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Research Article

Evaluation of Efficient Data Visualization System for the Assessment of Similar Data Visualization Issues

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Abstract:

Data Visualization approaches evaluation is an important task for the software and other industries. Often companies need successful visualisation methods with complex data and criteria that influence business decisions and persuade interested parties. This represents a similar problem in the development of a software prototype for Safety's revolutionary system with the goal of enhancing detection reliability through the use of multiple sensors and requiring an appropriate visualisation tool that meets all needs. The primary objective of the analysis is to analyse and filter the feedback of the current literature with respect to systems functionalities and various methods to explain the crude data with the aid of the developers and other team members. To test visualisation approaches in order to evaluate an effective process, define assessment criteria using corresponding metrics. The findings provide insights into how data visualisation tests for industrial problems can be conducted in real-time and the validation process can be used to evaluate an efficient data visualisation system. This research helps to accurately visualise their data by using similar technologies and offers a scientific approach for the assessment of similar data visualisation issues.

1. Introduction

In the present day, the Software industry is striving to deliver meaningful, usable and efficient products to the customers with real-world problems and applications. Software-intensive systems and software embedded hardware systems often undergo developmental changes and are introduced to various new functions to improve and create a new product. To illustrate this, organizations utilize different data visualizations methods which aides in convincing stakeholders, users and other practitioners in making decisions appropriately. Knowing which visualization method gives an effective and accurate intended outcome is inevitable. Data Visualization has become a process of converting raw data into understandable information and knowledge through graphical depiction. It is often the primary goal of an organization to meet the customer requirements with a high level of satisfaction, and it is not so surprising that an effective visualization tool, framework or method helps present the accurate comprehension of the data structures or trends. This mainly has an effect on the decision-making skills of a user and convincing the stakeholders. For example, a limited amount of data in the form of a verbal or written format is useful. Still, there is a significant difficulty in understanding the data when there is a huge amount of it being generated and even harder on a larger scale [1]. Generally, the graphical illustration or depiction shall allow the users to interpret the data in complex scenarios as it does in ideal conditions.

Data Visualization is a powerful concept through which complex and difficult problems are illustrated in a simple format. Data is either in a structured or unstructured form of information which is used to make decisions or take actions based on the requirements of a given problem. Having a surplus amount of data and no proper medium of presenting it is just considered to be unresourceful and leading to the failure of a product. Often, many industries require attractive and understandable charts, graphs or pictorial representation of the information which give meaning to the data [2][3][4].

Over the past decade, many industries have developed various products and made discoveries which surround us and our daily works, where every system, software and functionality of a machine is evaluated based on the reliable results. Reliability and understandability are key factors to many real-time applications and helps measure the correctness and consistency in the system. Understanding the need to measure or determine reliability ensures good efficiency, performance and accuracy of such applications [5][6]. These applications, for example, could be using a smartphone, travelling in an autonomous vehicle, production equipment, Heavy payload manufacturing machines and many more which are dependent on different safety factors which help them perform better. If these products or developments were to fail or show some signs of incorrectness or faults, then it would pose a great threat to humans and their surroundings.

The development of such machines and products undergo many years of research which contribute to all the performance and efficiency of such a system. Often these products require a software infrastructure to support all the features and operations. And synthesizing data from multiple team members involved in developing takes multiple iterations with significant challenges. One of the significant challenges which are the synthesis of data and visualization when different team members use other visualization methods, but require to show collective results to the stakeholders or customers. User satisfaction and understandability of data is a must for any software deployment.

This research aims at evaluating such visualization methods which play an important role to convince the stakeholders and customers with normalizing the usage of a single visualization method. The evaluation is performed in the development of a Software Demonstrator for (Group) Safety Radar System which requires to demonstrate the improved reliability in object detection [7].

Radar Sensor Technologies are being deployed across different platforms and applications to track the movement of objects and humans. Data collected through these sensors are of huge volume, which requires high computational requirements and good visualization methods/techniques. This paper is concerned with one particular radar technology, namely IWR6843 Milli-Meter Wave Radar Technology and the different data visualization methods used during the development of a software demonstrator with multiple radar sensors for improved reliability in detection [8].

An embedded software system, in this case, the safety radar system is a combination of software intelligence and hardware components which are programmed to perform a set of operations or tasks. During the developmental stages of such systems, data visualization plays an important role, which being said is to display all the requirements, features and functionality of the system. Many developers, software practitioners and team members tend to use a convenient or goal-oriented visualization method to depict the developed component. Now, it is a challenge if there are multiple visualization methods for different features of the system developed by different developers. This directly impacts on the understandability, performance and reliability of the system when the users and stakeholders try to make sense of what information if being illustrated. Post Development collaborating and synthesizing the data from various perspectives into a single data visualization method is again a time consuming and cost-effective process.

From the existing literature and company artefacts, we can learn which data visualization methods are utilized to illustrate the radar data. We would like to evaluate these visualization methods and design an evaluation study to determine an effective Data visualization method for similar data or applications.

2. Background

Data Visualization is a process of understanding a considerable amount of data which is crucial in making decisions for real-time problems [9][10]. Having Data in a verbal or written format is useful but comes with many challenges like when there is a large chunk of data and extracting meaningful information is difficult but can be easily navigated through simple illustrations like in graphs, charts or plots. This helps the user make decisions effectively and easily with a proper understanding of the data. Data Visualization methods have a wider scope of applications and use such as identifying patterns, trends and performing analysis.

Recent years have paved way too many growing industries like autonomous vehicles, heavy machine manufacturers, automated factories and much more. Most of these activities often include machines which work with sharp blades, hot tools, heavy payload carriers which might harm a human. Placing certain safeguards and preventive measures on these machines so that they do not harm any human is known as machine safety. Machine safety has a set of defined guidelines and rules which are to follow by specific industries and products which provide trust and safety to the users. Failing to follow the machine safety norms or policies would increase the risk of getting injured or damaged. For example, automobile manufacturing industries are equipped with heavy payload machines which assemble most of the cars; these workplaces are intervened by humans on a daily basis.

If the machine is not able to sense the presence of a human nearby and come to a PAUSE state or HALT state, it could harm the human [11].

Radar, a critical technology was first used during world war II when there was a need to locate and know the position of enemy ships. Over the years, radar has been growing and developed at a rapid rate. Radar is defined as a detection system which uses radioactive waves to determine the range, velocity and angle of certain objects. Millimetre-wave radar technology is operated at a wide bandwidth of the radioactive spectrum with short-range detecting capabilities and material penetrating capabilities. Modern-day radar detection systems use a significant amount of software computing and utilize huge lines of code to improve the detection capability of the system. Millimetre-wave Radar(mmW) is being used in the current real-world industrial problems and experimented in autonomous vehicles due to its low cost and high availability in harsh environmental conditions. Reliability in the safety radar systems indicates that there are more safety and availability, which means the probability of the false detection is very less compared to other detection technologies like infrared cameras, LIDAR and RGB imaging [12]. In this study, we observe the usage of more than one mmW radar module to improve the reliability by combining homogeneous data sets, instead of sensor fusion using heterogeneous data sets with two different sensor types.

Like many software embedded in hardware systems, the safety radar system also needs illustrative charts, graphs and plots to show the position of the objects initially when developing machine optimized algorithms and functions for further automation. More importantly, visualization is a core component in the demonstrating software which is presented to the stakeholders or customers to illustrate the capability and use of this system. There is no object detection when we cannot display the position of an object or human in-front of the radar modules [13].

In general, a radar system is a combination of hardware components and software intelligence which compose an image of the surroundings with relative positions, range, angle and velocity of the object. Producing these results consumes a lot of data processing which is binary in nature. The users need a simple and understandable form of information from the radar modules, which is illustrated using the visualization methods. It is safe to assume that, one cannot imagine what is it like the Radar modules are sensing without these visualizations and analyse the data leading to low reliability and safety. Similarly, there are different visualization methods used by other developers and practitioners while developing this new technology with multiple radar modules. Determining a single visualization method which can also be used to convince the stakeholders will impact the business intelligence and growth of the project.

3. Safety Radar System

The Safety Radar System proposed by ABB Jokab Safety comprises of an Evaluation Unit where the demonstration software is executed and a hardware setup with more than one radar module to improve the detection reliability using the mmW radar technology. The data is sent to the external Evaluation unit where it is transformed, processed and visualizations are made to show the positioning of the objects present in the field of contact [14][15]. This radar technology occupies the frequencies ranging from 30GHz - 300Ghz. The size of mmWave sensors is small and compact in nature as antenna size is inversely proportional to the frequency. These sensors have fair range resolution, can offer wider bandwidth of frequency and has a significant role in calculating or depiction the range, velocity and angle of the objects in the area of contact within reach of these sensors. Due to their robust build quality and low-cost feature, these have been easily accessible and offer consistent detection and operation in different environmental conditions. The imaging results illustration aspects deal with scanning the electromagnetic radiation emitted from the objects which are used to outline and detect the position of an object [16]. Bandwidth and Range Resolution is two important factors considered in the detection of humans/objects present in the area of contact for the radar sensors. Bandwidth is only the measure of the frequency in which the sensor is operating, but the ability to differentiate between one or more objects present in short distances is known as range resolution.

$$d_{res} = \frac{c}{2B} \quad (1)$$

Range resolution is evaluated using a mathematical formula where d(res) is the range resolution in m, B is the bandwidth of the radar and c the speed of light [17]

Data set

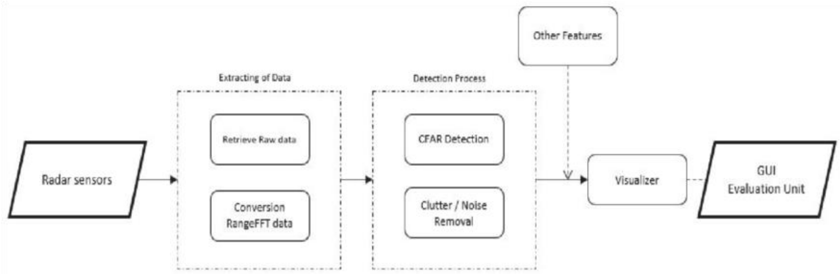


Figure 1: Safety Radar System Structure

Data collected from three radar modules in this system. A brief overview of the system is given in Figure 1. Real-time datasets are used in the visualization methods where the data is integrated using coordinate transformations. As part of this work, a newly developed code for the co-ordinate transformation engine is used in the software demonstrator, which combines data from multiple radar sensors, as shown in Figure 2. This sensor data consists of information in the form of a range, velocity, and the angle of objects with unique accuracy. Data samples are generated in a designed space with a radar reflector, object and human. The dataset has numerous variables which are used by a mathematical function with Fast Fourier transforms (FFT) that calculates the precise position of the objects by converting time-domain signals to a frequency domain.

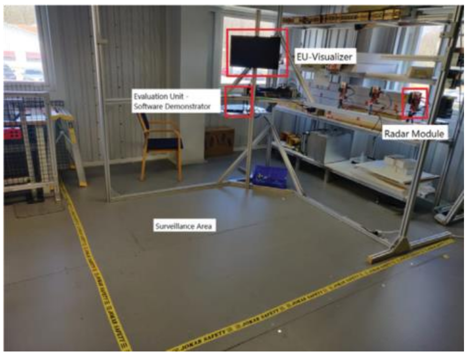


Figure 2: System Setup at the Company

4. Architecture

In this work, we give a glimpse of what goes behind the visualization process in the safety radar system and insight into the developed coordinate transformation engine developed to combine the data and visualize from multiple data sources (radar sensors).

The coordinate transformation engine is part of the demonstrator software for the safety radar system, a product at ABB Jokab Safety with multiple mmW radar modules to increase the detection reliability. It is illustrated through convincing visualization. A micro-service architecture (Figure 3) was designed keeping the continuous development and deployment of the services (features of the system) in mind. Visualization of the object detection was at the top of the architecture, which required a coordinate transformation service. It was developed for integrating three homogeneous data sets from the radar modules. This is a platform where most of the computation took place and executing relevant visualization methods to locate objects from multiple views. The dataset and format of the data utilized by all the components is same. Only Values or outcomes change depending on the functionality preferred. Interacting with the team members involved in the development of this system it was understood that integrating the data from multiple radar modules using the mmWaveStudio was too difficult due to the configurations within and lack of software support. Hence, a new software architecture was proposed. Implementation of the proposed architecture is done in the software demonstrator initially.

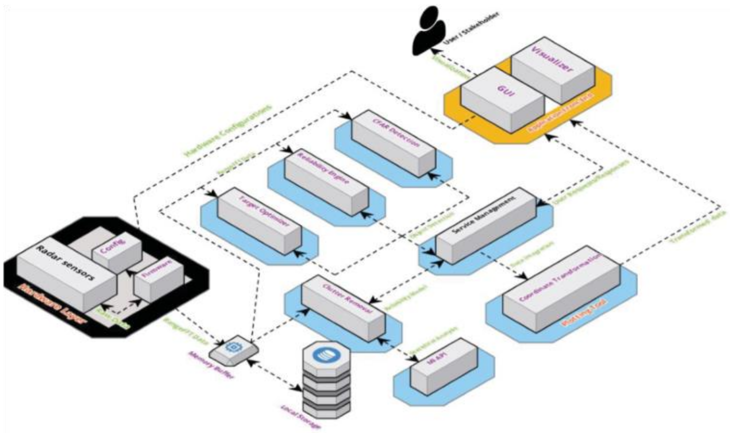


Figure 3: Demonstrator Software Architecture Overview

In this architecture, we can observe that all the data from other services are sent to the coordinate transformation engine where they are integrated and plotted using a visualizer. The RangeFFT data is a collection of velocity, speed and angular information of the radio waves emitted from the sensors. The raw data recorded is converted using a Fast Fourier transform formula which represents the position of the objects being detected. After which the various features are implemented and passed through the coordinate transformation engine.

5. Multi Vocal - Grey Literature

Multi-Vocal is performed in order to understand the given problem and gain perspective into this area of study. As most of the related work and important information articles with regard to the working of mmW radar technology is a new area of study to authors. Knowledge kits, documentation in the form of developers guide, user manuals and other relative information are furnished at the company serve more importance. Additionally, extensive knowledge of the existing literature on what visualizations methods are used for such systems should be tabulated. This provides a base to the research and development team at the industry for selecting the suitable methods for evaluation with respect to the features developed in the demonstration software.

Multi-Vocal Literature review is a mixture of both systematic literature review and grey literature which means exploration of published literary works and other sources like blogs, articles, company artefacts, company manuals, videos or white papers is performed. As the literature on data visualizations used in radar systems are scattered across various streams of sources and very limited work on visualizing mmW radar sensors data, this method was an apt selection to gather the required knowledge. Following are the two sections which state a well-structured protocol which is followed in collecting the relevant literature.

5.1 Data Collection

The MLR is categorized into two divisions wherein the 1st division we read the company artefacts, knowledge kits and search in Google for articles, websites or related documents. In the 2nd division, we perform a search in the scientific databases for related articles, journals or publications. Keyword and search strings are used for the electronic search, which is based on the scope of the problem and research questions. These are formulated in Table 1. All potential articles or useful information are filtered using the inclusion and exclusion criteria from source selection.

Literature search string Formulation

The effort put into searching relevant studies and papers is crucial in this research. Accumulating the required information in the literature is only possibly by effectively choosing the search strings and formulating them to perform the search across multiple scientific database platforms. Initially, the search strings are formulated based on the scope and objective of the research questions and related keywords to the research problem. Below is the Table 1 being the set of search strings used in both scientific databases and in google for grey literature.

Table 1: Multivocal Literature review: Search String Formulation

Keywords	Search Strings

Data Visualization, Radar, Sensors, Data, mmWave, mmWave Radars, Evaluation Metrics.	"Data Visualization" AND "mmWave Radars", "Data Visualization" AND "mmWave Sensors", "Evaluation of Data Visualization methods", "Data Visualization evaluation" OR "Evaluation of Data Visualization" OR "Data Visualization method evaluation" OR "Data Visualization approach evaluation"

Literature Source Section

After the relevant literature is search initially, rules from the inclusion and exclusion criteria are used to filter out unwanted articles and repeated content. Due to the presence of grey literature in this knowledge-gathering process, a re-screening of the filtered-out data is performed, which is considered as the literate insight into this research. Below Table 3 and Table 2 are the Inclusion and Exclusion criteria which are formulated to select relevant and credible studies from the gathered sources.

Exclusion Criteria

Table 2: Exclusion Criteria for the Literature

Exclusion description	**Study rationale**
Duplicate Studies	Replicated or duplicated studies are eliminated to maintain consistency in results.
Irrelevant and Incomplete papers	Studies with non-comprehensive protocol and results are excluded to avoid unwanted direction to the Research.
Grey literature in non-textual formats and from public opinion, discussion forums and networking	Discarded given these include general expression of thought with biased by personal choice and improper background evidence.

Inclusion Criteria

Table 3: Inclusion Criteria for the Literature

Inclusion description	**Study rationale**
Visualization techniques for radar data	Our research study essentially grounds on different visualization techniques available for radar data.
Understandability of visualizations by different stakeholders	Our research aims to draw a comparison between different visualization techniques available for radar data.

Full text access	Clear evidence and critical background are inevitable for sourcing the knowledge. Summarised variants cannot satisfy the research.
Include formal and grey literature	Given the research area is young, it is difficult to find formal literature answering the research objectives. It is important to include grey literature and organisation artefacts to answer the RQs.
Paper written in English Language	Translated sources often involve text discrepancies and expression bias inflicting and undesired direction to research.

Literature Quality Assessment

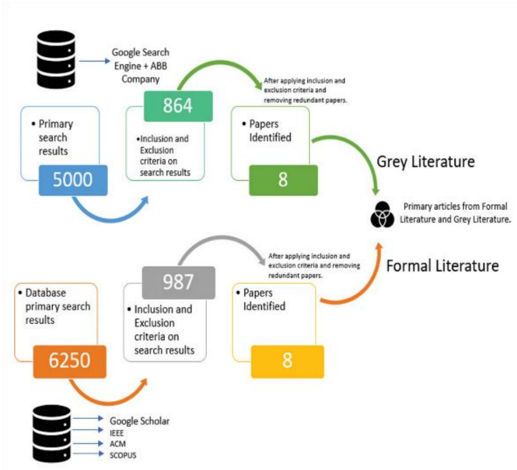


Figure 4: Literature Search Process results

This step in the MLR is important as all the content relevant to the scope of this study should be free of bias and should be retrieved from credible sources. This ensures that the data and knowledge gathered is usable with good standards.

5.2 Data Analysis

The literature data was extracted following the guidelines of Tore et al. [18] The two primary channels for sourcing were:

- Scientific Databases for Formal Literature: Peer-reviewed publication from ACM, IEEE, Springer, SCOPUS and Google Scholar.
- Google search engine and ABB Jokab Safety for Grey Literature: Articles available in textual formats with appropriate detail and background granularity across the Internet and company artefacts.

Data from public opinion, discussion forums and networking were discarded given these include general expression of thought with biased by personal choice and improper background evidence. Media formats other than text are excluded since these lack clear explanation or lack of detailed reflection. The complete literature was based on English as the original source language and not translated from any other textual or verbal means of expression to avoid translation discrepancies.

Authors	Title	Year	Source title	No.of cites	Link	Abstract	Author Keywords	Language of Original	Document Type	Access Type	Source	Use of the Literature Paper in Research
Barrett, Dennis, and Adrian Alvarez	*mmWave radar sensors in robotics applications* .	2017	Texas Instruments	3	https://scholar-google-com.miman.bib.bth.se/scholar?hl=en&as_sdt=0%2C	When you conjure up an image of robots, you might envision massive machine arms	Mmwave, Mmwave radars, application	English	Technical Report	Open Access	Google scholar	Point cloud data visualisation.
Novotny, D., J. Gordon, and J. Guerrieri.	Antenna alignment and positional validation of a mmWave antenna system using 6D coordinate metrology	2014	Proceedings of the Antenna Measurement Techniques	12	https://scholar-google-com.miman.bib.bth.se/scholar?hl=en&as_sdt=0%2C5&as_ylo=2000&as_yhi=2	We present the positional and alignment techniques and mmWave validation for the CROMMA, an antenna measurement	mmWave, Annetna, Validation, Antenna system	English	Article	Open Access	Google scholar	Time Domain plot (Amplititude, frequnecy, distance)
Andreas Schiessl,Sherif Sayed	Data statistics and image properties of a large multistatic mm-wave imaging system	2013	International Radar Symposium (IRS)	4	https://ieeexplore-ieee-org.miman.bib.bth.se/abstract/document/6581087	Near field radar systems offer potential solutions for security and nondestructive testing appplications.	Data Statistics, Image Properties, Multistatic,	English	Conference	Open Access	IEEE Xplore	No Results
Martin Ester, J Hans-Peter Kriegel	Traffic Monitoring Object Detection and Tracking Reference Design Using Single-	2017	Texas Intrusments		https://scholar-google-com.miman.bib.bth.se/scholar?hl=en&as_sdt=0%2C	The TIDEP-0090 demonstrates how TI's single-chip millimeter-wave (mmWave) technology	Traffic Monitoring, Object Detection, Tracking Reference	English	Article	Open Access	Google scholar	Heatmap, Scatter Plots
Uphoff, Jan Luca	Introduction to automotive FMCW Radar Technologies: Using Texas Instruments mmWave	2018	Texas Instruments		https://scholar-google-com.miman.bib.bth.se/scholar?hl=en&as_sdt=0%2C	The goal of the following thesis is to transfer radar basic theory in a practical work using	automotive FMCW Radar, Technologies	English	Article	Open Access	Diva Portal	Time Domain Plot, Scatter Plot, Azimuth Heatmaps
T. Haramiki and H. Nishino	A study of investigating diver's condition by radar	2019			https://books.google.se/books?id=zUeeDwAAQBAJ	the sensor should be in stopped or rebooted state for the changes to take effect. Visualizer	Diver's, Radar, Data visualisation	English	Book	only few pages of the book	Google Search Engine	
Rao, Sandeep	Introduction to mmWave sensing: FMCW radars.	2017	Texas Instruments	6	https://training.ti.com/sites/default/files/docs/mmwaveSensing-FMCW-	An FMCW radar transmits a signal called a "chirp". A chirp is a sinusoid whose frequency increases	mmWave sensing,FMCW radars.	English	Grey Literature	Open Access	Google Search Engine	Frequency time plot
	Real-time-visualization-using-a-2D3D-imaging-MMWave-radar	2004	SPIE		https://www.spiedigitallibrary.org/conference-proceedings-of-spie/5297/0000/Real-time-visualization-using-a-	The measurement and processing chain of the imaging system is reviewed along with the corresponding data statistics. Reconstructed data of a complex test pattern with specific 3D	Real Time Visualisation, 2D, 3D, Mmwave Radar	English	Conference	Not Acessessible	Google Search Engine	
	The Data Visualisation catalogue		Blog		https://datavizcatalog	Radar Chart	Data Visualisation	English	Grey Literature	Open Access	Google Search	Radar Chart
	Radar Chart	2020	Wikipedia		https://en.wikipedia.org/wiki/Radar_chart	A radar chart is a graphical method of displaying multivariate data in the form of a two-dimensional chart of three or	Radar Chart, Data Visualisation	English	Grey Literature	Open Access	Google Search Engine	Radar Chart
Sugimoto, Shigeki, et al	Obstacle detection using millimeter-wave radar and its visualization on image sequence.	2004	Pattern Regconition	74	https://ieeexplore-ieee-org.miman.bib.bth.se/abstract/document/1334537	Sensor fusion of millimeter-wave radar and a camera is beneficial for advanced driver assistance functions such as obstacle avoidance and stop&go	Obstacle, Detection, Mmwave, Radar, Visualisation	English	Conference	Open Access	IEEE Xplore	General Results
ti	mmWave Demo Visualizer	2017	Texas Instruments		http://www.ti.com/lit/ug/swru529c/swru529c.pdf?&ts=1589038394572	This user's guide presents the TI Gallery app – mmWave Demo Visualizer – for configuring mmWave sensors and visualizing point cloud objects	Mmwave, data visualisation, visualiser, demo	English	Grey Literature	Open Access	Google Search Engine	Heatmap, Scatter Plots, Time domian Plot, range doppler

Figure 5: Data Extraction from the Literature search

Data fetched, like illustrated in Figure 5 via both channels were processed through inclusion and exclusion criteria to capture relevant studies. To refine the results from Gray literature channels, the following practices were adapted from Bajwa et al:

- Clear browser search history and cache
- Turn off search predictions and sign out of Google services

Post removing redundancies and duplications, a total of 16 articles/papers were extracted from formal and grey literature, respectively. The result data was extracted to tabulated spreadsheet for data synthesis using thematic analysis [19].

Literature Data Synthesis

Data synthesis method relies on the type of RQ and data associated with our research. Different data synthesis methods include narrative synthesis, quantitative synthesis, qualitative synthesis, thematic analysis and meta-analysis. Narrative analysis lacks defined protocol and standard focusing on building hypothesis and theory, thus rendering the analysis impractical for our research which relies on theme generation from results of primary studies [20][21]. Quantitative synthesis does not allow quantitative meta-analysis from gray literature reports due to the quality and accuracy of reporting [22]. Qualitative analysis emphasis on process and insensitivity to aspect evidence is irrelevant for our study and hence is also rejected.

Thematic analysis is primarily based on diverse evidence types, hence ideal for our research. The protocol for thematic synthesis is [23][24]:

1. Manual inspection of results: The data extracted was carefully examined manually to identify obvious similarities and set a base start for further synthesis. In our case, all the primary studies revolve around data visualizations and radar technologies. Therefore, to identify relevant visualizations, we first try to investigate the use of different visualization techniques in the context of radar data.
2. Data encoding: Post manual exploration of the data, initial codes are framed based on the identified similarities. The structure of these codes is intended to answer the research questions. The encoding was done based on the following steps:

a. Identify different visualization techniques.
b. Examine their application and usability.
c. Validate its extensible on radar data.
d. Extract adaptation and mapping procedure of the visualization technique for radar data.
e. Extract user-experience and understandability of the visualization on radar data.

3. Code to theme transition: Repetition and redundancies were eliminated based on the categorisation of codes. With the narrowed categories, themes encompassing the majority of categories were generated.
4. Higher-order theme selection: Combination of themes was used in relation to synthesize better results and coverage of research objectives. They were structured with the emphasis to answer the research question.

5.3 Multi-vocal Literature Review Results

A total of 16 articles were filtered and presented after implementing the inclusion and exclusion criteria on the data retrieved from formal literature and grey literature. Online database systems like Google Scholar, IEEE Xplore, ACM Digital Library and Scopus were used for electronically searching the articles related to this study which contribute to the formal literature. And the company artefacts, user manuals, documentation and websites, papers from Google search engine contribute to the grey literature. Below is the table; the selected sources are furnished, which are further analysed using thematic analysis and potential data visualization methods are selected, which could be used in the case study.

During the initial search using the search strings tabulated in Table 1 a total of 6250 formal literature and 5000 grey literature were found which later were put through a series of the inclusion and exclusion criteria to filter out the duplicate, irrelevant studies followed by screening abstracts, the scope of the paper and related outcomes 987 of formal literature and 864 grey literature are collected. A careful and in-depth reading by the authors resulted in eight articles from the formal and eight grey literature which were identified as potential results for the MLR, as shown in Table 4.

Table 4: Multi Vocal Literature Review Results

Literature Paper ID	Selected articles for study	Type of Literature
LP1	Barrett, Dennis, and Adrian Alvarez. mmWave radar sensors in robotics applications. Technical report, Texas Instruments, 2017. [25]	Grey Literature
LP2	Antenna alignment and positional validation of a mmWave antenna system using 6D coordinate metrology. [26]	Formal Literature
LP3	Data statistics and image properties of a large multistatic mm-wave imaging system. [27]	Formal Literature
LP4	TI, Tracking Using. Traffic Monitoring Object Detection and Tracking Reference Design Using Single-Chip mmWave Radar Sensor.	Formal Literature
LP5	Introduction to automotive FMCW Radar Technologies: Using Texas	Formal Literature

	Instruments mmWave AWR sensor series.	
LP6	RAO, Sandeep. Introduction to mmWave sensing: FMCW radars. Texas Instruments (TI) mmWave Training Series, 2017.	Grey Literature
LP7	The Data Visualisation Catalogue - Radar Chart.	Grey Literature
LP8	Imaging Radar Using Cascaded mm Wave Sensor Reference Design.	Grey Literature
LP9	Obstacle Detection Using Millimeter-Wave Radar and Its Visualization on Image Sequence.	Formal Literature
LP10	mmWave Demo Visualiser	Grey Literature
LP11	mmWave Studio	Grey Literature
LP12	Texas Instruments AWR1642BOOST Radar Sensor Evaluation Module (EVM)	Grey Literature
LP13	Single-chip 60-GHz to 64-GHz intelligent mmWave sensor integrating processing capability	Grey Literature
LP14	Extending Reliability of mmWave Radar Tracking and Detection via Fusion with Camera	Formal Literature
LP15	ThuMouse: A Micro-gesture Cursor Input through mmWave Radar-based Interaction,	Formal Literature
LP16	Millimeterwave bistatic scattering from ground and vegetation targets.	Formal Literature

Due to lack of contributions and significant work in this field, extraction of usable information from the literature had to be thorough and verified at every step. It is observed that minimal studies discuss this research problem and most of the data extracted was found by similar mapping results and considering the need to find data visualizations methods which support and could be used to illustrate the raw data results generated from the safety radar system with multiple radar modules at ABB.

After carefully reading the literature, a data analysis method which was responsible for identifying relevant patterns, themes and codes which could determine potential data visualization methods was adopted.

5.4 Thematic Analysis Results

Thematic analysis (Figure 6) is carried out to categorize the codes into respective themes for better understanding of the interpreted results. It is a known and common approach to recognise, analyse and report the related codes from the papers in the form of themes. Here, In Multivocal Literature Review first, the data is collected by reading the Relevant Literature Paper for our study then they are broken down into codes. Later, themes are identified for organising the listed codes. This is done to show what are the different data visualization methods, how and why are they important in the radars and to our study of research. We have drawn the conclusions on different visualization methods through a thematic analysis where initial eight codes were generated as shown in table 5 where Cx (1,2,3,4, . . .) denotes codes.

Then later, these codes are organised into one theme.

Figure 6: Process for thematic analysis

Familiarizing with the Data

This is the initial phase, where one intends to read the collected literature paper and includes the necessary data for our research study. It involves continuous reading and complete understanding of papers for an effective expected result. To make the collected data meaningful and identify similar ideas, they are broken into codes and organised into themes. Subsequently, after getting familiar with the data, we iterated the process couple of times to remove duplication of data and to make sure the relevant and important information is not missed.

Generating Initial Codes

Relating to the situation, the data or information can be interpreted in a meaningful way by breaking down the necessary data into codes. Where codes in the thematic analysis are the collection of unit elements. There were two ways to code the data one was automated computer coding, which was using tools, and other was manual. We preferred to take manual coding so that we can observe the data closely and take only the necessary and required information from the papers through our research knowledge. In our study, we read 16 Literature papers consisting of 8 Grey Literature and 8 Formal Literature. By these 16 papers we have generated eight codes by organising the data into meaningful form during this process as Cx(x=1,2,3,. . .) from the data which is represented in below table 5.

Table 5: Codes from thematic analysis

Code Number	Code
C1	Contour plot
C2	Scatter plot
C3	Azimuth heatmap
C4	Frequency plots
C5	Radar Charts
C6	Range Doppler
C7	Time domain Plot
C8	Heap Map Temperature

Identifying Themes

Here, the generated codes are grouped into different clusters known as themes so that all relevant data will be gathered together. In our case, we have generated 1 Potential theme based on the codes formed for our study. Namely, what are the different visualization methods in radar systems? To group the codes into theme they are listed, compared and structured manually, which was done in reference to our formed research questions. After assigning the respective and relatable codes to the themes, they were refined and reverified to check if there were any similar data found in the data extracts which helped in making the data more readable and reliable.

Constructing Thematic Network

In this phase, the listed codes and themes are formulated into a network as shown in Figure 8 below.

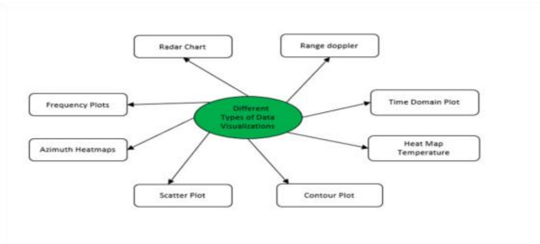
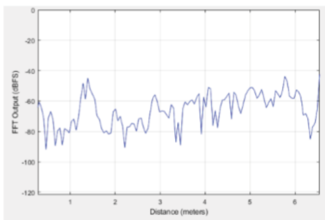


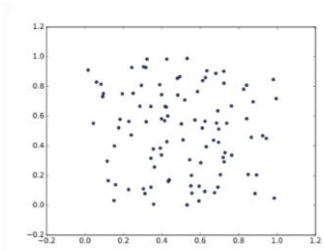
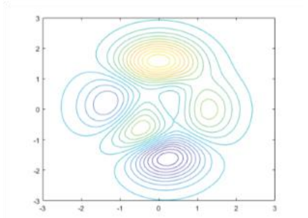
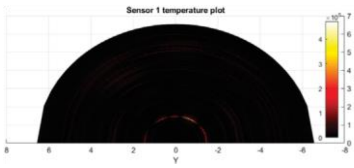
Figure 7: Thematic Network

Results from the literature

A detailed report of the thematic analysis is finally produced (Table 6) after the findings are related to our research objectives and system requirements. The selection of the relevant and utilizable data visualizations methods for evaluation is based on the features and intended outcomes of the system.

Table 6: Thematic Analysis: Results from the Literature

Data Visualization Method	Description	Template
Time-domain	It is a commonly applied graph in radar and sonar systems where a chirp denotes a signal with varying frequency against time. It is a plot between RangeFFT vs Distance in mmWave radar Sensors. It translates the chirp index and properties in Sine Wave form. Every peak in the waves represent a possible presence of an object.	

Scatter	It maps Cartesian values of a combination of attributes in a data. In mmWave radar Sensors, it plots the possible arch of the object in space using continuous coordinate values. Each point on the map denotes a possible location of object in the space.	
Contour	Contour plots visualize three dimensional surfaces on 2 dimensional planes. They are also called Level Plots and are useful for mapping multi-variable functions. Contour plots in mmWaves visualize the object location along with other possible noises in the experimental space. The potential objects in the graph are color coded with encircling shapes.	
Heat Temperature	The heat temperature plot is a minimalistic visualization for object detection in space with mmWave radars Sensors. The object arc is visualized with bright red arc and remaining plane is color coded black to nullify any noise or disturbance offering a clear view to the exact position of the surface in space.	

6. Conclusion

In this section, we narrow down the results and valuable conclusions with supportive feedback. Future works with potential limitations are also discussed. This work significantly presents a recognizable contribution to the information visualization, otherwise known as the data visualization community, where evaluation plays a crucial role. An exploratory case study with the intention of determining an effective data visualization method has been carried out with applications in radar technology and object detection. This work presents a refinement over evaluation studies and statistical analysis using empirical methods in an industrial scenario. The aim of this work was to address the which existing data visualization methods are being utilized in safety radar system with millimetre wave radar data and perform an evaluation to determine which data visualization method is more effective.

As part of the future work, we can consider implementing similar evaluation study on a similar data visualization problem with more participants and a greater number of data samples. There is also the matter of addressing critical descriptions and tasks for the evaluation if need be to a new problem. One could attempt at finding more metrics and provide additional evaluation criteria which could provide a quantitative approach for better evaluation. Different treatments and evaluation design like grouping the participants based on experience, familiarity and usability characteristics could be perceived. On the other hand, another study with similar research objectives could be made with more insight into the features of the data. Additionally, as this work was part of an Industry oriented research development with real-time implications, only a few employees with expertise in this domain were selected. More employees globally could be included as an extension over this research.

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