Introduction

With a growing bicycle population, many agencies are developing policies to support this vocal and politically connected community. With the adoption of specific mandates, such as California state law (AB1581) or agency specific policy directives, many traffic agencies are experiencing the challenging requirement to provide traffic signals designed with bicyclists taken into consideration.

Traffic signals have historically been programmed using the operational characteristics of motorized vehicles. Designing traffic signals with consideration for bicycles adds the issue of the minimum time a bicycle takes to cross the intersection is significantly longer than the time a motorized vehicle takes. A common estimate is if a vehicle min green time is 3 seconds, then the bike min green time should be 10 seconds. In the case of an eight phase intersection, if you assume bicycles are present in each phase, this will dominate the traffic signal timing plan and significantly reduce the operational efficiency of the traffic signal. The ability to determine if a bicycle is present or not will allow an agency to recapture these precious seconds and re-allocate them to efficiently move motorized vehicles through the intersection.

Bicycles present their own unique set of challenges to vehicle detection. Bicycles are small in size/profile and typically contain few ferromagnetic components, making detection by traditional means difficult. With this in mind, Sensys Networks, the leader in Ultra Low Power Wireless Sensor Networks, developed MicroRadar™. MicroRadar™ is a small battery powered detector which detects bicycles and differentiates between a bicycle and a motorized vehicle. MicroRadar™ expands the detection portfolio to include reliable and accurate detection of bicycles for traffic signal control applications.

MicroRadar™ detects bicycles by transmitting a very low power, high frequency RF pulse, which bounces off the target (bicycles and/or vehicles) and measuring the reflected energy profile of the RF pulse from the object. Using on board compute power, the sensor analyzes this profile to determine not only if an object is present, but the approximate size of the object to determine if it is a bicycle or a larger vehicle. Using the ability to detect and differentiate bicycles will enable traffic engineers to effectively time traffic signals for bicycles and motorized vehicles, simultaneously increasing safety and intersection efficiency.

Performance

A primary performance characteristic of MicroRadar™ has been characterized utilizing a bicycle similar to the one AB1581 subcommittee utilized in its bicycle detection testing after its formation. This Reference Bicycle-Rider was defined as a minimum 4’ tall person, weighing a minimum of 90 lbs., riding on an unmodified minimum 16” wheels bicycle, with non-ferromagnetic frame, aluminum rims, stainless steel spokes, and head light. The criteria used in this evaluation was that such bicycle-rider combination when properly placed in an approved detection system, shall be detected at least 95% of the time. Figure 1 shows a bicycle model (Dahon Curve SL) which was used in this testing:

Figure 1: Dahon Curve SL similar to this one was used in the AB1581 subcommittee bicycle testing

Sensys Networks tested MicroRadar™ utilizing a small bicycle which meets the Caltrans reference requirement. Vigorous testing showed that MicroRadar™ always detected the test bicycle when it was within the detection area as shown in Figure 2. The Caltrans requirement is for approximately a 6’ x 6’ detection zone (minimum). The crankshaft of the bicycle was used as the reference point for the distances shown in the graph. You can see from the graph that MicroRadar™ meets that requirement in that you can draw a 6’ x 6’ square within the shaded region.

Figure 2: MicroRadar™ Detection Zone with Caltrans Children’s Bicycle, MicroRadar™ sensor is located at 0, 0 pointing right. The square illustrates Caltran’s requirement of a 6’ x 6’ bicycle detection area

The Big Bang

The sensor transmits small bursts of energy at very low power levels, below FCC part B limits, and mixes the transmitted RF burst with a received RF reflection to generate an IF signal proportional to the return signal energy. The Big Bang is the name of the event which generates the radar pulse necessary to create and capture the radar profile. The impact of the Big Bang both is shown with a target at 6 feet meters in Figure 4 and with no target in Figure 5 on page 57.

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How MicroRadar™ Detects

Once the Big Bang takes place and the radar profile is gathered, it is further refined and analyzed within the sensor. Figure 5 illustrates what the typical baseline reading looks like with no objects present.

Figure 3: 512 IF Samples showing big bang and target at 6°

Figure 4: 512 IF Samples showing big bang and no target.

Figure 5: Detection bins showing big bang (on left) and no target.
Basic Detection

The simplest detection algorithm compares each bin to its baseline value. Any bin above the baseline triggers a detection event. The biggest issue with this method is how to determine these baseline values. One approach is to set the baselines to a fixed pattern, for example set baselines after the big bang to a single value, and set baselines during the big bang to infinity or a sloped line. This approach is OK for detecting vehicles but not good for detecting bicycles because the margin required to avoid false detection reduces sensitivity significantly. Since a single baseline is used for all bins any fixed obstacle (like a pole) will also be detected unless a range limit is applied. The baseline value for simple detection is set in the factory which means it will not adapt to installation or other variations.

A simple addition to this method allows a user to set the baseline by sampling the actual bin values after installation (i.e. using the recalibrate command currently used by magnetometers).

Adaptive Baseline for Bicycle Detection

After environmental field testing, it was found that the detected signal in the tail of the big bang was not stable over all environmental conditions. Rain and to some degree temperature and humidity would create nulls or flat lines in the otherwise decaying exponential of the big bang's tail. This phenomenon made it difficult to compute a one-time baseline for the detection of bicycles. Therefore an algorithm was developed to continuously update the baseline. The algorithm is feed-forward and therefore does not depend on successful detection to converge properly and therefore does not suffer from getting "stuck on". The feed-forward algorithm depends on the fact that over a long period, in this case 3 or 5 minutes, at least 10% (programmed in firmware) of the time no vehicles will be present near the MicroRadar™. The algorithm maintains a sorted list of 60 detection bin sets (excluding motion detection), one every 3 or 5 seconds, and takes the 10th percentile of the sorted list as the baseline. The list is sorted by overall energy across the bins (sum of the log bin values). Bins containing vehicles will appear in the upper percentiles of energy while those that correspond to no vehicles will be in the lower percentiles. In order to improve performance an average of 4 bin sets near the 10th percentile are used instead of a single bin set. To improve initialization speed, the 60 bin sets are first filled as fast as possible (60 consecutive one second or shorter readings), then revert to one every 3 or 5 seconds.
This algorithm can be used in conjunction with the factory default baselines to handle cases when occupancy goes over 90% (for example during extreme saturation).

**Differentiating Bicycles from Vehicles**

The basic method to differentiate bicycles from vehicles is based on measuring the bulk of the returned RF signal. Bulk can be defined either as the number of bins above the baseline (i.e. the number of distances that yield a reflection) or by summing the overall log energy above the baseline (i.e. related to the overall reflected energy). It was determined that bicycles yield relatively small bulk values and never go above a specific bulk value while vehicles can generate both small and large bulk values, but generally generate large values. Figure 8 (shown on right) shows a histogram of bulk values for vehicles and bicycles using the number of bins above baseline method.

**Deployment**

The deployment of MicroRadar™ can vary depending on the installation, but it will typically follow some basic guidelines. MicroRadar™ is suitable for installation in both dedicated bicycle lanes as well as shared lanes. The basic guidelines are similar for both; however different detection zone sizing will typically be utilized as most dedicated lanes are narrower than shared lanes. MicroRadar™ is intended to supplement existing vehicle detection with the ability to detect bicycles. MicroRadar™ can be used with any existing form of detection.

In the first scenario, MicroRadar™ is deployed inside the traffic lane and pulsing towards the intersection. The MicroRadar™ will typically be installed 6 feet (2 meters) from the limit line. This is illustrated in Figures 9 below. This orientation offers the best deployment when vehicle/bicycle differentiation is required.

In the second scenario, MicroRadar™ is deployed on the side of a dedicated bicycle lane and pulsing towards the curb. This is ill...
Competitive Advantages of MicroRadar™

MicroRadar™ offers many significant advantages over other technologies which detect bicycles, including inductive loops and video detection.

Inductive loops, while capable of detecting bicycles, can struggle to do so with normal loop configurations. D style loops, as shown in figure 12, enhance their capability to detect bicycles, but at a significant cost. D Loops are very destructive to the pavement due to the large sawcuts required. In addition, many of these sawcuts create sharp corners, increasing the stress on the pavement. These increased stresses can lead to premature pavement. The same sharp corners place extra stress on the loop wire itself. This stress will cause the loop wire to fail prematurely. When the loop fails, the loop will need to be replaced, further perpetuating this cycle.

Both inductive loops and video detection are not able to differentiate a bicycle from a vehicle. This requires the traffic signal control to assume that a detection event must be a bicycle and provide the necessary minimum green times for their safety. With MicroRadar™’s ability to differentiate a bicycle from a larger object, this will not be a required parameter.

Conclusion

MicroRadar™ offers the transportation professional the optimal method to reliably detect bicycles for intersection control. With this sensor’s ability to differentiate a bicycle from a larger object, traffic engineers will be able to safely and efficiently operate their intersections while taking bicyclists into consideration. With its fast and easy installation, the sensor will enable agencies to quickly respond to the growing needs of the bicycling community. MicroRadar™ extends the life of the roadway compared to numerous invasive sawcuts of D style inductive loops.