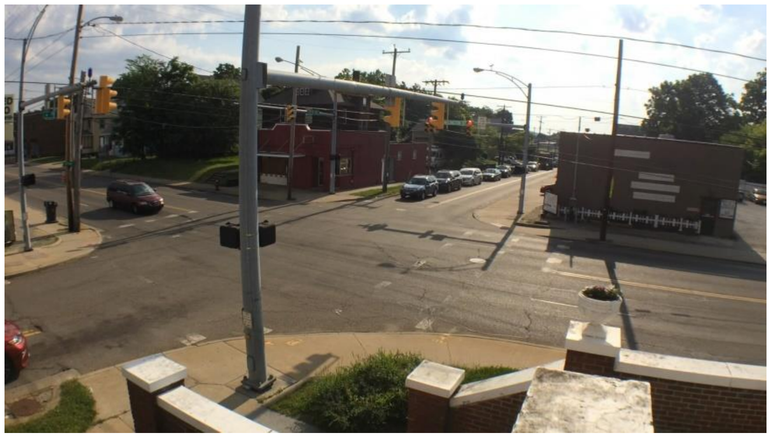
Development and Field Testing of an Automatic Turning Movement Identification System



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Prepared for:
The Ohio Department of Transportation,
Office of Statewide Planning & Research

State Job Number: 135141

Report Date: June 2017

Final Report

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/OH-2017-34		

4. Title and Subtitle	5. Report Date
Development and Field Testing of an Automatic Turning Movement Identification System	**June 2017**
	6. Performing Organization Code

7. Author(s) (include 16 digit ORCID ID)	8. Performing Organization Report No.
Ping Yi **Songling Zhang**	

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
The University of Akron **302 E Buchtel Ave.** **Akron, OH 44325**	
	11. Contract or Grant No.
	SJN: 135141

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Ohio Department of Transportation **1980 West Broad Street** **Columbus, Ohio 43223**	**Final Report** **June 2015 – June 2017**
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Today many intersections are operated based on data input from nonintrusive video detection systems. With those systems the video detectors can be easily deployed/modified for different application requirements. This research project is initiated to improve the convenience and coverage and reduce cost in turning movement data collection, by taking advantage of the existing video detection system at signalized intersections. This research involves hardware design and algorithm testing, where an automatic turning movement identification system (ATMIS) is developed to interface the current signal control system at each intersection.

The ATMIS is tested in different scenarios with variations in intersection configuration and weather conditions. The turning movement data obtained from the system are compared with the ground truth by watching the synchronous video. While the average accuracy level in the first phase of tests for most intersection movements reached 90%, additional improvements in the algorithm and hardware design to handle large-sized vehicles, irregular geometrics and pedestrians, have further advanced the data accuracy to be over 95% for the entire intersection. The major problem leading to the errors is due to turning buses at small intersections, where the size of vehicles can cause false detections. We found an effective solution to this problem by adjusting the camera angle or height, but it was not done for every such case partly because it adds to the busy daily work for the city engineers and partly due to the low volume for the turning movements at small intersections, where the error can be contained in the ADT data. It has been demonstrated that the ATMIS algorithm can effectively address variations in geometrics within the scope of this project, with no obvious degrading impact on the accuracy level by normal rain and snow.

17. Keywords	18. Distribution Statement
Automatic Turning Movement, Data Collection, Real-time, Video Detection, NTCIP, Microcontroller	**No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161**

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**	**23**	

Form DOT F 1700.7 (8-72) **Reproduction of completed pages authorized**

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Prepared in cooperation with the Ohio Department of Transportation
and the U.S. Department of Transportation, Federal Highway Administration

Acknowledgments

The research team would like to express gratitude and thanks to the engineers from the City of Akron, for their assistance during the field tests. This project would not have been completed without the support from the city. The research team also wants to thank the employees and engineers from Path Master, Inc., for their help in resolving hardware connection issues in field testing.

The research team is highly indebted to the Ohio Department of Transportation for offering such a great opportunity to test the proposed system, and for providing guidance and supervision throughout the project.

Our appreciations also go to the Akron Metropolitan Area Transportation Studies (AMATS), for their support to developing the project proposal. Last but not least, we are thankful to our colleagues at the Transportation Laboratory of The University of Akron, for their kind support and assistance in lab testing and field work for the completion of the project.

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1. Executive Summary

Turning Movement Information (TMI) refers to the number of vehicles completing left or right turns or through movements from each intersection approach. Obtaining TMI at signalized intersections is a major task in travel data acquisition for many applications. Traditional method for gathering TMI involves manual counts by sending people to collect such data at intersections. Obviously, it is very time consuming and costly to manually collect TMI, especially for wide area deployment.

The Transportation Lab at The University of Akron (UA) developed an Automatic Turning Movement Identification System (ATMIS) to assist in the data collection work. The main feature of ATMIS includes automatic data collection without human intervention in real time. The UA research team successfully conducted a proof of concept study in a lab environment (with simplified conditions) and initiated this field test project under the sponsorship of the Ohio Department of Transportation. The specific objectives of the field test project will include:

- Develop turning movement identification algorithm for different intersection configurations and signal control plans.
- Develop a system architecture to interface with the signal control system that collects signal control and detector status information in real time for turning movement identification.
- Identify the hardware and cost requirements in support of the system operation in the field.
- Evaluate the proposed system in different intersection geometric configurations under the influence of traffic and weather conditions.

With great assistance from the City of Akron and support from Path Master, Inc., this research project has been carried out without any real difficulties in planning, design, and testing of the proposed system. By interfacing with the existing signal control and video detection devices, the algorithm is executed in the central processer by analyzing and mapping the data obtained against established rules to identify turning movements

ATMIS is tested in different scenarios with variations in intersection configuration and weather conditions. The turning movement data obtained from the system are compared with the ground truth by watching the synchronous video. While the average accuracy level in the first phase of tests for most intersection movements reached 90%, additional improvements in the algorithm and hardware design to handle large-sized vehicles, irregular geometrics and pedestrians, have further advanced the data accuracy to an average of 98% for the through movements and over 95% for the entire intersection. The major problem leading to the errors is because of turning buses at small intersections, where the size of vehicles can cause false detections. We found an effective solution to this problem by adjusting the camera angles, but it was not done for every such case partly because it adds to the busy daily work for the city engineers and partly due to the low volume for the turning movements at small intersections, where the affect due to missing a few vehicles is limited in ADT calculation. It has been demonstrated that the ATMIS algorithm can effectively address variations in geometrics within the scope of this project, with no obvious degrading impact on the accuracy level due to normal rain and snow.

The field testing of the system at different intersections has demonstrated the feasibility and capability of ATMIS to work independently and reasonably accurately for its intended purpose. The algorithm and system hardware proves to be effective and reliable although further improvement can be made to handle other situations and testing purposes. The potential application of the system in the field is expected to enable ODOT and local planners and engineers to collect long-term turning movement data throughout the year without human intervention.

2. Project Background

Turning Movements Information (TMI) of vehicles at signalized intersections is important for many applications including traffic safety analyses, travel demand estimation, advanced signal control, and other applications in transportation system planning. TMI is also needed for system analysis such as estimating delay, level of services, and congestion.

Currently, Turning Movements Information is collected manually with handheld devices in the field, which is tedious and labor intensive involving high cost. Previous efforts on this problem relied on a mathematical model by solving an O-D matrix in which the turning movements represent distributions of the arriving flow to each intersection approach. However, such a matrix cannot be mathematically solved without using supplementary volume data from the local detectors; yet previous studies showed that the results from the O-D method are not reliable and accurate, because either the matrix is degenerate without a meaningful solution or the required data accuracy for the solution process is unrealistically high. Therefore, driven by the need to identify vehicle turning movements economically, accurately, and reliably in different geometric and traffic control conditions, an Automatic Turning Movement Identification System (ATMIS) has been developed in the Transportation Laboratory of the University of Akron. By interfacing with the existing signal controller and detection devices, the system was tested in a laboratory environment using video from the field. The results from the preliminary lab experiment showed that the methodology is very promising and it can potentially be expanded and enhanced for field applications.

Built on the lab test success, the current project was initiated to further test the effectiveness of this methodology at different intersection configurations in field operations. If proven through field tests, the methodology may lead to widespread applications across jurisdictions in intersection traffic data collection for both ODOT and local MPOs.

3. Research Context

Objective

The main objective of this research is to develop and evaluate a real-time system, which can automatically collect the Turning Movements Information at signalized intersections using signal control information and video detection data. The specific objectives of this project include:

• Develop turning movement identification algorithm for different intersection configurations and signal control plans.
• Develop system architecture to interface with the signal control system that can collect signal timing data and detector status information in real time for turning movement identification.
• Identify hardware requirements, communication data and detection needs, and estimate system cost in support of the system operation in the field.
• Evaluate the effectiveness of the proposed system under different intersection geometric configurations influenced by traffic and weather conditions.

Tasks

Task 1: Conduct a comprehensive literature review.

Task 2: Develop algorithms for turning movement identification in field testing.

Task 3: Define system architecture including the hardware needs for field implementation.

Task 4: Detector layout design for different intersection geometric configurations.

Task 5: Conduct field tests and data analysis for selected locations.

Task 6: Define and recommend system operation conditions and data accuracy.

Task 7: Prepare final report.

Literature Search

The estimation of O-D matrices for turning movements at signalized intersections, in terms of the counts of traffic from each entrance approach going to other exit approaches, plays a vital role in traffic control such as traffic volume estimation, signal timing and adaptive control, and dynamic traffic assignment. The turning movement counts have been historically estimated by manual counting method. Although this method is easy to perform for gathering Turning Movement Information (TMI), it is time consuming and costly due to labor intensive work and consequently not practical for wide area applications [1]. With the improvement in modern vehicle detection systems, Cremer and Keller sought to automatically handle this process by using the O-D matrix method as first introduced in 1981. Their algorithm uses a recursive structure in order to adjust the incoming traffic flow estimates as the intersection traffic flows increase or decrease, but this method cannot handle the situation if the changes in the incoming flows occur rapidly [2]. Later, Nihan and Davis [3] as well as Cremer and Keller [4] developed a set of dynamic O-D estimation models for intersections and small networks based on the prediction error minimization method. In their models, the volumes of vehicles flowing in and out of each intersection approach are used as input parameters. Given these parameters, the O-D matrix is then solved mathematically to get the turning movement information. Due to data limitation and the fluctuations of the continuous traffic flow, the results obtained by the O-D matrix method are not nearly stable and accurate for potential applications, especially for those requiring short time TMI. Alternatively, another method was developed by Jiao et al. [5] using the Genetic Algorithm to identify TMI. This approach was first introduced in 2003, and the simulation results were reportedly encouraging. However, this method is very sensitive to detection errors commonly seen in the field, which are associated with the type of detectors used, data reporting intervals, weather conditions, and variations in intersection geometry, etc.

Virkler and Kumar [6, 7] at the University of Missouri, Columbia developed and tested the Time and Place Systems (TAPS) method utilizing the phasing and detection information for TMI. TAPS separates right turning vehicles from the through traffic flow using an exclusive lane detector but the left turning vehicles in a shared lane can cause the error to vary from 5% to 70%. In recent years, Chen et al. [8] used a path flow estimator to derive TMI for an entire roadway network. The proposed method involves a new technique to derive the complete link and turning movement estimates for the whole network by using an origin destination (O-D) trip table with partial information for some link and intersection movement counts. However, the reported results indicate that the maximum errors of estimated turning movements can be too large and many small-observed turning movement volumes are highly overestimated. Another limitation of this method is the large time interval required in order to collect enough data for calculating turning movements.

Zhang et al. [9] tested a nonlinear programming approach to calculate intersection O-D matrix. Those methods rely on almost impossibly accurate field data from a large number of detectors to ensure feasible and stable solutions to the mathematical models. Perhaps the most relevant work to considering the influence on turning movement estimation by geometric and traffic condition in the field is by Gholami et al [10], where Genetic Programming (GP) is used to calculate the proportion of turning vehicle movements from shared lanes at signalized intersections. In their proposed work, three different techniques have been considered, which are explained in details as following:

1-Network Equilibrium (NE): the unknown movement is estimated based on the equilibrium state of volume in two consecutive intersections as shown in Figure 1.

2-Volume and Queue Length of Shared Lanes (VQ): If there are more vehicles in shared lane compared to adjacent lane(s), then probably new entered cars to shared lane decide to turn. See Figure 2.

3-Flow characteristics of shared lanes (FC): turning proportion is estimated based on headway of vehicles, position in the line. For example, cars which have smaller headways from their front car when they pass stop bar are more probable to go through.

Although this method has considered several possibilities to help determine vehicle movements, it uses known data on turning movements as input. In addition, the execution of its rules requires to use traffic formation data (normally not available), even though the assumptions in those rule may not be correct in each case.

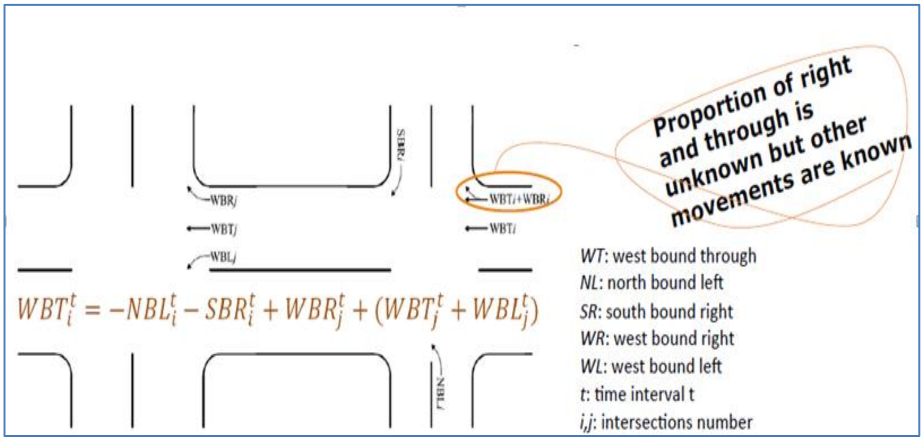


Figure 1 Network Equilibrium Method for Turning Movement Estimation

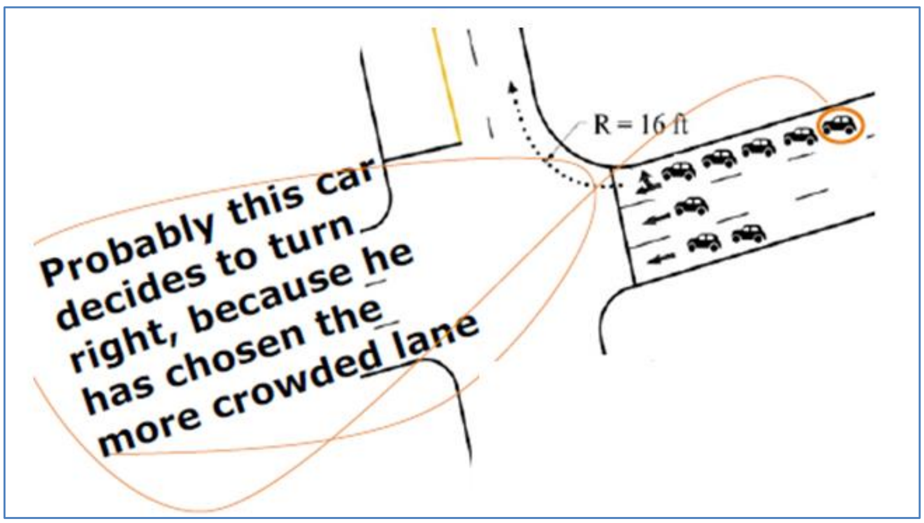


Figure 2 Volume and Queue Length Method for Turning Movement Estimation

In conclusion, the current literature on this subject shows that work on this subject is still very limited and most of the efforts are based on primitive methods or analytical models that require unsustainable assumptions for a complicated problem involving changes in traffic flow, geometric, and environmental conditions. In view of those limitations, our research project endeavors to develop and test a method for improved accuracy and application practicality in TMI collection. Our method not only uses the existing video detection capability at signalized intersections but also incorporates the signal timing information directly in the algorithm to identify the turning movement counts in real time.

4. Research Approach

The research team has built a system capable of automatically collecting turning movement data base on video detection data, traffic signal and time stamp information at a signalized intersection.

The system is connected to the traffic control cabinet and it reads the digital signals from the Synchronous Data Link Control (SDLC) port (port 1 on most traffic signal controllers) which contains traffic signal and video detection information. The digital signals are captured and interpreted by the microcontroller according to National Transportation Communications for ITS Protocol (NTCIP). The system gets the real-time traffic signal and detection information and sends it to the central processer, where the algorithm is executed to identify the vehicle turning movements based on pre-established rules. The following sections explain this process and the system framework in details.

General Application and Detector Layout

This system is designed to apply at a signalized intersection as exemplified in Figure 3(a). The intersection is equipped with the Autoscope video detection system by the City of Akron for traffic detection and signal control purpose, where each approach of the intersection is covered by a camera. Our system interfaces with the local signal control system to capture signal timing and the detection (detectors status) information from the Autoscope system. The detectors in Autoscope system are visual lines that can be edited according to the user requirements in the Autoscope software. Figure 3(b) shows the layout of detectors for one approach in the intersection, the black straight lines are the detectors.

(a) Field View of Intersection (b) Detectors Layout in Autoscope

Figure 3 System Application and Autoscope Detectors

Data Source (Digital Signals)

In the signal cabinet of the intersection shown in Figure 4(a), the main hardware components are the Signal Controller in Figure 4(b), the Autoscope Unit in Figure 4(c) (video detection system), the Malfunction Management Unit (MMU) and other electric accessories. These main parts share information via Port SDLC interface with 153,600Hz digital signals, the port highlighted in the red box in Figure 4 (b) is SDLC port. Three SDLC cables from the three main parts are connected to the same panel which is referred to as the SDLC Terminal Strip End, SDLC pinout is shown in Figure 5.

(a) Traffic Signal Cabinet (b) Signal Controller (c) Autoscope Unit

Figure 4 Traffic Control Components and SDLC Port

Pair 1 + Tx Data +	Blue Pin 1	Pair 2 + Tx Clock +	Red Pin 3	Pair 3 + Rx Data +	Green Pin 5	Pair 4+ Rx Clock +	White Pin 7
Pair 1 – Tx Data -	Black Pin 9	Pair 2 – Tx Clock -	Black Pin 11	Pair 3 – Rx Data -	Black Pin 13	Pair 4 – Rx Clock -	Black Pin 15

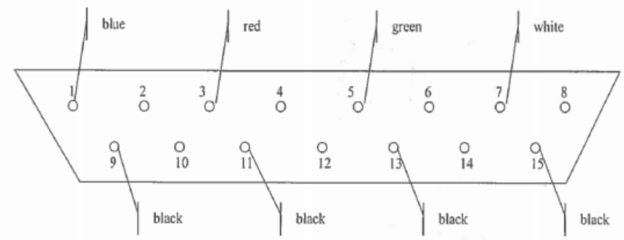
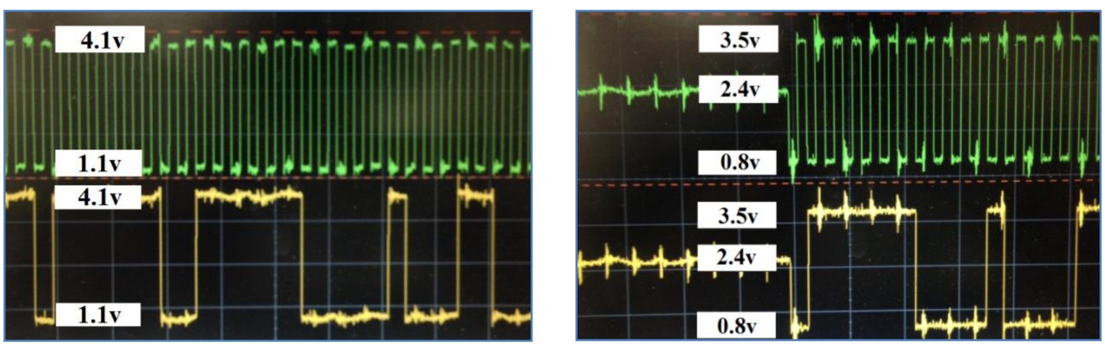


Figure 5 SDLC Port Pinout

The figure above shows the pinout of the SDLC port. It has in total eight pins (Tx Data +, Tx Data -, Tx Clock+, Tx Clock -, Rx Data +, Rx Data -, Rx Clock +, Rx Clock -). The Tx pins contain information including the traffic signals status, and the Rx pins contain information including the detectors status. Specifically, Data signals contain the information shared between the main components and the Clock signals specifies the length of each digital bit. All the above information is captured and interpreted by the microcontroller of our system.

System Structure (Hardware)

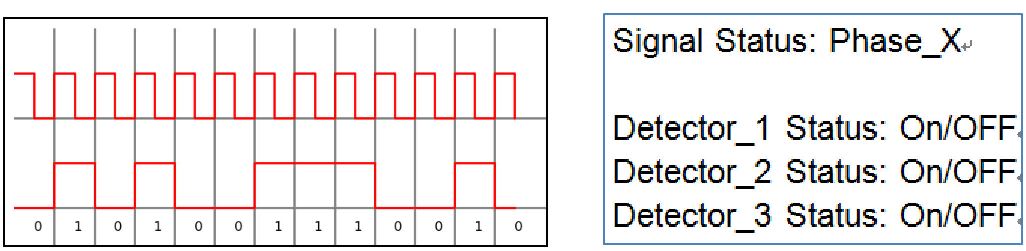
Our system connects to this SDLC port to capture digital signal information. The digital signals contain the information of the traffic signals and the video detection. Figure 6 shows the digital signals.



(a) Traffic Signals Information (b) Detection Information

Figure 6 Digital Signals from the SDLC Port

The microcontroller captures these digital signals and converts them into bit streams, according to the clock signal, and then interprets the bit streams into the traffic signals and detection information according to the NTCIP standard. Figure 7 shows an example.



(a) Bit Streams (b) Signal Interpretation

Figure 7 Interpreting Bit Streams into Desired Information

After the system receives traffic signal and detection data, it generates the time stamp according to the system clock, and sends all information to the central processer to execute the turning movement identification algorithm. The entire system structure is shown in Figure 8, and a picture of the hardware of the system is shown in Figure 9.

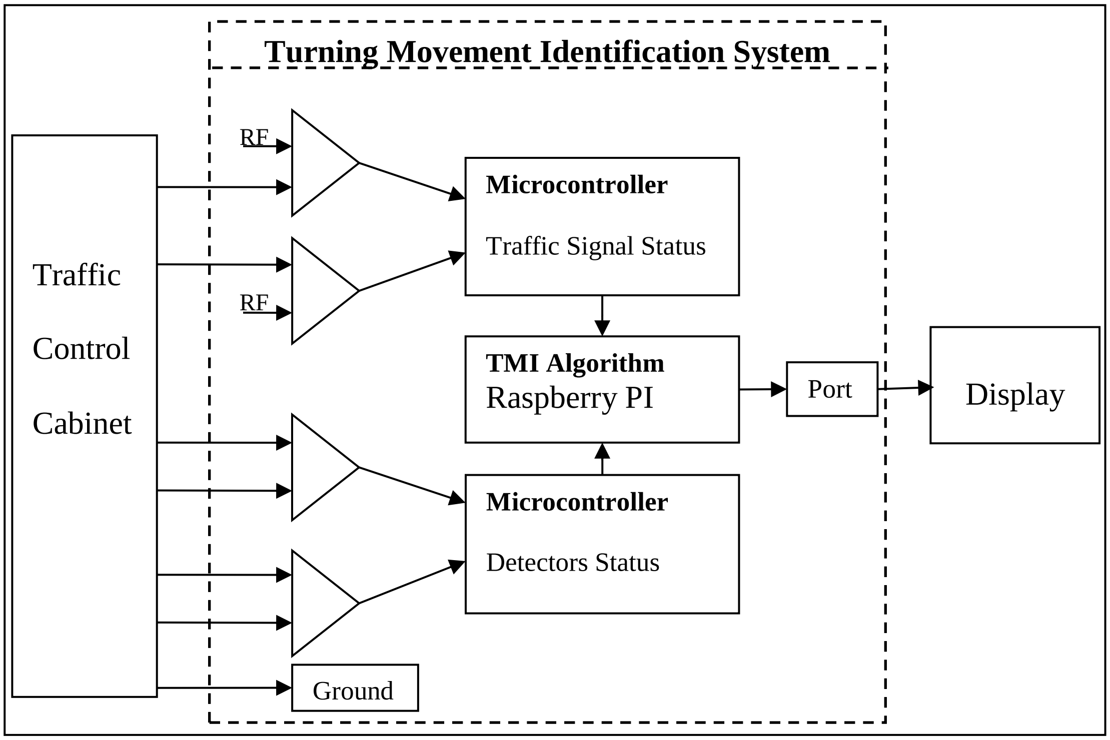


Figure 8 System Structure

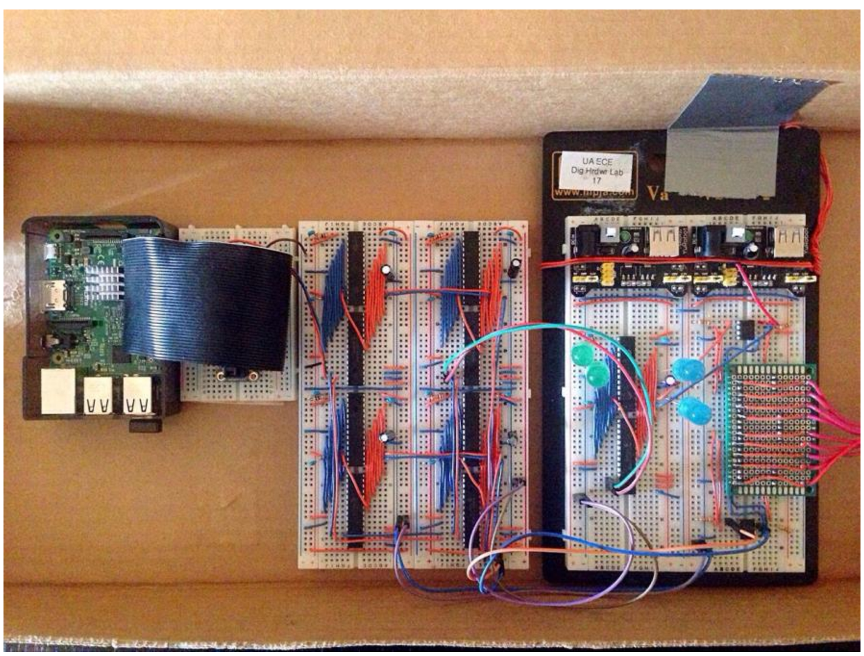
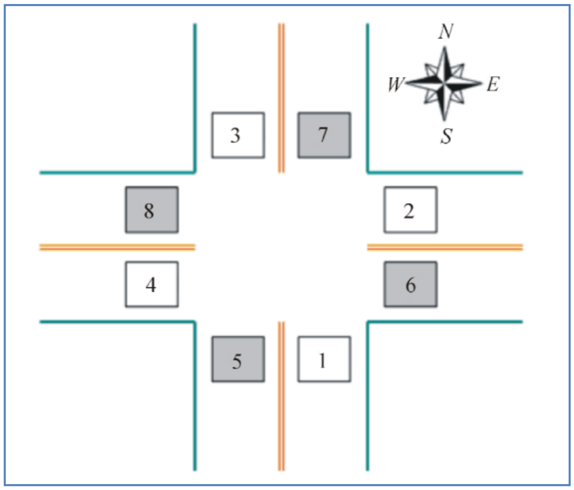


Figure 9 Turning Movement Identification System (hardware)

Algorithm and Flow Chart

The system algorithm makes use of the input information on traffic signal, detection and time stamp to identify the vehicle turning movements in real time. The basic concept of the algorithm is to match the detection sequence, with the help of traffic signal information and time difference between the activation and deactivation of detectors, to identify the movement of each vehicle at each intersection approach. Figure 10 shows the relationship between the detector pairs and the corresponding turning movements.



Input Det.	Output Det.	Movement	
1	7	Northbound Through	NT
1	6	Northbound Right Turn	NR
1	8	Northbound Left Turn	NL
2	8	Westbound Through	WT
2	7	Westbound Right Turn	WR
2	5	Westbound Left Turn	WL
3	5	Southbound Through	ST
3	8	Southbound Right Turn	SR
3	6	Southbound Left Turn	SL
4	6	Eastbound Through	ET
4	5	Eastbound Right Turn	ER
4	7	Eastbound Left Turn	EL

Figure 10 Detectors Layout and Corresponding Turning Movements

The white squares in the figure are the entrance detectors and the gray squares are the exit detectors. When an entrance detector changes its status from activated to deactivated, it means a vehicle has left this detector to enter the intersection and the system keeps track of the relevant information, including traffic signal status (Red, Green or Yellow), detector ID and the time stamp (Hour:Minute:Second - Month/Date/Year). When an exit detector changes its status from deactivated to activated, it means a vehicle has come out of the intersection and the system will try to match this detector with the prior entrance detector and identifies the movement of this vehicle.

Different possibilities may exist when the system tries to pair the entrance detectors with the exit detectors within a certain length of time: no match, one match and multiple matches. In heavy traffic situations multiple matches often occur, so the system takes advantage of the traffic signal and time stamp information to filter out the impossible or unlikely movements and choose the most reasonable turning movement. More details are explained in Figure 11 - flow chart.

Algorithm Flow Chart

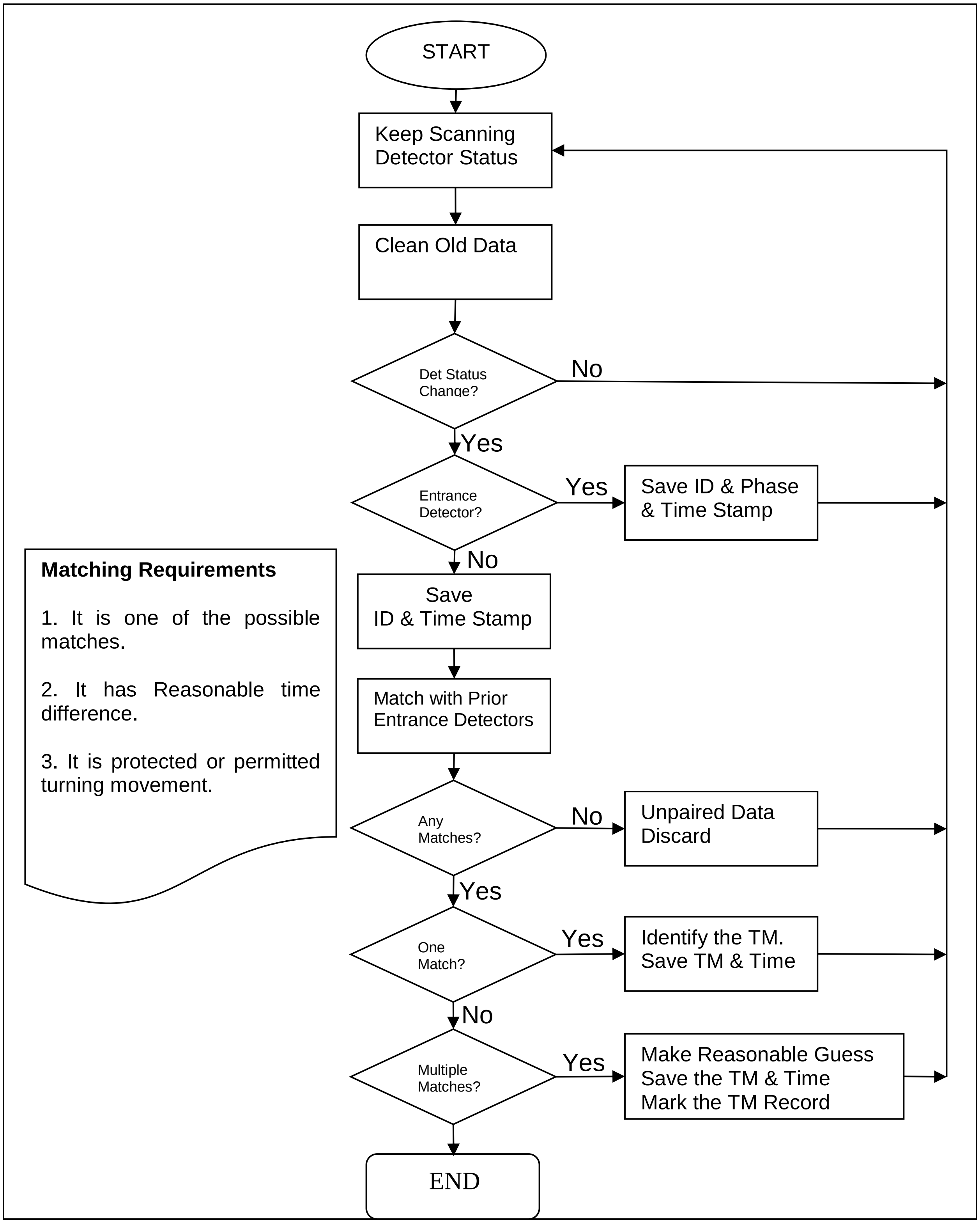
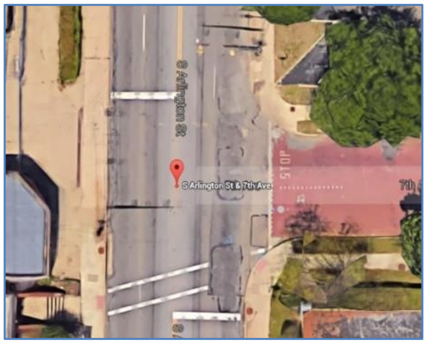


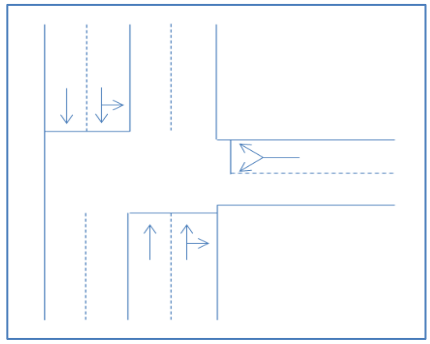
Figure 11 Vehicle Movement Identification Flow Chart

Field Tests at the Selected Sites

The research team has selected several intersections in Akron area as possible field test sites. For example, the intersection of Arlington St. & 7th Ave. (T intersection) and the intersection of Arlington & 5th Ave (four-legged intersection) are shown in Figures 12 and 13.



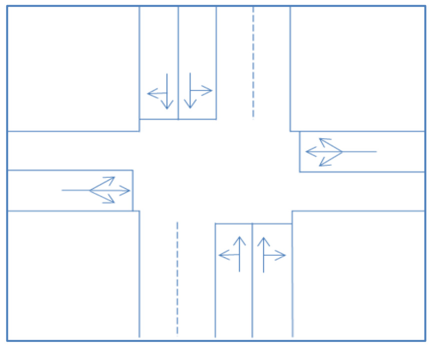
(a) Arlington & 7th Intersection, Akron



(b) Intersection Layout

Figure 12 Arlington & 7th Intersection

(a) Arlington & 5th Intersection, Akron



(b) Intersection Layout

Figure 13 Arlington & 5th Intersection

A number of tests have been conducted using the automatic turning movement identification system (ATMIS), including the preliminary tests based on a lab version of the hardware and algorithm. During the field tests, the system collected and processed all the information on traffic signals, the detector data and the time stamps, and execute the algorithm to identify vehicle turning movements as shown in Table 1. Details of each test is presented in the Appendix of the report.

Table 1 Sample of Raw Data Collection and Turning Movement Identification

Detector ID	Detector Status	System Time	traffic Signal Status	Time Stamp
DET-#09	OFF	14:43:2	Phase_2 GREEN	0:2
DET-#16	ON	14:43:3	Phase_2 GREEN	0:3
DET-#03	OFF	14:43:8	Phase_2 GREEN	0:8
DET-#09	OFF	14:43:8	Phase_2 GREEN	0:8
DET-#04	ON	14:43:9	Phase_2 GREEN	0:9
DET-#13	OFF	14:43:9	Phase_2 GREEN	0:9
DET-#03	OFF	14:43:10	Phase_2 GREEN	0:10
DET-#12	ON	14:43:11	Phase_2 GREEN	0:11
DET-#04	ON	14:43:11	Phase_2 GREEN	0:11
DET-#02	ON	14:43:12	Phase_2 GREEN	0:12

(a) Input Data Table

Entry-Departure	Turning Movement	Time
9-16	South-to-North	14:43:3
3-4	South-to-North	14:43:9
13-12	North-to-South	14:43:11
9-4	South-to-North	14:43:11
3-2	South-to-East	14:43:12
9-16	South-to-North	14:43:17
3-4	South-to-North	14:43:17
13-12	North-to-South	14:43:18
9-16	South-to-North	14:43:20
3-4	South-to-North	14:43:22

(b) Turning Movement Identification

5. Research Findings

The main objective of this research project is to develop and evaluate a real-time data acquisition system, which can be used to automatically collect vehicle turning movement data at signalized intersections using video detection and signal control information. The system has been developed and the feasibility of using the system for its intended purpose is proven after the system is tested at three intersections in the City of Akron from fall of 2016 to spring of 2017.

The intersections selected for field testing are based on the availability of video detection system already in operation at each site for signal control; they are included also because there are lanes in each intersection that are shared for all three types of movements (left turn, going through, and right turn) – representing the most complex and challenging situation because the algorithm is required to identify each movement separately and correctly.

The three intersections represent different scenarios with variations in geometric configuration and weather conditions. The turning movement data obtained from the system are compared with the ground truth by watching the synchronous video. After enhancements are made to the lab version hardware and the algorithm, the accuracy level has reached a volume weighted average of 98% in identifying the through movements (usually carrying much higher traffic volume) and over 95% for the entire intersection. It should be noted that although a large variation in the accuracy level for the left turn or right turn movements can be seen in the data tables, a continued improvement in the algorithm is expected to further increase the accuracy. After all, those movements represent only a very small portion of the intersection traffic; thus, the impact of the data error on traffic counts is limited. This fact is illustrated by the intersection wide volume weighted error in each summary table, which is in the range of 2% to 5%.

It is found that large sized vehicles such as a city bus making left or right turns at small intersections can lead to false detections (the aforementioned errors). Although the algorithm can help detect and correct such errors, a more direct and effective solution to this problem is by adjusting the camera angle or height. This requires the assistance by the local traffic control agency and a collaborative decision by ODOT whether it is necessary to make the camera adjustment. Depending on the traffic level and importance of certain turning movements, additional field work may not be worthwhile since missing a few vehicles will not cause large errors in the ADT calculation.

All the tests were conducted at small intersections with shared lanes in this project. It is anticipated that the results of the tests would be more impressive, especially on the left and right turns, if they were made at large intersections where turning movements follow specific lanes and designated signal phases without making wild turns by city buses. Furthermore, since the net Difference by the improved system in Tables 4 through 7 is much smaller than the absolute errors, it is believed that there is still room to improve the vehicle matching algorithm and further increase the accuracy level. In summary, the developed system has been demonstrated in the field tests that it can effectively address variations in geometrics within the scope of this project with reliable data output. In addition, test results also showed that there is no obvious degrading impact on the accuracy level of the system by normal rain and snow.

Since the system consists of electronics and software program, its operation is expected to be reliable and can support long term applications. Because this project is mainly a feasibility study, the system hardware has not been built into an integrated box for easy placement inside the signal control cabinet; an operational test of the system over its long term performance will require an integration of the system hardware, supported by stable power supply in a safe, dry, temperature controlled environment inside the cabinet.

6. Recommendations for Implementation of Research Findings

Recommendation for Implementation

The feasibility of using the automatic turning movement identification system (ATMIS) is proven when it is supported by a video detection system for signal control. This system needs stable power supply, and the ultimate design of the system is to integrate the hardware so that its size can be reduced for placement inside the traffic signal cabinet with a safe, dry, temperature controlled environment.

Because ATMIS is an electronic system running the turning movement identification algorithm, its operation is expected to be reliable to support long term applications. General weather conditions (rain and snow) have not been found to affect the system performance, although the system has not been tested under extreme weather (major snow storm or extraordinary rainfall).

Steps Needed to Implement

1. Set up the baseline for running the algorithm in the central processer according to the intersection geometry and signal control, including lane configuration and usage for turning movements.
2. Create entrance and exit detectors on the video detection system for the intersection configuration. They are independent detectors and will not interfere with the signal operation.
3. Associate the detectors with the signal control plans to define every turning movement.
4. Fine tune detectors locations after trial test and, if needed, make recommended camera angle adjustment for a better view of the intersection approaches.
5. Connect the system to the SDLC strip end in the traffic control cabinet.
6. Let system operate and automatically collect the turning movement data.

Expected Benefits from Implementation

1. Real time data collection – this system can collect the turning movement data in real time without delay. This makes the data very valuable for many real time applications.
2. Long term application – this system by design supports for 24/7 operation for 365 days a year; however, its long term performance has not been tested and verified. The system does not require any human intervention, thus saving time and labor cost.
3. Economical – the components used to build this system are not expensive, and it is feasible to apply this system to many intersections equipped with a video detection system.
4. Wide area application – this system could be applied in many intersections at the same time to collect network wide data.

Potential Risks and Obstacles to Implementation

1. The working environment needs to be dry, since the electrical circuits could be possibly destroyed by water. The temperature at the working environment should be within the system's temperature toleration, which is provided inside the signal cabinet.
2. Currently, the system can work with intersections already equipped with a video detection system, although in the future it may be designed to work with other traffic detection system as well.

Strategies to Overcome Potential Risks and Obstacles

1. Leave the system working in the traffic control cabinet when its size is adequately reduced, make sure the cabinet is closed and locked. Utilize the power supply inside the cabinet and make sure the cable connection is firm.

Potential Users and Other Organizations that may Be Affected

1. State DOT engineers and data analysts, local MPOs, local cities, and the consulting industry may be interested in using the system.
2. No negative impact will be created by the system.

Suggested Time Frame for Implementation

1. One person-week, including setting up the detector, testing the algorithm, and fine tuning the system.

Estimated Costs (for one intersection)

The estimated total cost of the ATMIS hardware per intersection is around two hundred (200) dollars, including twelve Microcontrollers, Raspberry PI, Micro SD Card, Resistors and Capacitors, Breadboard or PCB, Wires and LEDs, etc.

How to Evaluate the Ongoing Performance of the Implemented Result

Manually collect the turning movements and compare with the system results.

Bibliography

[1] Transportation Research Board, “Highway Capacity Manual”, Washington DC, 2000.

[2] M. Cremer and H. Keller, “Dynamic Identification of O-D Flows from Traffic Counts at Complex Intersections,” Proceedings of the 8th International Symposium on Transportation and Traffic Theory, Toronto, 1981

[3] N. L. Nihan and G. A. Davis, “Recursive Estimation of Origin-destination Matrices from Input Output Counts,” Transportation Research Part B, 1987.

[4] M. Cremer and H. Keller, “A New Class of Dynamic Methods for the Identification of Origin-destination Flows,” Transportation Research B, 1987.

[5] P. Jiao, H. Lu and L. Yang, “Real-Time Estimation of Turning Movement Proportions Based on Genetic Algorithm,” Proceedings of the Conference on Intelligent Transportation systems, Vienna, 13-15 September 2005.

[6] M. R. Virkler and N. Kumar, “System to Identify Turning Movements at Signalized Intersections,” Journal of Transportation Engineering, 1998.

[7] J. Tian, M. R. Virkler and C. Sun, “Field Testing for Automated Identification of Turning Movements at Signalized Intersection,” Transportation Research Record: Journal of the Transportation Research Board, 2004.

[8] A. Chen, P. Chootinan, S. Ryu, M. Lee and W. Recker, “An Intersection Turning Movement Estimation Procedure Based on Path Flow Estimator,” Journal of Advanced Transportation, 2012.

[9] X. Zhang, X. Cao and L. Sun, “Estimation of Intersection Turning Movement Proportion Using MATLAB,” Proceedings of CICTP 2012, Beijing, 2012.

[10] Gholami, Ali. "Using Detector Information to Determine Turning Movement Proportions in Shared Lanes."

Appendix – Testing and Data Analysis

Field test of ATMIS was carried out sequentially at four intersections in fall of 2016 to spring of 2017. Due to signal control equipment malfunction at one intersection during the test, data were obtained from only three intersections, including one T-intersection and two four-legged intersections. Although the equipment at the problem intersection was fixed later (the project team went back to verify that), the intersection was not used further because the communication cable to the intersection was disconnected due to a scheduled construction that affected a number of intersections.

All three intersections were selected based on the availability of video detection system already in operation at the intersection for signal control. In addition, the project team specifically looked for intersections with approaches where one lane is used for the left-turn, through, and right-turn movements. This represents the most complex and challenging situation because the algorithm is required to identify each movement separately and correctly.

During the field tests, a synchronous video was taken at the same time. The project team manually counted the turning movements from the video and compared the data with output from the system.

Initial Tests with Lab Version Algorithm

A. T-Intersection

The intersection of Arlington and 7th Ave. is a T-intersection, where Arlington carries a large amount of traffic and 7th is a minor side street. As shown in Table 2, results from a 16-minute test were conducted and summarized, broken down to shown data comparison for each movement.

Table 2 Field Test Result from Arlington & 7th

Arlington & 7th, 16mins, 05/12/16				
TM	Ground Truth	System Output	Difference	Absolute Error
SB-L	5	5	0	0.00%
SB-T	**132**	**125**	**7**	**5.30%**
NB-T	**144**	**145**	**-1**	**0.69%**
NB-R	12	14	-2	16.67%
WB-L	6	6	0	0.00%
WB-R	10	6	4	40.00%
Total	309	301	8 (net); 14 (absolute)	**4.5% vol. weighted**

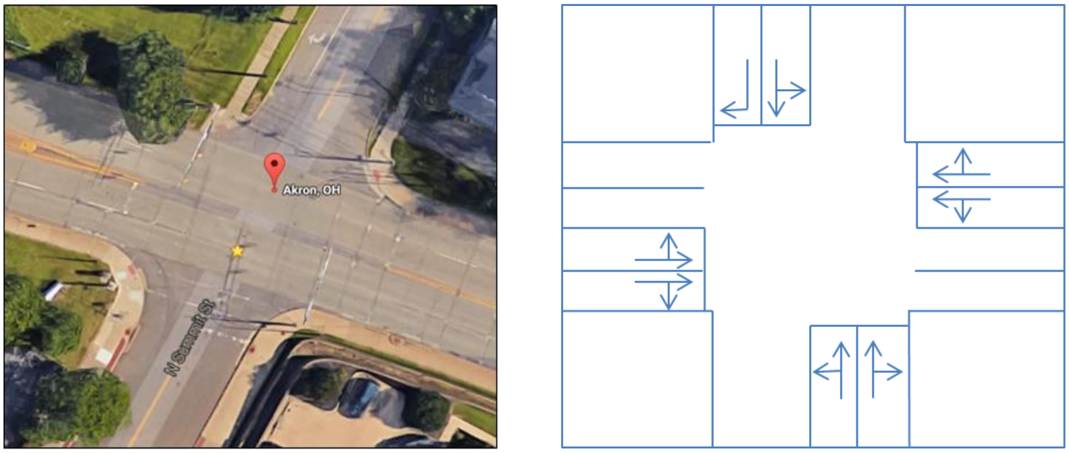
Note: SB-L means South Bound Turning Left;

Although errors are found in almost every movement and some of them represent even large percentages, the test results generally look fine and, collectively, the intersection wide absolute error (after converting negative to positive) is at 4.5%. The field test lasted only 16 minutes, since an engineer from the City of Akron was needed to open the signal cabinet and stay at the intersection as long as the cabinet is open. A short time period is more acceptable to the engineers due to their other work duties. Nevertheless, the traffic counts for 15 to 20 minutes are generally high enough to test the system's technical capabilities.

B. Four-Legged Intersection

Subsequent test at another intersection was prepared and ATMIS compatibility run checked and all cable connections made. However, a hardware problem occurred at the intersection that disturbed the normal handshaking between ATMIS and the signal system. Numerous attempts to restore the connection were made and a great deal of time was spent but all the efforts had failed, only to find a few months later that the communication equipment at the intersection had caused the problem and it was eventually fixed.

The project team moved to another intersection due to time constraint before the above problem was fixed. The intersection of M.L.King and Summit is a four-legged Intersection, shown in Figure 14, and it is selected to continue the test due to location convenience close to The University of Akron campus. This intersection includes four approaches and each one has one or two entry and exit lanes. There are total 14 lanes in this intersection, including one southbound right turn lane. A 30-minute test was conducted onsite in October of 2016, and the results of the test are summarized in Table 3.



(a) M.L.King & Summit Intersection, Akron (b) Intersection Layout

Figure 14 M.L.King and Summit Intersection

Table 3 Field Test Result from M.L.King and Summit

M.L.King & Summit, 30 mins , 10/28/2016				
TM	Ground Truth	System Output	Difference	Absolute Error
SB-L	16	19	-3	18.75%
SB-T	**2**	**2**	**0**	**0.00%**
SB-R	24	13	11	45.83%
NB-L	12	14	-2	16.67%
NB-T	**4**	**4**	**0**	**0.00%**
NB-R	18	23	-5	27.78%
EB-L	6	16	-10	166.67%
EB-T	**282**	**286**	**-4**	**1.42%**
EB-R	8	11	-3	37.50%
WB-L	18	20	-2	11.11%
WB-T	**369**	**397**	**-28**	**7.59%**
WB-R	19	20	-1	5.26%
Total	778	825	59 (net); 69 (absolute)	**8.9% vol. weighted**

Similarly, errors vary in Table 3 and the intersection wide absolute error is about 9%. It is observed that the through movements, which usually carry a higher volume, have a much smaller percentage error as compared with other turning movements.

Tests with Enhanced Hardware Design and Improved Algorithm

Error analysis by the project team using the system output from the initial tests revealed a number of problems, including detector miscounts, over counts, slow detector response, etc. In particular, the following factors caused most of the errors:

(1) The large-size vehicles such as long city buses could activate the detectors, especially, when they make wild turns
(2) The shadows of vehicles and the trees could cause false detection, and
(3) The pedestrians could activate the detectors.

The project team studied those problems and proposed corresponding solutions. Implementation of the solution strategies involved enhancements on the system hardware to provide more detection capabilities and faster data processing. In addition, the turning movement identification algorithm is improved to take advantage of the added detection capacity. Additional tests have been conducted using the improved system and results are presented next.

C. Additional Tests at Four-Legged Intersections

Using the improved hardware and algorithm, the project team moved to another site to continue the test. The intersection of Arlington & 5th Ave is a four-legged intersection (shown in Figure 13), where Arlington is a major arterial in south Akron and 5th Ave. is a minor street. The SB and NB include two lanes moving in and out whereas EB and WB are single lane approaches. Since there are no exclusive turning lanes, the left turn, going through, and right turn movements are made from shared lanes. A 20-minnute test was conducted and results are summarized in Table 4.

Table 4 Field Test Using Improved System at Arlington & 5th

Arlington & 5th, 20mins, 06/15/17				
TM	Ground Truth	System Output	Difference	Absolute Error
SB-L	4	4	0	0.00%
SB-T	**81**	**82**	**-1**	**1.23%**
SB-R	8	8	0	0.00%
NB-L	8	9	-1	12.50%
NB-T	**104**	**99**	**5**	**4.81%**
NB-R	5	6	-1	20.00%
EB-L	8	8	0	0.00%
EB-T	**3**	**3**	**0**	**0.00%**
EB-R	4	4	0	0.00%
WB-L	10	12	-2	20.00%
WB-T	**9**	**9**	**0**	**0.00%**
WB-R	7	8	-1	14.29%
Total	251	252	-1 (net); 11 (absolute)	**4.4% vol. weighted**

The Difference column in Table 4 shows that the number of mismatched vehicles is largely reduced cross the board and the volume weighted intersection wide error, calculated using the absolute error in order not to underestimate it, is less than 5%. Although some individual movements are still affected by large errors, those movements carry a very low volume and their contribution to roadway data collection such as ADT will be small. In contrast, the through movements (carrying a much heavier traffic volume represented in box text) are affected by much smaller errors.

Data checking on each movement showed that the improved algorithm using the enhanced system was able to eliminate errors due to shadows of vehicles and trees, and that the effects of pedestrians or cyclists were minimized. However, we also found that large size city buses are still responsible for most of the errors. At small intersections such as Arlington and 5th, wild maneuvers by long buses could activate the detectors in the adjacent lanes. A possible solution to this problem is by adjusting the camera angle/height, as learned from our experience at the T-intersection (to be presented later). However, no such adjustment was done at this intersection due to time constraint and our concern not to impose too much additional work to the already short-handed city engineers.

We continued to conduct a test on a raining day to assess the impact of weather on the performance of the improved system. It is logistically very difficult to set up the system and wait for the rain to come, since our activity must be coordinated with the city engineer and our equipment must be placed on a table under a large umbrella, leaving the signal cabinet door open in the meantime. After several attempts, we were able to conduct the test at the intersection of Arlington & 5th, and the results are summarized in Table 5.

Table 5 Field Test Using Improved System at Arlington & 5th on Raining Day

Arlington & 5th, 20mins, Rain, 06/07/17				
TM	Ground Truth	System Output	Difference	Absolute Error
SB-L	3	3	0	0.00%
SB-T	**82**	**79**	**3**	**3.66%**
SB-R	10	10	0	0.00%
NB-L	15	16	-1	6.67%
NB-T	**98**	**99**	**-1**	**1.02%**
NB-R	5	6	-1	20.00%
EB-L	26	24	2	7.69%
EB-T	**4**	**4**	**0**	**0.00%**
EB-R	8	10	-2	25.00%
WB-L	9	10	-1	11.11%
WB-T	**11**	**11**	**0**	**0.00%**
WB-R	10	11	-1	10.00%
Total	281	283	-2 (net); 12 (absolute)	**4.3% vol. weighted**

Comparing Table 5 and Table 4, which represent two weather conditions at the same intersection, we do not find any noticeable differences in the level of system performance. Specifically, the intersection wide volume weighted error is nearly the same, the errors for the though movements are also low (NB-T did better this time), and several turning movements are still affected by the city bus (without any camera adjustment).

The project team continued to conduct another test in a snow weather condition at the intersection of MLK and Summit Street. The winter season from late 2016 to early 2017 was warmer than usual with less snow and it snowed mostly during the weekend or at nighttime (when the city engineers were not at work). After we completed the system hardware and algorithm improvement this intersection was no longer available for use because of road construction. Therefore, we used a pre-recorded video from the intersection to carry out the test. Table 6 shows the summarized results from the test in next page.

Table 6 Field Test Using Improved System at M.L.King & Summit on Snow Day

M.L.King & Summit, 20mins (video tape), Snow Shower, 03/14/17

TM	Ground Truth	System Output	Difference	Absolute Error
SB-L	19	17	2	10.53%
SB-T	**24**	**23**	**1**	**4.17%**
SB-R	11	12	-1	9.09%
NB-L	2	2	0	0.00%
NB-T	**23**	**23**	**0**	**0.00%**
NB-R	16	15	1	6.25%
EB-L	12	13	-1	8.33%
EB-T	**67**	**68**	**-1**	**1.49%**
EB-R	0	0	0	0.00%
WB-L	21	21	0	0.00%
WB-T	**44**	**45**	**-1**	**2.27%**
WB-R	15	16	-1	6.67%
Total	254	255	-1 (net); 9 (absolute)	**3.5% vol. weighted**

Obvious improvements can be seen by comparing data in Tables 6 and 3. Under the improved system, the intersection wide volume weighted error is reduced to 3.5% from the previously 9% and the through movement error is kept very low.

D. Additional Test at T-Intersection

Another test was conducted at the intersection of Arlington and 7th Ave following all the above tests after the system improvement. Similarly, a 20-minute test was carried out and comparison results are summarized in Table 7.

Table 7 Field Test Using Improved System at Arlington & 7th

Arlington & 7th, 20mins, 06/27/17				
TM	Ground Truth	System Output	Difference	Absolute Error Per
SB-L	3	3	0	0.00%
SB-T	**131**	**129**	**2**	**1.53%**
NB-T	**150**	**151**	**-1**	**0.67%**
NB-R	13	13	0	0.00%
WB-L	6	6	0	0.00%
WB-R	3	1	2	66.67%
Total	306	303	3 (net); 5 (absolute)	**1.63% vol. weighted**

Comparing Tables 7 and 2 it can be seen that the improved system is able to not only reduce the absolute and net errors but also improve the intersection wide error percentage. The southbound through movement data benefited from minor adjustment of the camera angle. The westbound right turn remains to be a problem due to city bus turning at this small intersection. The project team understands the problem but did not ask the City of Akron to make additional camera position adjustment for this movement due to light traffic.