TRANSPORATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (University or Contractor):__Kansas DOT__________________________________

INSTRUCTIONS:
Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Project Number **TPF-5(351)**		**Transportation Pooled Fund Program - Report Period:** ☐ Quarter 1 (January 1 – March 31) ☐ Quarter 2 (April 1 – June 30) ☐ Quarter 3 (July 1 – September 30) X Quarter 4 (October 1 – December 31)
Project Title: Self De-Icing LED Signals		
Project Manager: Carla Anderson	**Phone:** 785-296-0357	**E-mail:** Carla.anderson@ks.gov
Project Investigator: Hongyi Cai	**Phone:** 785-864-2597	**E-mail:** hycai@ku.edu
Lead Agency Project ID: **RE-0721-01**	**Other Project ID (i.e., contract #):**	**Project Start Date:** August 15, 2016
Original Project End Date: **August 2019**	**Current Project End Date:** **June 2022**	**Number of Extensions:** 3

Project schedule status:

☐ On schedule X On revised schedule ☐ Ahead of schedule ☐ Behind schedule

Overall Project Statistics:

Total Project Budget	Total Cost to Date for Project	Total Percentage of Work Completed
$240,000 original, $360,000 with addendum	$ 350,743.89	99%

Quarterly Project Statistics:

Total Project Expenses This Quarter	Total Amount of Funds Expended This Quarter	Percentage of Work Completed This Quarter
$4,125.91	$4,125.91	3%

Project Description:

This pooled fund project will develop and demonstrate new self-de-icing LED signals for highway signalized intersections applications to solve a well-known problem of the existing LED signal light whose lens is too cool to melt snow and de-ice in wintery conditions. The self-de-icing LED signals will adopt one or both of two novel architectures (Figure 1), including (a) “Heated Lens Lighting Arrangement” that uses a single high-power LED and (b) “Heat Arrangement of LED Arrays in Low Profile” that deploys multiple LEDs. The heat generated by the LED(s) is harvested by the passive heat exchanger and stored to heat the lens for melting snow and de-icing in wintery conditions.

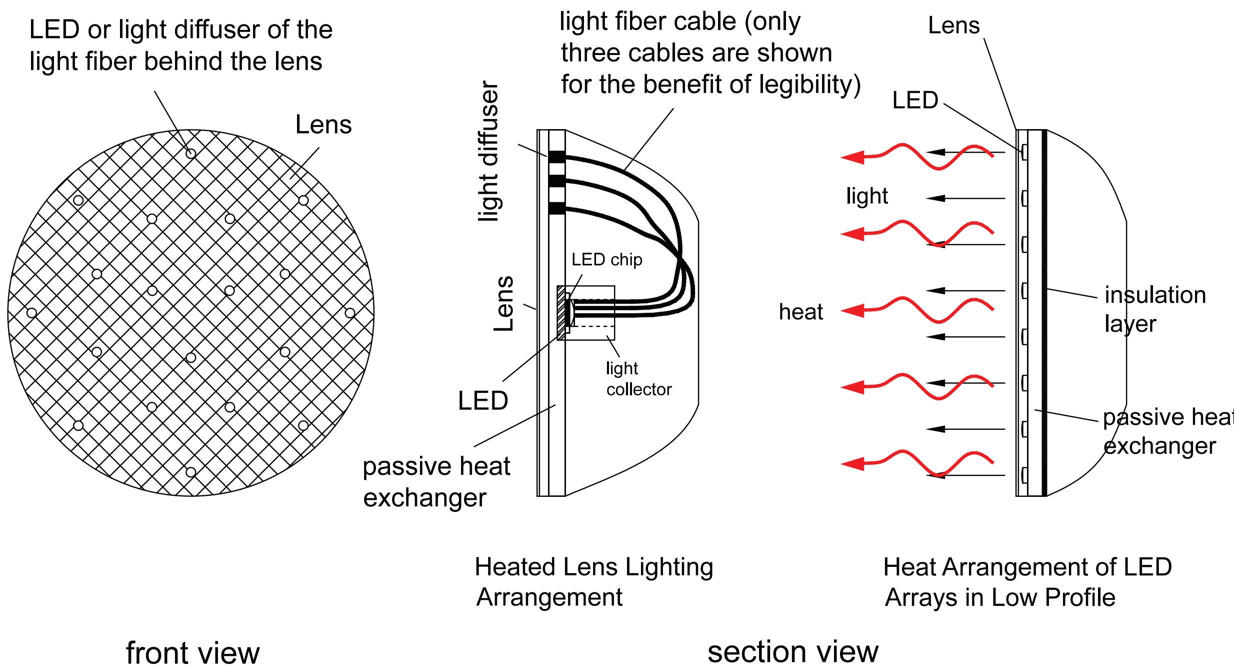


Figure 1 The concept of the self-de-icing LED signal light, which adopts new architecture of “Heated Lens Lighting Arrangement” or “Heat Arrangement of LED Arrays in Low Profile”

Fully working prototypes of the self-de-icing LED signals have been developed and tested in the laboratory. They have been tested in closed-course settings on the roof of an engineering building followed by field tests on highway intersection. Each participating agency is required to provide support of three years of funding ($20,000/year, totaling $60,000) and will be guaranteed a field test site in each state for testing the fully working prototypes catering to their specific needs of the new type of signals. The research team will work with each participating agency to identify the desired test site on highway intersections and the desired technical specifications for testing the prototypes.

The investigative approach for the proposed project is divided into three stages. Work in Stage 1 focuses on laboratory development and tests. Work in Stage 2 focuses on testing the three prototypes in a closed-course setting on the roof of the University of Kansas engineering complex and powered by the signal controller cabinet. Work in the third and final stage involves field testing of the developed prototypes on identified test sites. On-site demonstration of the prototype signals will also be held for project partners and state DOTs to initiate the implementation process. A final report will provide all relevant data and results along with plans for implementation of the self-de-icing LED signals in affected states.

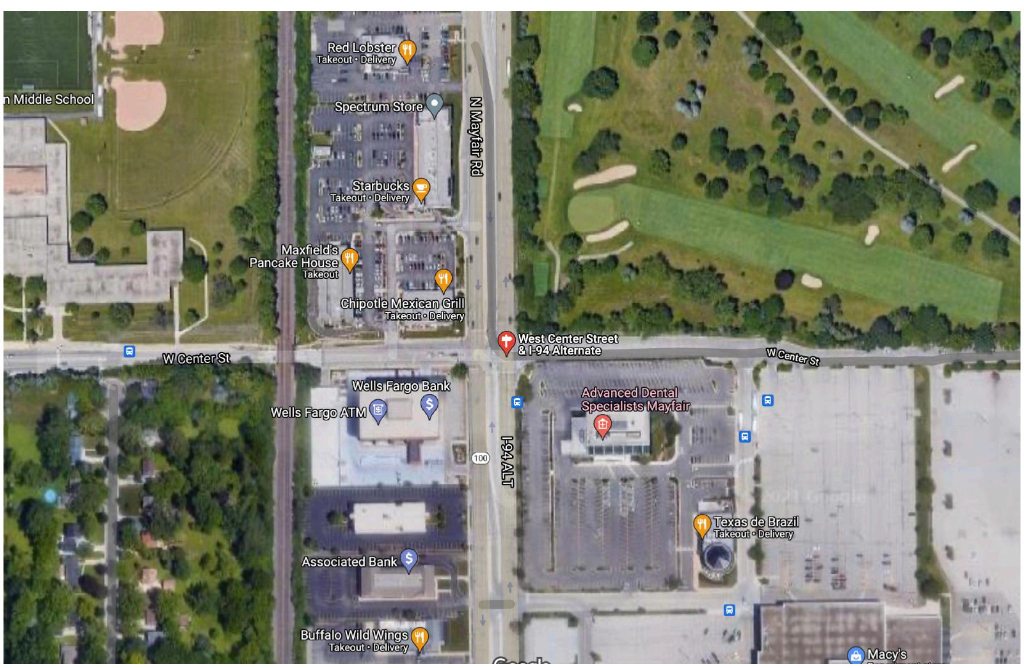
Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.)

During the fourth quarter (Oct 1, 2021 – Dec 31, 2021) of the project period, we have the following accomplishments.

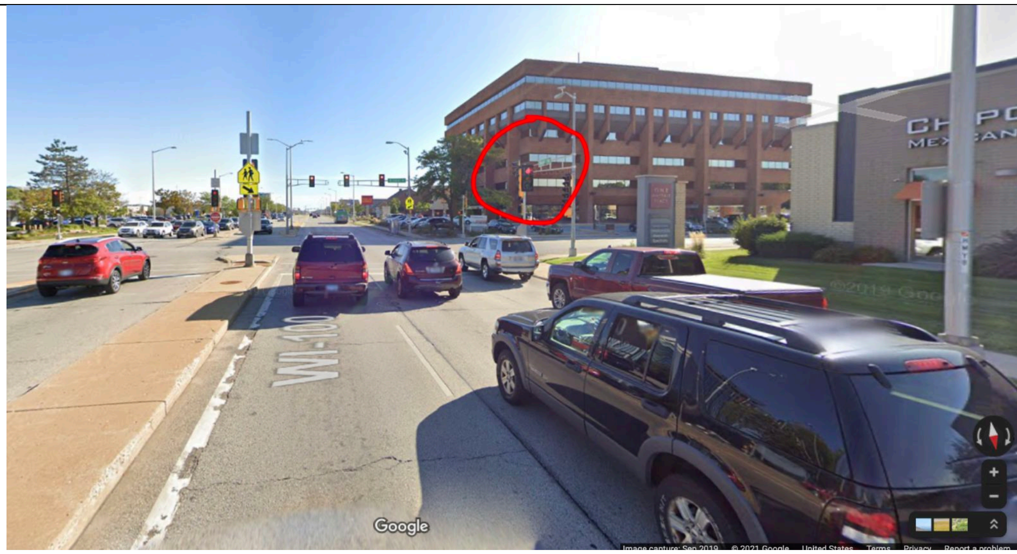
- Two new field tests were conducted in Wisconsin (location: STH 100 & Center Street, Milwaukee County, Wauwatosa, Wisconsin) and Michigan (location: MDOT OFS Operations Field Services, 6333 Lansing Rd, Lansing, MI 48917). The field installation and testing at those two new sites were successfully and the test data have been remotely retrieved on daily basis since then.
- Continue working with the factory to revise the mold for making the fourth-generation Fresnel lens disc with decreased design focal length of 10.5 mm to achieve 11.5 mm in mass production.
- We have completed writing the final project report. We have submitted the draft final report to KDOT on Oct. 30, 2021, and an updated copy on Dec. 7th, 2021.

More details are listed as follows.

Since summer 2020, we have been contacting Michigan, Wisconsin, Maryland, New Jersey and Pennsylvania DOTs to select a good field test site and trying to schedule the field installation at each site. So far, Wisconsin and Michigan have proposed a test site, as shown in Figures 1 and 2, respectively. We have scheduled a field trip to those two test sites in the first week of November, 2021 for field installation and test setup. Maryland is still conducting compliance tests of our signal prototypes with their own MMU unit and trying to solve the “dual indication” fault before a field test could be scheduled in the future. New Jersey and Pennsylvania are slow in responding and no follow-up schedule for field testing yet, hopefully, could be done in the future.



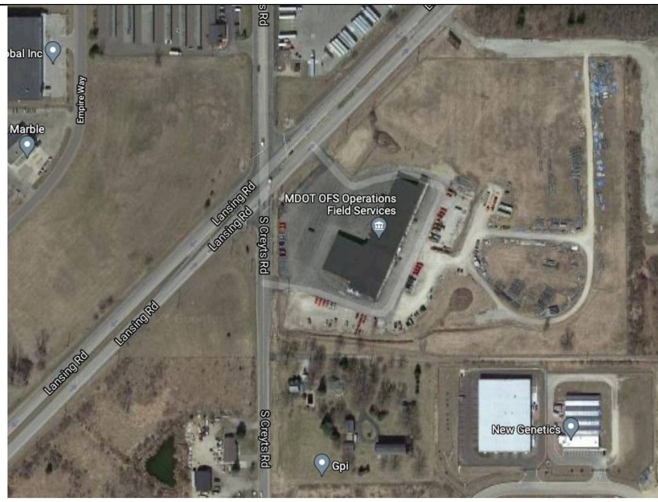
Location: STH 100 & Center Street, Milwaukee County, Wauwatosa, Wisconsin



The selected north-facing near-right signal for SB traffic

An existing PTZ camera to be used for good surveillance of the signal performance
(the right-most/lowest signal head)

Figure 1 The field test site in Wisconsin, located in the intersection of STH 100 & Center Street, Milwaukee County, Wauwatosa, Wisconsin, with a selected north-facing near-right signal for SB traffic. An existing PTZ camera will be used as a good tool for surveillance of the signal performance (the right-most/lowest signal head).



Location: MDOT OFS Operations Field Services,
6333 Lansing Rd, Lansing, MI 48917

The selected signal head in the back of the signal shop

Figure 2 The field test site in Michigan, located in the MDOT OFS Operations Field Services (6333 Lansing Rd, Lansing, MI 48917). The selected signal head is in the back of the shop, for convenience monitoring.

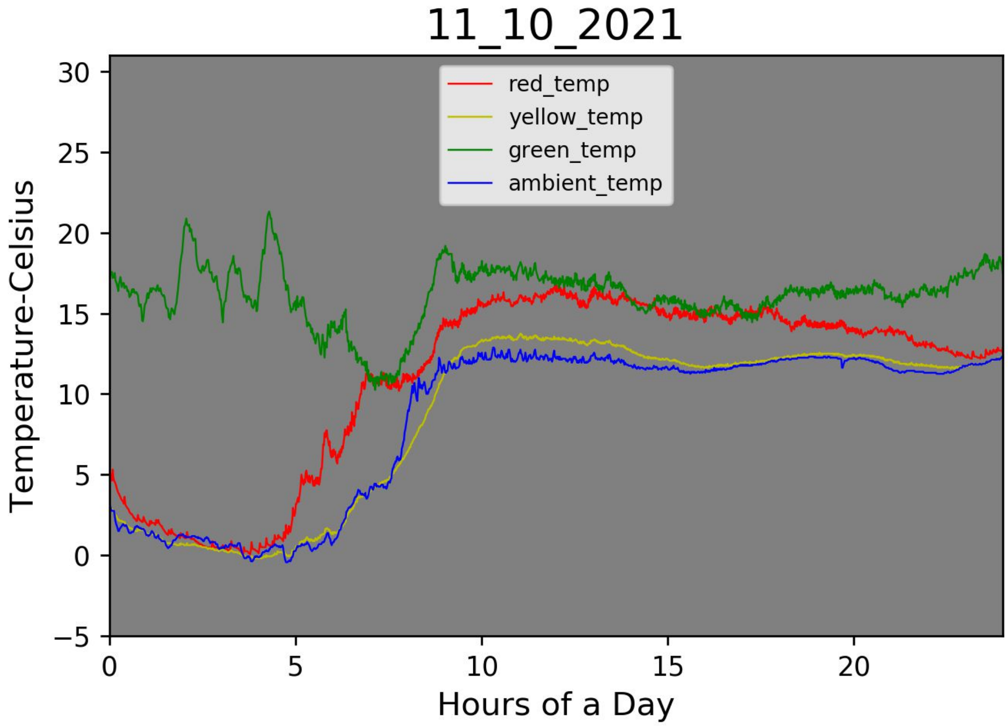
On November 3rd, 2021, we visited the test site in Wisconsin (Figure 1) to install the 5th generation prototypes (R, Y, G) and set up the remote data monitoring system mounted on the top of the pole behind the signal head. As shown in Figure 3, the signal crew with Wisconsin DOT helped the field installation, wiring and on-site testing. All tested signals are facing north. Since then, the real-time performance of the R/G/Y signals has been monitored and recorded by the remote system. All temperature data and pictures of the signal lens could be remotely retrieved in the KU lighting laboratory from the local computer of the remote monitoring system. As shown in Figure 4, the signals at the Wisconsin test site have been working normally in both mild and cold weather, ready for the upcoming severe winter storms.

However, it was found that, as indicated in most data figures, in the early morning before sunrise, the green signal light remained powered on almost all of the time at that intersection due to traffic demand while the red and yellow signals were rarely powered on, resulting in a large temperature increase on the green signal lens above the ambient air temperature, with minimal heat buildup on the red and yellow signal lenses. In future snowstorms, this traffic demand in the early morning before sunrise might leave temporary snow and ice buildup on the red and yellow signals (due to no power for approximately 6 hours), which could take a very long time to melt down when power is restored later, much longer than the otherwise needed time under normal operation conditions when possible snow and ice accumulation being prevented in the first beginning. This could be a problem for yellow and red signal lights at that intersection in extremely cold weather.






Figure 3 Field installation and setup of the onsite testing at the test site of Wisconsin, with the aid of the signal crew of Wisconsin DOT. A tunnel visor was installed with a hook for mounting the cable camera on each signal module. The signals are all facing north.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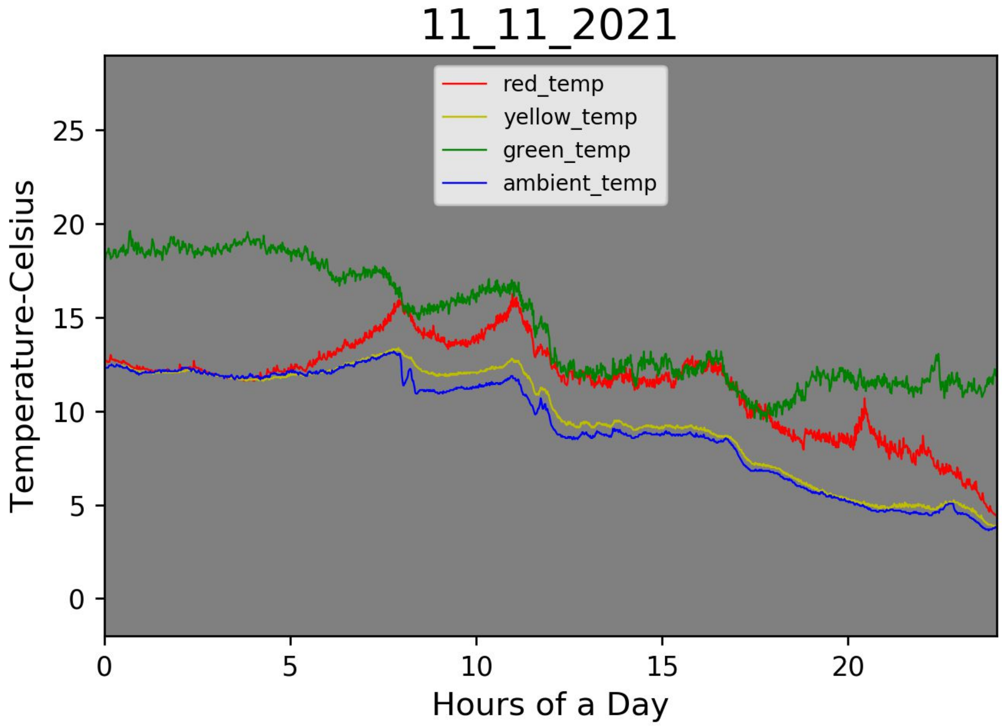
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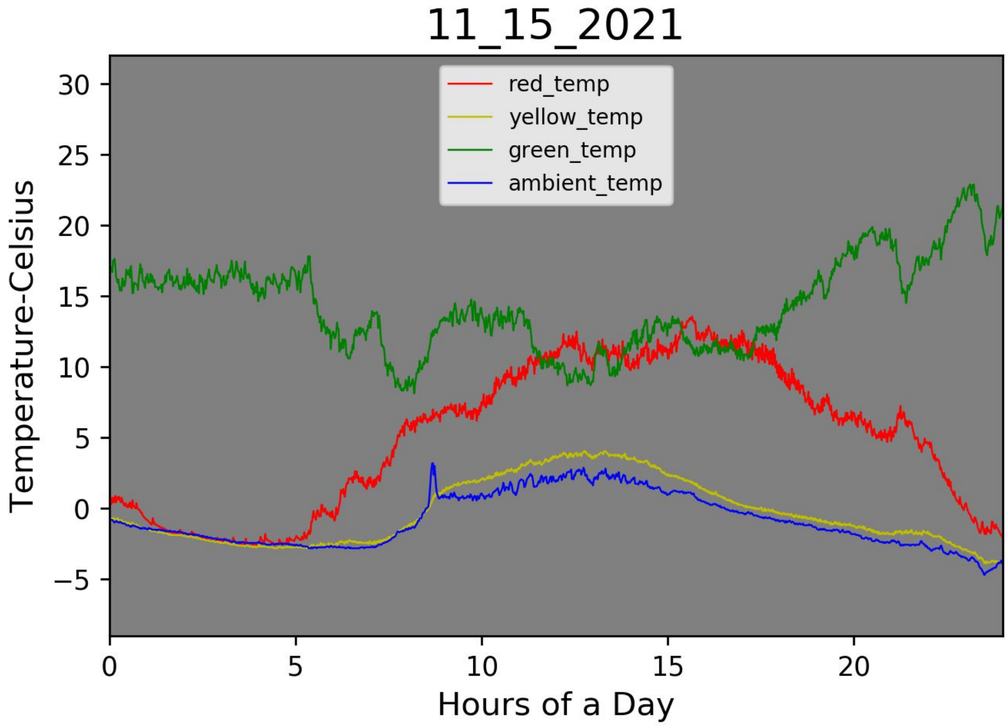
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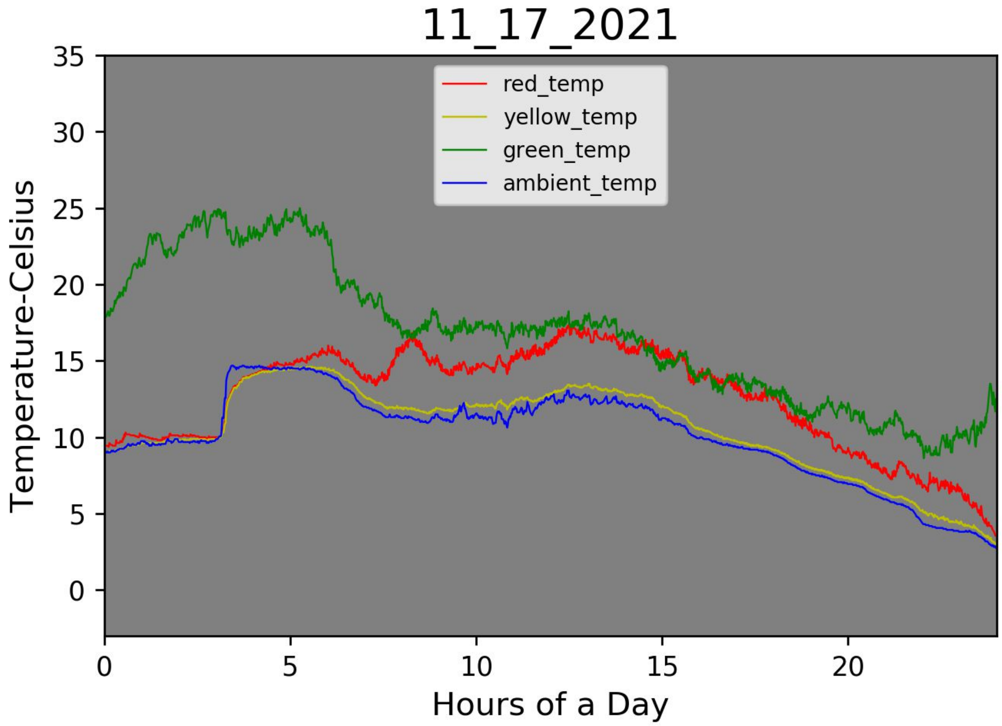
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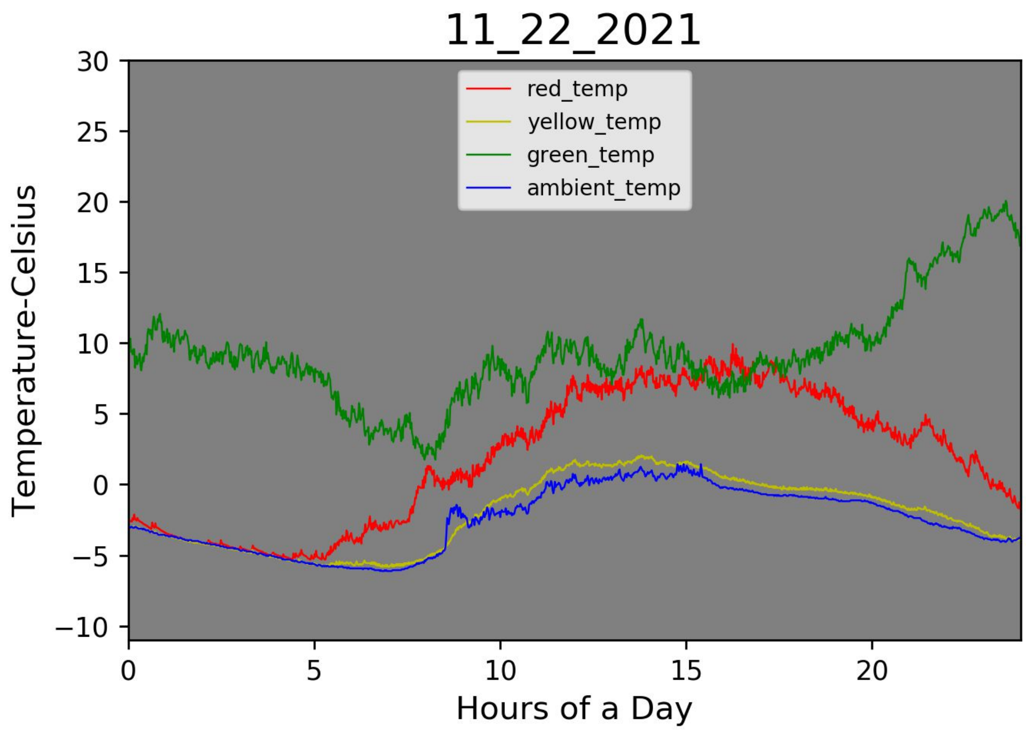
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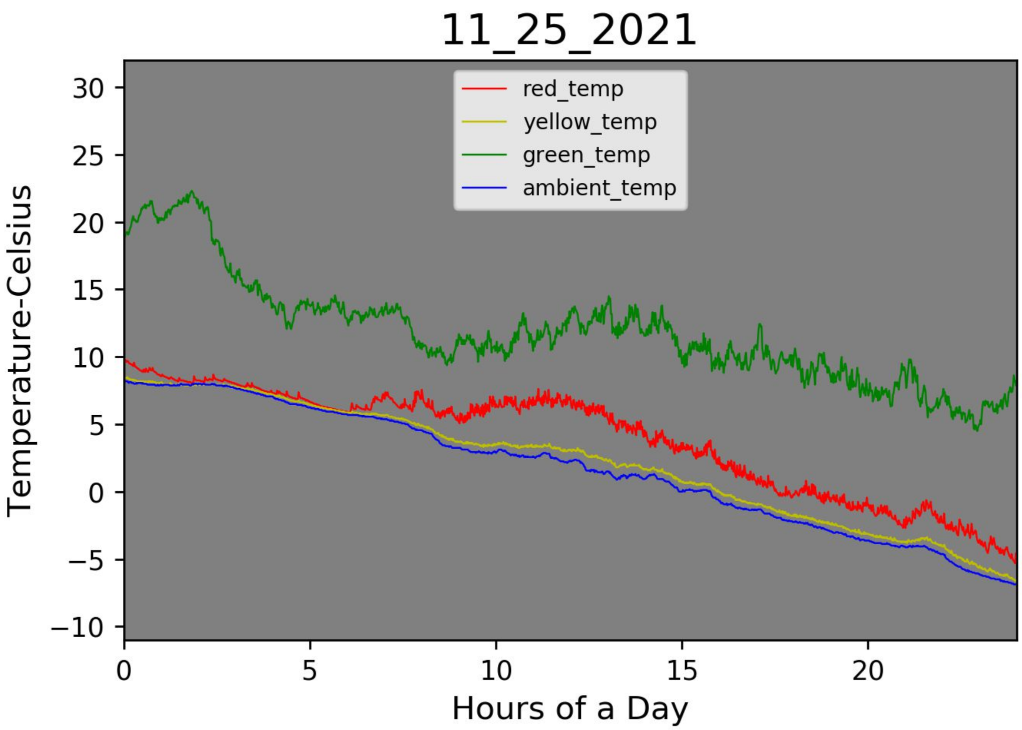
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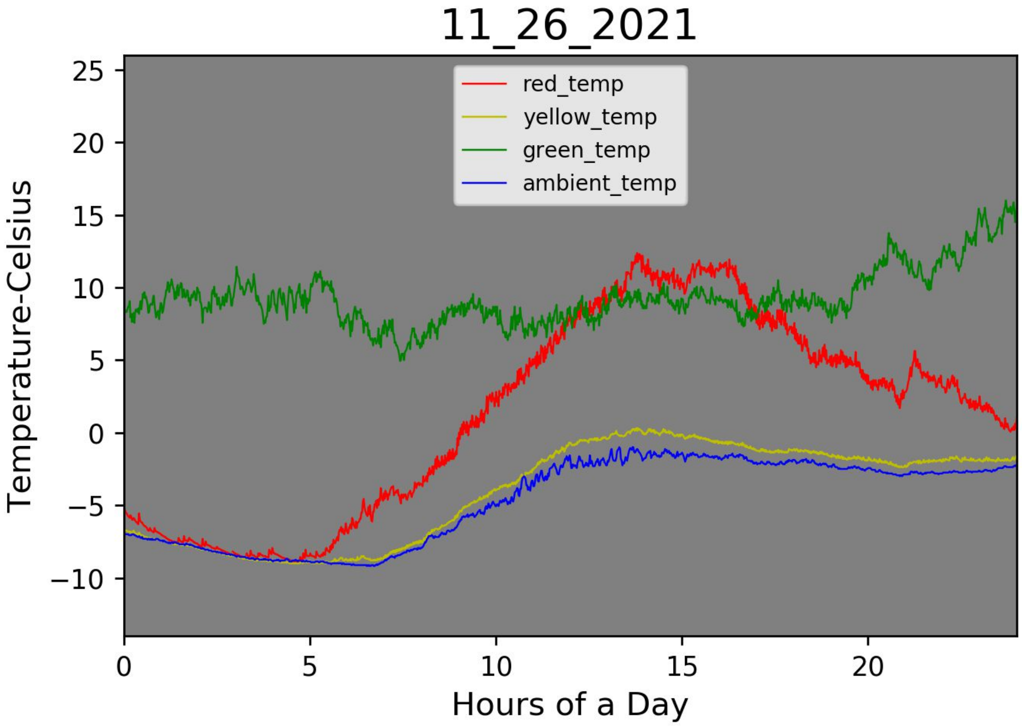
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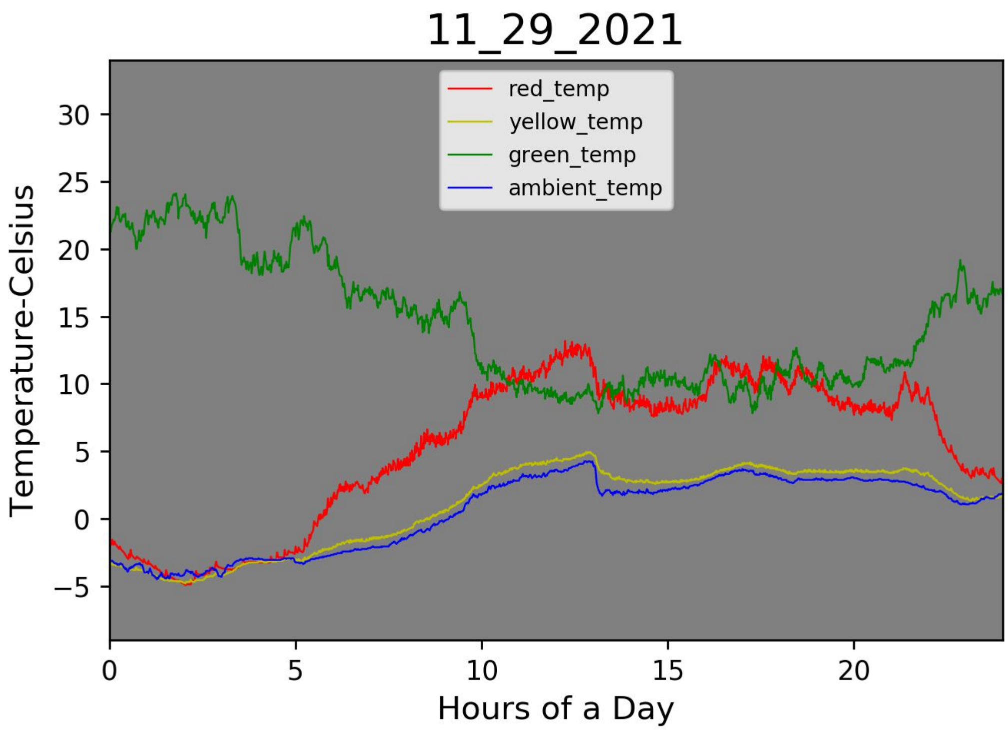


Figure 4 Wisconsin field test data collected in November 2021 after the field installation on November 3rd, showing the normal performance of the red, yellow, and green signal lights under mild and cold weather conditions, especially for the green signal light which had the longest power-on time. Note that due to traffic demand in the early morning before sunrise, the green signal light was remained always powered on at that intersection while red and yellow signals were rarely powered on, resulting in a large temperature gap between the green signal lens and the ambient air, with minimal heat buildup on the red and yellow signal lenses during the traffic control period (midnight - sunrise).

Next, on November 4th, 2021, we visited the test site in Michigan (Figure 2) and installed the 5th generation prototypes (R, Y, G) in front of the signal shop with the aid of the signal crew of Michigan DOT, as shown in Figure 5. The remote data monitoring system was also mounted on the top of the signal pole close to the signal head to collect real-time performance data of the signals, as shown in Figure 6. Since then, the test signals at the Michigan test site have been working normally in both mild and cold weather, ready for the upcoming severe winter storms.

It is worth mentioning that the signal timing of the tested signals could be adjusted by a signal control cabinet located inside the shop. As shown in Figure 6, before Nov 17, 2021, the green signal light had higher lens surface temperature due to its longer power-on timing than red signal light. This timing sequence was changed after Nov 17 to keep the green and red signal with well-balanced power-on timing, resulting in close temperature measured on the lens surface for both green and red light.



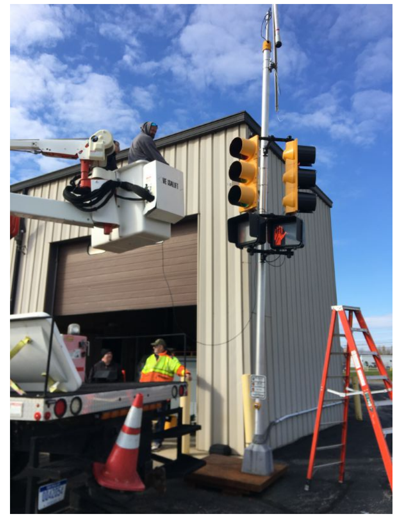
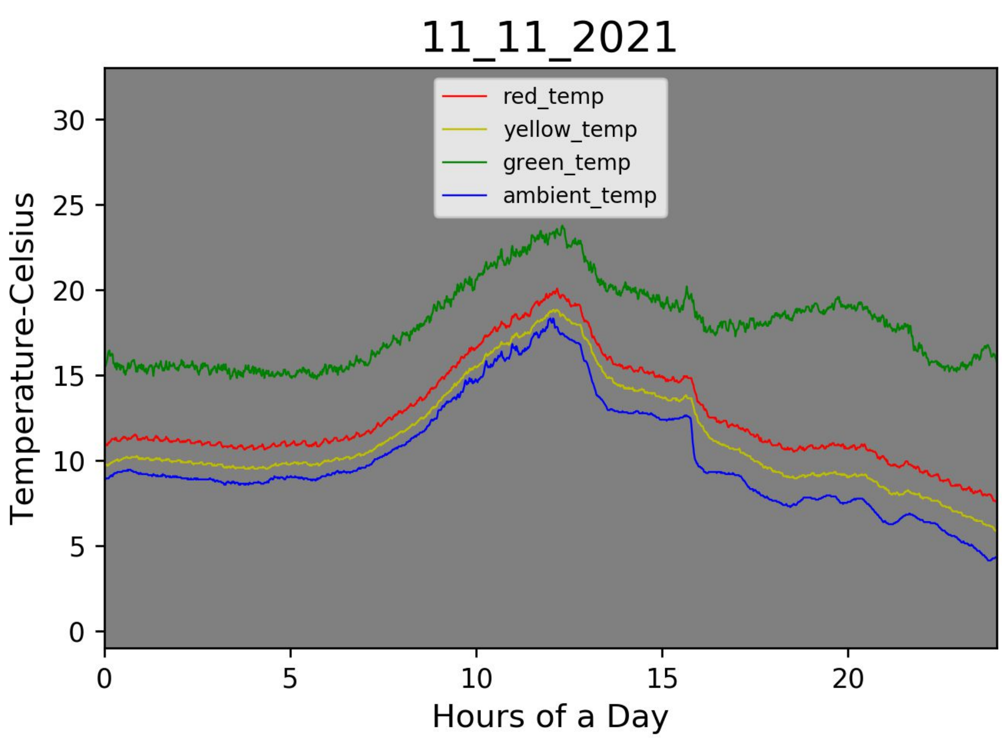



Figure 5 Field installation and setup of the onsite testing at the test site of Michigan in front of the signal shop, with the aid of the signal crew of Michigan DOT. A tunnel visor was installed with hook for mounting the cable camera on each signal module. The signals are facing north.

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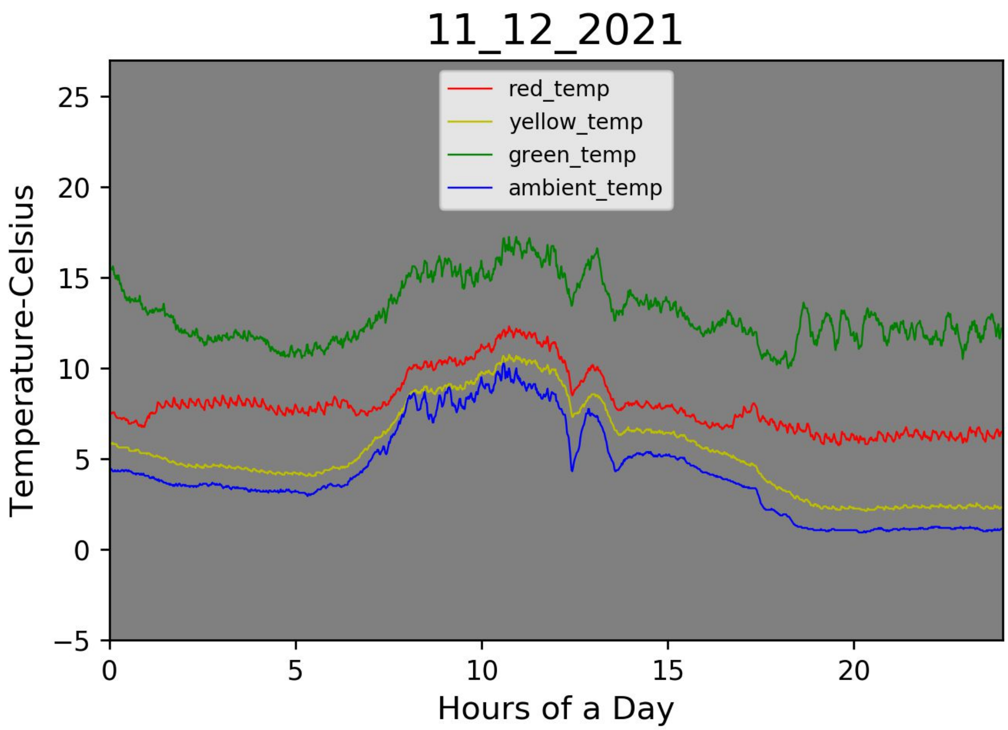
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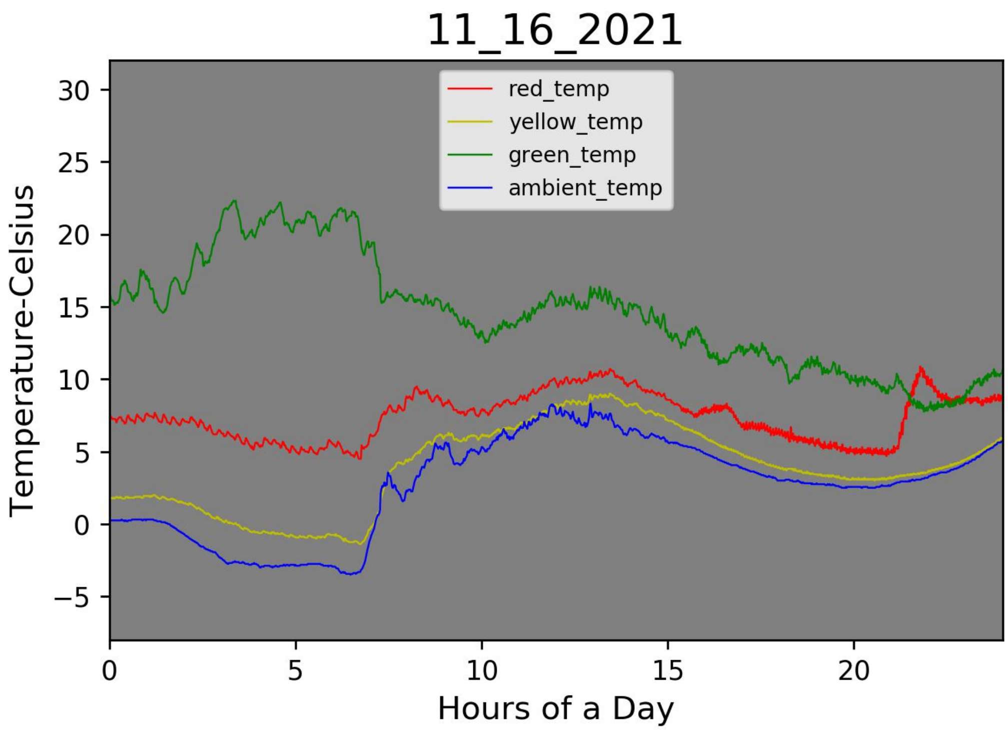
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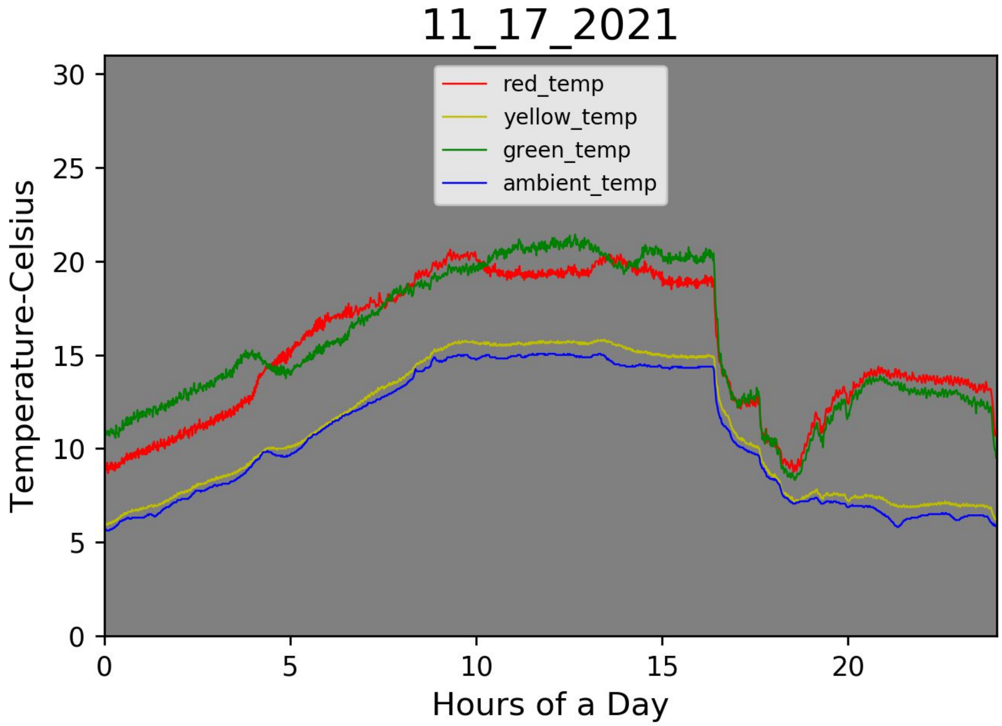
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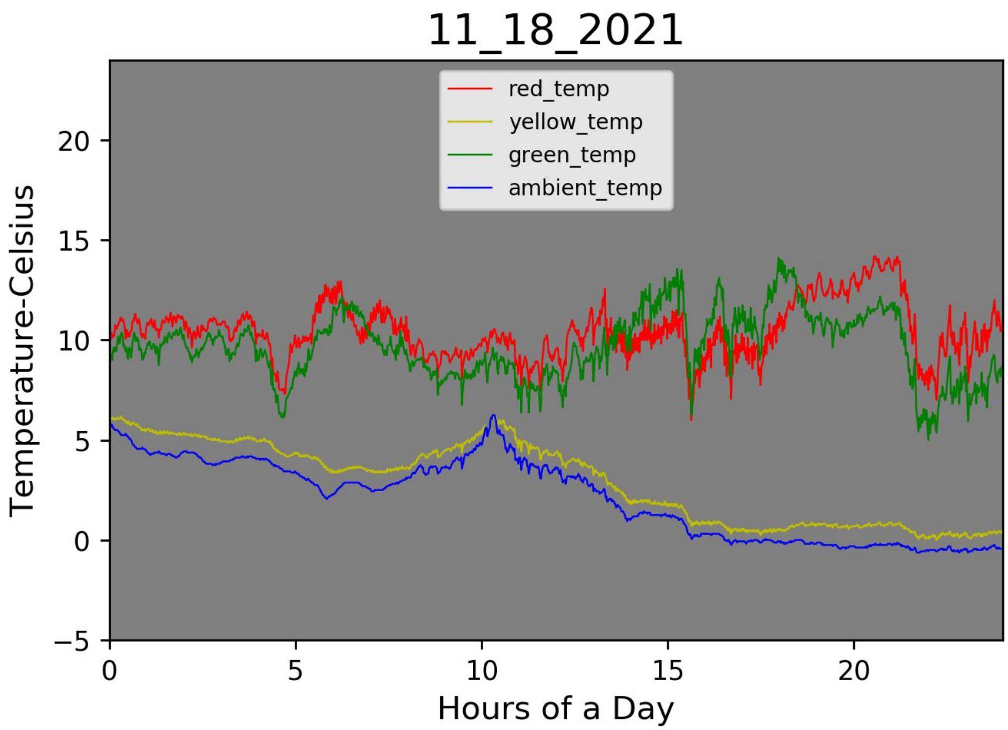
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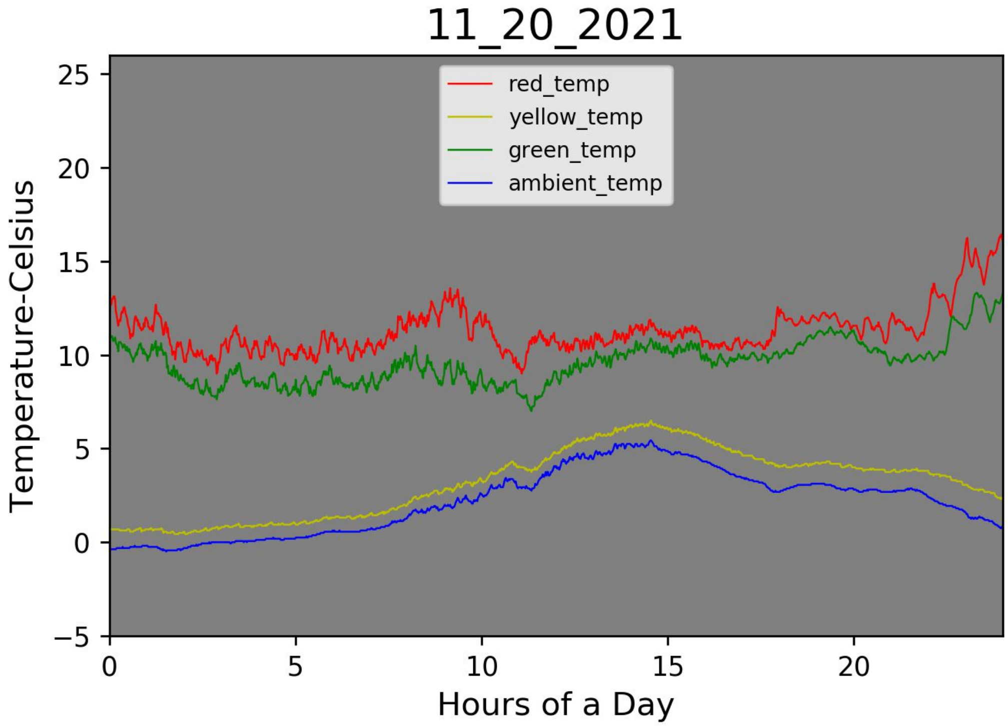
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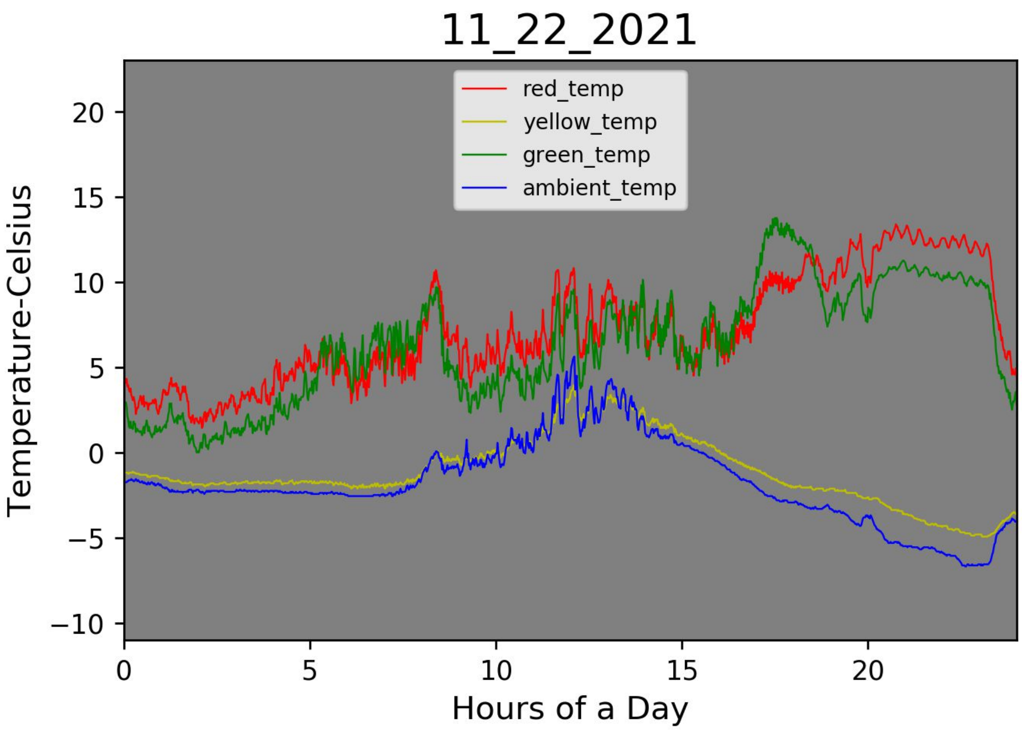
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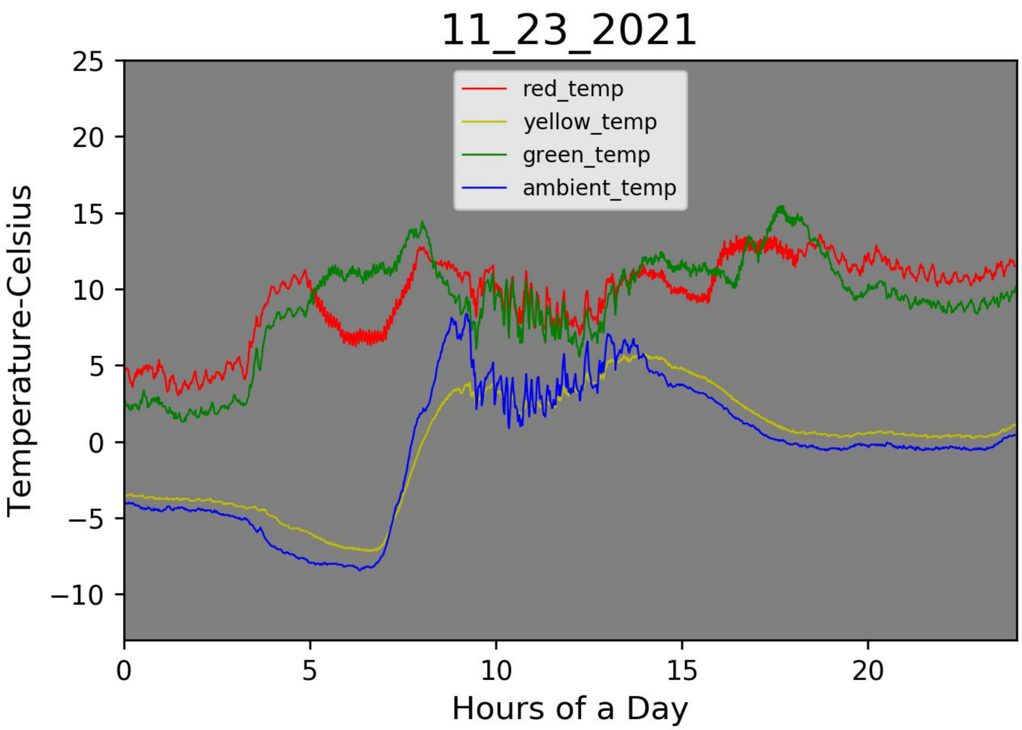
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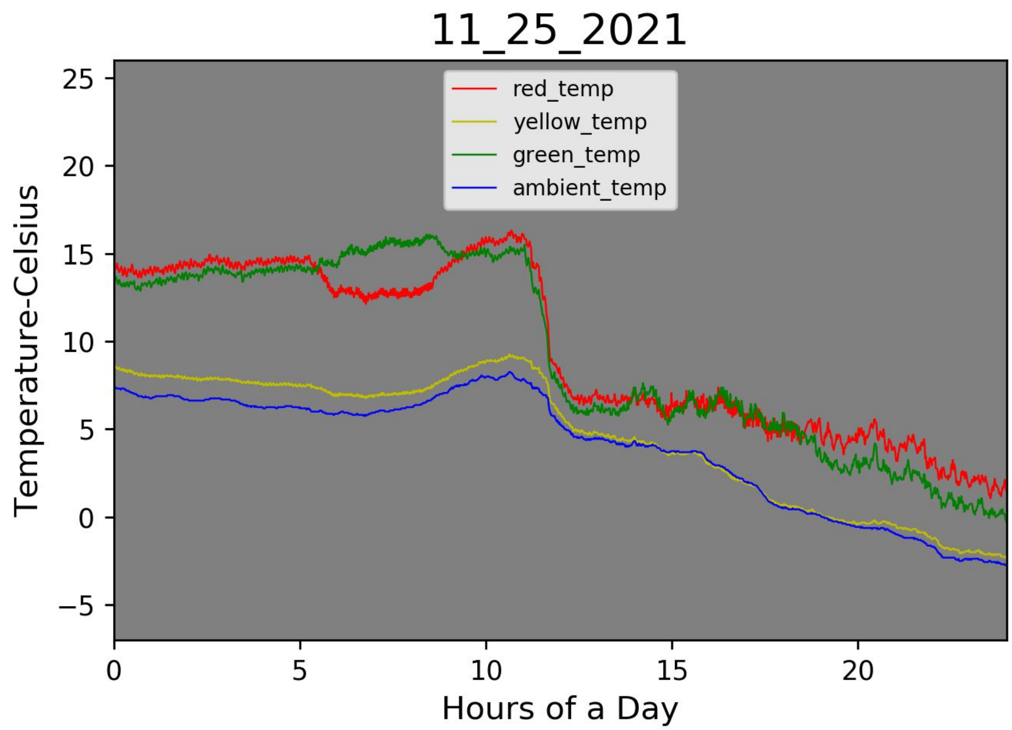
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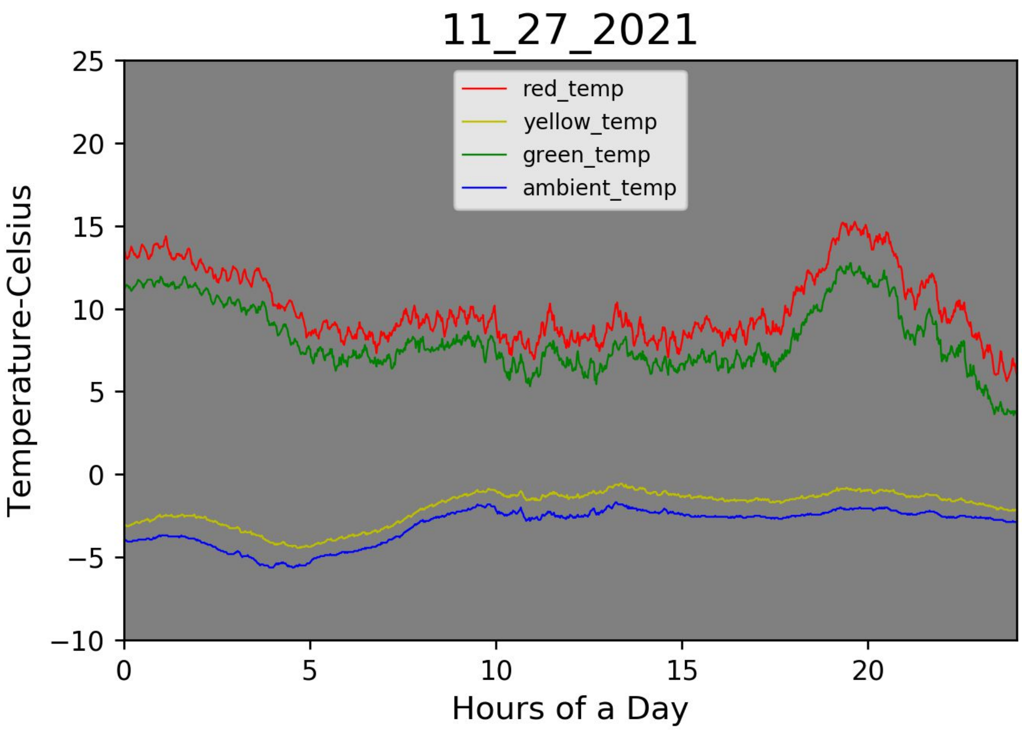
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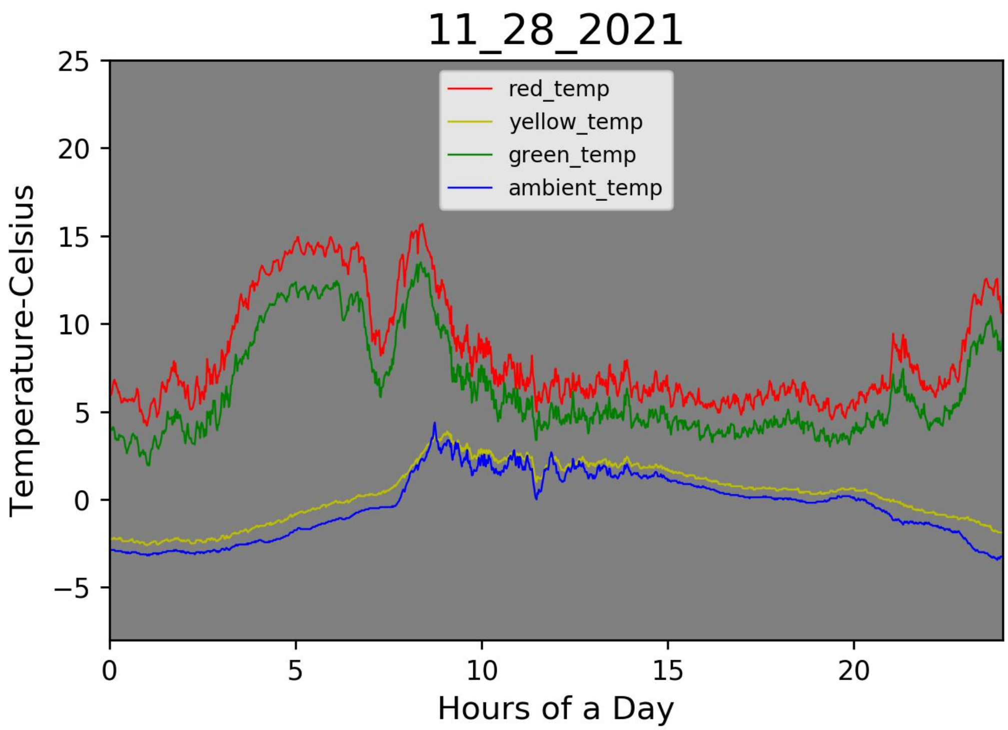
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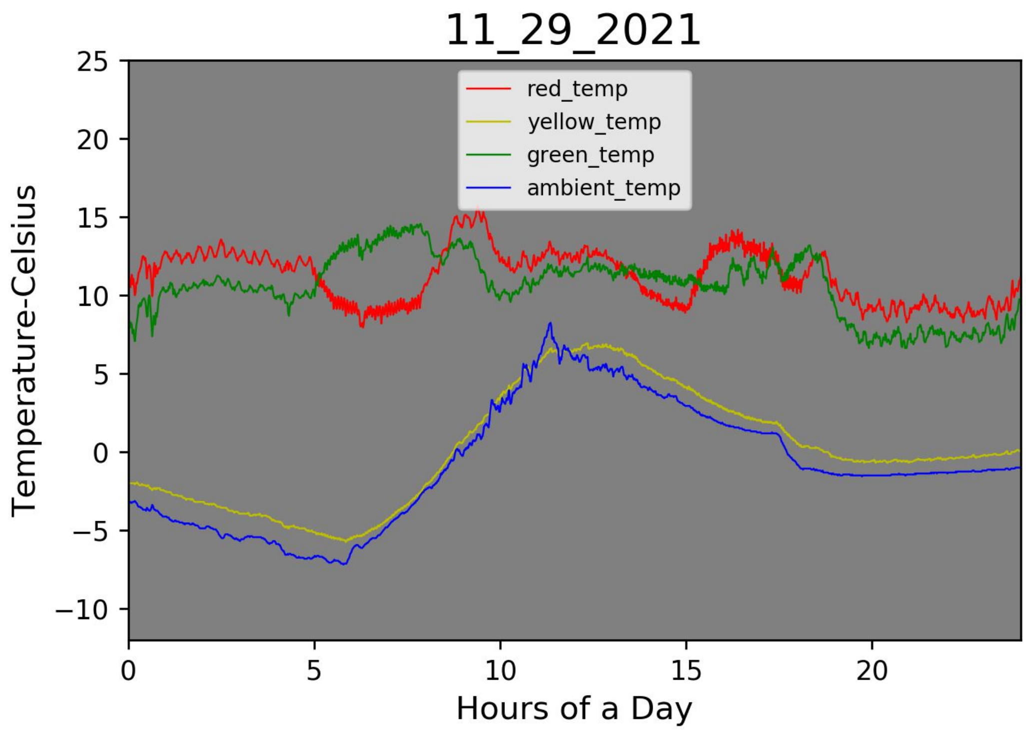

Figure 6 Michigan field test data collected in November 2021 after the field installation on November 4th, showing the normal performance of the red, yellow, and green signal lights under mild and cold weather conditions. Note that before Nov 17, 2021, the green signal light had higher lens surface temperature due to its longer power-on timing than red signal light. This timing sequence was changed after Nov 17 per our request to keep the green and red signal with well-balanced power-on timing, resulting in close temperature measured on the lens surface for both green and red light.

Anticipated work next quarter:

Starting from Jan 1, 2022, till June 30, 2022, we are planning to conduct the following tasks.

1. Review and approval of the final report.

Significant Results:

As of Dec 31, 2021, we have achieved the following significant results.

- This project was launched in Aug 2016 with six participating states (Kansas, California, Michigan, New Jersey, Wisconsin, and Pennsylvania) and an initial budget of $240,000. Maryland is expected to officially join the study by the end of this year with additional contribution of three years funding.

- An expert panel meeting was held in early March. Discussions were held on desired specifications of the prototype signals and possible field test sites as well as the field evaluation of the prototypes.

- Necessary equipment, components and insulation materials are being procured to develop and build the fully working prototypes of the finalized design and test for their thermal and lighting performance. We will continue to order LED drivers, electricity monitors, waterproof security video cameras, other mounting accessories and materials, etc., for monitoring the performance of the prototypes in the field tests in the upcoming winter season.

- Appropriate color LED modules, which are not available in the market, were designed in-house and custom-made with the aid of the industrial partner.

- Three preliminary prototype signals (Red, Yellow, and Green) of Type 1 have been developed in house, each deploying 26 custom-made color LEDs mounted in an array via "Heat Arrangement of LED Arrays in Low Profile". They are under laboratory testing for improvements.

- Tested the lighting and thermal performance of the preliminary prototypes of the Type 1 signal lights (Figure 1). Based on the test results, new design with a lot of changes and improvements has been finalized for final products.

- Finalized the design of Type 1 self-de-icing LED signals using 96 custom-made mediate-power color LEDs mounted in an array via "Heat Arrangement of LED Arrays in Low Profile". Designed in house and custom-made our own color LED modules (for each color R, G, Y) for making the fully working prototype signals of the first type with the aid of our industrial partner.

- Worked with the factories to optimize the mounting method of the custom-made LED modules on the 3-5 mm thick aluminum MPCB back plate serving as the passive heat exchangers of aluminum alloy for assembly.

- Custom-made three prototypes of the LED signals of Type 1 using 96 custom-made mediate-power color LEDs mounted in an array via "Heat Arrangement of LED Arrays in Low Profile", with regular paint coating, and finished laboratory testing for improvements and optimizations to finalize the design.

- Improved and custom-made three new signal light engines using 96 medium-power LEDs (0.25 Watt each) mounted in an array via "Heat Arrangement of LED Arrays in Low Profile" but with Tin coating (Figure 3) and tested them to improve the heating performance (to make faster heat transfer).

- Finalized the design of the signal lens that adopts a whole piece design with smooth and flat outside surface and integrated with 96 additional custom-made Fresnel lenses sitting inside the signal lens over each LED on the inside surface to focus the light serving as a collimator lens. Based on the testing results, the signal light engines with Tin coating may have superior thermal performance, however, further testing in the laboratory and field is necessary to validate the final choice.

- Identified and started custom-making the Fresnel Lens from HongXuan Optoelectronic company with diameter 15 mm and focal length 6 mm (model # HX-F015006).
- Developed the new whole-piece signal housing, new Fresnel lenses, LED drivers, and other accessories for the Type 1 self-de-icing LED signal lights, with the aid of the industrial partner.
- Found and selected a qualified plastic molding company to custom make the three parts of the plastic housing of fully working prototypes of Type 1 signals that deploy 96 mediate-power LEDs via the architecture of "Heat Arrangement of LED Arrays in Low Profile". The new housing will be used for the new LED signal lights.
- The non-provisional patent application for the invention of Type 2 self-de-icing signal light was officially approved by the USPTO and issued on Dec 26, 2017, patent No. US 9,851,086 B2.
- Started custom-making and modeling of the signal housing. Three samples were delivered for examinations and laboratory tests for necessary calibrations and further improvements.
- Started custom-making the LED drivers with desired specifications based on our test results. Seven LED drivers were delivered for sample testing.
- The custom-made signal housing is ready for production of products with possible minor adjustments for field tests in different states. Six improved samples have been delivered and thoroughly tested in laboratory and closed-setting tests on the roof.
- New type of screws for uses in the signal housing are self-designed and will be custom-made with Fastenal company.
- A company is custom making two improved and finalized types of LED driver, one for YELLOW and GREEN signal lights (output 0.8 A, maximum 30 Watts), the other for RED signal light (output 1.1 A, maximum 30 Watts). The new LED drivers have temperature Sensor control, when the temperature is above 4 degree Celsius, the LED driver output will be derated (For Yellow + Green LED lights, output current 0.5 A, approximately 17- 18 Watts; For Red LED light, output current min 0.6 A, approximately 15-16 Watts.) When the temperature sensor is turned off or failed for any reasons, the power output will be restored to 100% as default.
- The self-deicing signal lights have higher light output than the codes and standards required in all viewing angles from 0 deg to 70 deg as measured, even at the derated power output.
- We have been conducting a closed-course performance and reliability tests of the fully working prototypes mounted on the roof of the University of Kansas engineering complex - M2SEC building, in preparation for field tests.
- Seven states have officially participated in this project, including Kansas, California, Michigan, New Jersey, Wisconsin, Pennsylvania and Maryland to provide support.
- A project addendum is proposed to conduct two additional field tests, one in Wisconsin and another one

in a test site among Maryland, Pennsylvania, and New Jersey. A budget of $80,000 for the addendum is proposed to be spent starting on 5/18/2018 until the end of the project

- We have been continuously testing the closed-course performance and reliability of the prototypes previously mounted on the roof of M2SEC building. All signal lights were powered by the signal controller cabinet with real signaling time cycles (in a cycle length of 90 seconds, Red signal light ON for 50 seconds, Green signal light ON for 35 seconds, and Yellow signal light ON for 5 seconds. The temperature data were recorded every 10 seconds continuously over the entire test period, which will be continuously conducted over both winter and summer seasons in 2019.

- We have designed and custom-made new types of screws to improve the connection strength of the screws integrated with the plastic housing. This type of screws are finalized products to be used in all finalized plastic housing.

- We have designed and custom made two types of LED drivers, including one type of custom-made LED driver for **red signal light** (input: 100-240 VAC, output: 0.6-1.1 A, max 30 W), and a second type custom made LED driver for **green/yellow signal light** (input: 100-240 VAC, output: 0.5-0.8 A, max 30 W). Both types of LED drivers are now integrated with a remote temperature sensor for controlling the power output in light of the ambient air temperature. An on/off switch is designed for temperature controls in winter and summer modes which could override the operation of the temperature sensor.

- We have accordingly improved and finalized the plastic housing of the fully working prototype signals of Type 1 with changes/improvements listed below, with assist of the plastic molding company — Eco Molding. Eco Molding company has custom made seven samples of the finalized new plastic housing for validations tests before actual product production.

- We have produced 60 pcs of the finalized LED engines with the aid of the industrial partner, ready for the upcoming field tests.

- We have also updated and custom made 60 pcs of glass disc which have four small mounting holes removed on the edge (the original glass disc had 8 mounting holes).

- We also custom made plastic mounting bars for mounting the glass disc to the LED light engine.

- We are working on getting improvement on custom-made Fresnal lens model number HX-F0150115 (diameter 15 mm, thickness 2.0 mm, focal length 11.5 mm) to increase tolerance of the thickness (approximately 1.8 – 2.1 mm) while reducing the unit cost.

- We are in preparation for field tests. Three fully functional prototypes of the fourth generation were mounted on a signal pole on the roof of an engineering building, powered by a traffic control cabinet for closed-course performance and reliability tests.

- Three more fully functional prototypes of the fourth generation were also tested in a well-controlled cold room for the performance of the ambient temperature sensor connected to the LED driver for switching full/derated power output. Based on the test results, we are adjusting the power output of the LED drivers. We are also making minor adjustments of the signal housing for quick assembly of the real products. Results have been used to evaluate the readiness of the prototypes for field tests starting in next quarter.

- Corrected some problems and resolved issues of the custom-made LED drivers, including (1) decreased the size of the power connector of the temperature sensor, (2) decreased the length to 6 mm, (3) changed to more reliable single switch, (4) enlarged the inside size of the installation hole to 6mm x 4.5 mm, (5) changed the final designed output current of Yellow/Green LED drivers to 0.40 A (derated) /0.84 A(full output), (6) changed the final designed output current of Red LED drivers to 0.60 A (derated) /1.1 A(full output), (7) improvements on temperature measurement accuracy, redesigned logic circuits, and changes of electronic parts used on the LED PCB boards.

- The signal housing of the fourth generation LED signal lights was revised for quick assembly. We have received the new prototypes of the housing with desired changes, which were tested in the laboratory with satisfactory performance.

- Other parts like glass mounting discs have also been improved in house for enlarging the installation holes to fit the new housing.

- Additional vendors for Fresnel lenses were contacted for lower unit price with higher quality control than the current lens vendor. Based on the lab test results, a total of 5000 PCS of new Fresnel lenses (**Model #1511**) were ordered from the new vendor for field tests.

- Based on the lab test results on the second generation of LED drivers, a total of 21 pcs of the third generation of LED drivers were ordered for lab tests, in preparation for the field tests.

- A total of 21 new LED drivers of the third generation for the field tests were made and are under testing in the laboratory for their field performance and any possible further improvements in need for control of the yield rate in production.

- A new proposal was approved on extended work with increased total project cost of $360K and extended new end date of June 30, 2021.

- Field monitoring systems powered by Raspberry 3 B+ motherboard, fitted with three cable cameras used to monitor three signal lights (Red, Yellow, Green) in each unit, four temperature sensors used to record the lens' surface temperature of the three signal lights (Red, Yellow, Green) and the ambient air temperature, USB flash drivers used to store the year around test data (pictures and temperature dataset), power supplies, and mounting accessories, have been custom built in house and under testing in the lab and on the roof, which will be mounted at each field test site for year-around real-time monitoring and data recording of the new signals to be tested in the field.

- New fully working prototypes of the signal lights for field tests have been assembled and are under thorough final tests in the laboratory in preparation for upcoming field tests.

- A total of 21 new LED drivers of the third generation were tested for their field performance and further improvements needed for the control of the yield rate in production. Based on the test results, the third-generation LED drivers may need further improvements towards the fourth generation, which will resolve two issues: 1) light power-up delay (the time delay between power on and signal light on) for about 0.5-1 second, 2) Unstable output performance of the drivers, due to unsecured soldering of wire connections by hands.

- The field monitoring system consisting of a Raspberry PI computer, three cable cameras, four temperature sensors, USB flash drivers, power supplies, and mounting accessories, was built in-house and continuously tested in the laboratory and on the roof for field installation. The system will be mounted at every field test site for year-around real-time monitoring and data recording of the new signals.

- The first field test site was set up in Kansas at the intersection of County Rd 458 (or 1200 Rd) /US-59. All new equipment including the performance monitoring system for data recording were installed on side signals facing north and already survived the first snowstorm in December.

- More prototypes of the final products are in preparation for other test sites. Seven states (Kansas, California, Michigan, New Jersey, Wisconsin, Pennsylvania, and Maryland) are participating in field testing and evaluation of the prototypes.

- A remedying method in the laboratory for flattening the concaved lens surface, using supplemental heat beneath the lens and added weight on the top inside surface, a thermal lamp was installed inside a box below the glass on which the lens sits, the lens surface was monitored with four temperature sensors connected to a HOBO data logger.

- Talked with the fresnel lens company to modify the design and form factor of the currently adopted 96 individual lenses mounted in the housing to a whole piece of disc embedded with a total of 96 fresnel lenses on it.

- The field monitoring system has added mobile communication information device with data plan to remotely send the data of the signal performance back to the laboratory on daily basis for real-time performance monitoring, which is under testing on the roof.

- The problem of defective signal light housing with concave lens surface made during the production process has been solved with improved molding technology. A total of 100 new samples are made of Markrolon 2807 and tested with a maximum tolerance of 1.5 mm for mass production.

- A new fresnel disc with 96 small fresnel lenses integrated on it has been designed with the desired improvements and is currently being custom-made in a factory through injection mold.

- We have installed the new remote monitoring system with mobile communication in the Lawrence test site, in addition to the original reliable "local" data monitoring system that kept running in the past year.

- The self-de-icing signals have survived both winter and summer functioning as expected, without any signs of snow and ice accumulation on the signal lens in cold winter, and abnormal performance in hot summer.

- Corrections have been made in the injection mold for making the new fresnel disc with 96 small fresnel lenses integrated on it.

- A manual to be used by signal crews of different states for mounting the new self-de-icing signals and the corresponding data recording and remote monitoring system, for the upcoming field test site use.

- Forty (40) samples of the improved second generation fresnel lens disc were tested with satisfactory thermal performance but the lighting performance was not optimized due to increased focal length of 12.5-13.0 mm (> 11.5 mm).

- With improvements on the mold injection technology in the factory, 21 new samples of third generation fresnel lens disc was tested with shortened focal length of 11.9 mm, but still > 11.5 mm, and similar thermal performance.

- The fifth-generation prototypes and associated field remote monitoring systems have been fully prepared and tested for other field test sites to be conducted in Michigan, Wisconsin, Maryland, and New Jersey & Pennsylvania, which are participating in field testing and evaluation of the prototypes.

- Regarding the field tests, Michigan has provided a test site, while Wisconsin is reviewing the options now. Maryland is testing the prototypes for compatibility, while New Jersey is slow is responding.

- Two more field tests were conducted in Wisconsin and Michigan, with ongoing test data remotely collected from the test sites.

Circumstance affecting project or budget. (Please describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).

COVID-19