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DESIGN OF A SCADA SYSTEM FOR A TRAFFIC TURBINE

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Abstract: The aim of this paper is to present a Supervisory Control and Data Acquisition (SCADA) system implemented in NI LabVIEW for traffic turbines or road turbines. These turbines generate energy based on the wind flow of moving vehicles and must be located alongside roads where the traffic is high, such as highways, in order to maximize the amount of energy harvested. This way, some of the energy consumed by vehicles moving at high speeds can be recovered. This is a unique method of generating power, leading to the concept of sustainable and environmentally friendly highways. Power can be generated and stored by the wind energy conversion system. The SCADA system connects the individual turbines, traffic cameras and sensors to a central computer as well as the computer to remote users through a secured web-interface. The remote user can monitor electrical signals, such as power output, generator torque, wind speed, rotational speed, etc. as well as real-time video footage from the traffic cameras. It also records the electrical measurements in a SQL database for remote users to be able to process remote data, view historical measurements, etc. The system includes image processing software with vehicle detection and tracking in order to estimate the amount of energy that can be gained from traffic.
Keywords: SCADA system, LabVIEW, traffic or road turbines, vehicle detection and tracking

1. INTRODUCTION

The aim of this paper is to present a Supervisory Control and Data Acquisition (SCADA) system implemented in NI LabVIEW for traffic turbines or road turbines. These turbines generate energy based on the wind flow of moving vehicles on motorways. This way, some of the energy consumed by vehicles moving at high speeds can be recovered. The idea is to compensate for the amount of pollution produced by the burning of fossil fuels by introducing a potential source of clean energy, thus leading to the concept of sustainable and environmentally friendly highways. This unique method of generating power can be used to complement conventional energy sources. However, these turbines must be located alongside roads where the traffic is high, such as highways, in order to maximize the amount of energy harvested. The wind generated by highway traffic is an almost constant source of energy [1-6]. Yet, wind turbines to be used as traffic turbines need to be adapted to this purpose [7]. The type of wind turbine used should have certain characteristics in order to optimize the conversion and be cost effective.

There are three major categories of turbines: horizontal axis wind turbines (HAWTs), vertical axis wind turbines (VAWTs) and cross-flow turbines (Banki). Vertical axis turbines can be further classified into three categories: Savonius, Darrieus and a combination of both. Most wind turbines used today are the horizontal ones, yet the characteristics of these turbines, including the need for relatively strong winds and high starting speeds, make them inadequate for use as traffic turbines. Another option would be vertical turbines. They have a number of advantages over horizontal turbines, such as lower starting speeds (they start creating electricity at speeds of only 6 mph), they are invariant to wind orientation (able to generate power regardless of wind direction), low noise level and vibration (27-37 DB), lower production, maintenance and installation costs and smaller towers (they are mounted lower to the ground). It is also worth mentioning that these turbines work better that axial turbine under turbulences and gusty winds, which is a necessity for gaining power from moving vehicles. They have the ability to serve areas with wind speeds are lower than average and where taller structures, needed in axial turbines, can't be built. Roads and highways qualify as such. The major disadvantages of these types of turbines would be lower efficiency than the horizontal ones and the initial investment expenses tend to be higher. On the other hand, small scale systems (up to a few kilowatts) are less costly [5], [4], [8], [2] and [9]. As a result of these properties most of the turbines tested for use as a road or traffic turbines are VAWTs, namely Savonius turbines (typical Savonius: [9], [10] and Involute Spiral: [11]), Darrieus turbines (typical Darrieus: [8] and Helical Darrieus: [6], [7], [12-14]) and combined Savonius and Darrieus turbines [4, 5, 15]. There are also some examples of HAWT [16] and Cross-flow [17].

2. TRAFFIC TURBINE MODEL

The aerodynamic model of the traffic turbine is the same as for any given wind turbine [18], [19], [20]:

$$P_{wt} = 0.5A\rho C_P(\lambda) * v^3 \quad (1)$$

where A is blade swept area [m^2], ρ the specific density of air [kg/m^3], v the wind speed [m/s] and C_p the power coefficient. The power coefficient is given by the type of turbine used and relates to the efficiency of wind power conversion. Turbine efficiencies in the range of 35-40% are considered good, and this is the case for most large-scale turbines [8]. C_p depends on the tip-speed ratio λ, defined as:

$$\lambda = \omega_r R/v \tag{2}$$

where R is the radius of the turbine blade [m] and ω_r is the rotating speed [rad/s].

The mechanical part is considered as a two-mass model, consisting of a large mass (corresponding to the wind turbine inertia J_{wt}) and a small mass (corresponding to the generator rotor inertia J_g) [18], [19], [20]. The dynamic equation is:

$$T_{wt} - T_g = J * \frac{d\omega_r}{dt} \tag{3}$$

where T_{wt} is the turbine torque [N·m], T_g is the generator torque [N·m], J is the inertia of the turbine system [kg·m^2]. This is composed of:

$$J = J_{wt} + J_g \tag{4}$$

where J_{wt} is the inertia of the turbine [kg•m^2], J_g is the inertia of the PMSG [kg•m^2].

The power of the system can also be expressed as follows:

$$P_{wt} = T_{wt} * \omega_r \tag{5}$$

From (1) and (5), the turbine torque has the following equation:

$$T_{wt} = 0.5A\rho C_T(\lambda) * v^2 \tag{6}$$

where C_T is the turbine torque coefficient.

3. TRAFFIC ENERGY CONVERSION SYSTEM

There is very little information in literature on traffic-driven wind turbines, yet there are various designs for incorporating traffic turbines into the road. Each design has positive and negative aspects. The turbines can be built into the guardrails. This design is particularly complex because the guardrails must be fitted with vanes for the wind to reach the turbines inside [7], [6]. There is also a question of the height at which the turbines could be fitted to maximize the extracted energy [5], [1]. Other designs include turbines built into highway dividers or on overhead poles, but these require the construction of custom support posts [6]. The generated wind bursts depend on various factors such as traffic intensity, vehicle size and speed, distance between turbines and vehicles, impact angle and natural wind speed [3]. Due to the passing of cars on both sides, the wind speed is higher in the center than in the sides.

Therefore, the area with the highest potential is the median line of the road [2]. This would involve mounting the wind turbine on the center line of highways and, therefore, the wind turbine and the generator it operates must be small in size. This is also a condition that these devices do not disturb daily traffic. Small-scale wind systems remain a niche application, but interest in them seems to be increasing. This is due to the fact that they can be used to power rural communities in hybrid off-grid and mini-grid systems. The turbine must be capable of being driven by the turbulence caused by traffic in both directions, so it must be able to turn in the direction of the wind [5], [1], [8] and [7].

Choosing the right generator according to the application is important. Because the wind speed is not constant, the turbine rotation speed will vary frequently. Therefore, variable speed generators need to be used. In order to take advantage of the relatively low wind speed available in this configuration, the turbine rotation speed must be low and the generator must have a low starting speed [14]. Although a turbine may not provide an adequate amount of energy, a group of turbines on a long stretch of highway has the potential to generate a large amount of energy [5]. A possible structure for incorporating the road turbines in an energy conversion system can be seen in Figure 1. The diagram represents a DC microgrid structure, complete with loads, a storage system and a connection to the main grid.

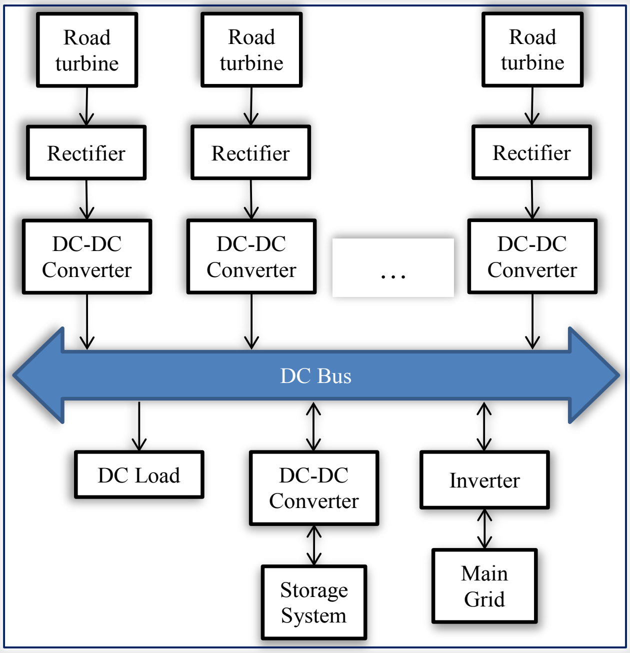

Figure 1. Traffic energy conversion system

The voltage produced by the generator must be rectified if it is AC voltage. The resulting DC voltage is sent to a DC bus through an appropriately sized DC-DC converter. The converter may contain a capacitor or a supercapacitor according to the power to be expected from the turbine. The generated energy could be sent to the power grid, contribute to the supply of local loads or be stored.

3. SCADA System

Since these turbines will operate in remote locations, rotate at low and variable speed, and are subject to extreme temperatures, wind gusts, corrosion, erosion, equipment failure, etc. supervisory control and data acquisition (SCADA) systems are indispensable. SCADA systems provide a cost-effective way to monitor the health of the power network, reducing operation and management costs [21].

The SCADA system (Figure 2) connects a traffic turbine, a traffic camera and sensors to a central computer. The SCADA application designed in LabVIEW, (Figure 3) monitors electrical signals such as power output, generator torque, wind speed, rotational speed, voltages, currents, etc. and can store these measurements in a SQL database. This system also contains an interface for remote viewing designed using LabVIEW Remote Panels embedded into a web page. Users can access the database for further processing, such as data mining, statistics, maintenance planning, anomaly detection, etc. [21].

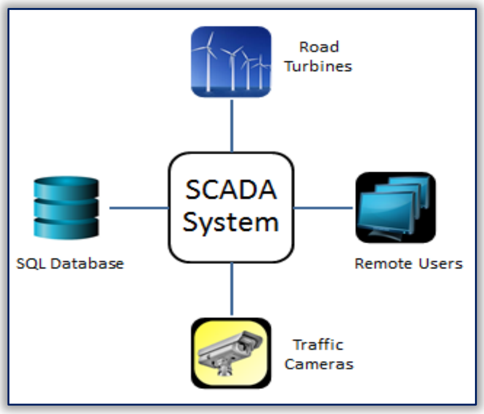

Figure 2. Diagram of the SCADA application

It is possible for users to monitor video footage from the traffic cameras. This is done through ActiveX technology; the ActiveX component is embedded into the LabVIEW application. More details are given in [22]. The system includes image processing software with vehicle detection and tracking in order to estimate the amount of energy that can be gained from traffic. This was tested using RC cars controlled through Bluetooth technology and a USB camera (Figure 4). The camera system can record such data as: the date and time, the location and the vehicle speed [23]. The cars are controlled using PWM in order to modify their average speed, making them variable speed vehicles. The position and orientation of the cars are obtained through object tracking. The camera is positioned directly above the road, in such a way as to capture as much of the highway as possible. The images obtained with the camera are processed using the NI Vision and Motion toolkit [24].

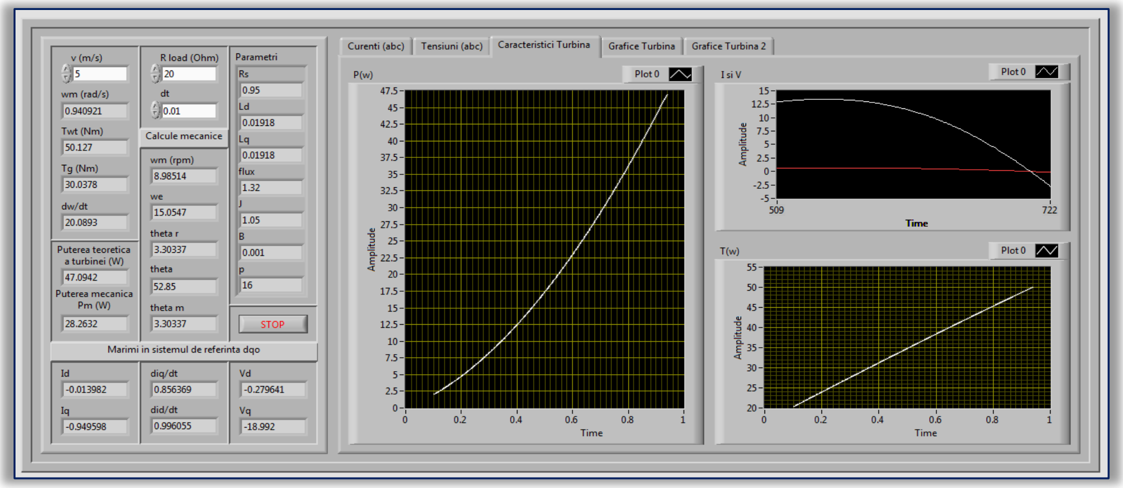

Figure 3. Front Panel of the LabVIEW application

The software works in two basic steps, namely detection and recognition. In the detection stage, the car's shape and color are detected. The area of interest is extracted and sent through a classifier to decide what type of car it is. The system performs a search for colors different from the actual road. A color threshold is applied to the image, transforming it into a binary image. The resulting binary images are passed through a shape detection function. Shape analysis helps sort the particles and focus the search on the ones most likely to be cars. Each of the particles in the image is tested against a set of features (a pattern) to decide whether it is a vehicle or not. Since there can be more than one vehicle in an image, there can be more than one particle in the binary image. This step has the purpose of activating only the recognition module based on the most likely matches for the vehicle in question. Since the shape of the car determines its category, an object only passes to the recognition module if there is a chance that the object might represent a vehicle of the category sought for in the recognition module. The obtained image is then passed through pattern matching. Pattern matching locates regions of a grayscale image that match a predetermined template, a reference pattern which constitutes an idealized representation of the features of the vehicle category. The template represents the searched object, namely the top of the RC car. Pattern matching works reliably under various conditions including poor lighting, blur and rotation, but it limited real-time capabilities. The machine vision application searches for the model in each acquired image, calculating a score for each match, that relates how closely the model matches the pattern found. If the measurement falls within a tolerance range, the part is considered good; else, the component is rejected. The major advantage of pattern matching is that it provides matches to the template regardless of the angle at which the object represented by the template is rotated [24], [25].

Using pattern matching, NI Vision will return the number of matches and their coordinates within the region of interest. If the object does represent a vehicle, the results of this search will help determine the car's position and orientation. This process will be executed a number of times in order to follow the car's movement. Execution duration is influenced by the number of different types of vehicles simultaneously detected in the image, the results of the intermediate functions of shape and color, the number of matching modules simultaneously active, the time it takes to receive data from the module, etc. [24], [25].

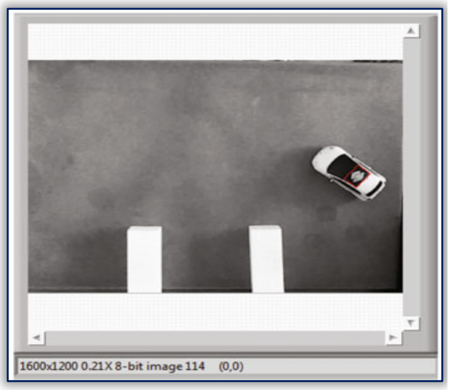

Figure 4. The RC car found through image processing [24]

4. RESULTS

Using the data presented in [1], the possibility of a correspondence between vehicle speed and wind speed was analyzed (Figure 5).

Table 1. Vehicle speed and wind speed for two different types of vehicles

Vehicle 1: SEDAN				Vehicle 2: BUS			
Vehicle speed		Wind velocity		Vehicle speed		Wind velocity	
m/s	km/h	m/s	km/h	m/s	km/h	m/s	km/s
22.22	80	12.52	45.072	27.78	100	23.981	86.332
30.56	110	20.94	75.384	30.56	110	26.837	96.613
33.33	120	23.03	82.908	33.33	120	30.912	111.283
36.11	130	26.43	95.148	36.11	130	33.868	121.925
38.89	140	29.67	106.812	38.89	140	36.117	130.021
41.67	150	32.12	115.632	41.67	150	38.331	137.992

The data was taken at heights determined in [1]. These points are the maximum points till which the velocity distribution caused by the motion of the vehicle propagates, constituting the maximum height at which the traffic turbine can be mounted in order to harness the wind speed. This height was found to be 3.3 for the sedan and 5.5 for the bus. The data show a linear dependency between the vehicle velocity and the wind velocity at the set height. For the sedan, the slope of the calculated linear function is 0.282 and the intercept is -10.208. For the bus, the slope is 0.278 and the intercept is 2.13163E-14. It is evident that the slope values are very close, which indicates that the vehicle type and the height mostly affect the intercept, having little to no impact on the slope. It stands to reason that the wind speed that enters the wind turbine can be determined by knowing the vehicle type and velocity (for determining the intercept) and the speed and direction of the natural wind. The variation in the velocity of the wind caused by the vehicle can be perceived as an impulse function which interacts with the natural wind. The vehicle type will also affect the duration of the burst of wind. Depending on the direction of the wind and of the vehicle this disturbance can be additive or subtractive. Therefore the road turbine has to work even with just the natural wind. The wind bursts caused by moving vehicles, although frequent, might not be enough to sustain energy production in the absence of natural wind.

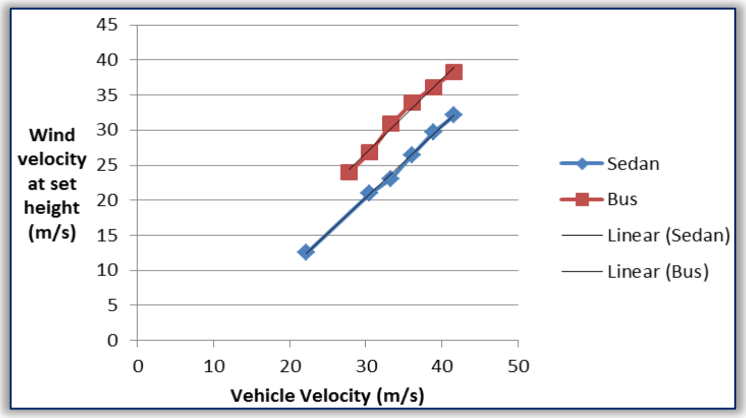

Figure 5. The dependence between vehicle velocity and wind velocity according to the type of vehicle

Increasing vehicle speeds increases the speed of the dispersed wind, thus increasing the power generated by the turbine. It supports the hypothesis that well-located wind turbines can be cost-effective [9]. It will never recover all the power dissipated by moving cars, but even a fraction of it could be an important source of energy [5]. A single turbine may not provide an adequate amount of energy, but a set of turbines on a long stretch of highway has the potential to generate a large amount of energy [4].

5. CONCLUSIONS

Traffic turbines are a unique method of generating power, but they have to be located in places where traffic is high and adapted to be used as such. Their power can be estimated using traffic cameras and image processing to determine the type and number of vehicles passing along the highway where the turbine or turbines are positioned. Data show a linear dependency between the vehicle velocity and the wind velocity. It stands to reason that the wind speed that enters the wind turbine can be determined by knowing the vehicle type and velocity (for determining the intercept) and the natural wind speed and direction. The direction of the natural wind determines whether the car-caused turbulence be of service of produce losses. The vehicle type will also affect the duration of the burst of wind. Also, the wind bursts caused by moving vehicles, although frequent, might not be enough to sustain energy production in the absence of natural wind. Therefore the road turbine has to be able to function with the wind conditions existing in that area. The turbulence produced by vehicles might have a different function, namely easy start-up for the turbines. The start-up speed of a turbine is always higher than the lowest wind speed at which the turbine continues to be productive; hence if the natural wind would be enough for the turbine to function but not enough for start-up, vehicle turbulence could be extremely useful. The fact that, given the right circumstances, vehicle turbulence has the effect of increasing the wind speed might be the key to making them productive and cost-effective. All of the power dissipated by moving cars will never recover, but even a fraction of it might be enough to make a difference.

References

[1] Hegde S S, Thamban A, Bhai S P M, Ahmed A, Upadhyay M, Joishy A and Mahalingam A 2016 Highway mounted horizontal axial flow turbines for wind energy harvesting from cruising vehicles, International Mechanical Engineering Congress and Exposition ASME 2016, Phoenix, Arizona, November 11 – 17, pp. V06BT08A043-V06BT08A043, American Society of Mechanical Engineers.

[2] Ayyadurai L, Palani S and Prem D 2013 Hardware Design of Vertical Axis Highway Windmill, International Journal of Advanced Electrical and Electronics Engineering, 2(3); pp 83.

[3] Hassan A, Vittala Vijaya C B 2014 Analysis of Highway Wind Energy Potential, International Journal of Engineering Research & Technology (IJERT), 3(4), 1496-1498

[4] Singh S, Singh S and Srivastava P 2010 Vertical Axis Wind Turbine for Generation of Electricity through Highway Windmill, SAMRIDDHI: A Journal of Physical Sciences, Engineering and Technology (S-JPSET), 7(2), pp. 99-104

[5] Mashyal S, Anil T R 2014 Design and analysis of highway windmill electric generation, American Journal of Engineering Research (AJER), 3(7), pp 28-32.

[6] Champagnie B, Altenor G, Simonis A 2013 Highway Wind Turbines, Florida International University, USA, thesis.

[7] De Jong B C P M 2015 Wind Turbines along highways: Feasibility study of the implementation of small scale wind turbines along the Prins Bernardweg Zaandam to Bolswarderbaan highway in the Netherlands, Delft University of Technology, the Netherlands, thesis.

[8] Divya B, Muthukumari S, Vaithiynathan G, Puvaneshwari G M and Mathew K 2012 Harnessing Electrical Energy in Highways by Smart Wind Mill International Journal of Engineering Research and Development, 3(12), 04-09.

[9] Nalathambi D K 2014 Installing savonius vertical axis wind turbine at open road side (highway) to generate renewable electricity, National Conference On Mechanical Engineering, 23-25 June, Malaysia.

[10] Belmili H, Cheikh R, Smail T, Seddaoui N and Biara R W 2017 Study, design and manufacturing of hybrid vertical axis Savonius wind turbine for urban architecture, Energy Procedia, 136, 330-335.

[11] Murodiya R and Naidu H 2016 Design and Fabrication of Vertical Wind Turbine for Power Generation at Highway Medians, Int. Eng. J. Res. Dev, 1, 1-10.

[12] Muthukumar A and Balasubramanian M 2012 VAWT Which Makes Use of the Turbulent Winds Generated by the Highway Traffic, International Journal of Engineering and Technology, 4(2), 170.

[13] Sharma M K 2012 Assesment of wind energy potential from highways, Int J Eng Res Technol (IJERT), 1, 1-8.

[14] Mithun R 2015 Design and Simulation of a Vertical Axis Wind Turbine for Highway Wind Power Generation, International Conference on Recent Trends in Engineering Science and Management (ICRTESM 2015), Volume: IJEEE, 7(1).

[15] Verma D and Pateriya A 2017 Vawt And Solar Panel Combined System Based Generation Of Electricity Through Highway, International Journal of Research In Science & Engineering, e-ISSN: 2394-8299, p-ISSN: 2394-8280, 3(3).

[16] Francis A, Raj H, Kumar A 2017 Wind Turbines For Roadways, International Journal Of Research Science & Management, ISSN: 2349-5197, 4(5).

[17] Tian W, Mao Z and Li Y 2017 Numerical Simulations of a VAWT in the Wake of a Moving Car, Energies, 10(4), 478.
[18] Szeidert I, Prostean O, Filip I, Vasar C and Mihet-Popa L 2008 Issues regarding the modeling and simulation of wind energy conversion system's components, Automation, Quality and Testing, Robotics (AQTR 2008), IEEE International Conference, vol. 2, pp. 225-228.
[19] Mihet-Popa L, Groza V, Prostean G, Filip I and Szeidert I 2007 Variable speed wind turbines using cage rotor induction generators connected to the grid, Electrical Power Conference, (EPC 2007), IEEE Canada, pp. 8-13.
[20] Budisan N, Groza V, Prostean O, Filip I, Biriescu M, Szeidert I and Stern M 2008 Rotation speed and wind speed indirect measurement methods for the control of windmills with fixed blades turbine, Instrumentation and Measurement Technology Conference Proceedings, (IMTC 2008), IEEE, pp. 912-916.
[21] Rat C L, Prostean O, Filip I, Vasar C, Remote Wind Energy Conversion System, Soft Computing Applications (SOFA 2018), awaiting publication.
[22] Panoiu M, Rat C L and Panoiu C 2015 Video streaming technologies using ActiveX and LabVIEW, IOP Conf. Ser.: Mater. Sci. Eng. 85 012023.
[23] Rat C L, Cuntan C D and Baciu I 2014 The Design and Simulation of an Intersection Control System, Annals of the Faculty of Engineering Hunedoara, 12(4), 216.
[24] Panoiu C, Panoiu M, Rat C L and Rob R 2016 The Computer Assisted Parking of a Bluetooth Controlled Car Using Fuzzy Logic, Soft Computing Applications, pp. 51-66, Springer, Cham.
[25] Panoiu M, Rat C L and Panoiu C 2016 Study on road sign recognition in LabVIEW, IOP Conf. Ser.: Mater. Sci. Eng. 106 012009.

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