environment, the method including:
receiving data obtained from a first ranging sensor device of the transportable apparatus configured to collect information relating to a 2D representation of an environment through which the transportable device is moving;
receiving data obtained from a second ranging sensor device of the transportable apparatus configured to collect information relating to at least a surface over which the transportable apparatus is moving in the environment;
using the second ranging sensor device data to estimate linear and rotational velocities of the transportable apparatus moving through the environment;
using the estimated linear and rotational velocities with the first ranging sensor device data to generate a new 3D point cloud of the environment;
obtaining data representing an existing 3D point cloud, and
seeking to match the new 3D point cloud with, or within, the existing 3D point cloud in order to localise the transportable apparatus with respect to the existing point cloud.

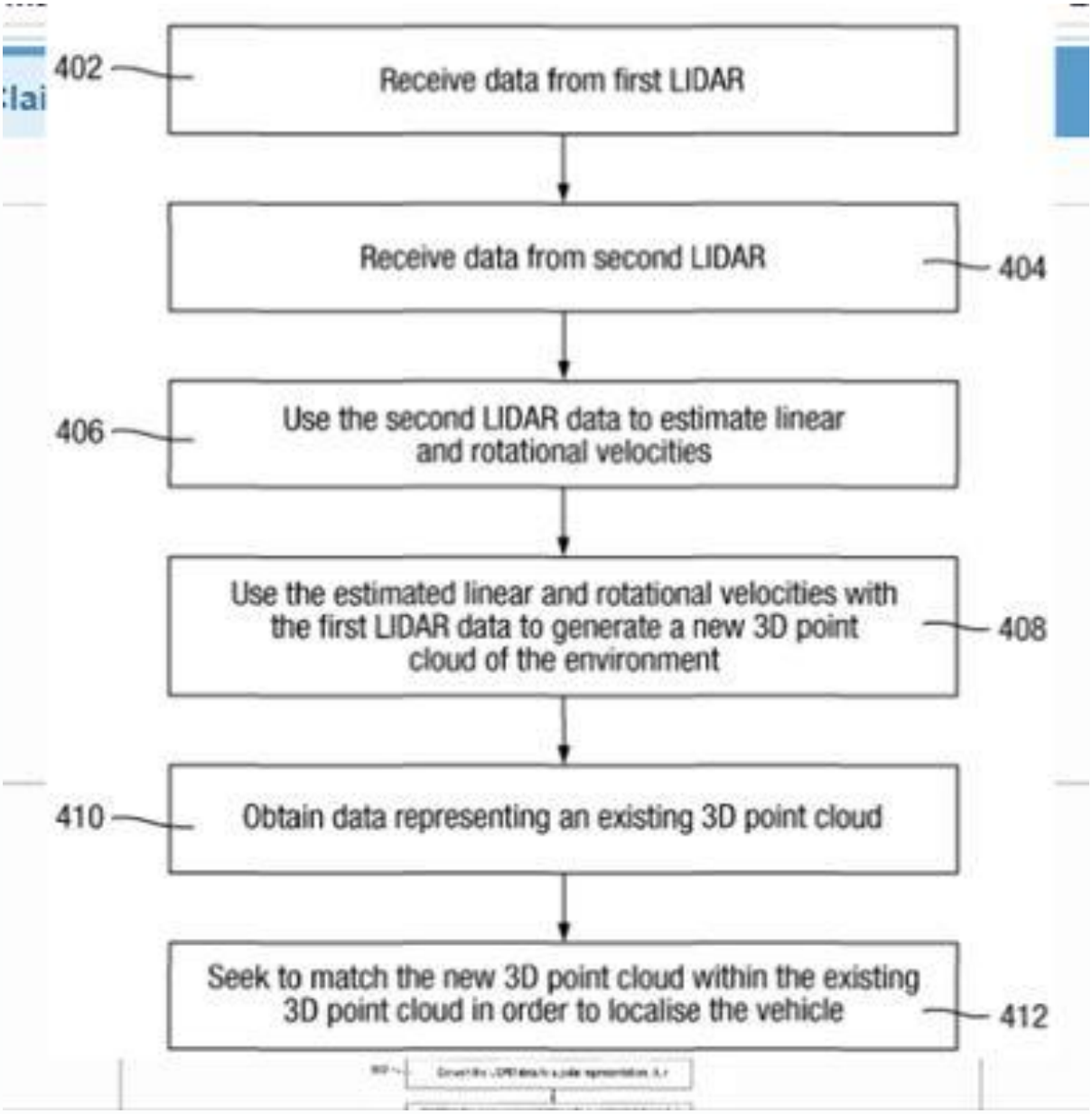

Figure 1. Flowchart showing example steps performed by the the processor

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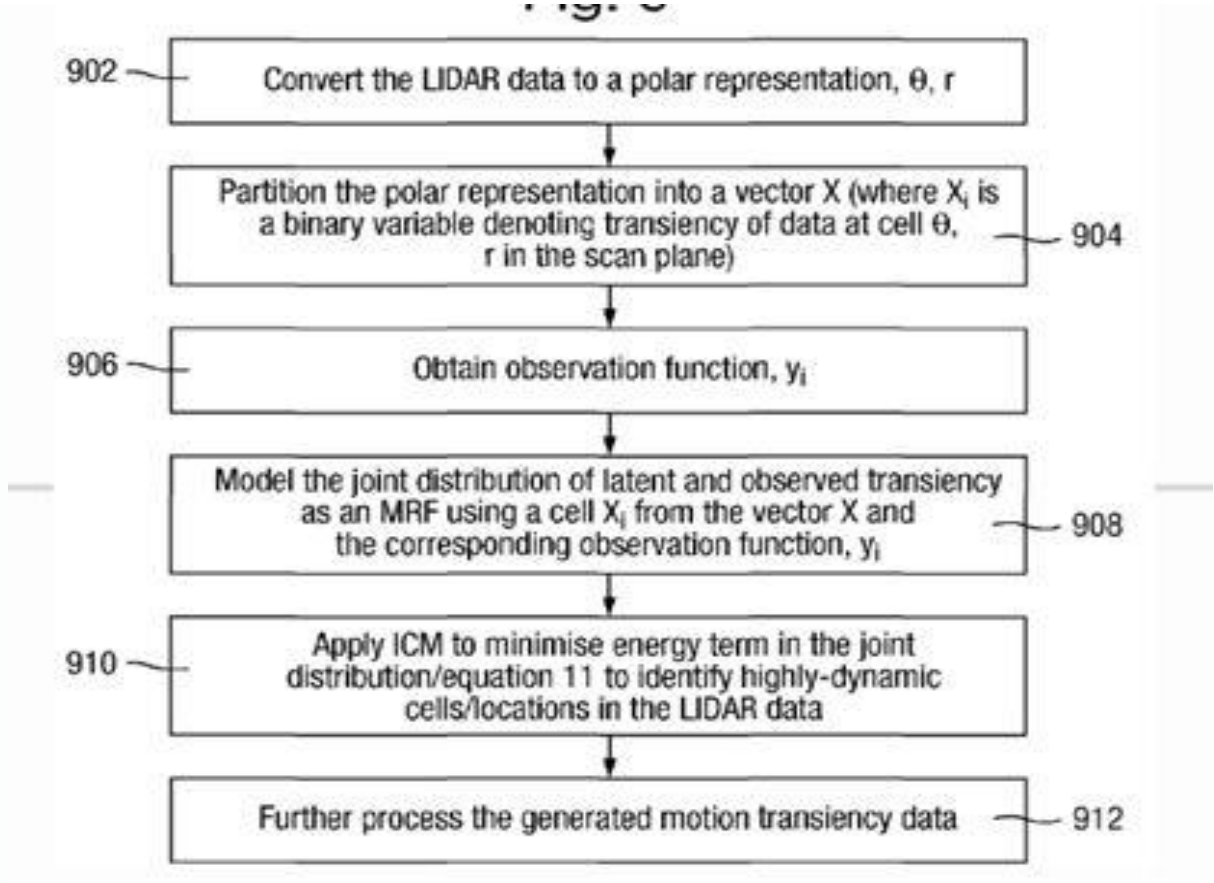

Figure 2. Flowchart showing example steps performed the processor in some embodiments in order to improve velocity estimation

Exact similar claims are given in the US[16] and EU[17] patent applications

The prior art includes a US patent of Self positioning device and method thereof where a sel-localising device is patented.[18] The major claims include a laser image taking device on a movable carrier taking i-th lot point data in space at time ti when the carrier moves. Here a processor controls the laser image device and the receiving coordinates. The processor executes a K-D tree algorithm to perform comparison of image in ti times to establish a two dimensional image profile. The principal patent document produces three- dimensional images of the environment while the prio- art produces only two- dimensional images of the environment.

(D) Vehicle with multiple light detection and ranging devices (LiDARs)

This is a PCT patent application filed in 24/02/2016 by Waymo LCC and published in 29/06/2016.[19] In US it is granted in 18/04/2017 and in other jurisdictions examination process

[16] US20150331111
Grant Number- 09945950
[17] EP2834668
[18] US2011097014- Self-positioning device and method thereof
[19] WO2016153687

is going on.

This patent application includes a vehicle equipped with multiple light detection and ranging devices. Here the major claims includes a first lidar and a second lidar to do the scanning purposes; and a controller configured to operate the vehicle based on the scans of the environment by the first LIDAR and the second LIDAR.

In the Australian patent filed in 2016[20] and in the US patent application[21], major claim also includes that the controller is configured to adjust the viewing direction of the second LIDAR based on data received from the first LIDAR. Later in 2018, a more specific patent application was filed in Australia which includes the functioning of the controller that tracks an object in the environment using: the first LIDAR, in response to the object being within a threshold distance to the vehicle, wherein the threshold distance is based on the first scanning resolution, and the second LIDAR, in response to the object being at greater than the threshold distance to the vehicle. This was actually claimed as minor claim in other patent applications even in US. This invention purely works on the 'threshold distance' criteria which is not claimed as major claims in other jurisdictions. The whole invention works only when the threshold criterion is reached. The below flowchart clearly explains it. And this is achieved through algorithms only. The flowcharts in the patent application actually intend to cover these algorithms. In effect the algorithms perform the innovation in the system and this is what that seek patent protection.

[20] AU2016236026
[21] US20160282468

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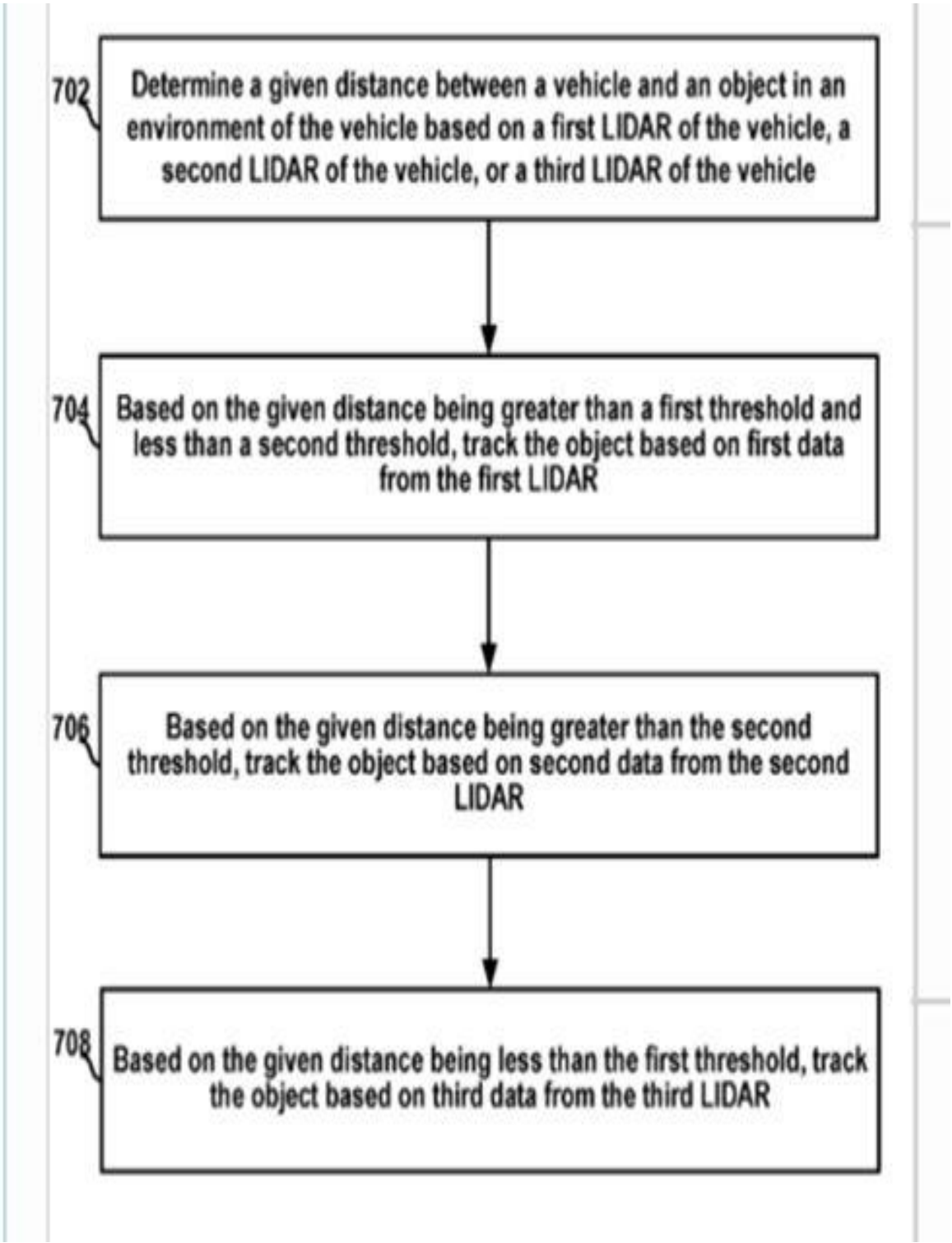

Figure 3. A flow chart of a method according to an example embodiment

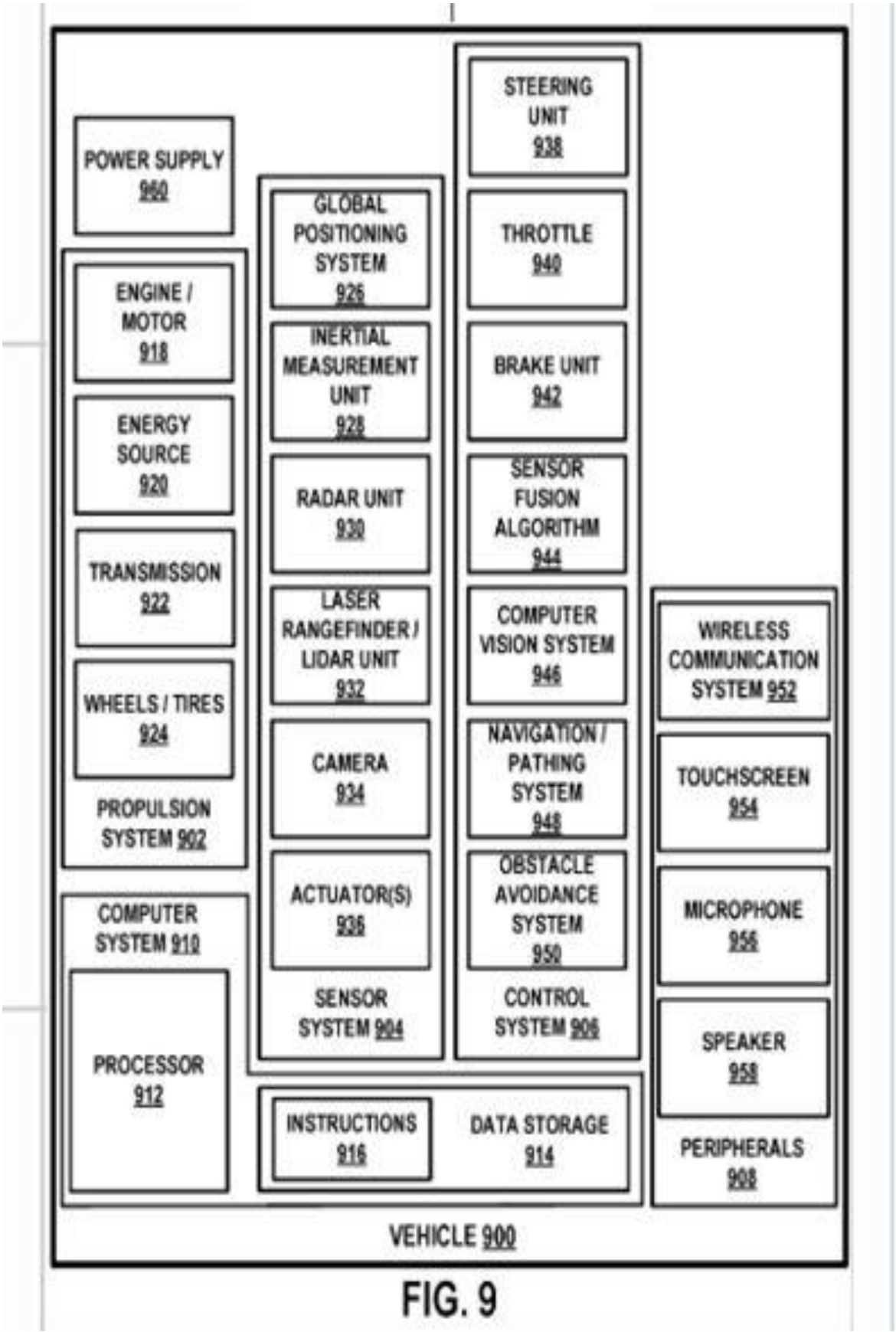

Figure 4. A simplified block diagram of a vehicle, according to an example embodiment.

(E) System and methods for using dissimilar LiDAR technologies

This patent application was filed in US in 03/11/2016 and European Patent Office in 27/10/2017 by Honeywell International Inc. It was published in 09/05/2018 in EU.

This application deals with systems and methods for using dissimilar LiDAR technologies. The major claims include one or more LiDAR optical modules to provide data of environment and one or more processing units to process data provided by the optical modules. The one or more processing units produces a plurality of similar LIDAR measurements, wherein the plurality of similar LIDAR measurements were produced using at least one of dissimilar processing and LIDAR optical modules.

The processing is done in such a way that providing the data to one or more processing units configured to process the data produced by the one or more LIDAR optical modules, wherein the one or more processing units produces a plurality of similar LIDAR measurements, wherein the plurality of similar LIDAR measurements were produced using at least one of dissimilar processing and LIDAR optical modules. A data bus coupled to the one or more processing units, wherein the pluralities of dissimilar LIDAR measurements are provided to other computation systems through the data bus.

Referring to the prior art, a US patent in 2011 uses a Doppler signal processor, wherein an output from sensors included in the optical autocovariance receiver is provided to the Doppler signal processor.[22] Another US patent uses a central data processing electronics[23] which is less efficient than the principal patent making use of more than one processing units.

[22] US8077294 (B1)- Optical autocovariance lidar
[23] US2015192677 (A1)- Distributed lidar sensing system for wide field of view three dimensional mapping and method of using same

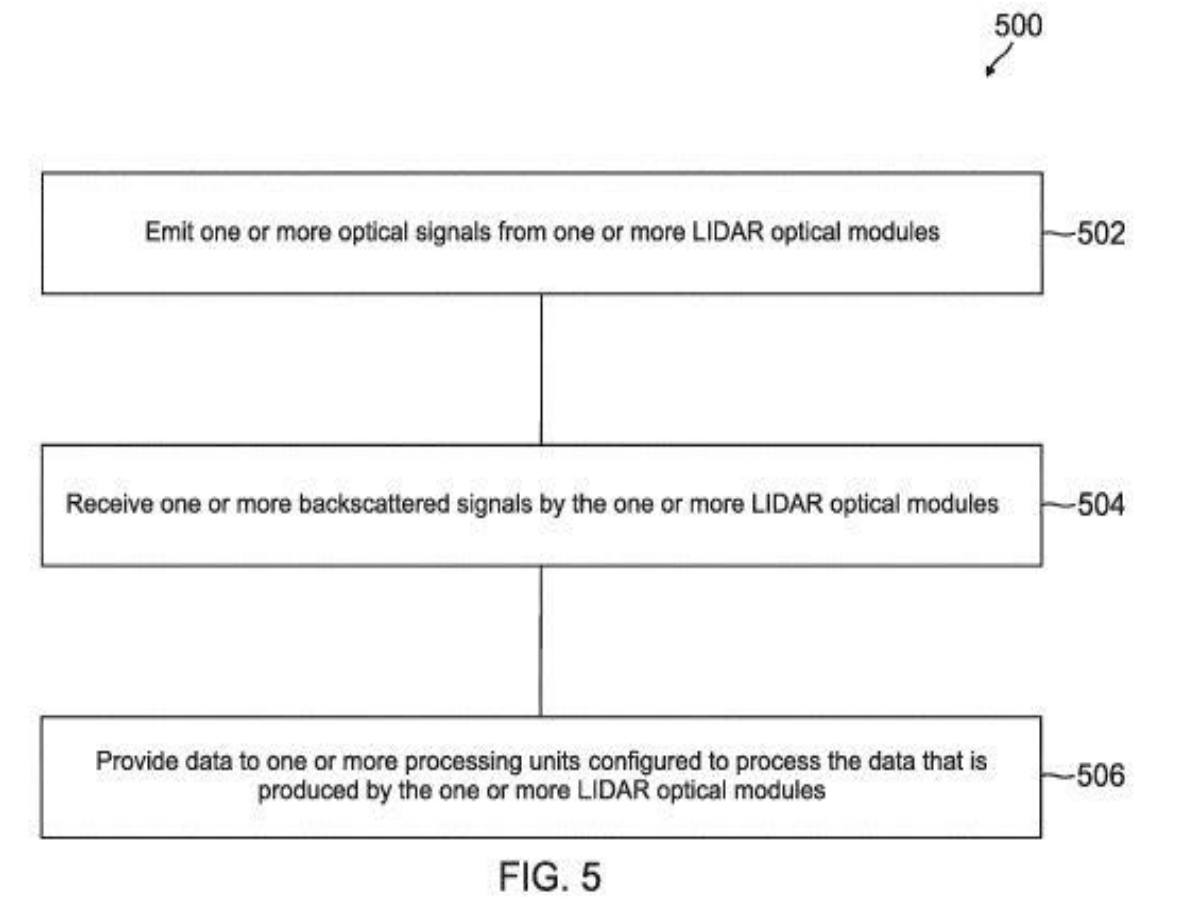

Figure 5. Flow diagram illustrating a method for gathering LiDAR data in accordance with embodiments described

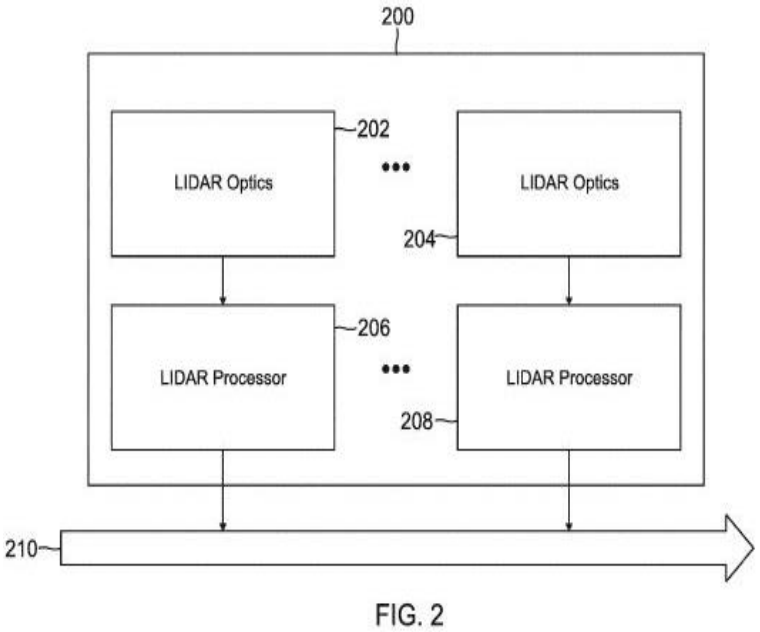

Figure 6. A block diagram illustrating a LiDAR data system according to one implementation

III. LIDAR SENSOR ALIGNMENT SYSTEM

This is a patent filed in European Union in 29/06/2018 by APTIV Tech Limited and published in 02/01/2019.[24]

Here the major claims include a first lidar and a second lidar configured to monitor two regions; a controller configured to receive the first and second LiDAR signals and recognize a target detected by both the first and second LiDAR sensors, utilize a first coordinate map associated with the first region to determine a first mapped location of the target, utilize second coordinate map associated with the second region to determine a second mapped location of the target, and associate the first and second mapped locations to determine if the first and second LiDAR sensors are aligned.

It generates a coordinate map and alignment model and utilises the same for detection purposes. The coordinate map and the alignment model are pre-programmed into the controller. The controller includes a processor and an electronic storage medium, wherein the processor is configured to receive and process the first and second LiDAR signals, recognize the target detected by both the first and second LiDAR sensors, utilize the first coordinate map associated with the first region and stored in the electronic storage medium to determine the first mapped location of the target, determine a second hypothetical location of the target associated with a second coordinate map orientated in a pre-programmed alignment configuration with the first coordinate map, utilize the second coordinate map associated with the second region and stored in the electronic storage medium to determine the second mapped location of the target, and compare the second hypothetical location to the second mapped location to determine if the first and second LiDAR sensors are aligned. When the two signals of the first and second lidar are aligned only, the controller initiates the action of imaging. A computer software product is executed by the controller for achieving this, which is the core of this invention. Thus we can say this is also a software driven invention where innovation solely lies in the software part.

Tracing the prior arts points to a US patent in 1997[25] which uses a coordinate transforming means for transforming the coordinates of an object detected by said laser radar in conformity with the coordinate axes of said display image to provide transformed coordinates. Another US patent 'Method and system for aligning a line scan camera with a lidar scanner for real time

[24] EP3422050
IPC- G01S 17/93, G01S 7/497
CPC- G01S 7/4972, G01S 17/87, G01S 17/936
[25] US5617085 (A)- Method and apparatus for monitoring the surroundings of a vehicle and for detecting failure of the monitoring apparatus.

data fusion in three dimensions'[26] uses a LiDAR scanner coupled to a Computer processor. Another patent 'Method for adjusting sensor during manufacture of motor car, involves comparing object positions determined relative to vehicle reference axis, to produce comparative data and adjusting preset sensor as a function of comparative data'[27] uses a computer program product for the processing purposes.

IV. CONCLUSION

We have looked into certain LiDAR patent applications, both granted and some recent patent applications, involving the data processing part of the LiDAR. In many of the patents, we could see a controller part which does the object tracking by classifying and processing the acquired LiDAR data which is the point cloud information of the LiDAR. From the above patent documents, we clearly see that it is the software part which does this job of analysis. Several algorithms efficiently do this task. Software is crucial in the data processing part, innovation in which facilitates real-time, efficient data processing. We could also see in the case of LiDAR, hardware innovation is also rapid to attain efficient, real-time environment understanding.

From the data collection part, what was gathered that a number of patent applications in this regard were rejected for lack of inventive step. These were one with software innovation. Majority of LiDAR patent applications for autonomous driving purposes are in the examination stage. Many of the crucial and advanced LiDAR patent applications are under the examination process or awaiting examination.

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[26] US2010157280 (A1)
[27] DE102011120535 (A1) (2013)