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INTEGRATING RADAR AND CARRIER PHASE GPS FOR CLASSIFYING ROADWAY OBSTACLES

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Abstract

This paper describes an integrated MMW radar and GPS / road-map system for autonomous on-road navigation. The radar sensor has a range of approximately 200 metres and uses a linear array of receivers and wavefront reconstruction techniques to compute range and bearing of objects within the field of view. It is integrated with a carrier phase GPS / road-map system to accurately detect and classify obstacles in the environment with respect to the driving lane of the vehicle.

1 Introduction

In the context of an autonomous automobile driving at moderate or high speeds, an obstacle detection sensor with a fairly long range is needed (refer also to [5]). This sensor needs to be able to operate robustly under adverse weather conditions when long range visibility is poor, and provide object location at a sufficient longitudinal and lateral resolution and data rate. A MMW radar sensor was designed to accomplish this task.

For a vehicle driving on a road, objects in the vehicle's driving lane and neighbouring lanes are of immediate concern. It is generally not possible to tell whether a detected target would interfere with the vehicle's planned motion in cluttered environments and/or on curved roads using only radar data. Additional road geometry information is required. Several options are available for sensing road geometry. Previously, we described an integrated system using a vision sensor for detecting road geometry [3]. In this paper we present results with a similar integrated system set up, however replacing the vision sensor with a GPS / road-map based sensor for acquiring road geometry information.

2 Radar Sensor

A detailed explanation of the operation of the radar sensor used in the experiments has previously been discussed in **[3]** and can also be found in [4]. In this section, we will therefore only summarize the performance characteristics of the radar and show some experimental results.

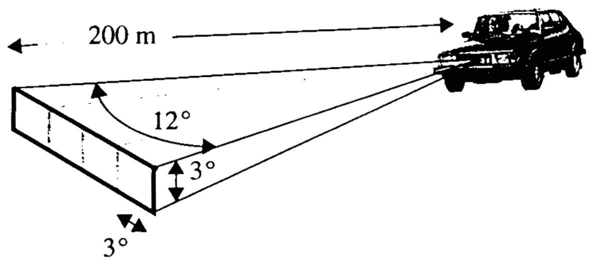

Figure 1 Sensor Geometry

The geometry of the radar sensor is shown in Figure 1. It has a vertical field of view (VFoV) of 3°, which provides a good compromise between good obstacle coverage in the vertical direction and avoiding false measurements due to ground reflections and returns from road signs or other structures located overhead. At longer ranges the ground (road) will reflect specularly. The horizontal field of view (HFoV) is 12" and divided into four angular resolution cells. Assuming an average highway lane width of **4** metres in the United States, the sensor covers one lane at a range of 19 metres and three lanes at a range of 57 metres. At a range of 95 metres the sensor covers an area of 20 m by 5 m.

The nominal maximum range of the radar is designed to be approximately 230 metres. By experiment we found that lorries can be detected up to 230 metres, cars up to 180 metres, people and animals up to a range of approximately 60 metres. The radar cross-section of a person is generally an order of magnitude lower than that of a vehicle and thus the detection range of **a** person is correspondingly smaller.

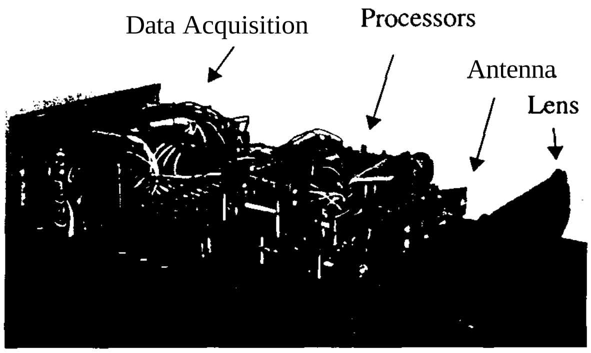

Figure 2 FMCW Radar Hardware

The radar is operated as a Frequency Modulated Continuous Wave (FMCW) system at 77 GHz with one transmitter antenna and a linear array of four receiver antennas (see Figure 2). Through FFT processing and wave front reconstruction techniques, the sensor can measure range, angular bearing and relative radial velocity (Doppler) to a target.

Target resolution, i.e. the ability to distinguish between two adjacent targets, depends on the number of sample points available and bandwidth. In range, we have a resolution of approximately 0.65 metres due to the FM sweep bandwidth of 240 MHz. In bearing, one resolution cell is $12^\circ/4 = 3^\circ$, since we have four receivers in the spatial dimension. It should be noted that therefore if two targets are at the same range, but their bearing is less than **3**° apart, they cannot be resolved anymore and are merged into a single target lobe.

Accuracy depends mainly on the signal-to-noise ratio (S/N) of the system. Through peak approximation in the Fourier Spectrum we obtained a relative accuracy of approximately 11 cm in range. In bearing we obtained a relative accuracy of approximately 0.07° .

It should be noted that here, resolution is the ability of the system to distinguish between two separate targets that are close together, whereas accuracy is the absolute accuracy with which a single target position can be determined. (See Figure 3 and Table 1).

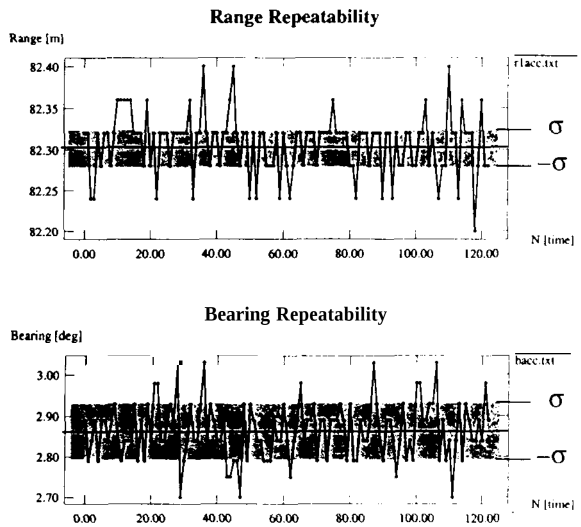

Figure 3 Range and Bearing repeatability and accuracy over time

	Bearing [deg]	**Range [m]**
num. of samples n	123	123
mean $\bar{x}$	2.86	82.31
standard dev. σ	0.0685	0.0364

Table 1 Statistics on Range and Bearing measurements

3 GPS and Road Map

Global Positioning System (GPS) uses a constellation of satellites to transmit coded signals which are tracked and decoded by GPS receivers to determine their location, velocity and direction of travel. In recent years, rapid advances have been made in the areas of GPS Receivers and in implementing various techniques to improve the positional accuracy. The cheaper price and improved performance of the receivers have made it possible to be widely used by the general public.

The location of the receiver is detemined by measuring the time elapsed between the transmission of signals from satellites and the reception of signals by a receiver. These measurements are affected by different sources of error like, receiver clock error, sattellite clock error, SA (Selective Availability)error, ionospheric delay, multipath errors etc. In a Differential GPS system, some of these pseudorange errors are minimized by comparing the receiver measurements with that of a reference receiver at a fixed, surveyed location. Such a system can yield a positional accuracy of < 2m.

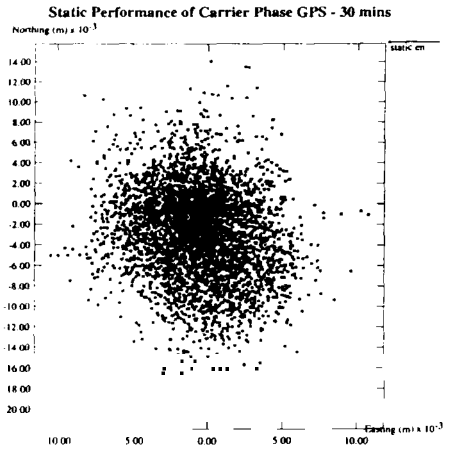

Figure 4 Static Performance of Carrier Phase GPS

In a camer phase GPS system **[2],** the receiver tracks the phase of the camer frequency along with the code measurements. By monitoring the total number *of* whole and partial camer cycles of the two GPS frequencies (L1 = 19 cm wavelenght and **L2 = 24** cm wavelength), much more accurate position solutions can be achieved. Figure **4** shows the static positioning accuracy of few centi-meters as recorded by NovAtel RT-2 DGPS system over a 30 minute period.

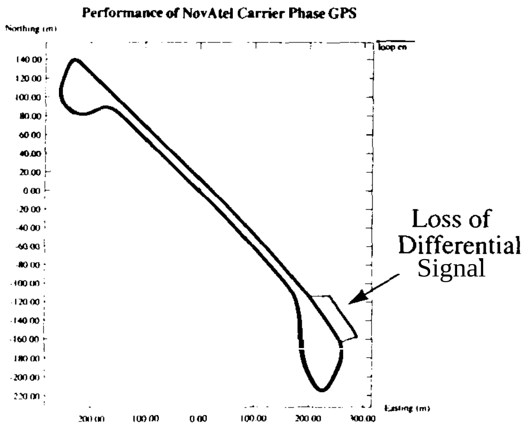

Figure 5 Dynamic Performance of Novatel RT-2

To indirectly measure the dynamic positioning accuracy *of* the RT-2 system, the test vehicle **was** driven repeatedly over the same segment of the roadway. Figure ***5*** shows the path tracked by the vehicle in **12** different runs. The total spread between different paths is **in** the order of –30 cm. (Figure **6**) **.** This includes the error introduced by the driver in maintaing the vechile path. The position data is available at the rate of 4 Hz to the host system. The overall latency is estimated to be around 50 to 100 ms.

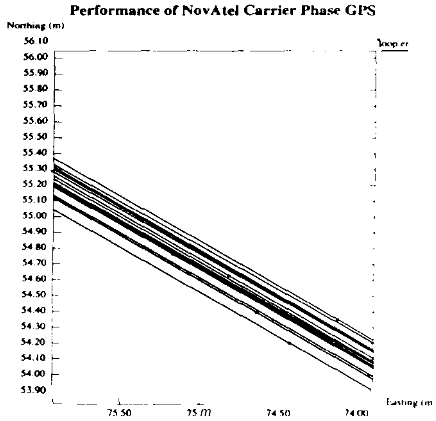

Figure 6 Detailed view of GPS performance

Using this GPS system, an accurate map of a portion of the road-network was created as shown in Figure 7 **.** In the integrated system, a seperate process reads the GPS data, accounts for the latency, matches the heading and location information with that of the map, transforms the geometry of the upcoming road segment to the coordinate frame of the radar sensor and sends the information to the radar process.

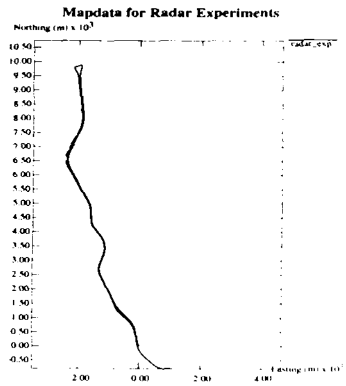

Figure 7 Road Map Data

Limitations of the GPS System: The major limitation of the GPS is its requirement for line-ofsight visibility to GPS satellites. For example, as shown in Figure **8**, going under an overpass can make the GPS receiver loose the lock on the various satellites that are being tracked. This effect is more pronounced in carrier phase GPS system, where the system has to recalculate the ambiguity in integer cycles in order to maintain the desired accuracy. However, this loss of positional accuracy could be handled by using a combination of motion sensors during that period.

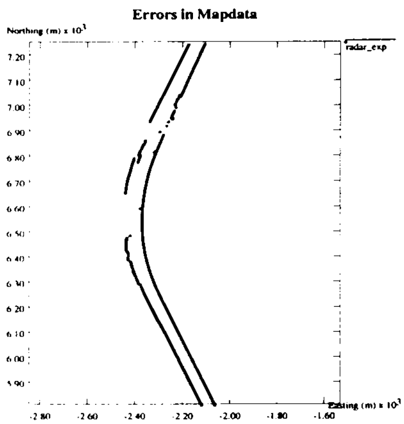

Figure 8 Errors due to loss of satellites

4 Integrated System and Results

4.1 Integrated System

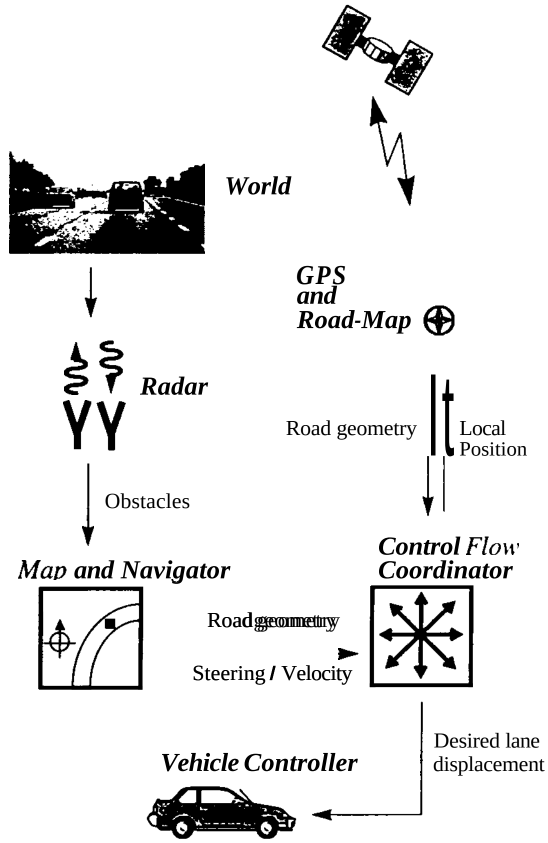

Figure 9 Data Flow Diagram

Figure 9 shows the interconnections for the data and control signal flow in the integrated system. The radar is used for detecting obstacle locations. The GPS/road-map system is used for sensing road geometry. Currently, only one of the road geometry systems is used at a time. Local vehicle position information is acquired from odometry, as computed by the controller using wheel encoders and a yaw sensor; global vehicle position is acquired by GPS.

The radar sensor sends detected obstacles to the Map/Navigator module. Here, obstacles are tracked through successive frames in a local grid map and combined with the road geometry information for danger level classification (refer also to [3] and [4]). Overriding velocity commands are sent back to the Control Flow Coordinator (CFC) in order to maintain a safe driving distance to preceding vehicles. Also, steering arcs that need to be inhibited in order to avoid collisions with vehicles or objects present in adjacent lanes are sent to the CFC.

4.2 Results

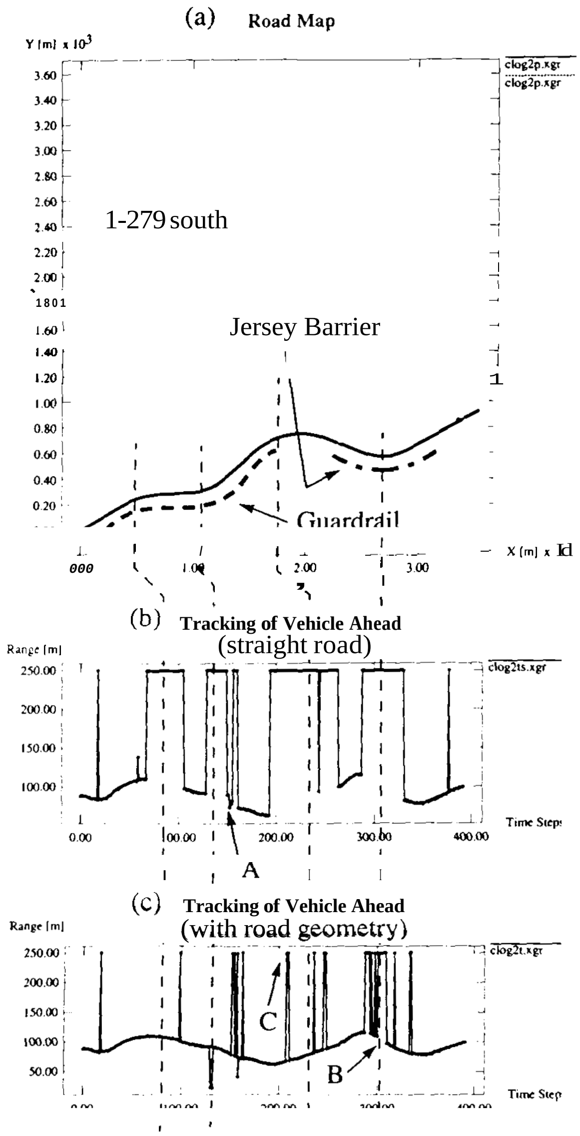

Figure 10 Tracking vehicle ahead in driving lane

At a range of 100 meters, in practice, the radar sensor can locate the lateral offset of an object approximately within

$$\varepsilon_{lat} = 100 \cdot \tan\ 0.1'' \approx 17.5 \quad [\mathrm{cm}] \qquad (1)$$

Overall, the error in lane-center and, hence, road geometry estimation from GPS/ road-map is less than 15 cm. Vehicles will generally drive close to the center of a lane, unless they are in the process of changing lanes. Assuming an average lane width of four meters, we observe that an object will always be placed correctly in its lane, given the total amount of measurement errors from above. This result has been confirmed by experiment as shown in Figure 10. Here, the additional information about road geometry allows us to track the preceding vehicle in our driving lane correctly through the curves (Figure 10(c)). If a straight road is assumed, as shown in Figure 10(b), the tracked vehicle **is** lost on the curved parts of the road.

In Figure 10, we can also make several additional observations: 'A' denotes a point where we erroneously detect the guardrail in our driving lane, as in this particular sequence we assumed a straight road. In 'B', the car being tracked, momentarily went outside the field of view of the radar because of the road curvature. Point **'C'** is an outlier in GPS data, where current vehicle heading was computed incorrectly.

Figure 11 shows a snapshot of the integrated radar and GPS/ road-map data.

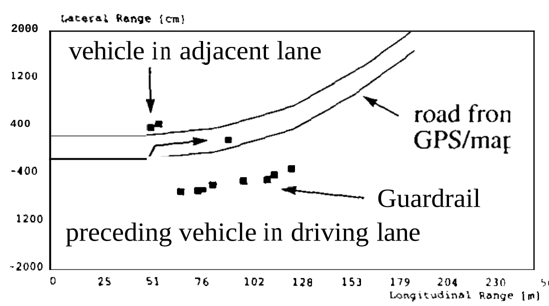

Figure 11 Integrated ***radar obstacle*** and ***GPS road-map***

5 Conclusions

The described integrated radar and GPS/road-map system demonstrates the ability of robust high speed vehicle navigation and obstacle detection. This is achieved by fusing data from two different sensor systems, radar and GPS/road-map, resulting in an improved vehicle navigation performance in a variety **of** different traffic and road scenarios. Results were obtained from the real system in a highway environment. Apart from being used in an autonomous navigation system, the sensor system would also be capable of providing relevant information about the local traffic situation to an intelligent cruise control (ICC) or a human driver. As an improvement over previous systems, it is able to operate on a highway as well as more cluttered environments such as rural roads. Improvements still need to be made **for** the camer phase GPS in order to better handle a momentary loss of satellites.

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