LED based systems for remote sensing of liquid levels in automotive fluid tanks

Quamrul Huda, Chelsea Ragbir, Matthew Hart, Andrew Anderson-Serson, Ben Ripka, et al.

Quamrul Huda, Chelsea Ragbir, Matthew Hart, Andrew Anderson-Serson, Ben Ripka, Alberto L. Cevallos, Anas Ahmed, Dan Priestley, "LED based systems for remote sensing of liquid levels in automotive fluid tanks," Proc. SPIE 12441, Light-Emitting Devices, Materials, and Applications XXVII, 124410I (14 March 2023); doi: 10.1117/12.2649648

Event: SPIE OPTO, 2023, San Francisco, California, United States

LED-based systems for remote sensing of liquid levels in automotive fluid-tanks

Quamrul Huda[1*], Chelsea Ragbir[1], Matthew Hart[1], Andrew Anderson-Serson[1], Ben Ripka[1], Alberto L. Cevallos[1], Anas Ahmed[2], Dan Priestley[2]
[1]Technology Access Centre for Sensors and System Integration, Northern Alberta Institute of Technology, Edmonton, Canada T5G 0Y2; [2]Imperial Oil Limited, Calgary, Canada, T2C 4P3

ABSTRACT

light-emitting diode (LED) based sensor system is developed for ex-situ placements at fluid-tanks to monitor the level of fluids through level gauge displays. The sensor system is designed for remote monitoring of operational status of industrial heavy equipment through a low-footprint internet of things (IoT) approach without involving extensive mechanical or electrical overhauling for sensor deployment. Sequential and non-sequential ray tracing simulation over visible and near infrared spectrum were conducted for optical beam propagation through air-fluid, air-glass, and glass-fluid interfaces. Fluid specific refractive index and propagation parameters were used in ray tracing simulation to design the optical path and wavelength of operation that are specific to fluids and the fluid tank configurations. Our low-footprint non-invasive approach of fluid level monitoring allows their deployment on industry installations with minimum interruption of services.

Keywords: Light Emitting Diode, non-sequential ray tracing, sensor, internet of things, remote sensing

1. INTRODUCTION

Fluid-tanks in large industry automobile engines sometimes are designed for visual observation of fluid levels through sight glasses. In large-scale industry operations involving numerous heavy equipment systems, monitoring of the status of engine operations through manual inspection become resource extensive and may impact operators' safety. Incorporation of in-situ measurement systems (e.g., float or ultrasonic sensors, LiDAR, etc.) involve interruption of system operations, and are incompatible in most cases for integration to a remote sensing network.

Reflection, refraction, and scattering of light propagation through typical fluids in automobile applications show strong dependence of optical properties on fluid types.[1,2] Light propagation through air, glass and liquid medium, and interactions at solid-liquid interfaces can be used in detecting the presence of liquid at certain levels.[3] In this paper, we report the development of an optical sensor system that can be deployed on sight-glasses of level gauge displays. An optimized detection system was designed through non-sequential ray-tracing simulation. The developed sensor was integrated through radio frequency communication for real-time remote monitoring of multiple fluid-tank status.

2. RAY TRACING ON LEVEL GAUGE DISPLAY GEOMETRY

2.1 Level gauge arrangement for fluid level display

A typical gauge display used for inspection of fluid level in large automobile systems is shown in Figure 1. The level of fluid is indicated in the gauge through the site glass assembly shown in the left. Level of fluid in the region marked with green background is desirable for regular operations of the automobile system. Fluid level in regions marked with red backgrounds represent low or high levels of fluid that are not recommended for the machine operations. Non-invasive

*qhuda@nait.ca; phone 1 780 729 5520; nait.ca/cssi

Light-Emitting Devices, Materials, and Applications XXVII, edited by Jong Kyu Kim,
Michael R. Krames, Martin Strassburg, Proc. of SPIE Vol. 12441, 124410I
· doi: 10.1117/12.2649648

ex-situ monitoring requires a sensor mechanism where level of fluid is accurately determined with respect to the designated safe level of equipment operations. Schematic arrangement of a sensor system for minimum level detection is shown in the figure where the middle and the right-most schematics represent the fluid levels in red and green operations conditions, respectively.

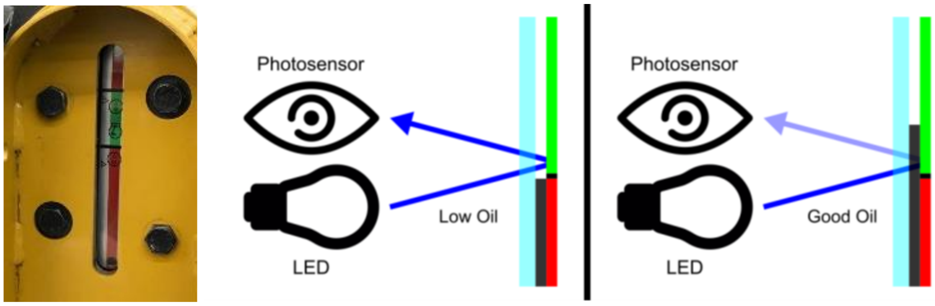

Figure 1. Schematic diagram showing optical detection through sight glass of fluid gauge.

2.2 Non-sequential ray tracing

We used the Zemax[4] simulator for non-sequential ray tracing of an optical system for implementation of an ex-situ monitoring system. Simulations for a simple system with point source of light are shown in Figure 2. Change of position of light beam in image plane for absence (left) or presence (right) of fluid in the optical path can be observed in the figure. A vertical displacement of several millimeters is shown by an arrow.

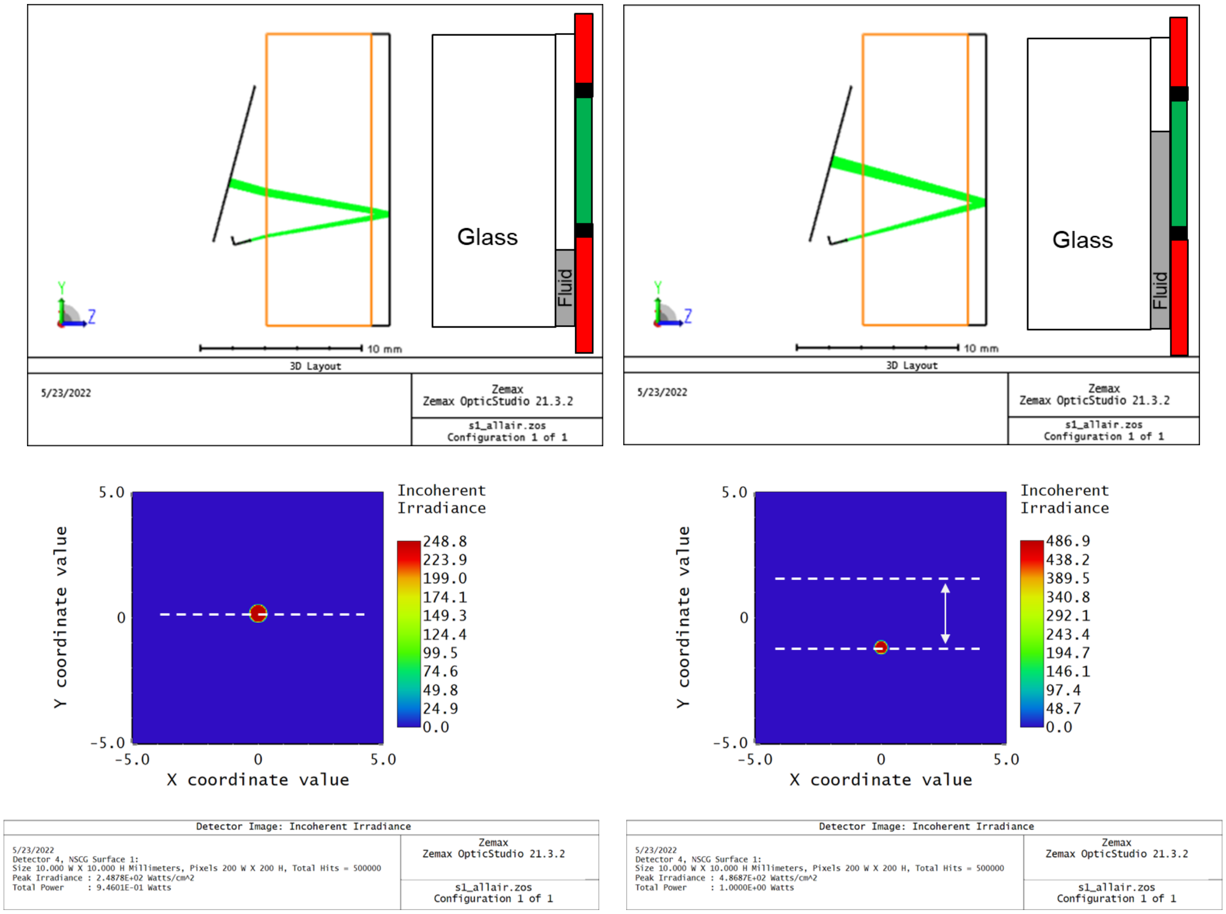

Figure 2. Light passing through sight glass and fluid. Displacement of beam in image plane shown by arrow.

2.3 Source broadening effect with LED emissions

For using an off-the-shelf light emitting diode, broadening of light beam at the source needs to be incorporated in the simulation. Effects are shown in Figure 3. It is apparent that the quality of light source in terms of beam divergence has strong effect on the pattern in the image plane. Simulation on constant source power but with varying full width at half maximum (FWHM) of beam divergence are shown in the figure. From design perspective, a well collimated beam, preferably from a laser source provides maximum intensity of signal with a well-defined beam shape. However, for practical applications on a low-footprint configurations with constraints on space, power consumption, specific geometrical shape/volume, LEDs were the preferred source of light for this application. Almost an order of magnitude difference in signal strength and selectivity can be obtained by LED specifications with appropriate FWHM as shown in the figure.

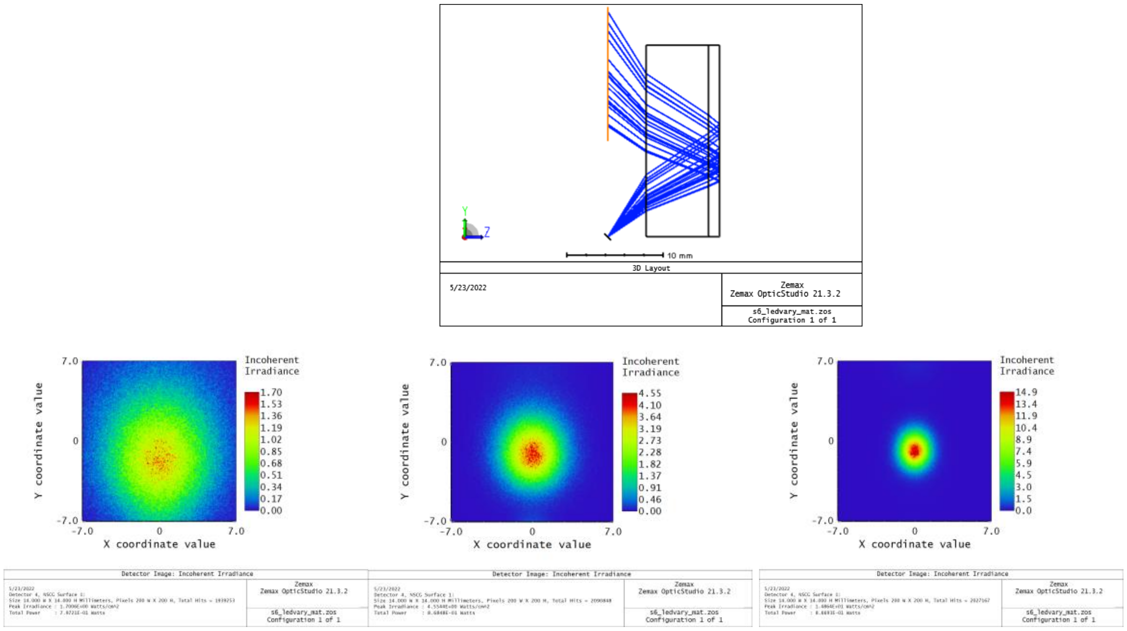

Figure 3. Simulation on optical signal pattern received in image plane for LED FWHM of 18, 10, and 5 degrees, respectively (bottom images from left to right). The optical path is shown on top.

2.4 Design optimization

Several parameters were optimized in designing an LED based detection system that can be deployed in a real-world scenario on automobile engine fluid-level detections. Some key design parameters were- light source, angle of incidence, source location, detector location, and detector responsivity. Significance of optical path optimization is shown in Figure 4 and 5, where ray tracing on the same optical source power and fluid-gauge geometry are shown before and after optimization, respectively. Light pattern on the image plane for an LED source with wider FWHM and a narrow incidence angle, shown in Figure 4, represents highly scattered beam in image plane with or without the presence of fluid. Sensitivity of detection system in terms of existence of fluid in the optical path is extremely low in this design.

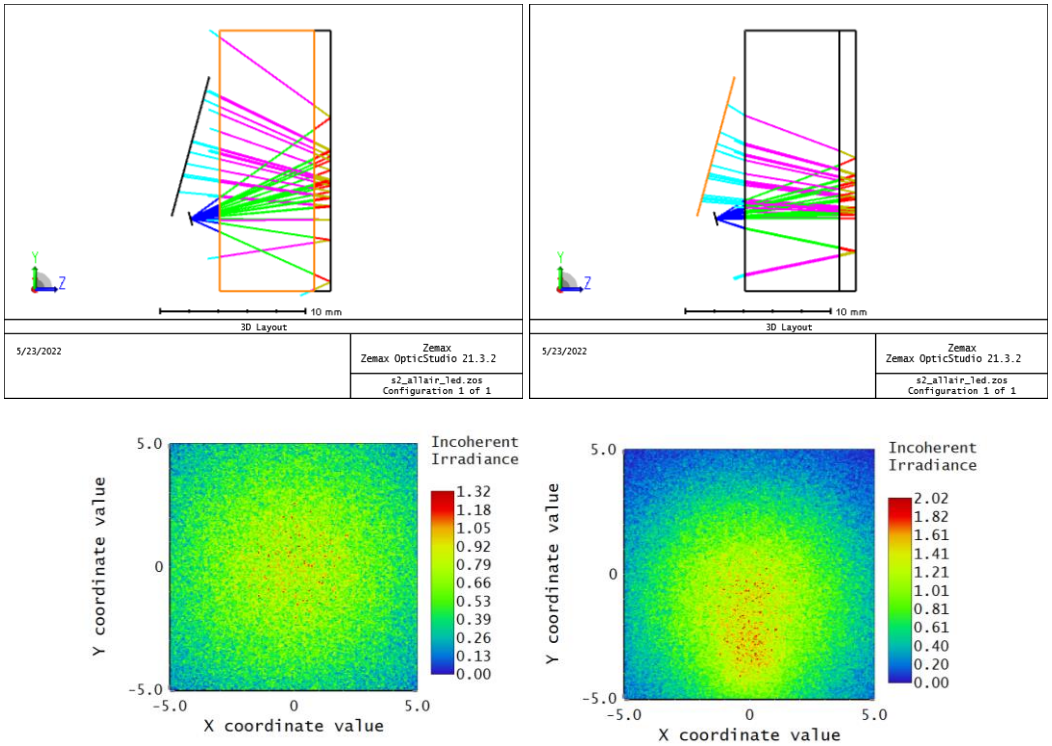

Figure 4. Simulation on optical signal pattern received in image plane for optical path through air (LHS) and fluid (RHS). Beam attenuation effect during propagation was not included in the simulation.

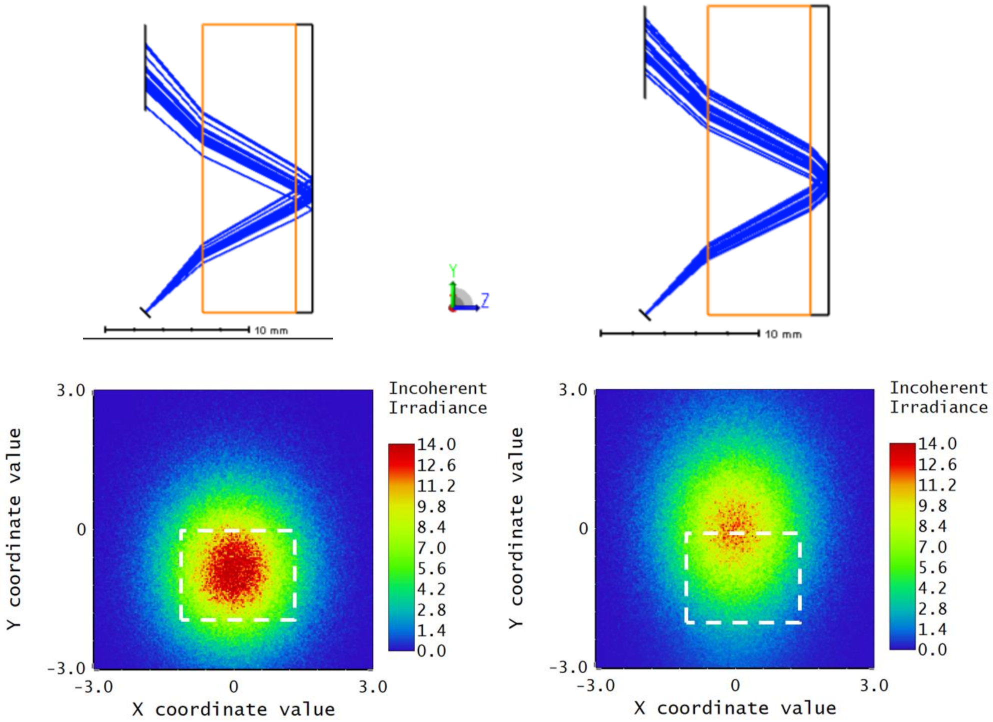

Figure 5. Simulation on optical signal pattern received in image plane for optical path through air (LHS) and fluid (RHS) for an optimized design. The optical paths are shown at the top. Integrated signal shown in specified area by dashed box shows strong selectivity in detecting the presence of fluid.

Strong selectivity in detection can be achieved through optimization of design parameters, as shown in Figure 5. Changes in beam pattern in the optical plane in presence of fluid in the optical path can be observed. Integrated detector signal in specified area in the image plane shown by the box with dashed line has strong selectivity in terms of presence or absence of fluid at a specific level of the fluid-gauge.

3. OPTICAL TRANSMISSION THROUGH FLUIDS

Table 1. Automotive fluids description.

Fluid Specimen	Type
1	Delvac
2	AST 20
3	AST
4	FDAO

Table 1 shows typical fluids used in automotive engine systems. Each fluid was tested through a spectrophotometer (Optizen Single Beam Type) to find out the effects of fluid properties on beam propagation. Figure 6 shows the transmission spectra for clean and aged samples. Significant difference in spectral response for different fluids can be observed. Design of the sensor system thus, in many cases, would need to include fluid specific selection of wavelength and optimization of system including beam propagation losses.

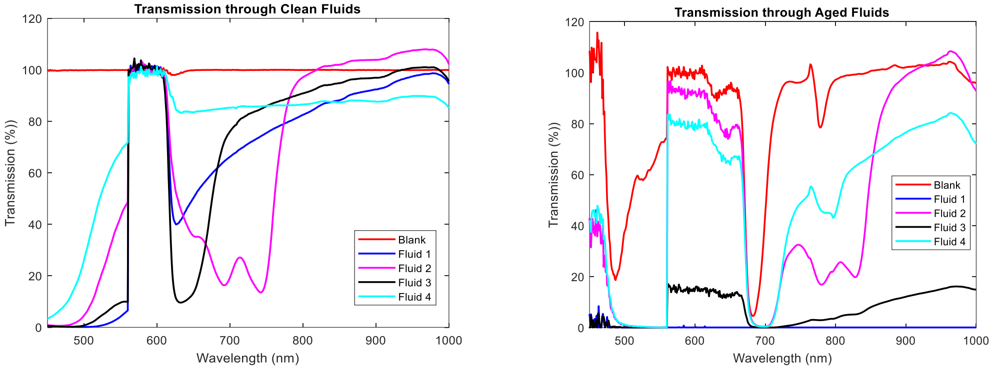

Figure 6. Transmission of light through different automotive fluids for clean samples (left) and aged samples after being deployed in engines for typical duration of recommended use.

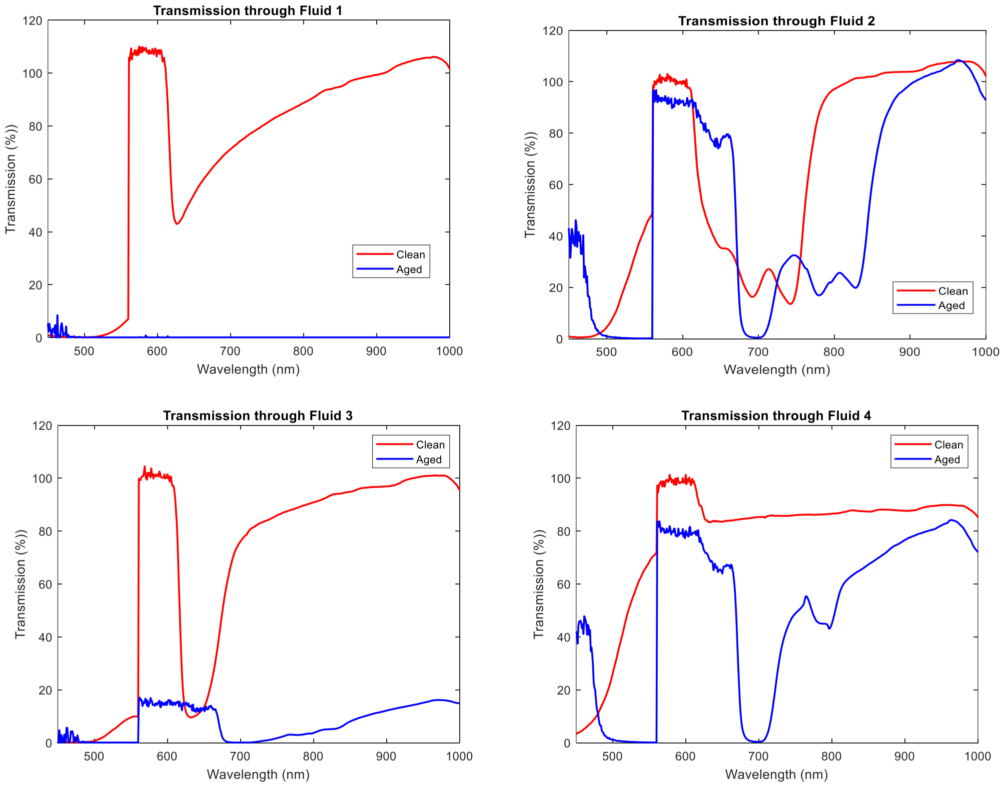

Figure 7. Transmission of light through different automotive fluids for clean samples and aged samples.

Status of optical transmission in aged fluids (i.e., fluids after their recommended period of use inside the engine) for different fluids are shown in Figure 7. It is apparent that optical transmission properties deteriorate significantly in aged fluids. Scattering and absorption of light in suspended particulates inside aged fluids as are likely to be the source of enhancement in attenuation. This phenomenon may be used as an indicator of the status of fluid inside fluid-tanks in a carefully designed optical system. Further work in this area is planned in future work.

4. SYSTEM INTEGRATION

The optical sensor system was integrated with a remote monitoring network through an Internet of things (IoT) based approach. Analog signals received by optical detector was transmitted through radio communication link using XBee modules.[5] Data from multiple sensors were collected by a custom-built network coordinator module, which then transferred the real-time information to a server where fluid-tank status can be observed through a user interface. Components of an integrated system for visualization of real-time status are shown in Figure 8.

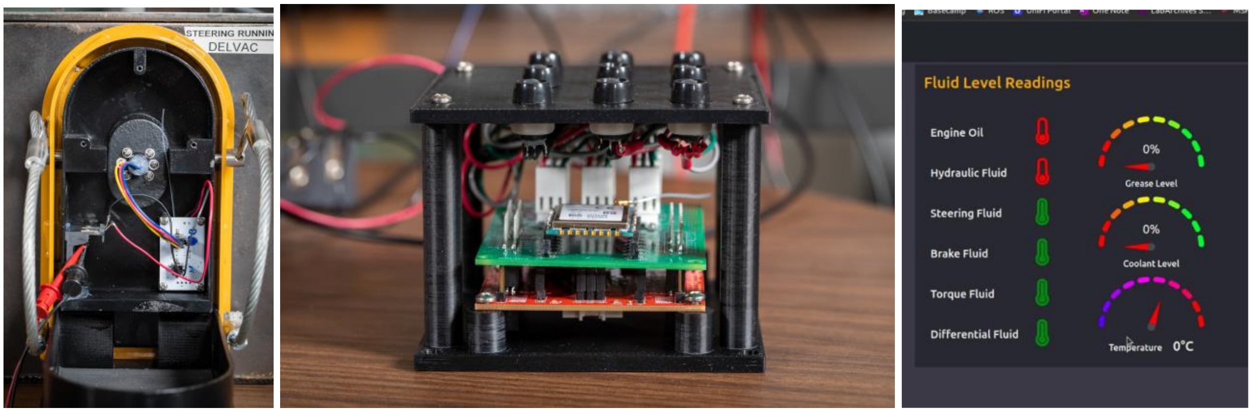

Figure 8. Integrated system for remote sensing of liquid levels in fluid-tanks- sensor deployed on top of tank sight-glass (left), network coordinator to collect data through radio transmission (middle), and user interface for visualization from remote location (right).

5. SUMMARY

We have developed an LED-based optical sensor system that is presently being tested on automotive fluid tank sight-glasses for ex-situ non-invasive monitoring of fluid levels. Optical path was designed through non-sequential ray tracing. Effects of beam broadening and angle of incidence of flight source, light propagation through air-glass and glass-liquid interfaces, and wavelength effects were studied in optimizing the system design. Variations in optical beam pattern in the image plane produced consistent differences in detector signals in presence or absence of fluids. The analog voltage from detectors were transmitted to remotely located server through radio frequency communications. User interface was designed for real-time visualization of status of fluids in the fluid-tanks.

REFERENCES

[1] Abdul-Munaim, A. M., Reuter, M., Koch, M., and Watson, D. G., " Distinguishing Gasoline Engine Oils of Different Viscosities Using Terahertz Time- Domain Spectroscopy," Journal of Infrared, Millimeter, and Terahertz Waves 36, No. 7 (2015).
[2] Mackney, D., Clague, N., Brown, G., Fish, G., Durham, J., " Automotive Lubricants and Testing," S. C. Tung, G. E. Totten, ASTM, West Conshohocken, PA, p. 23 (2012).
[3] Huda, Q., Hart, M., Anderson-Serson, A., Ripka, B., Cevallos A. L., Dekaban, M. A., Priestly, D., "Remote sensing of liquid levels inside automotive fluid-tanks through optical processes," Proceedings of the Canadian Society for Mechanical Engineering International Congress (2022).
[4] https://www.zemax.com/
[5] Ripka, B., Cevallos A. L., Anderson-Serson, Hart, M., Savela, S., Kilden, J., A., Dekaban, M. A., Priestly, Freitas, S. V. C., Battle, B., Huda, Q., "Unmanned IoT based automated inspection of large-scale mining haul trucks for assessment of vehicle operation readiness," Proceedings of the Canadian Society for Mechanical Engineering International Congress (2022).