Live Data Acquisition for Situation Awareness in Traffic Management Systems Using Laser Sensors

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***Abstract*—Traffic management systems help to organise the more and more dense traffic in cities. However, the classic approach for such systems is the use of traffic models, which incorporate a long-term knowledge of traffic situations in the respective city. This approach is not adequate for reacting to changes in traffic, either long-term changes, which have not been trained to the model, or short-term changes due to unexpected events. In this paper, we describe how we collect real-time traffic data using a laser scanner, evaluate the precision of the traffic measurements and assess the circumstances under which the results are useable for a professional traffic management system.**

***Keywords*-Situation Awareness, Sensor Data Acquisition, Vehicle Counting, Traffic Management.**

I. Introduction

In modern cities traffic is becoming a topic of more and more controversial discussion: On the one hand the need for transportation of people and goods from place A to place B is still increasing [1], on the other hand this causes severe problems, especially in cities with dense population (as the most European cities are): congestion, pollution, noise, etc. [2]. Traffic management systems are used to optimise the traffic according to pre-defined metrics. This is done for instance by setting the time periods for green and red phases of traffic lights.

Yet in most cases, traffic management systems are based on static traffic models only [3], i.e., static data that provide statistical information about characteristic parameters like traffic density in an area, throughput of an intersection, rates for different directions, etc. These information are provided for several situations (e.g., rush hour, night traffic, holidays, etc.), and for each of these situations some optimisation calculations can be performed.

For many operating traffic management systems these parameters are captured manually, e.g., by a person counting cars passing a certain position [4]. This is an unfavourable situation: First, the correctness of the data cannot be validated. Second, in order to integrate long-term traffic changes, the counting has to be re-done in regular intervals, and the model has to be optimised again in order to adapt to the changes of the regarded traffic situations.

However the knowledge of the current distribution of these parameters does not compensate for a situation awareness including live traffic data. To be able to include unexpected events like accidents or short-time changes like the opening of a new shopping mall into the traffic management system, a real-time capable solution for sensing the current traffic situation is an indispensable precondition. A dynamic traffic management system is able to react to every change detected, i.e., instead of making offline optimisations based on measured traffic data, the traffic management system reacts in real-time to the traffic measurements, thus setting up a closed-loop control [5]. This is called a *dynamic traffic management* system [3].

Such a system consists of the following logical distinguished parts:

- The sensing part: Several traffic parameters of interest for the traffic management have to be measured, e.g., the number of vehicles passing per lane and per time unit, the ratio of vehicles driving to the outgoing directions of an intersection, the average time a vehicle needs to drive from reference point A to reference point B, the average pollution caused by vehicles, etc.
- The communication part: The sensed values have to be collected in timely manner (with timing constraints). Thus the underlying communication network, which is used for transmitting the measured values to the control part, has to be dependable [6].
- The control part: Dynamic traffic management systems use the sensed values under real-time conditions for the respective traffic management tasks (e.g., control traffic lights or dynamic speed limits) according to existing rules [3].
- The actuator part: To influence the traffic in order to optimise the relevant traffic parameters according to a defined strategy, the traffic has to be controlled by suitable actuators. Here, the traffic lights are the easiest way to influence traffic in cities; dynamic speed limit signs are used on highways; but also *weak actuators* can be taken into account [7], like signs with the number of free parking slots in city centres, etc.

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During the project sTC-net [8] we worked on a prototypical solution of a dynamic traffic management system. The part of our group was the setup of a sensor system and the collection of sensor data, which are usable as input for a dynamic control system. This machine learning based control system was set up by a partner company.

In this paper, we describe the traffic sensing approach we used, based on a single row laser scanner system. First we give a brief overview of the state-of-the-art of scientific work in this area. In the following section we describe the architecture of the system we used to measure and collect data (hardware, software, communication infrastructure). The next section shows the traffic counting algorithm, which was implemented in Matlab [9], and how we validated the output of that algorithm. This is followed by an overview of the measurements we conducted with this system and the results of the measurements. After that, we present some conclusions that can be derived. Finally, we give an outlook at possible further research and development activities.

II. Related Work

There are several approaches for traffic counting and for sensing other traffic parameters like average speed etc.: Inductive loops; magnetic, piezo-electric and pneumatic sensors; microwave, infrared and ultrasonic radars; optical systems and floating car data (FCD).

For traffic counting, laser scanners are a popular alternative, especially overhead mounted at highways [10]. Zhao et.al. [11] propose to use horizontally mounted single row laser scanners to monitor the traffic at an intersection in a city. The applicability of such an approach to our scenario is limited, as a mounting at a height of less than one meter has two main disadvantages: First, as the lasers can easily be reached, they are potentially subject to vandalism. Second, pedestrians waiting at a position near the laser devices are "blocking" a large angle of the laser scanners.

Regarding traffic management systems, there are approaches to integrate live sensor data into dynamic traffic management systems [3]. Such systems could also exploit the sensor information to adopt their rule base, i.e., the underlying traffic model, by using machine learning methods (e.g., artificial neural networks [12], or genetic algorithms [13]).

For communication purposes, e.g., collecting the sensed data, wireless networks provide an easy to deploy solution [14].

III. System Architecture

Existing traffic counting solutions are using a large number of laser sensors. In typical installations [10], one laser sensor is installed above each lane in order to count the number of vehicles on this lane. In cities, it is often not possible to install a metal carrier above the lanes due to limited space. Consequently installing one laser per lane is not feasible. Besides that, for larger intersections, e.g., with 12 individual lanes (3 lanes per direction), installing 12 laser sensors is a cost factor that operators are not willing to pay in many cases.

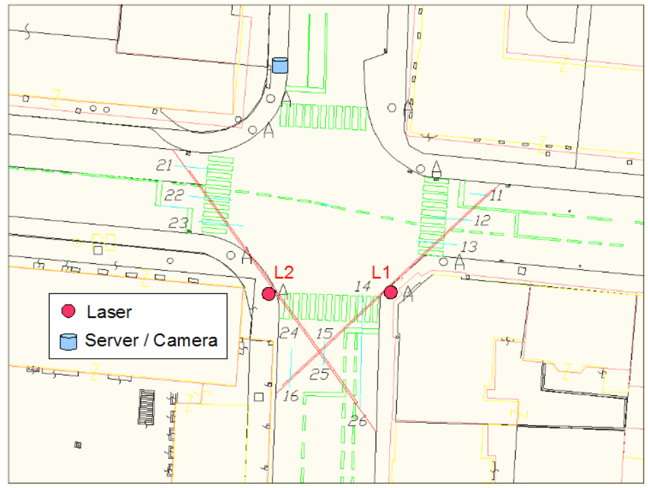

Figure 1: Intersection Salzburg Lehen

Our approach had the goal to sense the traffic on an intersection using a minimum number of laser devices and to setup an installation with minimal costs, being accurate enough to be used as input for a traffic management system. According to the requirements of the traffic management system of our partner a target value of 90% [8] for precision and recall [15] is sufficient. Here, precision is the ratio of correctly counted vehicles compared to all counts; recall is the ratio of correctly counted vehicles to all vehicles.

Figure 1 shows our installation at the intersection Ignaz-Harrer-Str./Rudolf-Biebl-Str. in Salzburg Lehen. Two lasers have been installed to count the vehicles to and from south and partially vehicles from west (Lane 23) and to east (Lane 13). For sensing the complete traffic on all lanes at the chosen intersection, four lasers would be required. The lanes are numbered according to the following scheme: The first digit is the number of the laser, and the second digit is a running index. Lanes may be scanned by two lasers, having two identification numbers then, e.g., Lane 24 = Lane 16.

The lasers were mounted on existing traffic light masts in order to minimize the effort and costs for mounting. As a consequence the position of the masts is not optimal for the used lasers. Thus we expected to get a good estimation under which circumstances (e.g., light, weather conditions) the measurements fulfil the required precision and recall.

For validating the conducted measurements a camera was installed. The camera's resolution does not allow for identifying the plates, but is sufficient for counting.

Figure 2 visualizes the measurement architecture at the chosen site. It consists of two lasers, three router boards and one server:

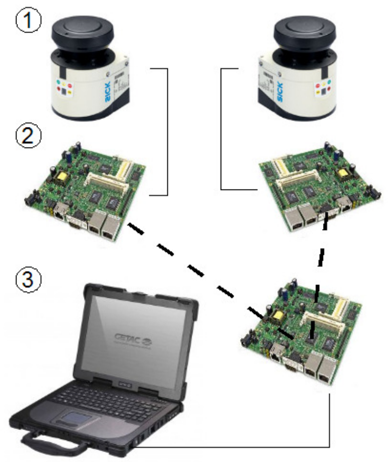

Figure 2: Measurement architecture

1) Laser: The LMS111 [16] is a single row type laser scanner from the company Sick with a high profiling rate of 50 Hz and wide viewing angle of 270 degrees. The LMS111 measures the distance to the reflecting object for each laser beam. On black background, this laser scanner has a maximum range of 18 m. The stepsize between two laser beams is 0.5 degrees; thus a single scan consists of 540 values. The last scan is stored locally and can be transmitted to the server upon request.
2) Routerboard: The Mikrotik Router Board 532A [17] is a fully integrated communication platform for high-speed, Ethernet and wireless networks with the Linux based Mikrotik Router Operating System. It offers the use of the R52 wireless module, which operates in 2.4 GHz and 5 GHz ranges.
3) Server: The server is a robust IP54 laptop with dual core and Win XP operating system. It is placed inside the intersection's main control cabinet. An application requests the laser measurement data in regular intervals and relays the collected data to a MySQL database on the laptop.

The lasers and the server are connected to the Routerboards via Ethernet cables. In order not to influence any other radio frequencies, the communication between the Routerboards is done in the 5 GHz frequency range. The embedded boards are installed in a splash-proof enclosure mounted in the proximity of the sensors on the respective traffic light masts.

IV. Algorithm

Our system requires knowledge about the individual geometry at the intersection. The mounting heights of the lasers as well as the horizontal distance from the laser to the borders of the individual lanes have to be known. A further step needed in initialization is to measure the ground, as the shape of the ground is not necessarily even. Unevenness or inclination of the ground influence the measurements and have to be identified in advance.

This is done best by simply sensing the empty intersection: The laser measures the distances to the road surface itself without any cars present. For places further away than 18 m from the sensor, we are not able to detect the road surface any more. We are using linear extrapolation of the detected surface then. This extrapolation only works for almost horizontal intersections.

Our newly developed vehicle counting algorithm itself consists of three major steps:

1) Pre-process the data for each lane
2) Count vehicles for each lane
3) Combine information from different lanes

Pre-processing the data sets is done as follows: Values, which are further away than the current lane of interest, are set to ground. Values, which are closer than the current lane of interest are replaced by "NaN" (the Matlab value "Not a Number") [9], as it is uncertain whether there is a vehicle behind this obstacle or not.

For the vehicle counting algorithm, the pre-processed data is used for each lane of interest. For each measurement value (which is representing the distance from the laser scanner to the reflection point) the height of the corresponding obstacle is derived, using a trigonometric calculation (cosine function) with the current angle of the laser beam and the height of the laser sensor as inputs.

Figure 3 shows 200 consecutive scans on a specific lane of interest. The color scheme changes from dark red for maximum distance to dark blue for minimum distance. White fields indicate that no value has been retrieved (NaN). The figure shows three cars passing the lane, where especially for Car 1 and Car 3 only a small number of measurement values have been retrieved. For the measurements on this lane an angle of 22 degrees is of interest; thus we are concentrating on the respective 45 scan points.

Due to the plain surface of cars and the acute measurement angle of the objects, many measurements do not produce correct values (NaN). As a consequence the algorithm has to detect a car even if it is represented by NaNs and not only by respective measurement values (i.e., smaller distances between laser and reflection point than for the ground). This can be observed for instance for Car 2.

Figure 4 shows same plot as Figure 3, but after determination of the height (above ground) of each individual scan point.

To deal with the NaN values a linear interpolation is used. The results of such an interpolation for the above example are shown in Figure 5. These interpolated values are used for classification.

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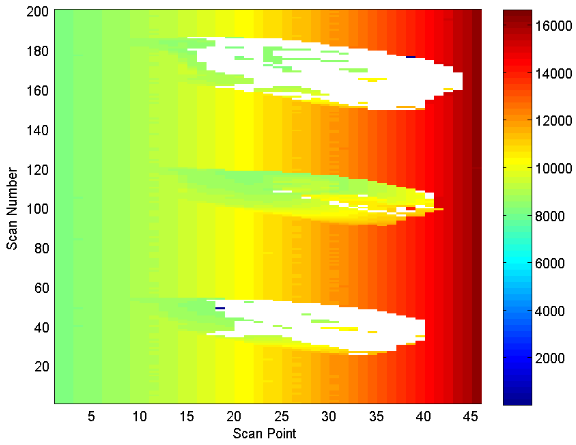

Figure 3: Representation of three cars (distance)

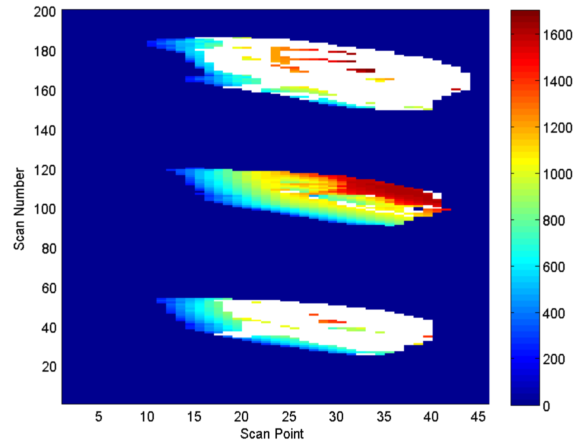

Figure 4: Representation of three cars (height)

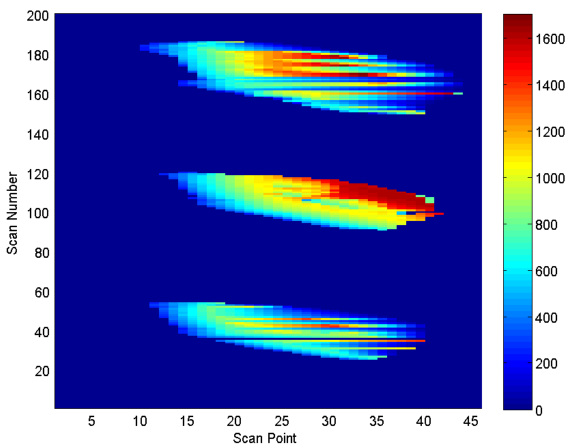

Figure 5: Representation of three cars (interpolated)

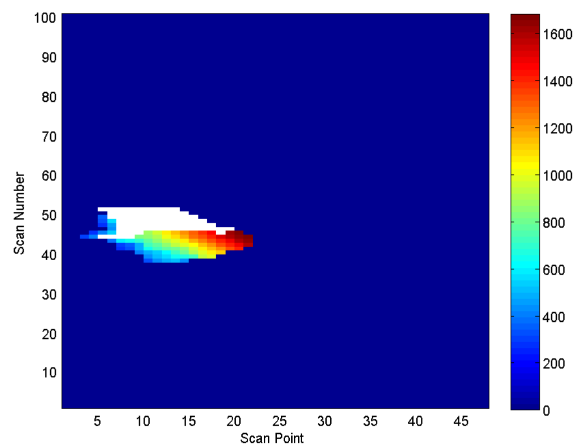

Figure 6: Representation of a pedestrian

In comparison to a car, a pedestrian leads to a smaller representation, as indicated in Figure 6.

A scan is classified in one of three categories:

- "Car Scan": This scan provides an indication for a vehicle
- "Clear Scan": The measurement reflects that there is no vehicle present on the lane
- "Unsure Scan": For this scan it cannot be determined whether a vehicle is present or not

A scan is classified as Car Scan, if two characteristics are met: First there has to be at least one block (of a pre-defined length) of (consecutive) values greater than zero. Second the average height within this block has to exceed the *MinHeight* threshold.

For classification as Clear Scan two other characteristics have to be met: First the average height has to be below the *NoiseHeight* threshold or the average is based on less than 5 values (the rest is interpolated). Second the NaN fraction (number of NaN values divided by the number of scan points for this lane) has to be below *MaxNaNtoClear*.

An Unsure Scan is one that falls into none of the above categories.

In our prototypical implementation the *MinHeight* threshold is set to 250 mm and the *NoiseHeight* threshold is set 100 mm. The value of *MaxNaNtoClear* depends on the lane and is configured between 0.2 and 0.9.

To count a detection as car, three Car Scans without a Clear Scan in between have to be present. Each Car Scan increases the *CarIndicationCount* whereas a Clear Scan resets this variable to 0. An Unsure Scan does not change the *CarIndicationCount*.

For traffic management systems it is important to consider the fraction of large vehicles like trucks or buses compared to the total number of vehicles. Thus our algorithm adds a further category for the scans, which is based on the maximum height value within one lane: A Truck Scan.

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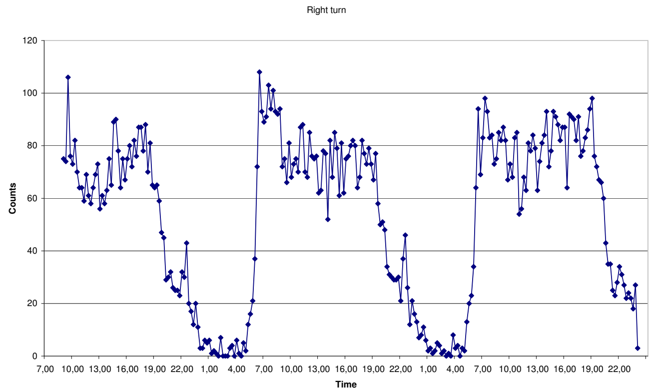

Figure 7: Right-Turn Lane 23 to 24

MEAS.	LANE 23		LANE 24		RIGHT TURN	
	PREC.	RECALL	PREC.	RECALL	PREC.	RECALL
M1	99.1	100	98.8	100	100	100
M2	100	100	100	100	100	99.1
M3	100	100	97.3	98.6	100	100
M4	97.7	100	97.0	98.8	100	99.2

Table I: Results for different conditions

	LANE 25A	LANE 15B	LANE 14	LANE 13	RIGHT TURN
PREC.	98.3	98.9	100	91.1	100
RECALL	96.7	98.9	100	99.5	98.5

Table II: Results for different lanes

This is a subcategory of a Car Scan, where additionally the maximum height exceeds 2750 mm. If we count five scans as Truck Scan (using the variable *TruckIndicationCount*), without a Clear Scan in between, the vehicle is classified as truck or bus; otherwise it is assumed to be a car.

After the counts of the separate lanes have been finished, the measurements can be combined in order to improve the rate of correctly measured turns. Lane 23 for instance is solely intended for right turns only; nevertheless it occurs that cars on this lane go straight ahead. To correct the counting for such (misbehaving) vehicles, we combine counts on Lane 23 and Lane 24: If within Z seconds after a vehicle was counted on Lane 23 there is no count on Lane 24, this item is removed from the number of right turning vehicles, as it probably was (illicitly) moving straight ahead. The parameter Z has to be adjusted according to the intersection's geometry.

Furthermore the validation process has shown that trucks and buses, which perform a right turn from Lane 23 to Lane 24 trend to sheer out to Lane 25, thus making a passing of two trucks/buses at the same time impossible. Thus whenever a truck/bus is counted on Lane 24, a truck/bus count from Lane 25 within a given time range is removed.

An important design goal was that the ability of the algorithm to be able to operate live, with a delay small enough to enable the traffic control in time. Thus we decided that the counting algorithm should basically operate on single scans. As mentioned, it only uses two status variables (*CarIndicationCount* and *TruckIndicationCount*) to proceed information between different scans. In practice, for traffic management systems a typically used counting granularity is 15 min.

V. MEASUREMENTS

We have performed a number of measurements on the intersection shown in Figure 1. The measurements were performed under different environmental influences: We have taken into account different weather conditions, day and night, as well as high and low load situations.

We performed 4 different measurements with a length of about 20 min each, and analysed the classification results compared with a manual counting based on the camera movie. Measurement M1 was performed at a high load situation in the morning with good weather conditions, M2 at a high load situation during snowfall, M3 at a low load situation in the night and M4 at a high load situation with sun in the afternoon. Furthermore we conducted a long-term measurement for 3 consecutive days. For the latter, Figure 7 shows the number of counted right turns.

As evaluation metrics, we use precision and recall [15]. Table I shows precision and recall for the counts on Lane 23 and Lane 24 as well as for the number of right turns. Precision and recall are close to 100% and comply with the requirement to exceed 90%.

We further evaluated the ability to count traffic on further lanes including interior lanes (e.g., Lane 15/25) where it is likely that an object on an exterior lane influences the measurement. Table II shows the results of these lanes based on Measurement M4.

These results show that also traffic on interior lanes can be counted with the needed precision and recall. Yet the values are lower due to influences of exterior lanes. Lane 15 resp. 25 is a split lane where the left part is used for left turns, and the right part to go straight ahead. Thus we split this lane also for our counting algorithm. We used the respective nearer lasers: Laser 2 for the left part (Lane 25A), Laser 1 for the right part (Lane 15B).

We observed a lower precision (yet still above 90%) for Lane 13: This is due to the mounting position of the laser; the laser beam crosses the cross-walk in the region of interest. It may occur that pedestrians or groups of pedestrians are counted as cars. This problem increases with the distance between the laser and the area of interest, as the angle gets more acute and thus laser beams reach the side of the car/pedestrian and not the roof of a car. However, these wrong counts for the pedestrians can be easily removed by post processing, e.g., by mapping incoming and outgoing traffic together (like it was performed for Lanes 23 and 24) or by simply taking into account the current phase of the traffic lights.

For interior lanes, which are further away from the laser devices, the counting algorithm does not obtain the required precision and recall of 90%; thus for counting Lane 11, 12, or 22 further lasers would have to be installed. The reason for these limits of the applicability of the laser devices is, that (besides the limited distance the laser is able to measure) the angle between laser beam and moving object gets too acute to obtain enough correct measurement values.

VI. Conclusion

We have shown the ability and the potential of the examined technology to work as a traffic sensor, measuring the number of two different categories of vehicles (cars vs. buses or trucks) passing a control point in a defined measurement period. The required measurement precision and recall (90%) have been reached, yet both values turned out to be very much dependent on the angle between laser and street surface and on the distance between device and the reflecting point.

VII. Further Work

An automatic adaptation to different geometries of intersections would help to reduce the effort of installing sensor systems at new intersections. This has potential to be researched in follow-up projects.

Another unsolved question is the integration of sensors and actuators from third-party providers by generating a generic interface in order to enhance the situation awareness of the traffic management system and to enable alternative control mechanisms to red lights and speed limits. For instance the integration of FCD could help to identify regions of high traffic density and slow speed. If drivers get informed of the current traffic situation this could enable them to avoid these regions for the time being.

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References

[1] The Austrian Federal Ministry for Traffic, Innivation and Technology (BMVIT), "Klug investieren, verantwortungsvoll sparen - Ausbauplan Bundesverkehrsinfrastruktur 2011–2016," 2009.

[2] M. Finkelstein, M. Jerrett, and M. Sears, "Traffic Air Pollution and Mortality Rate Advancement Periods," in *American Journal of Epidemiology, pp. 173-177*, 2004.

[3] Q. Yang, "A Simulation Laboratory for Evaluation of Dynamic Traffic Management Systems," Doctoral Thesis, Massachusetts Institute of Technology, June 1997.

[4] Ad Hoc News. (2010, April) Verkehrszaehlung 2010 hat begonnen. Accessed: 2011-03-30. [Online]. Available: http://www.ad-hoc-news.de/verkehrszaehlung-2010-hat-begonnen--/de/News/21208522

[5] M. Papageorgiou, C. Diakaki, V. Dinopoulou, A. Kotsialos, and Y. Wang, "Review of road traffic control strategies," in *Proceedings of the IEEE., 91 (12), pp. 2043-2067*, 2003.

[6] G. Panholzer, A. Veichtlbauer, P. Dorfinger, and U. Schrittesser, "Simulation of a Robust Communication Protocol for Sensor Data Acquisition," in *Proceedings of the Sixth International Conference on Wireless and Mobile Communications (ICWMC 2010), pp. 145-150*, September 2010.

[7] M. Vasirani and S. Ossowski, "Market-based coordination for intersection control," in *Proceedings of the 2009 ACM symposium on Applied Computing, pp. 747-751*. ACM Digital Library, 2009.

[8] Salzburg Research Forschungsg.m.b.H. (2011) sTC-net – Intelligente Sensoren im Verkehrsmanagement. Accessed: 2011-03-23. [Online]. Available: http://www.salzburgresearch.at/projekt/stc-net/

[9] The MathWorks, Inc. (2011) MATLAB - The Language Of Technical Computing. Accessed: 2011-03-23. [Online]. Available: http://www.mathworks.com/products/matlab/

[10] Road Traffic Technology. (2011) AutoSense Truck Body Classifier. Accessed: 2011-03-31. [Online]. Available: http://www.roadtraffic-technology.com/contractors/detection/osi/osi3.html

[11] H. Zhao, J. Cui, H. Zha, K. Katabira, X. Shao, and R. Shibasaki, "Monitoring an intersection using a network of laser scanners," in *Proceedings of IEEE Int. Conf. on Intelligent Transportation Systems (ITSC 08), pp. 428-433*, 2008.

[12] K. Dresner and P. Stone, "Multiagent Traffic Management: An Improved Intersection Control Mechanism," in *Proceedings of the Fourth International Joint Conference on Autonomous Agents and Multiagent Systems 2005 (AAMAS 2005), pp.471-477*. ACM Digital Library, July 2005.

[13] K. Fikse, "Accelerating the Search for Optimal Dynamic Traffic Management," Master Thesis, University of Twente, January 2011.

[14] D. Curiac and C. Volosencu, "Urban Traffic Control System Architecture Based on Wireless Sensor-Actuator Networks," in *Proceedings of the 2nd International Conference on Manufacturing Engineering, Quality and Production Systems, pp. 259-263*, September 2010.

[15] C. D. Manning, P. Raghavan, and H. Schütze, *Introduction to Information Retrieval*, 1st ed. Cambridge University Press, July 2008.

[16] SICK AG. (2011) LMS100 and LMS111. Accessed: 2011-03-29. [Online]. Available: http://www.sick.com/us/en-us/home/products/product_news/laser_measurement_systems/Pages/lms100.aspx

[17] MikroTik. (2011) Routerboard. Accessed: 2011-04-01. [Online]. Available: http://www.routerboard.com/rb500.html

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