US010094919B2

(12) **United States Patent**
Levi et al.

(10) **Patent No.: US 10,094,919 B2**
(45) **Date of Patent: Oct. 9, 2018**

(54) **RADAR-VISION FUSION FOR TARGET VELOCITY ESTIMATION**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 425 days.

(21) Appl. No.: **14/876,134**

(22) Filed: **Oct. 6, 2015**

(65) **Prior Publication Data**

US 2017/0097411 A1 Apr. 6, 2017

(51) **Int. Cl.**

G01S 13/42	(2006.01)
G01S 13/58	(2006.01)
G01S 13/86	(2006.01)
G01S 7/40	(2006.01)
G01S 13/93	(2006.01)

(52) **U.S. Cl.**
CPC ***G01S 13/58*** (2013.01); ***G01S 13/42*** (2013.01); ***G01S 13/867*** (2013.01); *G01S 7/40* (2013.01); *G01S 13/931* (2013.01)

(58) **Field of Classification Search**
CPC G01S 13/58; G01S 13/867; G01S 13/931; G01S 7/40
USPC 342/52
See application file for complete search history.

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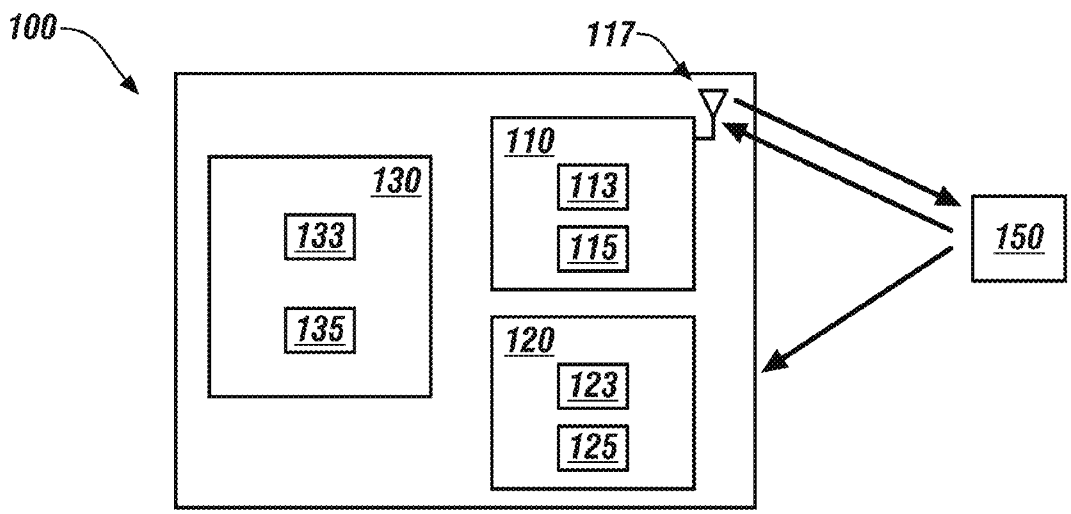
(57) **ABSTRACT**

A method of determining velocity of a target and a fusion system on a moving platform to determine the velocity of the target are described. The method includes obtaining, using a radar system, position and radial velocity of the target relative to the moving platform, obtaining, using a vision system, optical flow vectors based on motion of the target relative to the moving platform, and estimating a dominant motion vector of the target based on the optical flow vectors. The method also includes processing the position, the radial velocity, and the dominant motion vector and determining the velocity of the target in two dimensions.

20 Claims, 2 Drawing Sheets



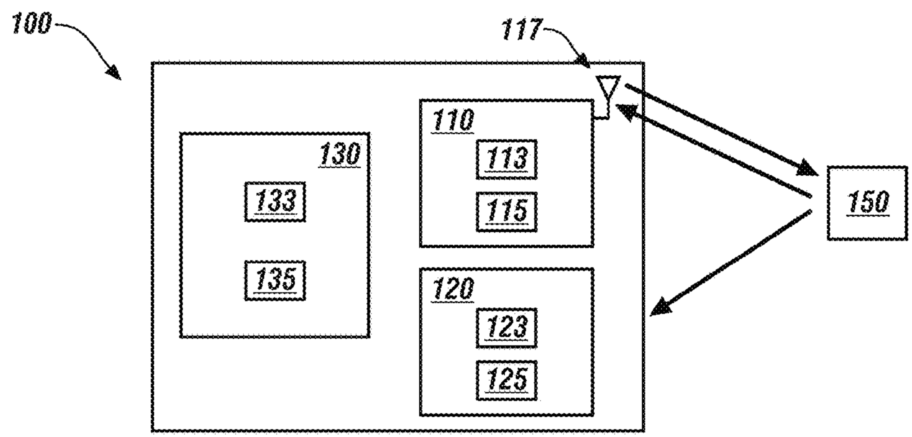


FIG. 1

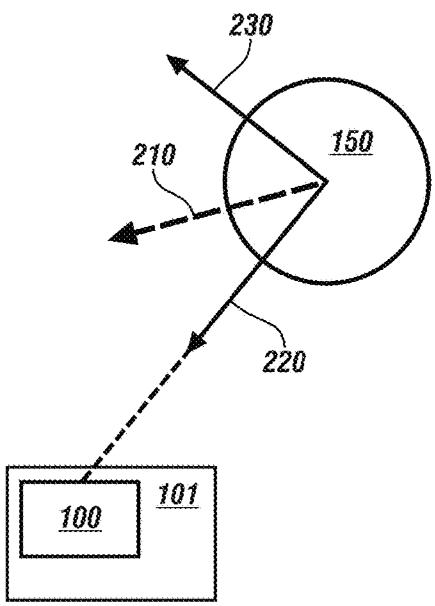


FIG. 2

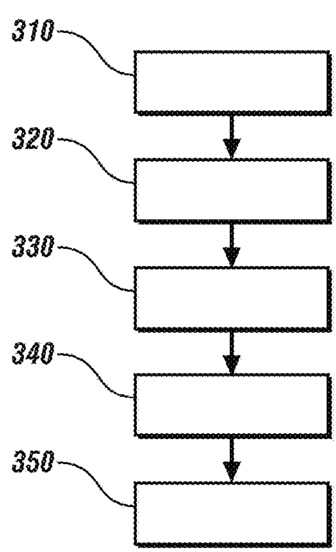


FIG. 3

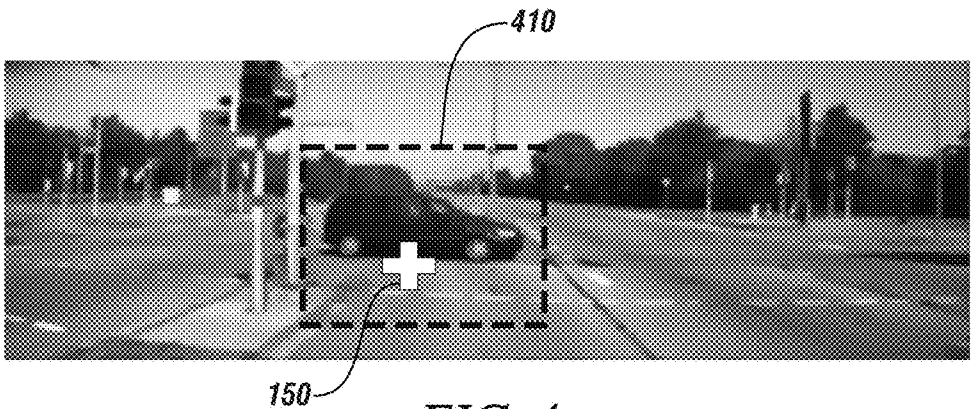


FIG. 4

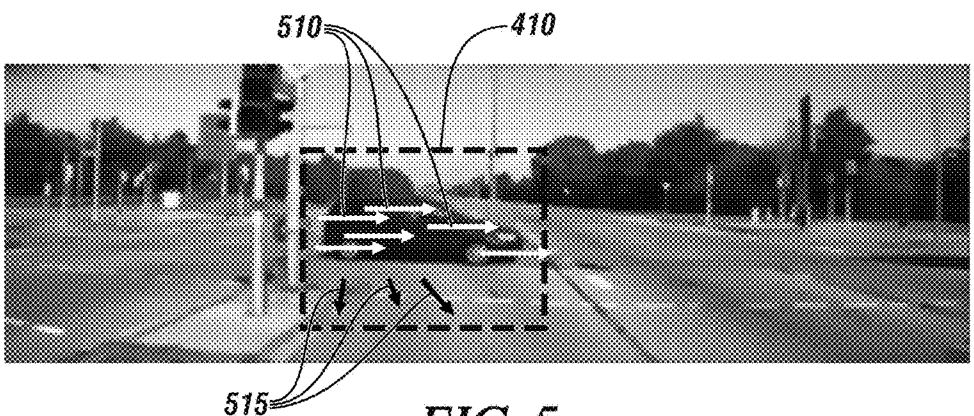


FIG. 5

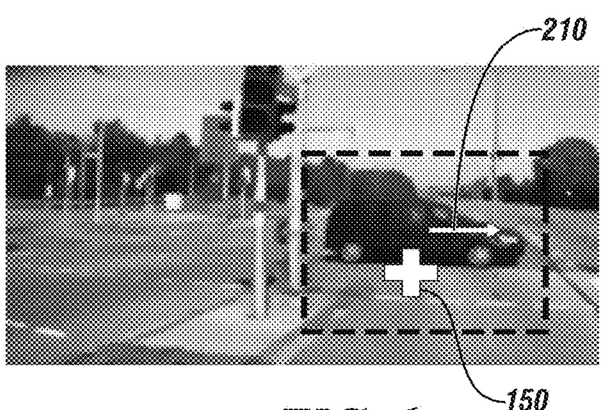


FIG. 6

RADAR-VISION FUSION FOR TARGET VELOCITY ESTIMATION

FIELD OF THE INVENTION

The subject invention relates to radar-vision fusion for target velocity estimation.

BACKGROUND

Information and data gathering using sensors is increasingly available on a wide variety of platforms including personal portable devices, vehicles, and computing devices. Many platforms make use of multiple types of sensors. In the case of vehicles of all varieties, for example, global positioning system (GPS) receivers in addition to other sensors—infrared, radar, vision (camera)—are increasing in use. Usually, the information gathered by each type of sensor is used for a different purpose. Accordingly, it is desirable to provide a fusion of radar and camera systems for target velocity estimation.

SUMMARY OF THE INVENTION

In one exemplary embodiment of the invention, a method of determining velocity of a target from a moving platform includes obtaining, using a radar system, position and radial velocity of the target relative to the moving platform; obtaining, using a vision system, optical flow vectors based on motion of the target relative to the moving platform; estimating a dominant motion vector of the target based on the optical flow vectors; and processing, using a processor, the position, the radial velocity, and the dominant motion vector and determining the velocity of the target in two dimensions.

In another exemplary embodiment of the invention, a fusion system on a moving platform to determine velocity of a target includes a radar system configured to obtain position and radial velocity of the target relative to the moving platform; a vision system configured to obtain optical flow vectors based on motion of the target relative to the moving platform and estimate a dominant motion vector based on the optical flow vectors; and a processor configured to determine the velocity of the target based on the position, the radial velocity, and the dominant motion vector.

The above features and advantages and other features and advantages of the invention are readily apparent from the following detailed description of the invention when taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features, advantages and details appear, by way of example only, in the following detailed description of embodiments, the detailed description referring to the drawings in which:

FIG. **1** is a block diagram of the fusion system according to embodiments;

FIG. **2** illustrates the obtained information and desired information for a fusion system according to embodiments;

FIG. **3** is a process flow of a method of determining target velocity according to embodiments;

FIG. **4** illustrates the target and RoI identification and position determination by the radar system according to the process flow shown in FIG. **3**;

FIG. **5** illustrates the computation of optical flow for points in the RoI according to the process flow shown in FIG. **3**; and

FIG. **6** illustrates the two-dimensional velocity of the target determined according to the process flow shown in FIG. **3**.

DESCRIPTION OF THE EMBODIMENTS

The following description is merely exemplary in nature and is not intended to limit the present disclosure, its application or uses. It should be understood that throughout the drawings, corresponding reference numerals indicate like or corresponding parts and features.

As noted above, many platforms have multiple types of sensors that gather data for different purposes. For example, a GPS receiver is used to determine position, vision or camera systems may be used to detect lateral motion (angular velocity), and radar systems measure range and longitudinal velocity. Embodiments of the systems and methods detailed herein relate to fusing the information available from a radar system and a vision system to overcome the limitations of each system. Specifically, the embodiments pertain to estimating target velocity based on a fusion of radar data and vision data. While the exemplary application of an automobile with the fusion system is illustrated for explanatory purposes, the embodiments are not limited to any particular platform.

FIG. **1** is a block diagram of the fusion system **100** according to embodiments. Although shown in FIG. **1** as being housed together for explanatory purposes, the fusion system **100** may be arranged with different components at different parts of a platform. A radar system **110** includes a transmit portion **113** and receive portion **115**, which may each use a different antenna **117** or share the antenna **117** in a transceiver arrangement. The radar system **110** transmits radio frequency energy and receives reflected energy, reflected from a target **150**. The reflected energy is shifted in frequency with reference to the incident transmitted energy based on relative motion between the radar system **110** and the target **150**. This frequency shift, known as the Doppler shift, may be used to determine the longitudinal velocity (relative velocity along the line of sight). The time from transmission to reception may be used to determine the range to the target **150** from the radar system **110**. The fusion system **100** also includes a vision system **120** which includes a camera **123** and an image processor **125**. The image processor **125** may use the images obtained with the camera **123** to determine angular velocity of the target **150** relative to the vision system **120**. The fusion system **100** further includes a processing portion **130**. This processing portion **130** includes one or more memory devices **133** and one or more processors **135**. The memory device **133** may store instructions as well as data obtained by one or both of the radar system **110** and the vision system **120**. The processor **135** determines two-dimensional velocity of the target **150** based on a fusion of information from the radar system **110** and the vision system **120**, as further discussed below.

FIG. **2** illustrates the obtained information and desired information for a fusion system **100** according to embodiments. The fusion system **100** may be part of a platform **101** such as a vehicle, for example. The fusion system **100** uses the radar system **110** to obtain longitudinal velocity vector **220**. The fusion system **100** uses the vision system **120** to obtain lateral velocity vector **230**. As noted and according to embodiments further discussed below, the fusion system **100** determines two-dimensional velocity **210** of the target **150** based on information from the radar system **110** and the vision system **120** that includes the longitudinal velocity vector **220** and the lateral velocity vector **230**. The target **150** may be a vehicle, a pedestrian, or any other moving object. Once the two-dimensional velocity **210** of the target is determined, the information may facilitate a number of applications. For example, by estimating the two-dimensional velocity **210** of the target **150**, the position of the target **150** at some future time may be predicted such that a threat assessment (e.g., determination of potential collision) or autonomous control decision (e.g., evasive action to avoid collision) may be undertaken. Two dimensional velocity **210** is of interest because a planar arrangement of the platform **101** and target **150** are assumed. In alternate embodiments, a third dimension may be added to the estimate and subsequent applications.

FIG. **3** is a process flow of a method of determining target **150** velocity (**210**) according to embodiments. At block **310**, determining a position p (including range r to target **150**) and radial velocity rv of the target **150** is performed using the radar system **110**. This process begins with identification of the target **150**. At block **320**, defining the region of interest (RoI) for the vision system **120** includes calibrating the vision system **120** with the radar system **110**. A calibrated vision system **120** has known parameters such as focal length, optical center, distortion, and three-dimensional mount position with respect to the platform **101**. Given these parameters, a one-to-one mapping function may be determined to map a pixel from the ground (or close to the ground surface) to a point in the platform coordinate frame and vice versa. In this manner, the vision system **120** is calibrated. The mapping is further discussed below. Computing optical flow for points in the RoI, at block **330**, involves obtaining two or more image frames using the vision system **120** and using known equations to determine optical flow vectors or motion of the target **150** relative to the vision system **120**. At block **340**, clustering is used on the computed optical flow vectors to find dominant motion $q=(q_u,q_v)$. Clustering involves assigning two optical flow vectors within a neighborhood to the same group if they are similar in terms of magnitude and orientation. Exemplary clustering algorithms include graph partition, mean shift, and watershed. The u-v coordinate system is the image coordinate system. At block **350**, computing target velocity (two-dimensional velocity **210**) includes using the minimization equation detailed below.

The dominant motion vector $q=(q_u,q_v)$, range r, and, from the radial velocity rv, radial speed s, and azimuth angle θ are all inputs obtained using the radar system **110**. Then, at block **350**, the two-dimensional velocity **210** is obtained as the solution to minimize:

$$v^* = \operatorname{argmin}_v \frac{\left|\frac{p^T v}{r} - s\right|^2}{\sigma^2} + (h(v, p) - q)^T \sum^{-1} (h(v, p) - q) \quad \text{[EQ. 1]}$$

The target **150** position vector p is given by:

$$p=(r \cos \theta, r \sin \theta)^T \quad \text{[EQ. 2]}$$

The accuracy of the radial speed s provided by the radar system **110** is represented by σ. This value may be part of the specification provided with the radar system **110**. Σ is the two-by-two covariance matrix representing the error of the dominant motion vector q estimate. Empirically, the sample covariance matrix of optical flow from the RoI may be used. h(v,p) denotes the function mapping the two-dimensional velocity **210** at position p in the top-down view x-y coordinate system (of the radar system **110**) to the motion vector q in the u-v coordinate system (of the vision system **120**). h(v,p) is pre-determined by the camera calibration process that is part of block **320** and assumes that the target **150** is moving on a flat ground surface. This assumption holds with the assumption of a planar arrangement of the platform **101** and target **150**.

FIGS. **4-6** illustrate processes discussed with reference to FIG. **3** for an exemplary target **150**. The exemplary target **150** is a van. FIG. **4** illustrates the target and RoI **410** identification and position determination by the radar system **110** (blocks **310** and **320**). The target identification by the radar system **110** is indicated by the "+." FIG. **5** illustrates the computation of optical flow for points in the RoI **410** (block **330**). Exemplary dominant motion vectors q **510** are shown, as well (block **340**). Each dominant motion vector q **510** is determined by its height in the world, range, azimuth, and both radial and tangential velocity. Exemplary non-dominant motion vectors **515** are also indicated in FIG. **5**. FIG. **6** illustrates the two-dimensional velocity **210** of the target **150** determined with the minimization equation shown in EQ. 1 (block **350**).

While the invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiments disclosed, but that the invention will include all embodiments falling within the scope of the application.

What is claimed is:

1. A method of determining velocity of a target from a moving platform, the method comprising:

obtaining, using a radar system, position and radial velocity of the target relative to the moving platform;

obtaining, using a vision system, optical flow vectors based on motion of the target relative to the moving platform;

estimating a dominant motion vector of the target based on the optical flow vectors;

processing, using a processor, the position, the radial velocity, and the dominant motion vector and determining the velocity of the target in two dimensions; and

performing, at the moving platform, evasive action based on assessment of a threat of collision posed by the target using the velocity of the target in the two dimensions.

2. The method according to claim **1**, further comprising defining a region of interest using the radar system.

3. The method according to claim **2**, wherein the obtaining the optical flow vectors using the vision system is for points in the region of interest.

4. The method according to claim **2**, further comprising calibrating the vision system with the radar system, the calibrating including determining a mapping function to map an x-y coordinate system used by the radar system to a u-v coordinate system used by the vision system.

5. The method according to claim **1**, wherein the determining the dominant motion vector includes clustering the optical flow vectors.

6. The method according to claim **1**, further comprising determining range r, azimuth angle θ, radial speed s, and position vector p from the position and the radial velocity, determining accuracy σ a of the radial speed s, and obtaining a two-by-two covariance matrix Σ representing error in the domination motion vector estimate.

7. The method according to claim **6**, wherein the determining the velocity of the target includes solving to minimize:

$$v^* = \operatorname{argmin}_v \frac{\left|\frac{p^T v}{r} - s\right|^2}{\sigma^2} + (h(v, p) - q)^T \sum^{-1} (h(v, p) - q),$$

v is the velocity of the target, h(v,p) is a function mapping the velocity of the target in an x-y coordinate system used by the radar system to the dominant motion vector q in a u-v coordinate system used by the vision system.

8. The method according to claim **6**, wherein the determining the accuracy σ a of the radial speed s is based on a specification of the radar system.

9. The method according to claim **6**, wherein the obtaining the two-by-two covariance matrix Σ includes using a covariance matrix of the optical flow vectors from a region of interest.

10. A fusion system on a moving platform to determine velocity of a target, the fusion system comprising:

a radar system configured to obtain position and radial velocity of the target relative to the moving platform;

a vision system configured to obtain optical flow vectors based on motion of the target relative to the moving platform and estimate a dominant motion vector based on the optical flow vectors; and

a processor configured to determine the velocity of the target based on the position, the radial velocity, and the dominant motion vector, and to assess a threat of a collision with the target using the velocity of the target, wherein evasive action is taken at the moving platform based on the assessment of the threat.

11. The fusion system according to claim **10**, wherein the vision system includes a camera.

12. The fusion system according to claim **10**, wherein the radar system defines a region of interest.

13. The fusion system according to claim **12**, wherein the vision system obtains the optical flow vectors for points in the region of interest.

14. The fusion system according to claim **12**, wherein the vision system is calibrated with the radar system.

15. The fusion system according to claim **10**, wherein the vision system clusters the optical flow vectors to determine the dominant motion vector.

16. The fusion system according to claim **10**, wherein the processor determines range r, azimuth angle θ, radial speed s, and position vector p from the position and the radial velocity, determines accuracy σ of the radial speed s, and obtains a two-by-two covariance matrix Σ representing error in the domination motion vector estimate.

17. The fusion system according to claim **16**, wherein the processor determines the velocity of the target by solving to minimize:

$$v^* = \operatorname{argmin}_v \frac{\left|\frac{p^T v}{r} - s\right|^2}{\sigma^2} + (h(v, p) - q)^T \sum^{-1} (h(v, p) - q),$$

v is the velocity of the target, h(v,p) is a function mapping the velocity of the target in an x-y coordinate system used by the radar system to the dominant motion vector q in a u-v coordinate system used by the vision system.

18. The fusion system according to claim **16**, wherein the processor obtains the two-by-two covariance matrix Σ using a covariance matrix of the optical flow vectors from a region of interest.

19. The fusion system according to claim **16**, wherein the processor determines the accuracy σ of the radial speed s based on a specification of the radar system.

20. The fusion system according to claim **10**, wherein the radar system includes a transceiver.

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