Smart Traffic Management System using Deep Learning for Smart City Applications

Guy M. Lingani
Department of Electrical Engineering and Computer Science
Howard University
Washington DC, USA
gmlingani@howard.edu

Danda B. Rawat
Department of Electrical Engineering and Computer Science
Howard University
Washington DC, USA
danda.rawat@howard.edu

Moses Garuba
Department of Electrical Engineering and Computer Science
Howard University
Washington DC, USA
mgaruba@howard.edu

***Abstract*—Already known as densely populated areas with land use including housing, transportation, sanitation, utilities and communication, nowadays, cities tend to grow even bigger. Genuine road-user's types are emerging with further technological developments to come. As cities population size escalates, and roads getting congested, government agencies such as Department of Transportation (DOT) through the National Highway Traffic Safety Administration (NHTSA) are in pressing need to perfect their management systems with new efficient technologies. The challenge is to anticipate on never before seen problems, in their effort to save lives and implement sustainable cost-effective management systems. To make things yet more complicated and a bit daunting, self-driving car will be authorized in a close future in crowded major cities where roads are to be shared among pedestrians, cyclists, cars, and trucks. Roads sizes and traffic signaling will need to be constantly adapted accordingly. Counting and classifying turning vehicles and pedestrians at an intersection is an exhausting task and despite traffic monitoring systems use, human interaction is heavily required for counting. Our approach to resolve traffic intersection turning-vehicles counting is less invasive, requires no road dig up or costly installation. Live or recorded videos from already installed camera all over the cities can be used as well as any camera including cellphones. Our system is based on Neural Network and Deep Learning of object detection along computer vision technology and several methods and algorithms. Our approach will work on still images, recorded-videos, real-time live videos and will detect, classify, track and compute moving object velocity and direction using convolution neural network. Created based upon series of algorithms modeled after the human brain, our system uses NVIDIA Video cards with GPU, CUDA, OPENCV and mathematical vectors systems to perform.**

Keywords*— *Deep Learning, Computer vision, Neural network, Convolutional Neural Network, Detection, Tracking, Counting, Video, GPU, Intersection.

I. INTRODUCTION

A smart city is a municipality that uses information and communication technologies to increase operational efficiency, share information with the public and improve both the quality of government services and citizen welfare [1, 10]. Traffic data collection is a key input ingredient to understanding and Improving Safety. Now a day every state or local government has some type of mechanism to collect traffic data such as magnetic loop, pressure tubes, radar gun, microwave sensors, and cameras. Statistics regarding street and highway accidents are so vital to any comprehensive understanding and treatment of the safety problem that their collection and analysis in every State and community are essential [2].

The goal of implementing traffic monitoring systems is to enable better decision-making through the use of collected data for all stakeholders such as government, business, and residents. The focus of any smart city should be its people, providing benefits such as: A better quality of life for residents and visitors; Economic competitiveness to attract industry and talent; an environmentally conscious focus on sustainability [3]. Accurate Traffic data collection allows reliable statistic which in return produce economic benefits by helping decision makers where to invest in safety improvement. An important step toward building smart cities starts by collecting targeted reliable information, analyzing them in order to implement sustainable solutions. Some of the challenge of collecting transportation information is human implication and the size of information to be processed particularly when video images are involved or real-time traffic images need to be processed.

In this paper will focus on extracting relevant information from collected data for public transformation agency. There exist several technics and devices to collect data traffic data, but we must concede that even with those technology human remain a big part of the process and those tasks are extremely labor intensive. Our goal is to reduce or suppress human intense labor need in the data processing by implementing autonomous monitoring system based on Computer Vision and Deep Learning. Such a system will detect track classified and count moving objects including direction, sense and velocity. Another key point is to eliminate human errors in order to produce accurate and reliable statistics.

Comparisons of traffic monitoring data collection systems have indicated their limits in autonomously and accurately collecting traffic data in road intersections. It is not clear, however that

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traditional monitoring system such as Magnetic loop, pressure tubes, Radar gun and Microwave sensors are capable of accurately collect traffic data in non-linear intersection. We did notice the lake of autonomous counting systems for orthogonal intersections as opposed to straight roads. Few monitoring systems even when using computer vision have not investigated or demonstrated traffic data collection for orthogonal intersections that implements left-turns, right-turn and drive-thoughts counting system. Several works in the attempt to ease the life of those who are collecting traffic data tells us a great deal about getting better monitoring systems. Ours researches and our preliminary tests in developing such a challenging monitoring system turned out to be very promising while implementing and testing independent components or modules based on the concept and approach we have developed.

II. REASONS AND BENEFITS

Our streets and highways are our laboratory. They speak to us, about their performance, through the data we collect and maintain. Timely, consistent, complete, accurate, and accessible data is vital to support decision making and reduce deaths and injuries [4, 12].Traffic safety is a health issue saving lives is the ultimate measure of success [4, 11]. In accordance with U.S. Department Of Transportation – National Highway Traffic Safety Administration- in its May 2015 report Intersection crashes in 2010 resulted in 8,682 fatalities, over 2.2 million injuries, and over 10 million Property Damage Only (PDO) damaged vehicles in 2010. This represents 26 percent of all fatalities and roughly 55 percent of all nonfatal crashes (including both nonfatal injury and PDO). Intersection crashes caused $120 billion in economic costs and $371 billion in comprehensive costs, accounting for 50 percent of all economic costs and 44 percent of all societal harm (measured as comprehensive costs) from motor vehicle crashes [6, 12]. The field-collected data is used to develop optimized traffic signal timings, with many benefits including but not limited to overall cost-benefit, fuel consumption reduction, air pollution reduction, travel time improvements, traffic signal hardware improvements, time saving for DOT and Startup Business opportunity based on actual data collection method in the in transportation industry.

III. BACKGROUND AND MOTIVATIONS ICATIONS

At Howard University Department of Transportation despite the use of new systems to collect road data, they are still relying on humans to process the recorded traffic videos. The process begins with a field trip to install cameras where the survey is to be conducted. The camera system does not have the ability to pan and tilt. After a certain period of time the camera is removed during a second field trip and brought back in a computer lab. Recorded videos are uploaded to a shared drive. The counting process is then conducted by several technicians. Each technician will watch a full recorded video and collect the statistics based on the study. In instance the number of cars turning right, the number of cars turning left or the number of cars driving through an intersection. The counting is done manually with an electronic counting board (Fig.1) or a paper based form (Fig.2) depending on the type of survey. During the counting the technician is required to classify cars, trucks, pedestrians and bicycles with regards to their respective direction and turning senses. We notice that speed is not collected in that case from the recorded videos

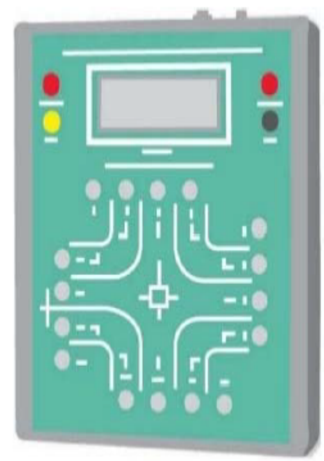

Fig. 1. Traffic electronic counting board .

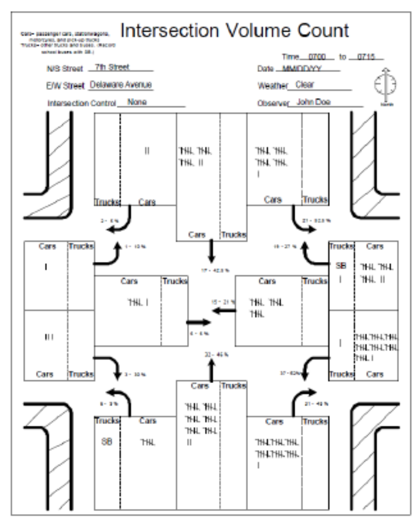

Fig. 2. Manual Intersection Volume Count Tally Sheet [9].

While it is easy to count moving cars in straight line, counting turning cars at an intersection is challenging due to the change of direction and sense of the vehicle.

IV. APPROACH

Our approach to solve the intersection counting burden uses recorded videos or live videos of an intersection as input. Howard University Department of Transportation traffic intersection recorded videos are used for that purpose. Below

Table I list our hardware and software used to implement our system.

TABLE I. HARDWARE AND SOFTWARE USED IN OUR SYSTEM.

Hardware / Software	Description
Computer CPU	HP Z240, Quad-Core i7-6700 3.4GHz, 32GB RAM
Computer Monitor	HPZ24n Monitor
Video cards	NVIDIA QUADRO M2000 , 4GB and NVIDIA QUADRO K620
Camera	USB video camera Logitech HD1080p real time object detection
Operating System	Linux CentOS 7
Opencv-3.4.3	Open Source Computer Vision Library with a strong focus on real-time applications.
NVIDIA-CUDA 10	CUDA is a parallel computing platform and programming model invented by NVIDIA.
Darknet	Open Source Neural Networks in C
Visual Studio	an integrated development environment-Microsoft

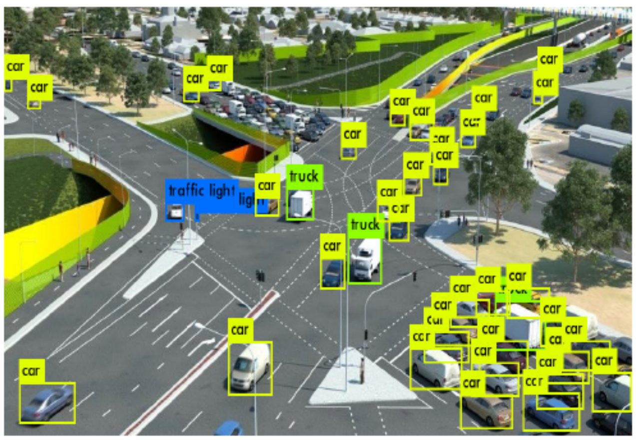

Fig. 3. Convolutional Neural network objects detection prediction.

detailed description of how our neural network is trained to detect, classified tract and return object coordinate will be set out in a forthcoming paper. Our focus here is to show our we tackle turning vehicle counts at an intersection. To do so our reasoning start when a vehicle is detected and its coordinates (x, y) is returned has it is moving. In Fig.3 vehicle are detected as they move and frame in a square box. The coordinate (x, y) of the box is returned as the vehicle position and compute in our coordinate system as shown in Fig. 4 and Fig. 5 for turning-right vehicle and turning left vehicle. With this approach a vehicle can be tracked and its moving direction, sense, and its velocity compute as it moves from video frame to video frame. On a personal computers (PC), the x coordinate is a given number of pixels along the horizontal axis of a display starting from the pixel (pixel 0) on the extreme top left of the screen. The y coordinate is a given number of pixels along the vertical axis of a display starting from the pixel (pixel 0) at the top of left of the screen as well. Our X-axis and Y-axis origin is shifted to the bottom center of the screen to match the intersection as shown in Fig5 and Fig.6 We then compute the positive angle to determine a moving vehicle direction and velocity over the time but summing up the successive vectors generate from its coordinates to the origin. The final direction is the resultant vector of all consecutive vectors to the origin (0,0). We are using the following reasoning in which a constant

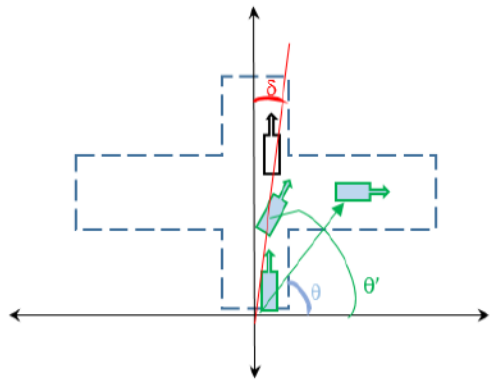

Fig. 4. Turning-right vehicle vectors in coordoonate system

angle delta δ defined and initialized as a threshold to determine at what extend a given vehicle final vector resultant positive angle theta (θ) from X–axis and the Y-axis is considered to be a right-turn or a left-turn or just a drive-through.

- For a right-turn Fig.4, the resultant vector positive angle (θ) is in the range of [0 ; (90 – δ)].

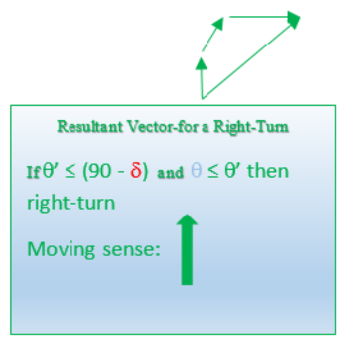

Fig. 5. Right-turn vehicle vectors resultante angle.

- For a left-turn the resultant vector positive angle is in the range of [(90 + δ) , (180+δ]

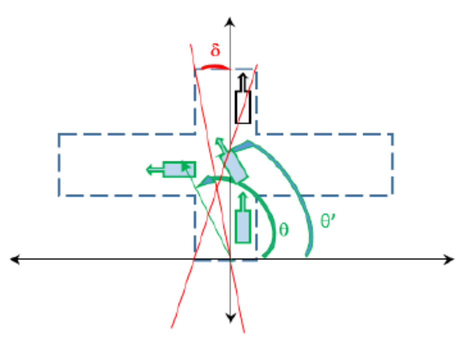

Fig. 6. Turning-left vehicle vectors in coordoonate system.

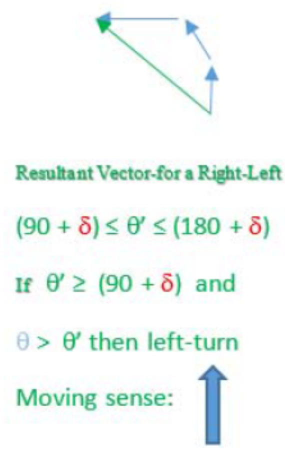

Fig. 7. Turning-left vehicle vectors resultante angle.

- A vertical drive-through is when the vehicle is moving from bottom to top or inversely; the resultant vector positive angle is comprise between [(90-δ); (90+δ)]. The sense is computed based upon the vector orientation or when the object Y-value is increasing or decreasing.
- For a horizontal drive-through when a vehicle is moving from right to left or inversely and the resultant positive angle is comprised between [(180 - δ) ; (180 +δ)]. The sense is compute based upon the resultant vector orientation or when the object X-values is increasing or decreasing.

Vectors allows us to compute not only moving object direction, sense and the magnitude from its coordinates over the time. As we detect, and track objects we also store their coordinates (Xt,Yt) as time function. Vectors magnitude also allow to compute a moving object velocity.

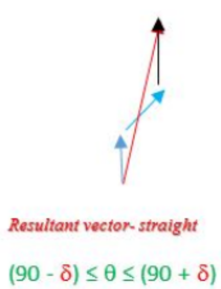

Fig. 8. Drvie-through vehicle vectors resultante angle.

Negative X-axis indicates left turn. Vehicle moving vector angle should be between to (180 and 90+delta). delta is the angle from positive Y-axis car final moving vector. The smaller the positive angle most likely car turns on right

In Computation atan2 uses two parameters.

double atan2(double y, double x);

It returns the principal value of the arc tangent of y/x, expressed in radians. To compute the value, the function takes into account the sign of both arguments in order to determine the quadrant.

*result = atan2(y, x) * 180 / PI*

Using the sign to determine the quadrant, atan2 return the positive angle in degree for Quadrant I and II.

For quadrant III and IV we will need to make some adjustment since *atan2(y , x)* will return a negative angle (clockwise) will we are interested in the positive angle counterclockwise from X-Axis.

We show below four quadrant and example of angle calculations. For quadrant III and IV correction is required to get the positive angle needed [7]

Vehicle positive angle in C++ from its X, Y coordinates as it moves.

```
#define PI 3.141592654

Double Turning-Angle(int x, int y)
{ double result, PositiveAngle;
  result = atan2(y, x) * 180 / PI; // result in degree from radian
  if ((x > 0) && (y > 0)) || ((x < 0) && (y > 0)) // quadrant 1 & 2
    PositiveAngle = result;
  if ((x < 0) && (y < 0)) || ((x > 0) && (y < 0)) // quadrant 3 and 4
     PositiveAngle = 360 + result;
  return PositiveAngle;
}
```

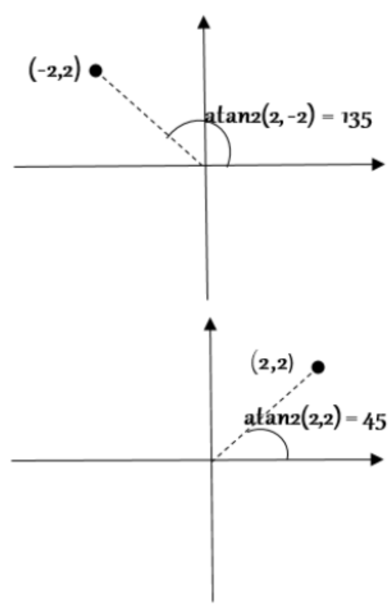

Fig. 9. atan2(y,x) returns positive angles in quadran I and II

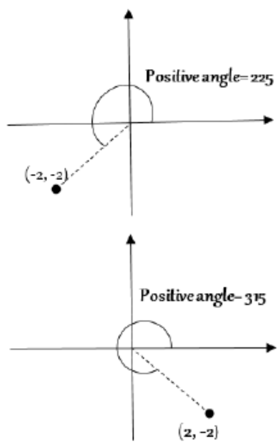

Fig. 10. Angle correction from atan2(y,x) in quadran III and IV.

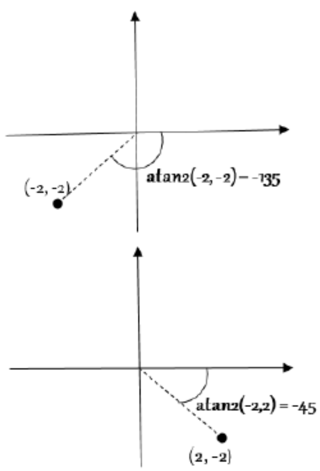

Fig. 11. atan2(y,x) returns negative angles in quadran III and IV

V. VECTOR VELOCITY

The vector from point A to B can be found as follow:

$$v = [(B.x - A.x), (B.y - A.y), (B.z - A.z)];$$

$$\text{vMag}=\sqrt{\text{v.x}^2 + \text{v.y}^2 + \text{v.z}^2}$$

vUnit = [(v.x / vMag), (v.y / vMag), (v.z / vMag),];

With a vector of magnitude one, we can give our object a speed value, and move it in any direction at constant (or not constant) speed:

$$\boxed{\text{Velocity} = [(\text{vUnit.x} * \text{speed}), (\text{vUnit.y} * \text{speed}), (\text{vUnit.y} * \text{speed})];}$$

AM Peak Hour
04/08/2015

	NB					EB					SB					WB					
Start Time	Left	Thru	Right	Ped	App Total	Left	Thru	Right	Ped	App Total	Left	Thru	Right	Ped	App Total	Left	Thru	Right	Ped	App Total	Int Total
7:45 AM	62	165	13	4	240	6	0	32	0	38	12	246	22	1	280	9	0	7	0	16	574
8:00 AM	68	159	12	2	239	6	1	40	0	47	12	249	14	2	275	17	0	10	1	27	588
8:15 AM	51	172	11	6	234	6	1	40	0	47	6	233	7	0	246	8	4	10	0	22	549
8:30 AM	49	155	6	0	210	10	3	51	0	64	13	220	10	0	243	17	0	9	0	26	543
Total	230	651	42	12	923	28	5	163	0	196	43	948	53	3	1044	51	4	36	1	91	2254
PHF	0.85	0.95	0.81		0.96	0.70	0.42	0.80		0.77	0.83	0.95	0.60		0.93	0.75	0.25	0.90		0.84	
HV %	0	4	67			0	0	1			53	5	0			78	0	81			

☑ Cars ☑ Trucks ☑ Pedestrians ☑ Bikes

Fig. 12. Intersection Count from Howard University Traffic DDOT.

VI. RESULTS

According to HU department of transportation, count accuracy manual count accuracy is around 80% to 95%

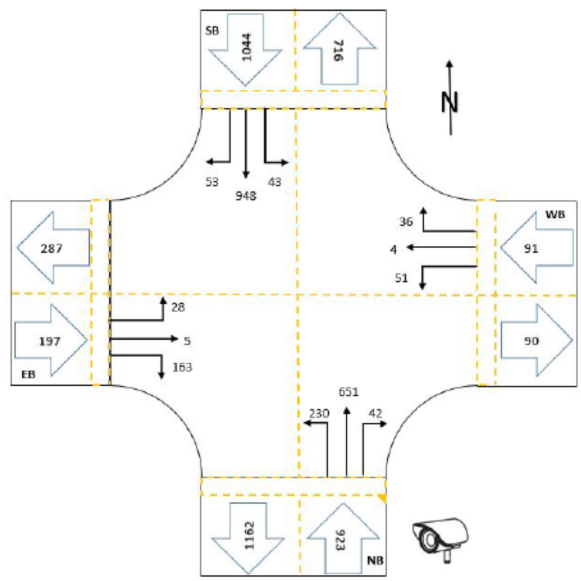

Fig. 13. Intersection traffic break down Count Howard University DDOT

Error that will affect our accuracy result:

- Bigger truck hiding a smaller vehicle.
- Computer vision is affected by varying lighting and weather condition. Vehicles too close might appear as a single vehicle.
- Video missing frames affecting vehicles tracking
- Our system will produce result as shown on Fig.13 and Fig.14

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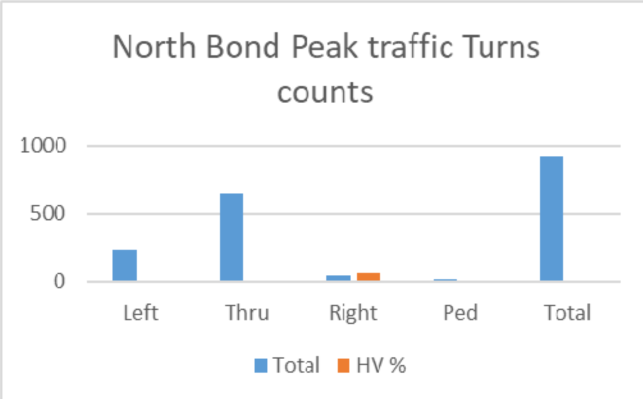

Fig. 14. Intersection North Bond traffic count during peak hour

VII. CONCLUSION

Deep learning with the use of convolutional neural network is the perfect solution for implementing a working monitoring system that effectively detect, track and accurately counts traffic moving objects in an intersection. As we have shown it possible to track and count with accurately higher than human beings and cost effective. Human ability to focus for a long period of time allow an accuracy around 80%. Ours researches and our preliminary tests in developing such a challenging monitoring system turned out to be very promising while implementing and testing independent components or modules based on the concept and approach we have developed. Some issue still needs to be address like the light change, the weathers and the threshold distance between cars. Future work will focus on addressing these issues.

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