# Simple Lane Estimation from Received Doppler Signal Strength in Traffic Monitoring Systems

Orlando J. Hernandez
*Department of Electrical and Computer Engineering*
*The College of New Jersey*
Ewing, USA
hernande@tcnj.edu

***Abstract*— In traffic monitoring systems, one estimates the lane where a vehicle is travelling using the Range Fast Fourier Transform (FFT) of received Frequency Modulated Continuous Wave (FMCW) radar signals. In practice, to determine the lane where a vehicle is traveling, it is not necessary to determine the range from the radar unit to the vehicle with the precision available from FMCW signal processing. This paper considers a simple technique to determine the vehicle lane from the doppler radar signal strength, which is simpler to process to determine speed. We show that this simpler signal processing can produce adequate results with much less complexity, and thus power consumption, which is important to minimize in remote battery powered traffic monitoring systems.**

***Keywords— localization, radar sensors, received signal strength, traffic monitoring systems***

## I. INTRODUCTION

The last few years have seen a significant increase in research and development activities in the areas of traffic control and monitoring systems, in the context of cyber-physical systems such as autonomous transportation and smart cities. One statistical metric collected in traffic control systems is the lane in which a vehicle is travelling, along with several others such as speed.

On way to determine the travel lane of a vehicle is to use FMCW radar signal processing using the Range FFT to calculate the distance between the sensor and the vehicle, thus determining the travel lane. However, this is a computationally expensive approach, which yield much higher accuracy that is needed for the simple task of travel lane estimation. Computational complexity translates to higher power consumption, which is an unwanted characteristic in battery powered traffic monitoring system. These systems are expected to operate remotely and unattended with a typical battery life of several weeks.

This paper presents an alternative approach to travel lane estimation using a metric derived from the received signal strength. The focus is on simplicity and low computational cost. Using this approach, we show that acceptable levels of accuracy can be obtained for the estimation of travel lane identification when tested with real time field data of traffic monitoring systems.

## II. THEORY

Consider a doppler radar data acquisition system, such as the one depicted in Fig. 1.

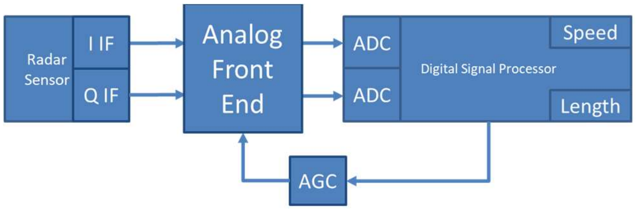

Fig. 1. Speed and Car Length Signal Processing

The In-Phase (I) and Quadrature (Q) Intermediate Frequency (IF) components of a doppler radar frequency shift are produced by a sensor and pre-processed by an Analog Front End circuit with Automatic Gain Control (AGC). These signals are digitized and organized into frames, and Digital Signal Processing (DSP) is applied as to calculate the Speed and Length of a vehicle. The length of the vehicle is calculated by using the speed of the vehicle and the time during which a vehicle reports a valid (non-zero) speed.

The frame-by-frame AC components of the I and Q signals can be used to compute a Mean Absolute Value (MAV), which yields a measure of the energy being returned by the vehicle. This metric can be used to distinguish in which lane the vehicle is travelling. The reason to use this metric, which is similar to the Root-Mean-Squared (RMS) value of the frame is that the MAV is much less expensive to compute than the RMS value, and therefore much more attractive for embedded systems that require low power operation to maximize battery life. The advantage of this approach also has a cost advantage over the FMCW and FFT approach, as FMCW radar sensors are less expensive than Doppler radar sensors.

For a frame length N, where N is a power of 2, of a signal that has been centered about 0 by subtracting the mean value:

$$MAV = \left\{ \sum_{i=1}^{N} |x_i| \right\} \gg \log_2 N \underset{\substack{CORRELATIVE \\ EQUIVALENCE}}{\Longleftrightarrow} RMS = \sqrt{\left( \frac{1}{N} \sum_{i=1}^{N} x_i^2 \right)} \tag{1}$$

Where >> represents a binary right shift operator.

## III. PRACTICAL IMPLEMENTATION

For a practical implementation of this approach to determining a vehicle's lane of travel, some additional operations are necessary. First, since the analog I and Q IF signals have been preprocessed using AGC on a frame-by-frame basis, these frames need to denormalized by the AGC gain that was used to acquire the signals. Then we must choose which signal to use for a given frame to record the calculated MAV, I or Q. Since both signals contain the same information of reflected signal strength, we choose to record the MAV for the stronger signal, the highest of the two MAVs. The other consideration is how to assign a single MAV value for a vehicle, as indicated by the speed. 0 speed determination marks the beginning and end of vehicles (gaps), and the speed of a vehicle and the time duration of this non-zero speed is also used to calculate the vehicle length. To assign a single MAV to a vehicle the frame-by-frame MAVs during a valid vehicle, the average of the frame MAVs is computed. After the vehicle MAV has been determined, it is normalized by the vehicle length, because larger vehicles will reflect more energy at the same distance than smaller vehicles. Then this metric is added to the population of vehicles statistics and the well know Otsu thresholding algorithm is applied dynamically to the vehicle MAV/L to assign the travel lane, near or far. The complete algorithm is given below in C-like pseudo code:

```
while (car) {// speed not zero, not gap
   for each frame i {
      compute MAVI  // MAV for signal I
      computer MVQ  // MAV for signal Q
      if (MAVI > MAVQ) $MAV_i$ = MAVI
      else $MAV_i$ = MAVQ
   }
}
MAVC = average ($MAV_i$) / L
add MAVC to vehicles population statistics
apply
   Otsu (vehicles population statistics)
      -> travel lane
```

## IV. RESULTS

The following table shows the performance of the proposed approach on several field test with real time traffic patterns. Two variants of the approach were tested as well. On was to use the peak frame MAV during a vehicle event to calculate the vehicle MAV. This is the output of a maximum nonlinear digital filter with a variable window of length equal to number of samples or frames during a vehicle event. The other variant considered was to not normalize the vehicle MAV figure by the calculated length of the vehicle. As shown, the original approach performed best with an average 80% accuracy rate weighted by the number of vehicles in each of the test cases, and over all test cases. This performance is adequate for the application in question, and is less expensive and energy consumption friendly that a traditional FFT based approach to calculating actual distances from the radar to a vehicle target.

TABLE I. RESULTS OF FIELD TESTS

| Test Case (Cron) | Data Points | MAV Peak | MAV Average | MAV Peak / L | MAV Avg / L |
|---|---|---|---|---|---|
| 1 | 44 | 65.9% | | 79.6% | |
| 2 | 160 | 79.8% | | 83.8% | |
| 3 | 125 | 53.6% | 53.6% | 82.6% | 86.4% |
| 4 | 102 | 85.3% | 94.1% | 78.4% | 87.3% |
| 5 | 123 | 50.4% | 54.5% | 54.5% | 68.3% |
| Total | 554 / 350 | | | | |
| Average Acc | | 67% | 67% | 76% | 81% |
| Weighted Avg | | 67% | 66% | 76% | **80%** |

## V. CONCLUSIONS

We have considered the estimation of the lane of travel of a vehicle in a monitored traffic system. We have shown that the underlaying estimation problem can be efficiently solved by using the MAV metric of the I or Q IF signals from a Doppler radar sensor. The efficiency of this approach has direct implications in the realization of the system in terms of reduced power and cost, such that this approach can be advantageous when compared to an FMCW and FFT approach.

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