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Application of Deep Learning Techniques to Detect and Estimate the Risk of Wrong-Way Driving (WWD) Incidents

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<tr><td>Abstract</td><td colspan="3">The report presents an effective and adaptable traffic monitoring system designed by Auburn team based on deep learning technique which can be qualified for various road scene. One of the most important application is Wrong-Way driving (WWD) detection at freeway interchange terminals. Although different agencies have implemented several kinds of WWD detection systems such as loop detector or radar detector, the deployment always costs too high and a long term of construction period is required. This fact highly limited the exploration of WWD incidents at different locations. The solution presented by this report can be used for WWD detection only rely on basic portable road cameras. Then the computer version and tracking technique are applied to recognize WWD movements. This system has been tested by AU team to recognize more than 5000 hours videos from 58 partial cloverleaf (parclo) interchanges in 11 states. Including AL, CA. TX, FL, GA, NC, SC, AR, VA, TN, and MS. And the system identified 360 WWD incidents from these videos. Also, these videos were watched manually by AU researchers to count the number of WWD incidents and verify the detection results. The solution finally been proved having higher accuracy detecting WWD incidents than manually watching. Further iterations of this system are counting cars, detect illegal acts and evaluate traffic conflicts. This solution provided a 100% low-cost methodology to extract traffic information from existing videos or real time monitors. And the algorithm can be qualified for multiple purpose for both DOT or research institute.</td></tr>
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1. DESCRIPTION OF PROBLEM

1.1 Background

Wrong-Way driving (WWD), which can be defined as a vehicle driving against the legal traffic direction. Based on the Fatality Analysis Reporting System (FARS) database, it was reported that approximately 360 people dead from 270 fatal WWD crashes on freeway each year since 2004, resulting in a 1.34 fatality per WWD fatal crash. Beside of the severity, another fact is that WWD crashes are rare comparing to other types of crashes. According to the limited crash records, it is very hard to identify where the Wrong-Way vehicles starts from. In other words, in order to prevent WWD crashes, researchers must focus on improving the locations which make vehicles driving on Wrong-Way. As a result, when most agencies conducting WWD prevention, they usually choose to improve the nearby interchange terminals based on WWD crash locations (usually on freeway segment). However, whether these interchange terminals are the entry points of WWD crashes are questionable.

Although different agencies have applied some ITS technologies focusing on WWD prevention, such as thermal camera detector, radar detector and loop detector. These countermeasures are only deployed at few locations with WWD crashes nearby, due to the high costs and long-terms of construction need. On the other hand, these kinds of ITS countermeasures are all reactive countermeasures, which means it can only detect and send notifications after WWD happened. To better solve the WWD problem, more research need to be done focusing on eliminate the risk of WWD.

Based on previous research, the number of WWD incidents generated at specific location, i.e., drivers driving against the legal direction of the traffic flow and self-corrected instead of ending up with crash, can be used as a factor to evaluate the potential risk for WWD crash. Furthermore, the traffic condition also affects the generation of WWD incidents, i.e., the WWD incidents always happened during midnight and early morning since there’s no other vehicles for reference.

1.2 Problem Statement

A WWD prediction model has been developed by the AU research team to identify the high-risk locations for WWD happening. To verify the results based on the model, the high-risk locations need to be monitored and check whether there are recurring WWD incidents. Since the WWD incidents are also rare events, the field verification always requires more than 72 hours video to find out whether the recurring WWD incidents exist. So how to detect the WWD incidents from a huge amount of videos become a problem for AU researchers. As shown in **Figure 1**, the gray vehicle is trying to enter the freeway through the exit ramp even there’s two “DO NOT ENTER” signs exist.

Figure 1: Example of WWD Maneuver Recorded by camera

2. DESCRIPTION OF SOLUTION

To dealing with the large amount of videos, a new method based on YOLO V3, an object detection algorithm, was developed to extract the WWD incidents. This solution can be also applied for other different problems such as counting cars, detecting illegal traffic movements and estimation of potential conflicts. To better describe how it works, This part was split into five parts: “Video recording”, “Preprocessing”, “Detection”, “Tracking”, and “Wrong way Driving detection”.

a) Video Recording

In this part, two kinds of cameras are used for different purpose. For long-term monitoring purpose, the real-time monitoring camera were applied. As **Figure 2** shown below is the 4G camera monitoring system design for the project. The video camera will installed on the target location and facing to the problematic exit ramp. To ensure the video camera operating all day, the lead-acid battery with solar panel will be applied together with the video camera. The solar panel will supply enough electricity for the camera and recharge the lead-acid battery during a sunny day. As for the day without enough sunlight, the lead-acid battery will be the back-up electricity supply. While the 4G camera is taking the real-time video, the camera will automatically upload the video to the cloud by using the Wi-Fi signal generated by the hotspot. By doing this, the researchers can receive the real-time video from the target site.

Another kind of camera used in this study is portable traffic cameras (COUNTcam2). They were mounted at the roadside of the target terminals. The cameras have a wide, color viewing with an angle of 170 degrees to accommodate the entire terminal. They can record videos with a resolution of 720P up to 72 hours when fully charged.

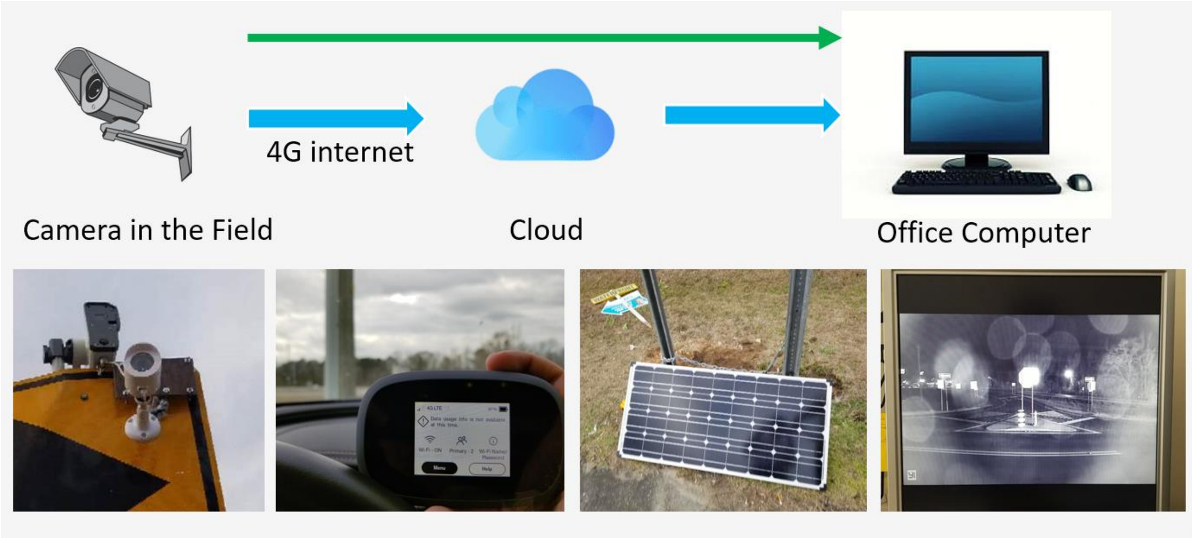

Figure 2: The 4G Video Monitoring System

2.2 Preprocessing

In this study, all the videos used for analyzing were pre-recorded videos. However, the solution applied in this study can be also applied for real-time video analysis. The first step conducting object detection is to split the video into frames. In this project, the video quality recorded by camera is at 10 frame per second, which means 10 pictures will be taken in 1 second. For example, 18000 frames of picture would be recorded in 30 minutes. Considering about the efficiency, 3 frames per second already good enough for computer to track the trajectory of the object. So the split policy was set to keep one frame for every three frames, which means that given a 30 minutes video, we will only need to analyze 6000 frames, that will save us 2/3 time comparing to analyze all the frames.

2.3 Detection

Detection is always the first step for many computer visual tasks and our task is no exception. For our problem, after we get the split images of videos, the first task is to detect the vehicles inside of the images. There are plenty of algorithm that can perform object detection, in our problem we choose Yolo V3 to detect the images. Yolo V3 is the third generation of Yolo and it makes a big improvement on speed and accuracy on yolo algorithm. Yolo V3 is trained and tested end-by-end. In training phase, there are huge amount of labeled data used as training samples to minimize the loss function. In test phase, feed an image to the trained model and the model will output the coordinate, label, and confidence of object in image. There are two reasons for choosing Yolo V3 as our detection algorithm: 1. The speed of Yolo V3 is fast enough that can process around 40 images per second. 2. The accuracy of detection is acceptable for our task. As figure 3 shown below, the Yolo V3 was used to create labels and coordinates for vehicles in each frame, each vehicle will be circled by using a rectangular and the coordinate of the four points of the rectangular would be recorded. Once the split frames were analyzed by Yolo V3, all the vehicles and their coordinate information in each frame were recorded into a text file. So far, all the information needed for WWD detection have been converted into text format, the rest of analysis will be focusing on the vehicle's coordinate information.

Figure 3: Creating Label and Coordinate by using Yolo V3

2.4 Tracking

By using Yolo V3, all vehicles in each frame were labeled and their coordinate in each frame were recorded. But only the vehicle coordinate information is not enough to generate the object's travel route. So, the trajectory of each vehicle from frame to frame needs to be calculated. The algorithm "SORT" would be applied to conduct this task. SORT is the abbreviation of "Simple Online and Realtime Tracking", it is a state-of-art multiple object tracking algorithm that proposed in 2016. It achieves state-of-art performance at that time and the most important thing is Sort is 20 times faster than SOTA, which is also tracking algorithm proposed in 2016. The SORT takes a sequence of coordinates which we got from Yolo V3 as input, based on the coordinates of previous frames, the SORT will make a prediction for coordinates of current frame, to assign the predictions to the target of current frame, IOU (Intersection over union) distance is used to measure the similarity between predictions and target coordinates. IOU distance is to calculate the ratio of overlapping between 2 rectangular, the bigger the value of IOU, the more similar two rectangular are). These assignments are solved optimally using the Hungarian algorithm.

2.5 Wrong-Way Driving Determination

After all these steps above were conducted, the trajectory of each object can be determined. To further judge whether the vehicle's trajectory involved WWD, as shown in **Figure 4**, a line based on our experience needs to be drawn. This line is more likely to be an "invisible fence". Any vehicle's trajectory that cross the fence would be considered as the candidates of WWD incidents. Before further introducing how to determine whether the car cross the line, some notations need to define: the coordinate of two ends of the line can be represented as $P_1(x_1; y_1)$ and $P_2(x_2; y_2)$ and the coordinates of four point of the rectangular used to locate the vehicle can be represented as $Q_1(x_1; y_1)$;$Q_2(x_2; y_2)$ $Q_3(x_3; y_3)$;$Q_4(x_4; y_4)$. A rectangular is intersected with a line-segment only when any two edges of rectangular is intersected with line segment. To determine whether these two line-segments are intersected, we can use cross product (As shown in **Figure 5**). Assume we have two line-segments P_1, P_2, Q_1, Q_2, we can follow **Equation 1** shown below:

$$
\begin{aligned}
d_1 &= (P_2 - P_1) * (Q_1 - P_1) \\
d_2 &= (P_2 - P_1) * (Q_2 - P_1) \\
d_3 &= (Q_2 - Q_1) * (P_2 - Q_1) \\
d_4 &= (Q_2 - Q_1) * (P_1 - Q_1)
\end{aligned}
\qquad (1)
$$

when $d_1*d_2 < 0$ and $d_3*d_4 < 0$, these two line-segments are intersected. Similarly, the cross product can be applied to each side of the rectangular and determine whether the rectangular is crossed with the "fence".

Figure 4: The Baseline for Judging WWD movements

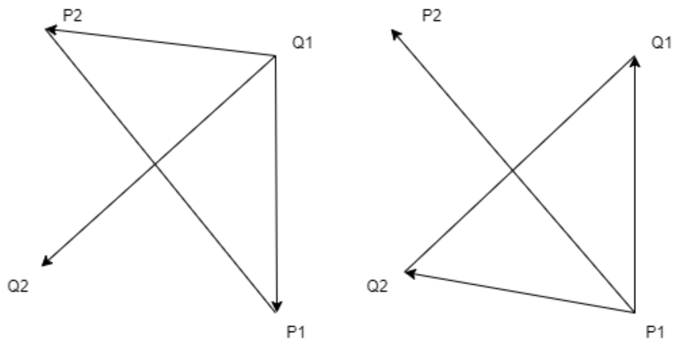

Figure 5: Cross product Calculation

In some situations, even some vehicles drive crossed the "fence", it is not WWD. Such as the vehicle drive from the exit ramp to the crossroad. To pick out the car that behave anomaly, a vector is needed to represent the Wrong-Way direction, as shown in **Figure 6**. The black arrow indicates the direction of wrong way driving

Figure 6: Direction Vector for WWD Judgement

The two ends of the arrow can be represented with $V_1(x_1, y_1)$ and $V_2(x_2, y_2)$, and the direction of the arrow can be represented by using V_{arrow}, as shown in **Equation 2**. Once a vehicle crossed the fence, coordinates of that vehicle of current frame and next frame will be recorded. As a result, the driving direction of that vehicle can be determined by using the adjacent two frames of rectangular central points $C_1(w_1; z_1)$, $C_2(w_2; z_2)$, represented as $V_{driving}$, as shown in **Equation 3**, which is another vector. To calculate the degree of angle between driving direction and arrow direction, we can use Cosine metric as shown in **Equation 4.**

$$v_{baseline}: (x_2 - x_1, y_2 - y_1) \quad (2)$$

$$v_{driving}: (w_2 - w_1, z_2 - z_1) \quad (3)$$

$$\cos(v_{baseline}, v_{driving}) = \frac{v_{baseline} * v_{driving}}{|v_{driving}| * |v_{baseline}|} \quad (4)$$

Once the degree of angle between driving direction and the arrow direction was calculated, a degree threshold can be set as θ, which indicates the tolerance for WWD direction. If the degree of angle between driving direction and the arrow direction are smaller the threshold angle been set, the incidents will be recorded as WWD incidents. Otherwise the system won't send any alert. The smaller the θ is, the more similar the output driving direction would be with the arrow direction. As shown in **Equation 5**. As shown in Figure 7, The WWD vehicle were recorded by the algorithm.

$$Wrong\ Way\ Driving = \begin{cases} Yes & when\ \ cos\theta > cos\ (v_{baseline}, v_{driving}) \\ No & otherwise \end{cases} \qquad (5)$$

Figure 7: Recorded WWD Incident

3. CO-OPS FOR SOLUTION

3.1 High-Level Functional Architecture

The functional architecture of the purposed solution including two parts, as shown in Table 1, including the field camera combo and the devices required in TMC.

Physical Object	Functional Object	Functioanl Description
ITS Roadway Equipment	Traffic Monitoring Camera	Monitors the traffic movements at target location
	Network Module (Optional)	Remote data transferring
	Solar Panel (Optional)	Provide power supplement
Traffic Management Center	TMC Basic Surveillance	Monitoring the traffic condition in target area
	Computer with High Performance Graphic Card	Perform high speed object detection

Table 1: High-Level Functional Architecture

3.2 High-Level Physical Architecture

The physical architecture of the system mainly based on several algorithm, which enables the WWD detection function, as shown in **Figure 8**. What's more, the algorithm can also used for other purpose such as counting cars, reporting unusual traffic movements, etc. Just by changing the rules.

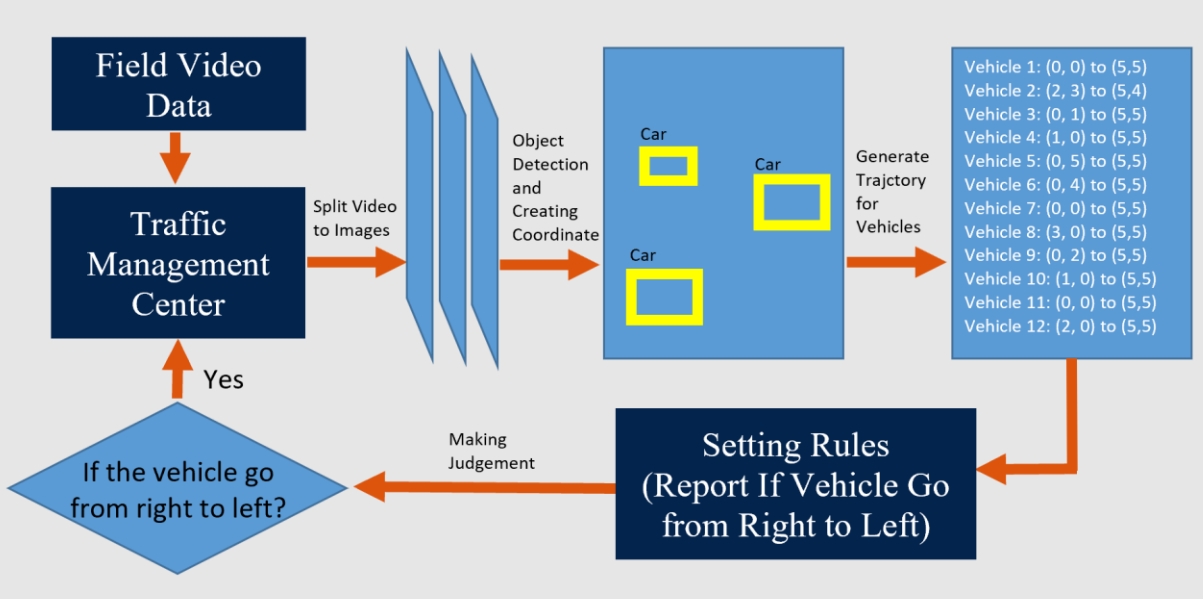

Figure 8: High-Level Physical Architecture

3.3 High-Level Enterprise Architecture

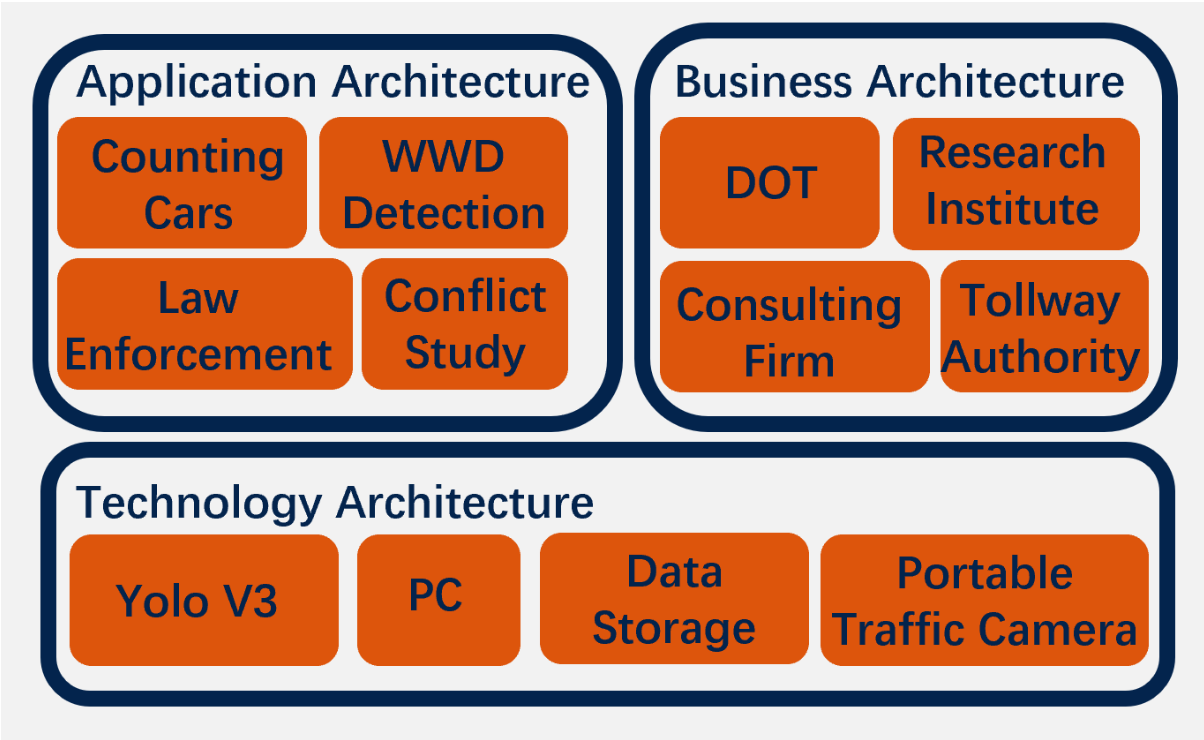

Figure 9: High-Level Enterprise Architecture

4. ESTIMATION FOR THE WORK

The estimation of the work contains two parts, the cost breakdown summarized the cost for devices and laborers within the project. Additionally, the timeline illustrates the time breakdown for the project. The detailed information is shown as follow:

4.1 Cost Breakdown

This project was aimed to use low-cost way to achieve the purpose of data collection. The whole system will finally deliver to the state government or the academic institution to identify more potential sites with high WWD risk and enlarge the WWD incidents /crashes database. As a result, the device such as cameras, solar panel, and other accessories are one-time purchase and are good for at least two years. Besides, the internet provider which is used to provide internet access for the camera should be paid monthly. Rather than installing on the filed permanently, the whole system is portable and aimed to collect the WWD incidents at certain locations temporarily. The gas and rental car costs should be considered for researchers to deploy the system on the field and bring it back. As for the current condition, the WWD monitor system were implemented at the south off-ramp terminal of I65, Exit 208 in Alabama, which is one of the locations that had frequently WWD incidents. The total cost for the gas and car rental fee would be $170/round trip. This cost will be varied in the future depends on different conditions and monitor sites. **Table 2** listed below, is the detailed information about the cost breakdown. It will cost $1,470 for a single site exclude the gas and rental car costs.

Device	Quantity	Cost Per Unit	Total Cost
	Single Site		
Camera	1	$500	$500
Solar Panel	1	$79.99	$80
Lead-acid Batteries	1	$159.99	$160
Related Accessories	1	$250	$250
Internet Provider (whole year)	1	$480	$480
	Single Site Total Cost		$1,470
Other Cost			
Gas	price may be varied		
Rental Car			

Table 2: Cost Breakdown

4.2 Timeline

The timeline for this project is summarized in **Table 3**. The whole project already started in January 2020 and is anticipated to be finished in 12 months. After the whole system was tested and validated on the field. The whole system can be generalized to the government and academy agency to obtain more WWD related data and develop the proper models in the future.

	Year 2020											
Task	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Problem Identification												
Equipment setting												
Algorithm development												
System Deployment												
System Testing & Validation												
Stakeholder assessment												
System Deployment (more sites)												
Data analysis & Model Development												

Table 3: Timeline

5. ANTICIPATED IMPACTS

5.1 Operational benefits

The whole WWD detection system can enhance the WWD data collection effort. The proposed WWD detection system is easy to install and operate. Only the 4G high-resolution camera, solar power panel, and the image detection software are required for this system. There are only three operation steps: installing the camera, downloading the videos from the cloud, and using the machine learning based software to automatically detect and counting the WWD vehicles. Additionally, compared with other existing ITS WWD detecting devices based on the thermal or motion detection technology, the detecting results from this video-based image object detection technology are much more accurate.

5.2 Safety benefits

With the usage of the WWD detection system, a number of the WWD incidents or crash will be collected, which will enlarge the WWD database and befit for the future WWD analysis. More solutions to mitigate WWD will be proposed with the increasing of the WWD database. Besides, the site monitor by using the whole system can help the state government and agencies to identify the sites with the potential WWD risk. After that, the geometric design and countermeasure deficiency can be analyzed and the proper solution will be developed to reduce the number of WWD incidents/crashes.

5.3 Mobility benefits

With the aid of the WWD detection system, a number of the high-risk WWD sites will be identified and improved. Considering the potential impacts of the recurring WWD movement, the improvement of the sites will reduce additional conflicts and severe crashes caused by WWD, which may save drivers time and increase travel mobility.

5.4 Economic benefits

The whole WWD detection system is low-cost and durable. Compare with the current loop detector based WWD detection system, which is easy to damage and has a high maintenance fee. Out detection system consistent with the low-cost devices which are hard to be damaged. Additionally, the whole system can detect the WWD movements automatically, which saves time compared with counting WWD movements manually. More importantly, since the whole system is portable and easy to install on the field, there is no need to hire professional workers to install the whole system, which saves the labor fee.

5.5 Environmental benefits

The team chose the solar power panel to power the ITS device, which is a kind of recyclable and sustainable resource compared with traditional battery (the traditional battery cannot support the camera for more than three days). Also, solar energy systems generally don't need a lot of maintenance. The only thing need to do is to keep them relatively clean, so cleaning them a couple of times per year will do the job. Currently, in the market, the most reliable solar panel manufacturers offer 20-25 years warranty.

5.6 Other benefits and risk

The risk of this ITS WWD detection model is device safety. Since most of them are installed in rural areas, the cameras and the solar power panel might have the risks of being stolen or damaged by unexpected people or wild animals. So there are still some needs for the safety and security treatments. Another challenge for this WWD detection system is to find a proper location to install the camera to covers all the target movements on the filed. This requires the engineering judgment and filed experience.