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# AUTOMATED TRAIN OPERATIONS (ATO) SAFETY AND SENSOR DEVELOPMENT


## SUMMARY

In support of industry and Federal Railroad Administration (FRA) objectives to develop methods to safely facilitate increased automation in freight rail operations, Transportation Technology Center, Inc. (TTCI) performed a requirements analysis and initiated a safety analysis for a locomotive-borne sensor platform (SP) to support automated train operations (ATO). In addition, TTCI conducted research into sensor types for use by the SP, which showed that a suite of sensors working in concert is needed to meet SP requirements.


## BACKGROUND

An SP is composed of sensors mounted on a locomotive. These sensors monitor the external environment ahead of and around the lead locomotive. The SP performs a set of processes to provide actionable object of interest (OOI)- and condition of interest (COI)-related data (e.g., object classification, object position) to other onboard systems.

## OBJECTIVES

The objectives of the ATO Safety and Sensor Development Project were to: 1) define functional system requirements for a locomotive-borne sensor platform to support the ATO concept, 2) identify available commercial off-the-shelf (COTS) sensor technologies that may be capable of performing the required SP functions to support ATO, and 3) further develop a safety assessment of the ATO SP concept.

## METHODS

TTCI researchers reviewed the initial drafts of the ATO onboard segment requirements to determine system objectives and/or segment requirements that should be satisfied by the SP. These objectives represented a high-level list of functions that SP must be able to perform to satisfy the operational needs and safety requirements of the ATO system. Market research was conducted to learn about available COTS sensor technologies that may be leveraged by the platform. Market research consisted of seeking publicly available information on sensor types, sensor systems, and sensor components which can best satisfy the SP requirements. The safety effort of this project was focused on operational hazards and regulatory requirements that may apply to the SP. Deliverables of this effort include a preliminary hazard list, draft SP safety requirements, and SP developer's guidance.

## RESULTS

Research on available sensor types identified sensor categories best suited to meet SP needs. Factors such as falling snow, rain, fog, dust, object composition, bright and dark environments, and many others result in varying output responses from each sensor type. The limitations of sensor types, coupled with a dynamic operating environment, indicated that a single sensor type could not satisfy all SP requirements.

### Visual Cameras

High-resolution image sensors, coupled with high-frame-capture performance, means that a high volume of information about the environment is encoded within their outputs for later processing. Image capture supports object detection and classification because data from these sensors contain information about object shape and size. Binocular image capture also supports object ranging and object localization for tracking. Depending on the binocular configuration and sensor image resolution, optical sensors can be used to range objects on the order of miles or in close proximity. Note that visual optical systems are challenged by rain, snow, dust, or any other optical lens obstructions.

**Thermal Cameras**

Thermal cameras provide visual information about the environment in addition to temperature context. The temperature signature supports detection and identification of fires, operating vehicles, machinery, people, and animals ahead of the locomotive. Binocular configurations of thermal cameras may also be used to obtain range information for distant and nearby objects. Like visual cameras, thermal cameras can also be negatively impacted by rain, snow, dust, or any other object that obstructs the lens.

**Infrared (IR) Cameras**

IR cameras have several distinctive properties potentially beneficial to the ATO SP. The near-IR range of light has a strong propensity to reflect off foliage. This sensitivity creates a strong response from IR cameras to foliage that may benefit processes that discriminate OOIs and COIs from plants that contribute to image clutter. Another useful property of an IR camera image is that the sky appears very dark due to properties of atmospheric light scattering. This atmospheric scattering effect allows IR camera images to easily cut through atmospheric haze and see more clearly under water, as less light from the sky reflects from the water's surface.

IR light sources can also be used to illuminate a dark environment, allowing an IR camera to effectively see in low-light conditions. These benefits, unique to IR cameras, are combined with their general ability to discern object shape and size for detection and classification, as well as ranging distant or nearby objects when in a binocular configuration. These cameras can be negatively affected by weather conditions which may obstruct the camera lens but may be better suited to see in certain weather conditions (e.g., falling snow, falling rain) where IR light passes through more easily.

**Spectral Cameras**

Spectral imaging cameras leverage specialized optical sensors that can create an image using any desired combination of bands from the electromagnetic spectrum. This gives these cameras superior spectral resolution compared to other types. Cameras with sufficient spectral resolution can determine the composition of objects at a distance. This property of spectral imaging cameras offers the potential for improved differentiation of OOIs from clutter over visible light or infrared cameras alone. These cameras are susceptible to lens obstructions due to weather as mentioned for other types of cameras, but their high spectral resolution may increase their ability to see through weather that scatters less light in certain electromagnetic bands (e.g., snow, rain, fog).

**Light Detection and Ranging (LiDAR)**

LiDAR systems fire a laser beam downrange and study the return signal to determine the distance to an object. This is done at a very high rate to piece together a 3D collage of distance values representing the surrounding environment. This image not only contains information about distance to objects but can also be used to discern object shape and size. Since LiDAR systems rely on a strong signal return from the laser source, any weather conditions that may scatter the returning signal will negatively affect the LiDAR's operation (e.g. rain, snow, dust, lens obstruction). LiDAR system are also limited by their operating distance, often only a few hundred meters.

### Time-of-Flight (TOF) Cameras

TOF cameras operate on the principle of time-of-flight – transmitting a signal into the environment and calculating the distance to objects based on how long the signal takes to return. TOF cameras illuminate the entire field-of-view with a pulse of light, generally from an LED or laser, and calculates the range of the entire field-of-view simultaneously. This gives an accurate 3D picture of the environment on every illumination cycle. The generated 3D image contains distance information at every point within the image. This is useful for object ranging, tracking, as well as discerning object size and shape for object detection and classification. It is difficult for some TOF cameras to operate in bright outdoor environments due to saturation of the image sensors. This technical limitation will have to be considered when sourcing COTS systems. TOF cameras are also limited by the maximum distance they can accurately range objects. Generally, these systems operate from several centimeters to a few hundred meters.

### Radio Detection and Ranging (RADAR)

RADAR can be used for object ranging, tracking, and, to some extent, object identification. RADAR systems have an advantage in their maximum range, with RADAR range capability being on the order of many miles. COTS RADAR systems are available at relatively low cost. RADAR systems can also convey information about an object's composition. By analyzing the reflected electromagnetic energy from an object (the object's unique electromagnetic reflectivity), inferences regarding the object's physical composition can be made. Objects also respond differently to different frequencies of RADAR signals, with lower frequency signals penetrating deeper into objects proportional to the signal's wavelength. This can provide a further advantage to the SP in classifying objects and detecting objects through obstructions such as foliage or densely falling snow, rain, or fog. RADAR systems have several considerations with respect to downrange radiation exposure; they can be dangerous to people or livestock downrange because electromagnetic energy can penetrate tissue and cause heating due to energy absorption.

### Temperature Sensors

Modern temperature sensors tend to be relatively low in cost and operate on a wide temperature range. Considerations for temperature sensors are essentially limited to their desired output. Sensors typically have an analog current or analog voltage output, but sensors with digital output protocols do exist. The difference in cost between output types is negligible, and the output type has little impact on temperature sensor performance.

## CONCLUSIONS

A draft set of possible performance requirements were developed for a locomotive-borne sensor platform to support the sensing of risks and hazards associated with the environment in which an ATO train is operating. To satisfy SP requirements, TTCI concluded that a suite of various sensor types, working in unison, will be necessary. The SP safety analysis efforts identified the need for an SP developer's guide that provides information to potential SP system developers regarding the various safety assurance processes and tests that must be performed to meet industry safety objectives.

## FUTURE ACTION

Field testing of COTS sensor technologies should be performed to better evaluate the performance and capabilities of sensors and sensor systems in the railroad environment. This testing will allow for the validation and/or revision of SP system functional and performance requirements based on real-world experience. Field testing must also explore the use of multiple types of sensors and the fusion of data from those sensors to enhance SP functionality beyond what can be done with a single sensor type. Future decomposition of SP system level requirements will need to be conducted to identify those functions that must be common across all SP implementations while not infringing upon a SP developer's ability to innovate.

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