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A NEW RAILYARD SAFETY APPROACH FOR DETECTION AND TRACKING OF PERSONNEL AND DYNAMIC OBJECTS USING SOFTWARE-DEFINED RADAR

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ABSTRACT

In a typical railyard environment, a myriad of large and dynamic objects pose significant risks to railyard workers. Unintentional falls, trips and collisions with dynamic rolling stock due to distractions or lack of situational awareness are an unfortunate reality in modern railyards. The challenges of current technologies in detecting and tracking multiple differently-sized mobile objects in situations such as i) one-on-one, ii) many-to-one, iii) one-to-many, iv) blind spot, and v) interfering/non-interfering separation creates the possibility for reduction or loss of situational awareness in this fast-paced environment. The simultaneous tracking of assets with different size, velocity and material composition in different working and environmental conditions can only be accomplished through joint infrastructure-based asset discovery and localization sensors that cause no interference or impediment to the railyard workers, and which are capable of detecting near-misses as well. Our team is investigating the design and performance of such a solution, and is currently focusing on the innovative usage of lightweight low-cost RADAR under different conditions that are expected to be encountered in railyards across North America. We are employing Ancorteks 580-AD Software Defined RADAR (SDRadar) system, which operates at the license-free frequency of 5.8 GHz and with a variety of different configuration options that make it well-suited for generalized object tracking. The challenges, however, stem from the unique interplay between tracking large metallic objects such as railcars, locomotives, and trucks, as well as smaller objects such as railyard workers, in particular their robust discernment from each other. Our design‘s higher-level system can interact with the lower-level SDRadar design to change the parameters in real-time to detect and track large objects over significant distances. The algorithm optimally adjusts waveform, sweep time and sample rate based on one or multiple detected object cross-sections and subsequently alters these parameters to be able to discern other objects from them that are in close proximity. We also use an ensemble method to determine the velocity and distance of target objects to accurately track the subject and larger objects at a distance. The methodology has been field-tested with several test cases in a multitude of weather and lighting conditions. We have also tested the proper height, azimuth and elevation angles for positioning our SDRadar to alleviate the risk of blind spots and enhancing the detection and tracking capabilities of our algorithm. The approach has outperformed our previous tests using visual and acoustic sensors for detection and tracking railroad workers in terms of accuracy and operating flexibility. In this paper, we discuss the details of our proposed approach and present our results from the field tests.

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NOMENCLATURE

ADAS	Advanced Driver Assistance Systems
ATx	Adaptive Transmit
bw	Bandwidth of the transmitted signal
CW	Continuous Wave
DESERVE	DEvelopment platform for Safe and Efficient dRiVe
$\mathbf{D}_r$	Doppler resolution
EoD	Employee On Duty
FMCW	Frequency Modulated Continuous Wave
FRA	Federal Railroad Administration
fs	Sampling frequency
FSK	Frequency Shift Keying
KA	Knowledge Aided
OOPDA	Observe, Orient, Predict, Decide, Act
$\mathbf{R}_r$	Range resolution
RCS	Radar Cross Section
SDRadar	Software Defined Radar
SLA	Sense Learn Adapt
sn	Sample number
SoC	System on Chip
tm	Sweep time

INTRODUCTION

Railroads have been one of the safest workplaces for the Employees on Duty (EoD), due to constant monitoring, regulations and employee trainings. The seven 'class I' railroads, in conjunction with Federal Railroad Administration (FRA), have researched and introduced regulations, novel methods of training their employees, efficient employee management, freights and assets, etc. to provide a better and safer workplace environment for their employees. The trend in reducing number of fatalities and EoD deaths can be seen as the direct result of the actions taken by the railroad industry. Even though the efforts to make the workplace environment safer for EoDs directly influences how EoDs interact with a highly dynamic environment such as railroads, the consequences of railroads being *dynamic environment* cannot be ignored. Railroads consist of different *primary locations*, where the majority of EoDs are stationed, including main/branch lines and yards. The number of casualties in main/branch lines and yards are significantly higher than all the other locations, contributing to 35.1 and 26.4% of casualties in between 2014-2017 [1, 2], respectively. On average, around 1450 occurrences in main/branch lines and 1100 occurrences of deaths and fatal injuries in yards have been recorded in the FRA database during the same period of time [1, 2]. The silver lining in this trend is the change of statistics over time, which are on average -3.3% for main/branch lines and -15% for yards. However, these numbers are still alarming. Specifically, deaths and injuries have been recorded based on '49 CFR Part 225', which has detailed overview on accident reporting incidents, investigations and classifications [3]. In section 225.12, the "employee" includes all the terms: employee on duty(class A), employee not on duty, contractors and volunteers (class D). However, there are accidents, which are reported based on non-trespassers (class E) and trespassers involved in the event occurrence. Therefore, in our paper we strictly use the term 'personnel' to include class A, class D and class E persons in the railroad environment.

In our previous paper, we have shown how the dynamic environment affects workplace and contributes to different hazardous scenarios. We have also compared and identified railroad personnel incidents in terms of statistics and similar workplace environments [4, 5], i.e. construction. We have also identified the workplace hazards specific to railroads, which are falls, slips, trips, stumble and collision. In the FRA database the majority of hazards are identified as slips and falls due to walk surfaces and weather conditions, which translates to almost 10% of the total EoD fatalities [1, 2]. Collisions in different situations, i.e., driving, sitting, standing, etc., encompass almost 5% of the reported cases [1, 2]. Therefore it can be stated that the workplace environment risks in railroads primarily revolve around walk surfaces, fall hazards, weather conditions and finally the possibility of getting struck by objects. In both yard and main/branch line environments, outdoor work conditions are affected by dynamic weather conditions, ballast surfaces/spikes, irregular surfaces, heavy moving equipment/vehicles, rolling stock and freight. However, because of the dynamic, convoluted environment of yards and the mentioned hazards, yard engineers, conductors, foremen and clerks face 6% of the casualties, which is second-highest in terms of percentage of total number of casualties [2]. These are also the main causes of fatal casualties in a workplace like the railroads. These causes of hazards cannot be removed entirely, but regulated or prevented by extensive training and passive monitoring. The fall and collision hazard can be thus considered correlated to be one hazard influencing the occurrence of another, along with weather conditions, which negatively contributes to these events. We can also observe from the database that the majority of the events ($\sim 10\%$) happened next to tracks or at their own workstations, which supports our previous claim that regulations may prevent workers from coming close to the tracks, while still not being able to eliminate the danger from this dynamic convoluted environment, where the multiplicity in dynamicity is overwhelming.

Through understanding the risks and challenges in protecting the railroad workers resulting from our previous research, we decided to select a sensor fusion method combining various sensors such as vision sensors and RADAR, and embedding intelligence to be able to work autonomously in the yard.

In this context we proposed a Software Defined Radar (SDRadar) based multi-personnel and rolling stock detection and tracking solution as one component of this overall system. The scope of selecting a radar-based solution is to provide a solution that is weather-proof and doesn't suffer from limited visibility. The radar being software-defined allows us to add semi-cognition in the device to look at the environment and autonomously decide the location and velocity of the assets present in the vicinity. We have studied the range of the SDRadar and its targets as objects based on their sizes, threats and priorities for detection. The smart detection algorithm in the SDRadar can change its parameters to accurately identify the personnel present in the line-of-sight if there is a moving threat present. The algorithm works like a feedback controller, which guarantees efficient detection of multiple personnel through scanning within observable range and then finding larger moving objects moving towards or away from the personnel. We are presenting initial field test results based on indoor and parking lot test environments. Indoor testing evaluates a cluttered environment at limited scale, whereas parking lot testing focuses on a railyard-comparable large-scale environment with personnel and vehicle interactions.

RELATED WORKS

In general, radar has been used for detecting objects at different distances in both commercial and military domains for decades. The advantage of radar being used as a sensor in an environment is in its robustness in different operating conditions. Radar, unlike 2D-visual sensors (camera, stereo vision camera, etc.) works in low-light visibility and different weather conditions (rain, fog, etc.) [5]. These advantages over vision sensors made it popular in various application scenarios, i.e. automotive radar for autonomous driving [6, 7], collision warning for air traffic PARASOL [8], railroad crossing safety [9], blind-spot detection and construction worker safety-alert system [10], obstacle detection and individual status detection of objects in proximity for collision warning [11], etc. The most popular application scenario of consumer radar, thus excluding military and air surveillance systems, are found in Advanced Driver Assistance Systems (ADAS) to avoid potential collisions and accidents. These radar systems range from narrow-band radar to wide-band and ultra wide-band radar, including both long-range and short-range radar. The majority of automotive cruise control radar systems, starting with developments in the early 1970s, are based on mmWave frequencies [7] for assisting drivers in detecting blind spots, lane changes, braking cars ahead of them, etc. Nowadays, radars are not only used in ADAS for collision warning and blind spot detection for large objects, but also detecting smaller Radar Cross Section (RCS) objects such as pedestrians [12]. Researchers also identified the severity of collisions is significantly higher when heavy vehicles are involved [13]. The authors in [13], proposed DESERVE (DEvelopment platform for Safe and Efficient dRiVe), which is a training method using ADAS that might help drivers to better acquaint themselves with roads and driving environments. This positive trend in automotive radar research and application is due to efficient semiconductor development in the present decade, when mmWave radars are designed with CMOS transistor based System on Chip (SoC). High speed transistors contributes towards lower power, noise and better form factors [14]. Therefore, in higher-level designs high detection resolution from the radars can be found with low computational complexity. The extensive growth in automotive radar design of small form factor and low power consumption can thus be leveraged in other collision-prone dynamic environments too.

The radar research over the last decade also shifted towards cognition-based radar systems [15] and provides a variety of opportunities towards solving complex environment problem where clutter can eventually alleviate radar performance. In a complex operating region, cognition allows the radar systems to optimize signal processing for better target tracking and detection. The major challenge in radar detection is in cluttered environments when interference may stem from undesirable targets impeding radar accuracy [16]. The main advantage of designing cognitive radar systems is having feedback from the receiver to the transmitter that makes the radar adaptive and able to focus on primary targets without sacrificing performance detecting interferences or clutter. In this domain, knowledge-aided (KA) processing or adaptive transmit (ATx) techniques use the processing resources available to the radar [17] in the processing back end. The method of cognition for sense-learn-adapt (SLA) approach through observe, orient, predict, decide and act (OOPDA) can be applied to radar-centric applications based on KA and ATx for fully adaptive tracking and detection of objects [18]. Therefore, there is a significant opportunity of research to use cognitive radar in commercial domains, where clutter and dynamicity make detection and tracking harder than in conventional environments.

THE PROBLEM STATEMENT

Railroad environments are complex and dynamic, and make proper monitoring and training of railroad personnel both challenging and vital. An environment like a railyard is a large-scale operating region distributed into different sub-operating regions. Each sub-operating region has its own set of personnel and their movement in the environment should be regulated or monitored. Therefore determining the movement of assets and personnel individually in these regions is hard. A simple solution could be installing a number of infrastructure sensors or vision sensors within this environment to cover the entire region. However, the sheer number of sensors to cover a large-scale environment and finding suitable installation locations to avoid blind spots may make this approach for detection and tracking of personnel infeasible. Even the distribution of sensors and installing apparatus over assets need to follow particular set of guidelines [5]. Therefore, we define the set of particular challenges as shown below, in order to clarify the research problem to the reader:

Dynamic environment

Railroad environments are dynamic, and this dynamicity varies according to the *primary locations*. In main/branch lines, the probability of collision, falls, slips or trips for the personnel is limited due to space constrained operation. However, due to trespassers or any other non-personnel crossing or even approaching the tracks unrestricted, the number of casualties increases. Furthermore, whenever the number of tracks on a line increases the probability of collisions or falls increases significantly as well. In a yard environment, numerous operations are occurring simultaneously, predominantly in a scheduled and efficient manner. Most of the yard operations are also autonomous. A yard is a large-scale dynamic work environment, consisting multiple tracks with moving or static freight, Hi-rails, trucks or heavy vehicles near tracks for loading/unloading, rolling stock, etc. All of these assets move in a constrained environment in a semi-regulated manner. The personnel working in this environment have to work in a similar regulated and informed fashion to avoid fatal situations. However, as mentioned before, regulations may make workplace environments safer as a preventive measure when there is a deterministic set of interactions occurring, but they cannot address other factors such as human errors resulting in workplace fatalities, especially when human errors can propel a set of interactions towards the occurrence of a larger accident in these dynamic environments. We show below how a dynamic environment may interact with human errors,

One-to-One situations These are singular occurrence-cases where one asset collides with another personnel or non-personnel such as,

> where a trespasser may move across the tracks to trigger a collision fatality or move along the tracks towards or farther from the freight/rolling stock,
> or where a yard engineer inspecting a track or freight may fall or stumble over the track triggering a fatality or 'near-miss' event.

Many-to-One situations Cases where multiple-asset movements make any mobility by the personnel/non-personnel dangerous. These situations are highly unlikely but most dangerous for the personnel. Avoiding this kind of event without proper support may not be possible.

In yard environments, train and railcar movement is often controlled remotely by remote control operators or via humps in hump yards. Therefore, in scenarios like this, the sudden stop of these moving trains or railcars is not possible in a timely fashion. Similarly, on mainlines trains moving at 55 mph may very well take over a mile to come to a complete stop. Therefore, emergency scenarios should be handled and detected when the train is farther than one and half miles away from a potential incident site. In both cases, for yards and main/branch lines, the dynamicity is different. Hence, the measures for detecting these events must be carefully chosen based on the constraints we have discussed.

Detection Measures

Detection and tracking an event of a near-fatal situation is challenging in dynamic environments. The environment is cluttered and distributed, which introduces several blind spots for line-of-sight detections. More often, the distributed environments are monitored with distributed sensors creating a sensor network. However, increasing the number of sensors may increase reliability in detection, but that reliability comes at the cost of separate maintenance of a sensor network. A distributed sensor network on average can operate at 60% of its distribution, which does not fulfill the required reliability guarantee. Even when ignoring the reliability issue in this case, the number of the sensors to monitor a large-scale system can be huge and may not operate as standalone sensors in different cases [5]. Therefore, distributed sensor networks should employ sensor fusion. Distributed sensors cannot detect or identify the proximity of assets and personnels concurrently without actually putting sensors on-board assets or personnel. Supplying power to this sensor network to continuously work year-round without fail is also challenging. Moreover, if we consider the adverse effect of weather on the sensors, the robust outdoor deployments for both mainline/branch and yards seem infeasible using distributed sensor networks.

A plausible sensor network solution may employ vision sensors. The research in object detection, classification and tracking with vision sensors is in a mature state. There is a multitude of research going on to detect falls, trips, and gait through vision sensors. Therefore, detecting working posture, classifying personnel and trespassers independently, classifying assets, as well as detecting proximity and risk level through vision sensors can be be achieved using vision sensors. However, the primary requirement for a work environment such as the railroads is robustness rather than trivial detection and classification. For one, the range of vision sensors is limited. They can't operate in low-light conditions. Dirt, fog, snow and other environmental effects often render vision sensors virtually blind. Therefore, robust performance from vision sensors cannot be achieved in an environment where these weather and environmental conditions may occur.

Blind Spots

For any collision warning system blind spot detection is one of the hardest challenges. Vision-based sensors are line-of-sight sensors and fail to detect objects that are not in their line-of-sight. For example, a person hidden behind a railcar cannot be detected using a vision sensor. Even with height adjustment it is impossible to detect such a ‘hidden object’. Many a times trespassers may stay hidden behind an object or a person finds itself obstructed by a large object, thus avoiding the vision sensor’s surveillance. We identify this as one of the most challenging problems in designing collision warning systems, because even planned and optimized distribution of sensors may not find these hidden objects.

Finally, based on the above findings we can propose a summarized problem statement for this context that we are attempting to solve as:

- multi-object, multi-cross section object detection and classification in a cluttered environment,
- individual accurate and low-latency range and velocity detection,
- prioritized detection and tracking of personnel and non-personnel,
- rapid person-to-object proximity determination for risk evaluation and neighbor support,
- clutter recognition and adaptable sensing of environment
- detection of ‘hidden objects’

USING SOFTWARE-DEFINED RADAR

Virtually the entire functionality of Software-Defined Radar (SDRadar), similar to Software Defined Radio, can be controlled by its software. That means, waveforms, filtering, clutter cancellation, sample points, sweep time, bandwidth, etc. all can be changed on the fly by software according to specific requirements and adapting to time-varying conditions. Though radars have been used for detecting targets for a long time, software-defined radars are a newer addition to the family. SDRadar systems provide clear advantage through cost reduction and also inherent flexibility of signal generation and signal processing. It often is also possible to run the software locally or remotely in order to control the SDRadar for target distance and velocity detection. The hardware we utilize for our presented method is Ancortek’s SDR-KIT-580AD [19]. The SDRadar kit operates using a 5V power supply, and utilizing separate transmitting and receiving antennas. Figure. 1, shows the in-house kit we have in the lab for indoor and field testing. It also is equipped with the SDR-PM 402 processor module with the ability to integrate C-band frequencies (4-8 GHz). The center frequency of the module is in the ISM band of 5.725-5.875 GHz. It has waveform support for FMCW, FSK and CW waveforms, which we will be considering as our waveform library [20]. It can support wide band scenarios for increased range resolution and customized bandwidth may be expanded to 800 MHz for ultra-wide band scenarios. Narrow-band waveforms can be used to detect objects at large distances. Table 1 shows the summary of features available in the SDRadar [19].

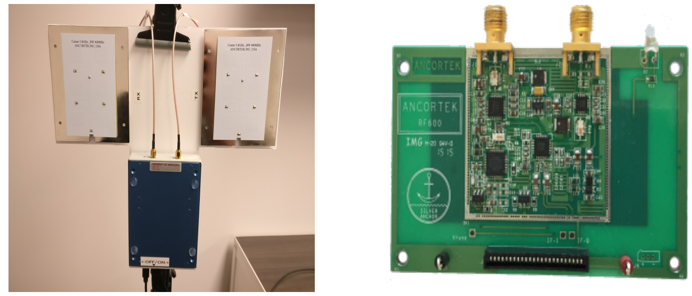


FIGURE 1: ANCORTEK SDR-KIT 580AD AND EXPERIMENTAL SETUP

The Reason for using SDRadar

As we previously discussed, radar systems are robust, weather-independent, consume relatively little power and have been extensively tested in different safety-constrained application scenarios. Another key observation is that when it comes to radar, blind spot detection can be done easily, because it captures the reflections through multipath. Therefore, we summarize the reason behind using radar systems as i) providing a large coverage area, ii) consumes relatively little power, iii) is robust in different weather and environmental conditions, iv) accurately detects and tracks large objects and multiple radar cross section objects with clear Doppler separation, v) detects blind spots and hidden objects, vi) detects objects in low visibility and harsh operating conditions. The reason behind selecting SDRadar over conventional radar is the ability to control the radar system through software and obtain optimal control over the parameters. The problem with highly cluttered environments is interference and shadow detection of lower radar cross section objects. Therefore even with marginal Doppler separation between two objects the detection of lower radar cross-sectional objects may not be possible. Even though wideband and ultra-wideband radar systems provide better target detection at shorter range, narrowband signals provide better target detection at longer range with Frequency Modulated Continuous Wave (FMCW). In our SDR-kit, pulsed waveform support is not available currently, so we instead focused on the use of continuous-wave waveforms. Due to FMCW’s range resolution being inversely proportional to bandwidth, increasing bandwidth provides better range resolution. The power draw in wideband and ultra-wideband is also lower than narrowband signals. Therefore, we can exploit these varying characteristics of CW radars, changing different wavelengths, sweep time and sometimes waveforms to scan the operating region to find and detect people amid clutter. Using SDRadar we can achieve not only flexibility in processing radar information, but also it is possible to learn about the environment and adaptively scan the environment prioritizing personnel in vicinity.

TABLE 1: FEATURES OF ANCORTEK SDR580AD.

Feature	min.	typ.	max.	units
Frequency range	5.6		6.0	GHz
Expandable frequency range	5.2		6.0	GHz
Bandwidth	50		400	MHz
Extended bandwidth	50		800	MHz
Tune voltage	0		5	V
Power output	18	19	20	dBm
Conversion gain over Rx channel	26	28	30	dB
Maximum input power		10		dBm
Supply voltage	4.75	5	5.25	V
Supply current	650	670	700	mA
Operating temperature	-40		85	C^0
Image rejection rate	20		30	dB

Theoretical Analysis of Utilizing SDRadar

Analyzing the problem statement mathematically we can determine that through adapting a limited number of parameters we can achieve optimum results: i) range resolution, ii) clutter, iii) Doppler resolution at large distances > 100 m, iv) range of the target object and range of potential collision risk if within range. The important parameter to work with in this context is the clutter. Conventional,y clutter cancellation can be performed in software averaging over some time periods without the target object. However this does not provide sufficient clutter information in a dynamic environment. Clutter cancellation needs to store information regarding dynamically changing clutter or interferences present in time-variant scenarios such that even in congested and dynamic environments target objects can be detected and tracked. Therefore, for ease of understanding we will analyze the SDRadar performance with FMCW. The parameters in FMCW that are controllable are bandwidth, sample number ($fs \times tm$), where, fs is sampling frequency and tm is sweep time. Therefore, changing the sample number and sweep time we can change the sampling frequency. Changing these basic parameters provides us the opportunity to change the range/Doppler resolution and range limits. The range resolution can be calculated by $\mathbf{R}_r = c \times \frac{tm}{2 \times bw}$, where c is the speed of electro-magnetic wave and bw is the available bandwidth. The Doppler resolution can be calculated by $\mathbf{D}_r = \frac{c}{fc}$, where fc is the center frequency of the radar. From this we can conclude easily that the Doppler resolution of the radar is constant or cannot be changed through software. However, as we can change the radar sample number, sweep time, and bandwidth on the fly we can instead adapt the range resolution to achieve better accuracy in multiple-target detection and tracking. The maximum range can be found simply as $fs/2 \times \mathbf{R}_r$.

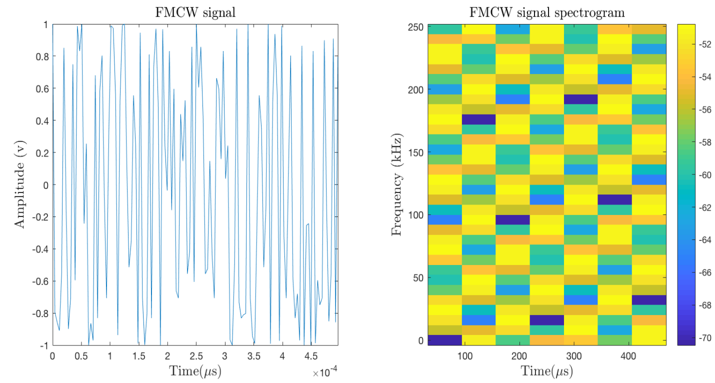
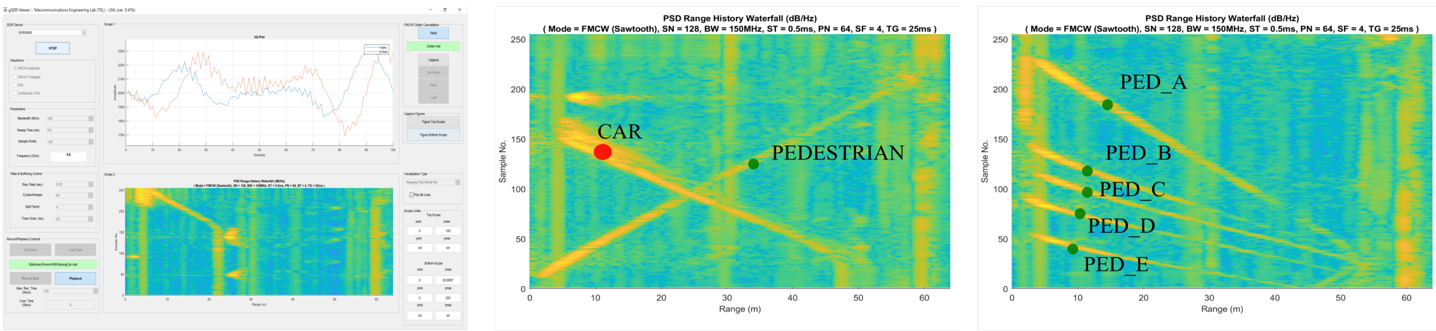


FIGURE 2: FMCW WAVEFORM AND ITS SPECTROGRAM

Outdoor Experimentation with SDRadar

As the SDRadar is very easy to use in indoor and outdoor scenarios we have conducted basic field tests with the radar to check if the SDRadar is fully functional and shows merit of detecting point targets (with Radar Cross Section of 1, i.e, human target) in difficult cluttered scenarios. To test these scenarios we have used the highest range resolution in the radar, e.g., $bw = 400$ MHz, $tm = 0.5$ ms, $SN = 128$, where SN is the sample number. The range resolution we can achieve is in millimeters and the maximum range can be ~ 24 m. This is not an ideal test scenario for outdoor testing, but for ground reflections and understanding in later clutter cancellation algorithms this scenario provides us the opportunity to study point targets and their closely correlated movements. Theoretically, the radar can be tested for a maximum range of ~ 3.1 km when, $bw = 100$ MHz, $SN = 1024$, $tm = 0.5$ ms, with decent range resolution. The range resolution is useful for separating two targets individually. In our case, due to wideband bandwidth availability, the cases of target differentiation problem should not occur. We have created a random clutter environment in outdoor 24m region, and three scenarios: i) two personnel facing in the same direction and a separation between them of ~ 18 m, ii) two personnel at 8 m and 24 m, iii) car and two personnel respectively at 3m, 10m and 15 m. Figure 4, shows the field test spectrogram of the range-Doppler plot. From the plots it can be seen that there was not a lot of movement observed due to static placement of the participants. We had to use clutter cancellation methods to bring out the participant point and larger objects clearly to show them in plots. As we have used FMCW waveform for both outdoor and indoor scenarios, the pulse and its spectrogram are shown in Fig. 2.

For detailed understanding of the SDRadar and the software defined by our lab, Fig. 3 (i) shows the software and Fig.3 (ii) - (iii) show some more outdoor scenarios, where the location of cars and personnels are shown in the figure.



(i) (ii) (iii)

FIGURE 3: FIELD TESTING - (i) GUI TO CONTROL THE PARAMETERS, (ii) CAR AND PEDESTRIAN PARALLEL MODEMENT, (iii) MULTIPLE PEDESTRIAN MOVEMENT

Indoor Experimentation with SDRadar

Indoor experimentation with radars are useful to replicate/emulate a large-scale cluttered environment with less dynamicity at a smaller scale. The most challenging scenarios can be obtained with multi-path and reflections. A generic approach for clutter cancellation for radars can be achieved through first measuring radar returns of the environment without the presence of the target object, to effectively baseline the environment. Then during real time observations, when the target is present we can remove the cluttered scene from the observations, thus depicting a clear and better range estimation. Figure 5 illustrates the range estimation using a waterfall plot where observing the clutter and clutter cancellation method shows better estimated range. In the figure the target is approaching and receding from the radar line-of-sight for a short period of time.

PROPOSED METHODOLODY

We have discussed the capabilities of SDRadar and the software we have designed to locate personnel and track them individually and separately from the cluttered dynamic environment. Thus far the parameters have been controlled manually in these tests. However, the entire process of adapting the parameters to detect and track personnels should instead be automated. This enables the fully automatic detection and tracking, in each case optimally balancing performance and precision. The only practical way to control this operation is to design and implement a control system and define input, output and disturbances. As we have seen before, the input can be a multi input system where we define a derived input as range resolution. The disturbances should be the clutter and output is the detected range. This range estimate feeds back into the controller to refine this achieved output result. Therefore, we designed Algorithm 1, shown below, to run and control this process:

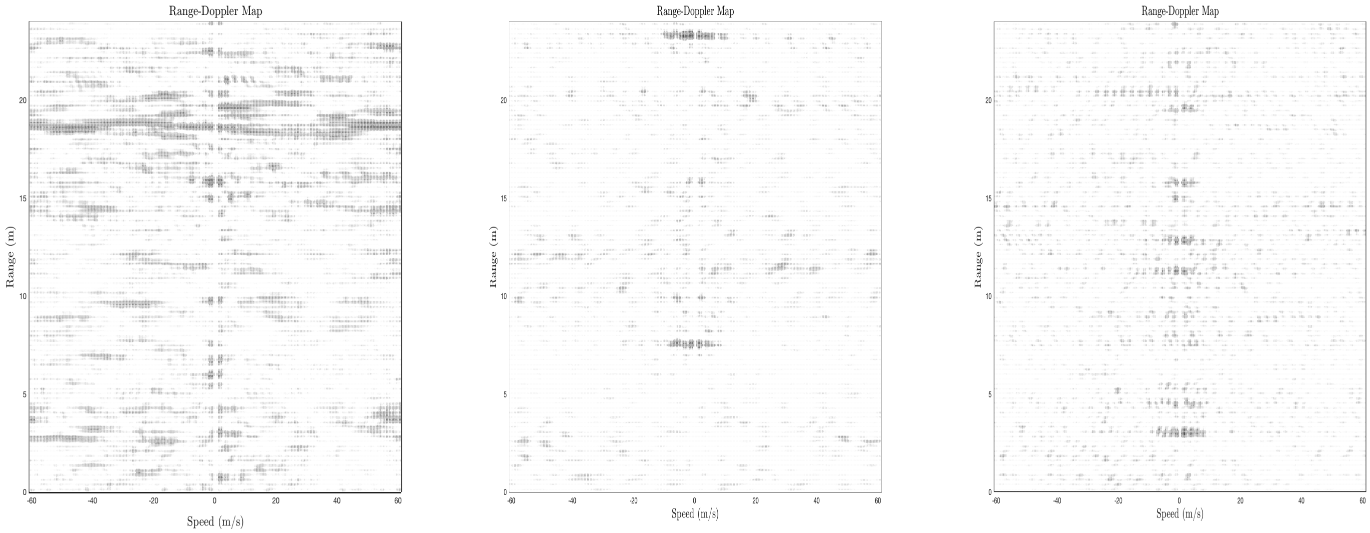
Algorithm 1: ALGORITHM FOR THE CONTROLLER

function detectRange;
Input : rangeResolution $= \varepsilon$
Output: detectedRange
if *targetDetected* **then**
    detectedRange $\leftarrow$ fmcw_range_doppler_function();
    rangeResolution $\downarrow \varepsilon$;
    function detectRange()
else
    rangeResolution $\uparrow \varepsilon$;
end

Now, according to Algorithm 1, this function is a recursive controller and it is based on range resolution. Based on the desired range resolution we then can adjust bandwidth, sweep time and sample number for FMCW. We can run different estimation techniques on the radar systems to determine accurately the location of the target. In the next section, we will show the simulation results for our proposed methodology.

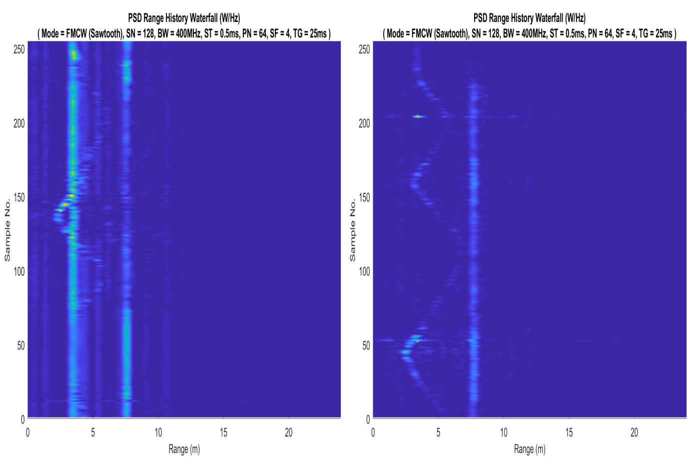
SIMULATION RESULTS

The simulation of the above algorithm clearly shows that we can achieve better estimation of range by adapting range resolution and sweep time. In our simulation we have used exact parameters for antenna gain (12 dBi), noise figure (3.4) and receiver gain (28 dB), as specified in the Ancortek 580AD datasheet. We have created a simulated scenario for a test study where two targets of different radar cross section are present. One target, which is a car at 50 m distance and at a speed of 20 km/h is moving towards the target, whereas another target a personnel is moving at a speed of 6 km/h from a distance of 30 m. We have simulated the scenario to test the scope our proposed methodology. The simulation observations have been chosen as



(i) (ii) (iii)

FIGURE 4: RANGE DOPPLER PLOT OF SCENARIOS (i-iii) FROM LEFT



(i) (ii)

FIGURE 5: INDOOR SDRADAR OBSERVATION WITHOUT AND WITH CLUTTER CANCELLATION

shown in Table 2.

Therefore, in Fig. 6 we can see that velocity estimation accuracy for multiple targets fluctuates. As the velocity of second target can not be estimated precisely, the accuracy of the first target remains constant for three of the observations. This phenomenon is the result of using FMCW sawtooth. However, Utilizing triangular FM or FSK waveforms solves this problem, and this can easily be seen through SDRadar's settings control. Using

TABLE 2: SIMULATION PARAMETERS

Parameter	value
Maximum Range	50, 60, 70, 80, 100 m
Sweep Time	0.1, 0.5, 1, 2, 4 ms
Range Resolution	2, 1, 0.5, 0.2, 0.1 m

our proposed controller design to scan for pedestrian and adaptively control parameters, we observe an interesting trend in the resulting plots: During range estimation it can be seen that the best estimation can be found when the radar maximum range is close to the distance to the primary target object itself, independent of sweep time and range resolution.

CONCLUSIONS

The scope of this paper is to identify the potential hazardous challenges railyard personnel face, and to conceptualize and evaluate a solution that improves worker safety by providing early alerting without encumbering the personnel. The discussed solution is based on Software-Defined Radar, which is a unique solution to the problem for locating personnel within the yard and along mainline tracks, without manual interactions and frequent maintenance. To show the merit of the proposed infrastructure-based sensor solution over others we have

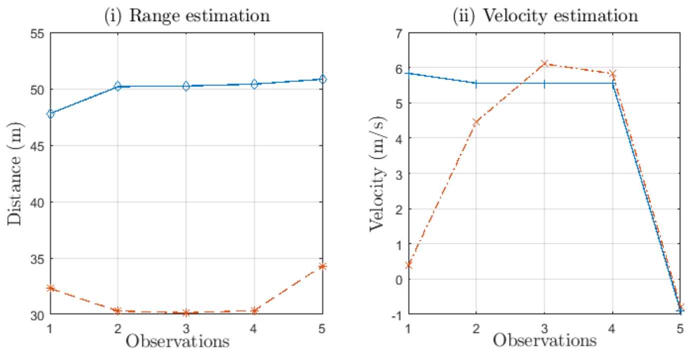


FIGURE 6: RANGE AND VELOCITY ESTIMATION

field-tested Ancortek's SDR580AD in different scenarios and obtained results that demonstrate the feasibility of the proposed approach. We could obtain accurate results and insights into the most promising application conditions for using the radar under most difficult cluttered and dynamic environments. According to our research studies, radar can be used in yards and mainline environments as a temporary or permanent installation for personnel safety and management. The high resolution detection methods show us that the results obtained can be further analyzed for detailed clutter analysis and differentiation between objects of different and similar radar cross section. Additionally, we have shown the capabilities of the designed software and have proposed a controller for cognition to adapt operational parameters within the software. The simulation results confirm the logic behind designing the controller itself. Our future research direction is to study enhanced cognition for radar detection and tracking for autonomous operation.

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