Data Article

Dataset for trailer angle estimation using radar point clouds

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ABSTRACT

The automotive industry is interested in the estimation of vehicle trailer rotation (trailer angle or hitch angle) due to its use in trailer control algorithms. We present an experimental dataset collected in a study of the estimation problem \cite{1} and a MATLAB code implementation of the study. The data collection apparatus is a truck mock-up that is attached to a flatbed trailer at the hitch ball. Two radars are installed in the taillight fixtures of the truck and a camera is installed in the truck's tailgate like a typical backup camera installation. A rotary motion sensor is also installed at the hitch ball to provide ground truth measurement of the trailer angle. To aid analysis of the dataset, both radar detections are transformed onto a vehicle coordinate system (VCS) having its origin at the hitch ball i.e. the different radar viewpoints are combined into one with respect to the hitch ball. The MATLAB code presented with this article has two major functionalities. The first functionality is the visualization of both radar detections, the combined radar detections in the VCS, the camera images, and the ground truth angles, as the trailer rotates. The second functionality of the code is the

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replication of the estimation results in [1], which used only the radar detections from the dataset.

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### Specifications Table

| Subject | Engineering |
|---------|-------------|
| Specific subject area | Estimation of vehicle trailer rotation (trailer angle or hitch angle). The problem is illustrated in Fig. 1. |
| Type of data | Multisensor data collected from two radars, camera, and a rotary motion sensor. Algorithm implementation of [1] (MATLAB code). |
| How data were acquired | Two radars, a camera, and a rotary motion sensor were connected to a 2.50-GHz CPU, 12-GB RAM computer with USB cables for data collection. Each radar is a TI AWR1642BOOST sensor [2] which operates within the 76 – 81-GHz frequency range. The radar has two transmit and four receive channels. Its half-power transmit beamwidth at boresight is about 0.25rad ≈ 14.3° in azimuth. It provides detections in two dimensions i.e. range and angle. It also provides signal strength and Doppler information. The detections were collected in MATLAB [3]. The camera’s sensor is the Basler daa1280-54uc [4], having a 1280px x 960px resolution, a frame rate of 54 fps, and a size of 4.8 mm x 3.6 mm. The lens used for the camera is the Evetar E3I64A model [5], having a focal length of 2.1 mm and a field of view (H x V) of 130° x 96°. The camera images were also collected in MATLAB. A Go Direct® Rotary Motion sensor by Vernier [6] was used in its 0.25° accuracy setting. The sensor supported Python programming in place of MATLAB. Therefore, its measurement data was shared across Python and MATLAB engines so that the data could be streamed with those obtained from the radars and camera for multisensor data collection in MATLAB. The MATLAB version used is 9.9.0.1538559 (R2020b). |
| Data format | Raw Analyzed |
| Parameters for data collection | The data collection was performed in an indoor laboratory environment. The ground surface in the laboratory was smooth. The choice of the environment and the ground surface is to obtain a dataset that is almost free of environmental noise sources, such as sensor vibration on roads, to facilitate an initial study of the estimation problem. A flatbed trailer type was used for the data collection. The radars were installed in the taillight fixtures of a truck mock-up at a height of about 16 cm above the trailer’s flat surface. The radars were tilted down (pitch axis) at an angle of about 7° to ensure the trailer’s detection. The constant false alarm rate (CFAR) range detection threshold of each radar was reduced to 3 dB to obtain more trailer detections. As a consequence, the reduction in detection threshold increases the false positives. The operations of both radars are not synchronized. Each radar operated independently. The detections were collected in a point cloud format (range, angle, signal strength, and Doppler) as provided by the manufacturer [2]. The trailer was placed directly behind the truck and the rotary motion sensor was set to a 0° reading before data collection. The trailer rotated at a low speed during data collection. For instance, in one of the instances provided in the dataset, a rotation cycle (up to about 40° trailer angle in both radar directions) completed in about 97 seconds. This was motivated by low angular-speed trailer control applications such as those implemented for automated backup assist. Data was collected from the multiple sensors at a 3 Hz rate in a sequential manner and in the order: passenger radar (PR), driver radar (DR), camera, and the rotary motion sensor. The low data collection rate seems to be sufficient for an initial study of the problem and for the low angular trailer-speed scenario considered. If it took t seconds to read the data from all sensors in an iteration, the data collection procedure waited for (1 / 3 – t) seconds after reading the sensors before proceeding to the next iteration. Meanwhile, t < ¾ seconds to the best of our knowledge. |

(continued on next page)
Description of data collection | The apparatus used for the data collection is a truck mock-up that is attached to a flatbed trailer at the hitch ball. It was placed in an indoor laboratory environment. Two radars and a camera are installed at the rear of the truck. A rotary motion sensor is also installed at the hitch ball to provide ground truth measurement of the trailer angle. A 0° true trailer angle means that the trailer is directly behind the truck. Fifteen (15) sets of data were collected in the same indoor environment. For each set, the apparatus was rotated at true trailer angles of about 40° in both radar directions to collect multisensor data.

Data source location | Institution: Michigan Technological University
City/State: Houghton, MI 49931
Country: United States

Data accessibility | Repository name: Mendeley Data
Direct URL to data: https://doi.org/10.17632/wy24m7y7tb

Related research article | K. T. Olutomilayo, M. Bahramgiri, S. Nooshabadi, J. Oh, M. Lakehal-Ayat, D. Rogan, D. R. Fuhrmann, Trailer angle estimation using radar point clouds, Signal Proc. 188 (2021) 108221. doi:https://doi.org/10.1016/j.sigpro.2021.108221. The article is cited as [1].

Value of the Data

- The presented data does not only contain raw multisensor dataset, it also contains MATLAB codes for the dataset visualization and for an implementation of the algorithm in [1] to replicate research results.
- The data is useful for researchers that are interested in the estimation of vehicle trailer rotation. Those who study and design trailer control applications may also be interested in the dataset.
- We have identified that the publicly available literature for the vehicle trailer rotation estimation problem is limited, especially those that consider radar sensors. Hence, the dataset will enable further research of the problem. The trailer images, provided for visualization purpose in [1], may also be used for the estimation.

1. Data Description

The data described in this article is provided to facilitate the estimation of vehicle trailer rotation i.e. the trailer angle or hitch angle \( \theta \), which is illustrated with a truck and trailer diagram in Fig. 1. The data is hosted in the repository provided in the Specifications table and it can be categorized into two major parts. Both parts are described as follows.

![Fig. 1. A truck and trailer diagram showing two radars and a camera installed on a truck [1]. The data from the sensors can be used to estimate the trailer angle (or hitch angle) \( \theta \).](image-url)
Multisensor dataset was collected from two radars, a camera, and a rotary motion sensor using the experimental apparatus shown in Fig. 2. The apparatus is described in more detail in Section 2. Fifteen (15) data collection instances were carried out. The multisensor data collected in each instance was saved in a folder. All fifteen data folders are then saved in a dataset directory for ease of reference. The camera was activated in the first ten data-collection instances. It was not activated in the remaining five instances. Therefore, ten out of fifteen data folders in the dataset directory contain camera images.

In each of the data collection instances, the apparatus was rotated through a range of about $[-40^\circ, 40^\circ]$ true trailer angles. A $0^\circ$ true trailer angle means that the longitudinal axes of both the trailer and the truck are aligned. The trailer angle takes a positive value when the trailer rotates towards PR and a negative value when the trailer rotates towards DR.

A MATLAB code is provided in the repository to visualize the multisensor data in a choice folder. Figure 3 shows a sample frame from the code visualizer.

1.2. Algorithm implementation of the estimation procedure in [1]

The algorithm presented in [1] estimates the trailer angle using only the radar detections from the dataset. The trailer images in the dataset aided visualization of the rotation procedure, the images were not used in the algorithm. A MATLAB code implementation of the algorithm is provided in the repository to replicate the research results.

2. Experimental Design and Transformation of Radar Detections

The truck and trailer schematic in Fig. 1 is modelled using the experimental apparatus shown in Fig. 2. The apparatus consists of a truck mock-up, which is a rear gate of a truck mounted on a three-wheel platform, and a flatbed trailer. The trailer was fixed in its position with wheel chucks while the truck mock-up (apparatus) was rotated for data collection. This was done to prevent the platform from being displaced if the trailer rotated. Hence, the rotation of the trailer described in this article is the effect of rotating the apparatus.
Fig. 3. A frame from the MATLAB code visualizer, modified from Olutomilayo et al. [1]. It shows the detections from both radars (collected in the radar coordinate systems, illustrated in the Fig. 4 geometry), the combined radar detections in the VCS, the camera image, and the ground truth angle measurement of the trailer rotation $\theta_{\text{truth}}$ (which should be estimated). An option to turn off the display of the rectangular box in the VCS, illustrated in white, is included in the code.

Fig. 4. A schematic diagram showing the radar geometry parameters. Parameters $\alpha$ and $\beta$ are the radar mount angles. The horizontal axis of the VCS, indicated in blue, aligns with the truck’s lateral line at perpendicular distances $v_1$ and $v_2$ as shown in the figure. This geometry generalizes that which is provided in [1] for when $v_1 \neq v_2$, i.e. when the radars are not symmetrically positioned on the truck. Again, due to the possibility of asymmetrical positioning of the radars, $w_1$ and $w_2$ may not be equal.

The sensors (two radars, a camera, and a rotary motion sensor) are installed as described in Fig. 2. The makes and models of the sensors and the conditions that were considered for data collection are provided in detail in the Specifications table.

The center of trailer rotation is the hitch ball position. Therefore, to aid visualization and further analysis of the dataset, the radar detections are transformed onto the VCS, having its origin at the hitch ball position as shown in Fig. 3. The radar geometry shown in Fig. 4 illustrates the rotation parameters (radar mount angles) $\alpha$, $\beta$ and translation parameters $w_1$, $v_1$, $w_2$, $v_2$ used for the transformation.

Let the detections from PR and DR be $X \in \mathbb{R}^{2 \times m}$ and $Y \in \mathbb{R}^{2 \times n}$, respectively. The detections are transformed onto the VCS as follows.

$$X_{\text{VCS}} = Q_\alpha X - \begin{bmatrix} w_1 \\ v_1 \end{bmatrix}^T_{m}$$ (1)

$$Y_{\text{VCS}} = Q_\beta Y - \begin{bmatrix} w_2 \\ v_2 \end{bmatrix}^T_{n}$$ (2)
where $\mathbf{1}_k$ is a column vector of $k$ ones, $^T$ indicates a transpose operation, $X_{vcs}, Y_{vcs}$ are the transformed PR and DR detections, respectively, and

$$Q(\varphi) := \begin{bmatrix} \cos(\varphi) & -\sin(\varphi) \\ \sin(\varphi) & \cos(\varphi) \end{bmatrix}$$

is a rotation matrix which rotates a two-dimensional vector at an angle $\varphi$ in the counterclockwise direction for positive $\varphi$.

The radar geometry parameters for the experimental apparatus were directly measured with a meter rule and the protractors that are locked at the top of the plexiglasses described in Fig. 2. The parameters were measured as

$$\alpha = 19.0^\circ, \quad \beta = 20.0^\circ \quad (3)$$

$$w_1 = w_2 = 0.8 \text{ m}, \quad v_1 = v_2 = 0.32 \text{ m} \quad (4)$$

Both transformed detection sets are then combined as $Z_{vcs} := \{X_{vcs}, Y_{vcs}\}$ in the VCS for visualization as shown in Fig. 3.

**Ethics Statement**

The multisensor dataset was collected at Michigan Technological University, Houghton, MI 49931, United States. The sensor mount parameters, dataset, and the algorithm’s implementation do not represent a particular deployment standard. They are intended to facilitate the study of the estimation problem.

**CRediT Author Statement**

Kunle T. Olutomilayo: Investigation, Formal analysis, Methodology, Software, Data Curation, Visualization, Writing – original draft, Writing & review & editing; Mojtaba Bahramgiri: Investigation, Formal analysis; Saeid Nooshabadi: Funding acquisition, Formal analysis, Supervision; JinHyoung Oh: Conceptualization, Formal analysis, Project administration; Mohsen Lakehal-Ayat: Conceptualization, Formal analysis; Douglas Rogan: Conceptualization, Formal analysis; Daniel R. Fuhrmann: Funding acquisition, Resources, Supervision, Project administration, Writing – Review & Editing.

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships which have, or could be perceived to have, influenced the work reported in this article.

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