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SMART 2023 Editors

Lasse Berntzen, University of South-Eastern Norway, Norway

SMART 2023

Forward

The Twelfth International Conference on Smart Cities, Systems, Devices and Technologies (SMART 2023), held between June 26th and June 30th, 2023, continued a series of events covering tendencies towards future smart cities, specialized technologies and devices, environmental sensing, energy optimization, pollution control and sociocultural aspects.

Digital societies take rapid developments toward smart environments. More and more social services are digitally available to citizens. The concept of 'smart cities', including all devices, services, technologies, and applications associated with the concept sees a large adoption. Ubiquity and mobility added new dimensions to smart environments. Adoption of smartphones and digital finder maps and increasing budgets for technical support of services to citizens settled a new behavioral paradigm of city inhabitants.

We take here the opportunity to warmly thank all the members of the SMART 2023 technical program committee, as well as all the reviewers. The creation of such a high-quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and effort to contribute to SMART 2023. We truly believe that, thanks to all these efforts, the final conference program consisted of top-quality contributions. We also thank the members of the SMART 2023 organizing committee for their help in handling the logistics of this event.

We hope that SMART 2023 was a successful international forum for the exchange of ideas and results between academia and industry and for the promotion of progress in the field of smart cities, systems, devices, and technologies.

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Using Convolutional Neural Networks for Parking Sign Detection

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***Abstract*— Automatic detection and classification of parking signs play an important role in autonomous and human-driven cars as it may lead to significant traffic reduction. Existing approaches mostly focus on traffic sign detection. Although there are a few studies in recent years that focus on parking sign detection, this field of study faces a lot of challenges such as the diversity of parking signs in different countries, the fact that the size of parking signs is usually smaller than that of normal traffic signs and the difficulty of understanding their meaning, a challenge that extends even to human drivers. This paper proposes a novel method for detecting and classifying parking signs using visual information. This study is conducted on a custom dataset of nearly 16000 images of parking signs in Vancouver, Canada. We base our approach on the YOLOv7X network, which is a powerful object detection algorithm, and obtained a mean Average Precision (mAP) of 95% on the test set, a notable result compared to the existing state-of-the-art object detection algorithm.**

Keywords- Autonomous Driving; Parking Sign Detection; Object Detection.

I. INTRODUCTION

Nowadays, artificial intelligence and machine learning technologies are used in day-to-day activities, having a significant impact on our everyday lives. Machine learning is a key technology that enables autonomous driving. Object detection and classification play a vital role in autonomous driving, as they are necessary for detecting pedestrians, cars, traffic lights, and traffic signs on the roads. Automated parking sign detection is a key factor of smart city infrastructure, as it has the potential to greatly reduce traffic congestion by notifying human drivers and autonomous vehicles of available street parking spaces ahead. Researchers, governments, and industry have all taken an interest in this topic because of its significant impact on the environment and productivity.

Parking sign detection and classification may be considered similar to traffic sign detection; however, the parking signs are usually smaller and more diverse. While the traffic sign detection task has drawn a lot of attention [1]-[3], very few researches have been conducted on parking sign detection and classification.

In their study [4], Mirsharif et al. proposed a supervised computer vision method to automatically detect and locate parking signs in San Francisco. They extract the potential regions of the image that may contain the parking sign by using a sliding window and then obtain a Histogram of Oriented Gradients (HOG) for each candidate. Based on the resulting features, the Support Vector Machine (SVM) learning algorithm classifies parking sign types using a linear function. After combining potential detections from multiple viewpoints, a map of the street is created that shows the location of the signs. However, this work is limited to only detecting parking signs, falling short from identifying their content. A more recent approach is based on a YOLOv5 network to generate a real-time parking sign detection model that detects parking signs with a mean Average Precision (mAP@.5) of 96.8% [5]. However, this method is also limited to detecting the presence of a parking sign. Chau et al. [6] proposed a different approach that is also based on YOLOv5 to first detect the parking signs and then classify them by using symbol detection. This method achieved an accuracy of 96.8% for parking sign detection and 98.3% for symbol detection. Their two-stage methodology is able to both detect the signs and classify the symbols inside the signs. However, at the end of their method, there is another step needed for combining the symbols and providing a unique meaning for the detected signs and their proposed method lacks this step.

In our previous work presented in [7], we trained a YOLOv4 model on our British Columbia (Canada) parking sign dataset to detect and classify parking signs. For input frame size of 416x416, this method achieved a mean Average Precision (mAP) of 93.01% in detecting and classifying parking signs, while the accuracy (mAP) increased to 98.56% for input frames of 1080X1080 size.

In this paper, we introduce a larger and more comprehensive dataset for parking signs used in the Province of British Columbia (BC), Canada. Using this dataset, we train a YOLOv7 network to detect and classify the BC parking signs into three main categories: parking is allowed, no stopping, and no parking. The reason for this classification is that our scheme is part of a street parking availability pipeline, where we first detect whether parking is allowed or not in a specific area and then share this information with another network that detects street parking availability and combines the information to make the final accurate decision that is shared with human-driven and autonomous vehicles. We compare the performance of our proposed model with that of the state-of-the-art approach presented in [7]. We compare the accuracy and speed performance of the YOLOv7X model with the retrained (on the new dataset) state-of-the-art YOLOv4 model presented in [7]. Evaluations showed that YOLOv7X outperformed YOLOv4, with YOLOv7X achieving a mAP of 95% at a threshold of 50% overlap and

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YOLOv4 reaching a mAP of 86% at the same threshold. The YOLOv7 model also performed better on generalization and inference time compared to YOLOv4.

The rest of the paper is organized as follows. In Section II, we present our method and dataset and briefly explain the networks we have trained. Section III presents and analyzes the visual and numerical results, and Section IV concludes the paper.

II. Our Proposed Method

A. Our New Dataset

In this paper, our first task was to extend the dataset with additional video sequences from the city of Vancouver, BC. To this end, our team captured additional video sequences under different weather and light conditions around the city of Vancouver. The resulting comprehensive dataset consists of 15838 unique frames that were extracted from all the video streams. We used the Computer Vision Annotation Tool (CVAT) to label these extracted frames. We grouped the parking signs into three main categories: no stopping, no parking, and parking allowed. Figure 1 shows examples of different signs present in frames of our dataset. Each of the labeled frames contains one or more parking signs. The labeling process draws a rectangular bounding box around each of the signs in the frame (see Figure 2). In total, our dataset consists of 7824 no stopping signs, 4091 no parking signs, and 7053 parking-allowed signs.

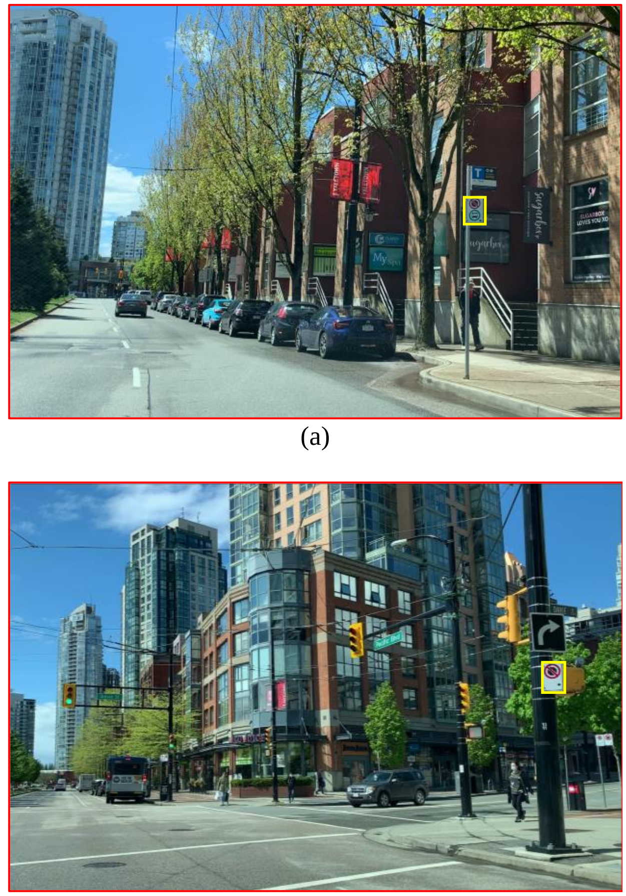
We exported the labels in the format supported by YOLO, meaning that for each frame there is a text file containing the class number (for example 0 corresponds to the stopping sign, 1 to the no parking sign, and 2 to the parking-allowed sign) and the coordinates of the bounding boxes. We used 12180 frames for training, 3090 for validation, and 567 for testing.

B. Our Network

We base our approach on the YOLOv7X network architecture [8]. YOLO, which stands for You Only Look Once, is a well-known family of real-time object detection networks, with the original YOLO object detector first introduced in 2016 [8]. This network architecture proved to be much faster than its peer object detectors and established itself as the choice for real-time object detection applications. Since then, different versions of YOLO have been introduced, with each one of them offering a significant increase in performance and efficiency. YOLOv7, being the latest official YOLO version, can predict bounding boxes more accurately than its peers at much faster inference speeds [9]. YOLOv7

(a) (b) (c)

Figure 1. Examples of (a) no parking (b) no stopping and (c) parking allowed signs.



(a)

(b)

Figure 2. Some examples of the images in our dataset.

uses an Extended Efficient Layer Aggregation network E-ELAN as the final layer aggregation, an extended version of the ELAN [10] computational block. The multiple paths supported by E-ELAN offer a shorter distance for the gradient to back-propagate through the layers, allowing the network to converge faster. Compared to YOLOv7, which increases the

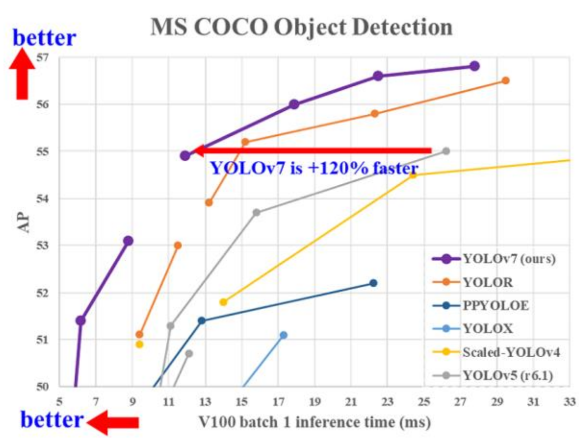


Figure 3. Comparison of YOLOv7 with previous object detection networks [9].

depth or width to improve performance, YOLOv7x introduces a compound scaling on the neck, which increases the depth and width of the entire model simultaneously, leading to improved accuracy. Figure 3 shows the improvements of YOLOv7 over the prior YOLO versions in terms of Average Precision (AP) and computational time over the Common Objects in Context (COCO) dataset [11].

III. OUR APPROACH

We compared the street parking sign detection and classification performance of YOLOv7X trained on our new dataset against that of the state-of-the-art YOLOv4 also retrained on the same dataset. Both networks were trained using Canada's Digital Research Alliance's computing clusters [12]. We used a Tesla v100 Graphics Processing Unit (GPU) for the training and testing phases. The mAP metric is used to evaluate the performance and accuracy of the models. A model's average precision is determined by measuring its precision and recall at various Intersection-Over-Union (IoU) thresholds. Recall that IoU is equal to the ratio of the area of overlap between the predicted bounding box and the ground-truth bounding box to the area of the union between the two boxes. As YOLOv7X supports mosaic augmentation, which combines several frames into a new one, we had to disable this option for our implementation. The reason for this decision comes from the fact that mosaiced frames would introduce signs on the top, left, and bottom of the scene, thus misleading the network and reducing the accuracy.

YOLOv7X supports input images of 640x640 and 1280X1280 pixels. Since parking signs are rather small objects, the detection and classification tasks become more difficult for low-resolution images, so we decided to use 1280X1280 input images. Note that we also use the same resolution for the YOLOv4 network for a fair comparison.

Table I below shows the results of the validation set for the two models at 0.5 IoU threshold. We observe that the YOLOv4 model scored a mAP of 91% while YOLOv7X reached a mAP of 97% for the same dataset, a significant increase in performance.

The models were then tested on 567 unseen frames from our test dataset. The total number of bounding boxes for signs used as ground truth was 720 (several frames have more than one sign). Table II shows the results of precision, recall, and mAP on the test dataset at a threshold of 0.5 for YOLOv4 and YOLOv7X. As it can be seen, YOLOv7X achieves a mAP of 95% while YOLOv4's mAP is only 86%. In terms of precision and recall, YOLOv7X and YOLOv4 have the same precision (93%), while YOLOv7X outperforms YOLOv4, yielding a recall of 92%, which is almost 10% higher than that of YOLOv4. From the above, we can conclude that our YOLOv7X model significantly outperforms the state-of-the-art model in detecting and classifying street parking signs.

Regarding the complexity and inference time reduction reported in previous studies, YOLOv7 needs 75% fewer parameters while it requires 36% less computation in comparison with YOLOv4. In our experiments, using the same hardware setup, the inference time for YOLOv4 was approximately 530 milliseconds, while YOLOv7X completed

TABLE I: VALIDATION RESULTS

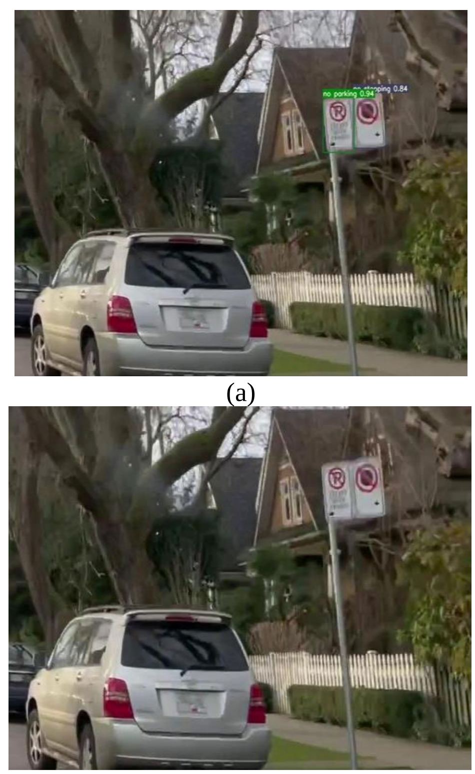
Model	mAP @ 0.5
State-of-the-art (YOLOv4)	0.91
Ours (YOLOv7X)	**0.97**

TABLE II: TESTING RESULTS YOLOV4 AND YOLOV7X FOR PRECISION, RECALL, AND MAP ON THE TEST DATASET AT A THRESHOLD OF 0.5

Model	Precision	Recall	mAP @ 0.5
State-of-the-art (YOLOv4)	0.93	0.81	0.86
Ours (YOLOv7X)	**0.93**	**0.92**	**0.95**

TABLE III: TESTING RESULTS OF YOLOV4 AND YOLOV7X FOR THE THREE DIFFERENT CATEGORIES AT A THRESHOLD OF 0.5

Model	No stopping	No parking	Parking allowed
State-of-the-art (YOLOv4)	0.85	0.90	0.85
Ours (YOLOv7X)	**0.90**	**0.98**	**0.91**



(a)

(b)

Figure 4. Visual results on a test image for (a) YOLOv7X and (b) YOLOv4.

the same task in 25 milliseconds, making the latter a better candidate for real-time implementation for sign detection.

Table III shows the mAP at 0.5 for the three different classes for both YOLO models. It is obvious that for all three categories of parking signs, YOLOv7X performs better than YOLOv4. In both models, the highest mAP belongs to the No Parking class. YOLOv7X had 98% accuracy and outperformed YOLOv4 by 8%. YOLOv7X achieved a mAPs of 90% for the No stopping class and 91% for the Parking allowed class, again exceeding YOLOv4's performance. Overall, the results suggest that YOLOv7X significantly exceeds YOLOv4's performance in the detection and classification task.

Figure 4 shows the same frame of a scene processed by YOLOv7 (Figure 4 a) and YOLOv4 (Figre 4 b) for visualization purposes. We observe that YOLOv4 did not detect the signs, while YOLOv7X detects and classifies both signs with high confidence (0.84 and 0.94). Note that here we show only one frame, but YOLOv4 failed to detect the signs for the entire duration of this scene.

Figure 5 shows a very rare image sample in our dataset, where there are 4 signs in the frame, whose visual quality is rather poor. It may be seen that despite that, YOLOv7X detected and classified all the signs correctly. On the other hand, we observe in Figure 6 that YOLOv4 only detected one of the four signs in the frame and failed to detect the rest of the signs. This proves that YOLOvX is more capable of detecting parking signs in images with poor visual quality.

IV. CONCLUSION

We proposed an innovative parking sign detection and classification scheme that is based on the YOLOv7X network architecture. The network was trained and tested on a custom dataset of almost 16000 frames that were extracted from videos captured by our team with a car camera in the streets of Vancouver, BC. We used a three-class strategy to classify our dataset and since the objects in our dataset were small and

Figure 5. An example of YOLOv7X's ability to accurately detect several signs even at very poor visual quality.

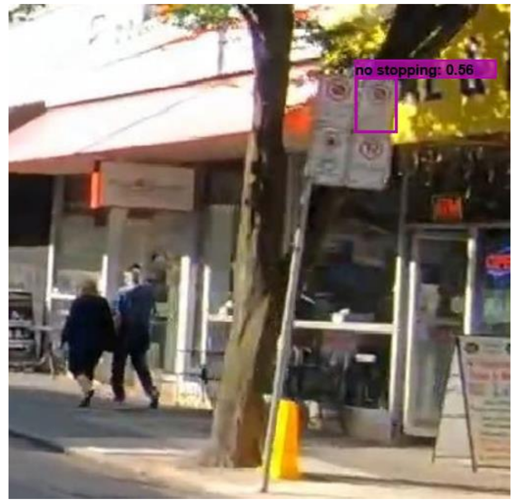


Figure 6. The exact same frame from figure 5 processed by YOLOv4 model.

hard to detect, we chose the input image size to be 1280 by 1280 pixels.

Performance evaluations have shown that the YOLOv7x model outperforms YOLOv4 in terms of both accuracy and detection and is much faster than YOLOv4. Additionally, YOLOv7X is capable of detecting and classifying small and low-quality signs (i.e., weather deteriorated, low light conditions) present in video frames.

In the future, we plan to expand our current dataset by adding more videos from different parts of the city and under different weather and light conditions. We will also extend our initial three-class strategy to more classes that will include time information and different municipality related restrictions and then develop a new method that can detect and classify parking signs according to all these classes.

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Technology Acceptance of Older People (55+) in Complex Sociotechnical Systems such as Smart Homes

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***Abstract*—The emergence of Smart Homes is driven by increasing digitization and individual living conditions, which can improve living comfort, safety, and energy efficiency. Smart Homes can maintain home autonomy and quality of life in old age, but their implementation requires high technology acceptance from users. This study aims to investigate the interdependencies between older (55+) users and complex sociotechnical systems in the living environment, such as Smart Homes, to determine the significance of acceptance factors and particularly the influence of digital literacy on it. The research, as part of a dissertation, includes quantitative surveys and qualitative interviews to identify the factors that strongly influence the acceptance of technology by older adults. The goal is to develop a relevant theory and tailor technical solutions to the diverse needs of users, ultimately increasing technology acceptance and positively influencing the design of such systems.**

Keywords-Technology Acceptance; Smart Home.

I. INTRODUCTION

Increasing digitization and individual living conditions influence housing preferences and lead to the emergence of Smart Homes, which can improve living comfort, safety, and energy efficiency. Smart Homes can help maintain home autonomy and quality of life in old age, but their implementation requires high technology acceptance from users. Therefore, designing Smart Homes to meet individual needs and abilities is crucial for successful implementation. Non-use of connected technology may lead to higher costs and assisted living forms in the future. The challenge is to design technology adequately for older adults and sensitize society to their difficulties in dealing with technology [1]. For example, the use of a Tangible User Interfaces (TUI) application has the potential to enhance technology acceptance among older individuals and potentially improve their quality of life [2].

Consequently, the research question arises to find a model that is considering multigenerationality and digital literacy, as well as aimed at a holistic integrated use of technology including all relevant factors to predict technology acceptance of older adults (55+) regarding complex socio-technical systems in the living environment. Furthermore, it is intended to determine the importance of acceptance factors in such a setting for older adults. The aim is to have a positive impact on the development and implementation of technology to bring the greatest possible benefit to society.

Section II of this paper provides an overview of the theoretical foundations, including diffusion theory, innovation resistance theory, Fogg Behavior Model, Uses and Gratifications Theory, Gibson's Affordance Theory, Technology Acceptance Model (TAM), and Unified Theory of Acceptance and Use of Technology (UTAUT), to understand Smart Home acceptance among older adults. Section III reviews the current state of technology acceptance research, emphasizing the need for representative samples. In Section IV, the objective is to investigate the interdependencies between older users and sociotechnical systems, focusing on acceptance factors and the impact of digital literacy. Section V outlines the research design involving quantitative surveys and qualitative interviews to identify influential factors and develop a comprehensive theory. Section VI introduces a mixed-method approach, combining literature review, quantitative surveys, and qualitative interviews, to analyze the acceptance of Smart Homes among older adults. Section VII concludes the paper by summarizing the research objectives and outlining potential avenues for future work.

II. THEORETICAL BACKGROUND

The theoretical background for the acceptance of Smart Homes by older adults is described by various theories. Regarding this, the diffusion theory describes the processes that are associated with the introduction of innovations in a social system [2]. The innovation resistance theory deals with reasons why people resist or reject innovations [3]. The Fogg Behavior Model describes factors that influence a person's behavior [4]. The Uses and Gratifications Theory, in turn, states that the choice of media depends on the individual needs and interests they want to satisfy [5]. Gibson's Affordance Theory states that objects in an individual's environment are perceived not only by their physical properties but also by their potential for action or affordances [6]. The TAM by Davis from 1989 describes perceived ease of use and usefulness as central acceptance-building variables [7]. The UTAUT expands on TAM and identifies additional factors that influence technology usage intention. Gender, age, experience, and voluntariness of use also affect the intensity of these factors [8]. As all models are established, widely used, and specifically designed for investigating acceptance, they will also be considered in the context of the dissertation.

III. STATE OF THE ART

The state of the art on technology acceptance research is heterogeneous and encompasses various research strands ranging from individual user acceptance to societal acceptance of technologies. The topic of technology acceptance of older people in Smart Homes can be classified within the movement of technology assessment, which deals with the impact of technologies on society and the environment [9].

The TAM as a key model in this context has been confirmed by numerous studies, but there are still many unexplored areas of application that could contribute to the predictive validity of TAM. Future research should focus on the moderating role of individual variables, the inclusion of additional variables in the model, the investigation of actual usage, and the relationships between actual usage and objective outcome measures, as well as the older adult population as a target group. The examination of more representative samples of older adults is essential, as previous studies often only include relatively young and highly educated participants [10].

In general, the topic of technology acceptance is being continued today in other contexts, such as innovation research, and is sometimes referred to using other terms such as technology dialogue or technology openness [11]. Nonetheless, the question of how new technologies are received, evaluated, and classified by potential users, consumers, and the public remains relevant [12].

IV. OBJECTIVE AND RESEARCH QUESTION

The dissertation aims to investigate the interdependencies between older (55+) users and complex sociotechnical systems in the living environment, specifically Smart Homes comprising Smart Home and Ambient Assisted Living (AAL) applications. The focus is on examining the acceptance of these systems and understanding the significance of acceptance factors, including the influence of digital literacy. Rather than focusing solely on specific components, the study emphasizes the integration of various elements (e.g., voice recognition, touch-sensitive devices) within a Smart Home system. The goal is to develop a comprehensive understanding of the interplay between aging in a technological society and technology acquisition and acceptance. Additionally, the study investigates the potential for positively influencing the acceptance of complex sociotechnical systems, such as Smart Homes. This research aids in developing relevant theoretical frameworks, and facilitates the customization of technical solutions to meet the diverse needs of end-users, ultimately enhancing technology acceptance and informing system design. The study's insights provide valuable guidance for technology creators, including user interface design, usability improvement, and support and training provision to enhance digital literacy among older adults.

V. RESEARCH DESIGN

In the empirical part, quantitative surveys and qualitative interviews are conducted to identify the factors that strongly influence the acceptance of technology by older adults. First, a literature review is conducted to identify existing tools and studies on technology acceptance. The identified factors are then examined in a quantitative questionnaire design before serving as a starting point for an exploratory design based on grounded theory. Qualitative interviews are conducted to gain a deep understanding of the technology use and related conditions of older participants. The data is systematically analyzed to develop the theory. Knowledge gain occurs through iterative data collection and analysis. This process continues until theoretical saturation, the point at which sufficient information is available and no new insights are gained. Subsequently, an evaluation of the theory is conducted with a control group in either the same or an equivalent setting. The aim is to recognize the theory's pros and cons and enhance it as required to attain a superior comprehension of the investigated phenomenon.

VI. METHODOLOGY

In the dissertation, a mixed-method approach is chosen as a methodology, which consists of a literature review, a quantitative survey, and a Grounded Theory. This combined approach is often chosen when it comes to examining a complex phenomenon from different perspectives and gaining a more comprehensive understanding. Conducting a quantitative survey is considered particularly suitable for surveying many individuals and establishing measurable variables in relation to each other. Grounded Theory, in turn, enables the discovery of new theories based on empirically obtained data by providing insights into users' experiences, attitudes, and beliefs. Overall, Grounded Theory is a flexible and adaptable data analysis procedure that is well-suited for complex phenomena, as well as to consider the participants' perspective and capture the complexity of social processes and interactions [13]. The combination of both approaches obtains a more comprehensive picture of technology acceptance.

The research design consists of several steps. Firstly, the specifics and developments of technology applications in Smart Homes are described. Secondly, a literature review is conducted to identify existing theories and models related to technology acceptance. Relevant literature sources are evaluated to extract significant factors. In the third step, a quantitative questionnaire design is developed to examine the identified factors. A representative sample of older adults is surveyed, and the data is statistically analyzed. The fourth step involves using the quantitative results as a starting point for qualitative interviews. Grounded Theory is applied to extract new insights from the data and advance theory building. The fifth and final step entails evaluating the theory. A test is conducted to identify the strengths and weaknesses of the theory and improve it if necessary.

VII. CONCLUSION AND FUTURE WORK

In conclusion, this study employs a mixed-method approach to identify influential factors impacting the acceptance of Smart Homes among older adults. The findings will provide valuable insights into the interdependencies between older users and sociotechnical systems, offering a comprehensive understanding of this relationship. In addition, these findings will guide technology creators in designing user-friendly interfaces, improving usability, and delivering effective support and training for older adults.

To further advance the field, future research should focus on the practical application of these findings in real-world settings. Evaluating the effectiveness of implementing technology and its impact on the quality of life for older adults is crucial.

By bridging the gap between research and practice, this study aims to contribute to the development of age-friendly technologies and empower older adults to fully embrace the benefits of living in a technologically advanced society.

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Inspiration from Systematic Literature Reviews to Predict the Future of Food Services in Smart Cities

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***Abstract*—The fifth industrial revolution is set to transform the industry-consumer relationship, particularly impacting the urban-based food services sector. To gain insights into its potential trajectory, a systematic literature review employed a modified Non-negative Matrix Factorization algorithm to quantitatively identify emerging research trends and existing work in smart cities, food, nutrition, and artificial intelligence. The study revealed that smart cities will facilitate automatic connections between consumers, farms, restaurants, and health systems. With automated management systems triggered by meal orders, waste reduction, minimized environmental logistics costs, customization of consumer preferences, and personalized health recommendations can be achieved.**

Keywords-personalized nutrition; food services; smart cities; artificial intelligence; NMF.

I. INTRODUCTION

The upcoming fifth industrial revolution will be characterized by an unprecedented level of automation [1].

Due to its primarily urban-based operations, the food services sector is expected to be highly impacted. To gain insight on how this sector can evolve, a search on papers relating smart cities and food services was conducted. However, given the limited number of papers available, two complementary literature reviews had to be devised.

This article is structured as follows: first, in Section II, a description of the quantitative literature review methodology is introduced. Then, in Section III, the topics that emerged from this analysis are presented and, finally, in Section IV, the implications of the findings are discussed. These are summarized in the concluding section of the article, Section V.

II. METHODOLOGY

A. Information gathering

After performing a number of searches, it was found that two complementary searches returned more than 100 articles. One search used the *PubMed* MeSH term "*nutritional physiological phenomena*", together with the expression "*artificial intelligence*". This search returned 157 articles. The second search used the *Web of Science* and the keywords *("smart cities" or "smart city") and (nutrition or food)*. This search returned 381 articles. For each article, the title, the complete abstract and the year of publication (see Fig.4) were registered and later processed and analyzed.

B. Data Processing

To make a quantitative literature review, computational Natural Language Processing (NLP) [2] techniques were applied on titles and abstracts. This involved converting every letter to lowercase, removing non letter characters, tokenizing the text (in order to analyze words individually), removing stop-words (the most common English words, such as '*the*', '*or*', '*what*', etc.) and stemming (reducing inflected words to their word stem or root form, i.e. the words '*simulation*', '*simulator*' and '*simulate*' can all be reduced to their stem '*simul*'). In addition to ignoring English stop-words, 647 articles were collected from *Semantic Scholar* using the keyword "*biotechnology*". Since biotechnology is a scientific topic, the goal was to analyze the relative frequency of words in typical scientific articles, and to remove scientific stop-words without removing words specific to the areas under analysis. With this collection of scientific articles, the frequency of occurrence of each word (3133 and 5336 in the *PubMed* and *Web of Science* searches, respectively) was compared to its frequency of occurrence on the selected titles and abstracts (regarding the *Semantic Scholar* search). Then, the 100 words that appeared more frequently in the selected titles and abstracts than on the other articles (related to biotechnology) were selected. This eliminated words that appear frequently in scientific texts (such as prove, demonstrate, experiment, etc) but do not provide information for this analysis.

C. Modified Non-negative Matrix Factorization algorithm

In order to identify the different thematic areas for each search, a Non-negative Matrix Factorization (NMF) algorithm was used. This algorithm finds an approximate factorization of the input matrix V into two other non-negative matrices [3], W and H, such that $V \approx WH$. In this case, the input matrix V was defined as a binary matrix, where each row is associated with an article and each column is associated with one of the 100 words. Each entry is either 0 or 1, depending on whether the word is present. The NMF algorithm compresses the information contained in the $n \times m$ input matrix V because W and H have smaller dimensionality, respectively $n \times k$ and $k \times m$. Therefore, each line in V, a vector containing the pattern of words in an article, will be decomposed as a linear combination of the corresponding line in W and the matrix H, which has a small number of lines (k). Each line in H can be seen as a topic; entries of H with higher values highlight the most relevant words in that topic.

Given that the number of articles used in these searches is relatively small (in statistical terms), some topics (lines in the H matrix) have one entry (word) dominating all others, as shown in the example in Figure 1. There, the word '*propos*' has a significantly higher value than the others. This would mean that the presence of the word '*propos*' would be enough to associate it to a topic, which is a typical example of over-fitting due to the small number of articles used.

To overcome this problem, an iterative formulation of the NMF algorithm was developed such that whenever the weight associated with a word in the matrix H represents more than 20% of all the weights in the same topic, the corresponding entry for that word in the input matrix V is decreased by 1%, as detailed in Figure 2.

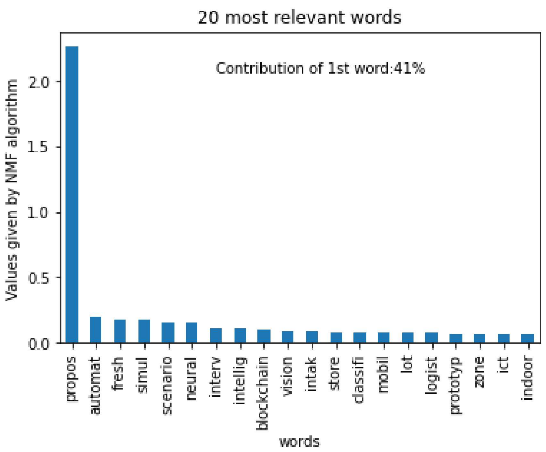

Figure 1: Bar chart representing the 20 words with the highest values for a row of the H matrix of the NMF algorithm before being modified (from the articles in Web of Science searches).

The application of this algorithm in the example in Figure 1 changed the values of the highest weights in matrix H as shown in Figure 3.

Now, a larger number of words is necessary to define a topic. Furthermore, the semantic consistency of the several words defining each topic shows that this procedure produces much more meaningful results.

III. Results

Table I shows the 15 most common words on both searches. These words, although related, are not coincident, showing that the two searches are not redundant.

Algorithm 1 Modified NMF

$N \leftarrow$ number of articles
$V \leftarrow (N \times 100)$ binary matrix where $V_{ij} = 1$ if article i contains word j
$W, H \leftarrow$ NMF decomposition of V
$l \leftarrow$ list of the words where $max(H_i)/\sum H_i > 0.2$, for each topic i
while l is not empty **do**
  for every article a **do**
    for every word w in l **do**
      $V_{aw} \leftarrow$ decrease 1%
    end for
  end for
  $W, H \leftarrow$ NMF decomposition of V
  $l \leftarrow$ list of the words where $max(H_i)/\sum H_i > 0.2$, for each topic i
end while

Figure 2: Algorithm of the modified NMF

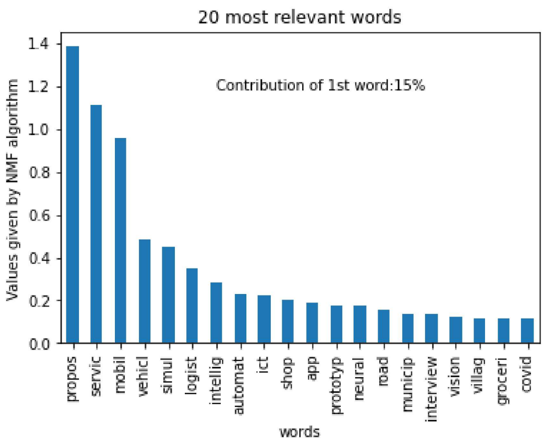

Figure 3: Bar chart representing the 20 words with the highest values for a row of the H matrix of the modified NMF algorithm (from the articles in Web of Science searches).

The number of articles published per year on each search is shown in Figure 4. The growth in activity in recent years, on both cases, demonstrates the significance of these topics to the scientific community.

TABLE I: MOST COMMON STEM WORDS IN BOTH SEARCHES PERFORMED, SORTED FROM MOST TO LEAST COMMON.

Search	15 Most Common Words
Web of Science: smart cities and (*food or nutrition*)	urban, water, iot, propos, servic, sensor, internet, infrastructur, plan, mobil, intellig, spatial, scenario, store, fresh
PubMed: nutritional psysiological phenomena and *artificial intelligence*	diet, artifici, patient, intellig, dietari, machin, intak, ai, imag, behaviour, person, intervent, diabet, algorithm, glucos

In Table II, the 6 themes identified for each search are summarized.

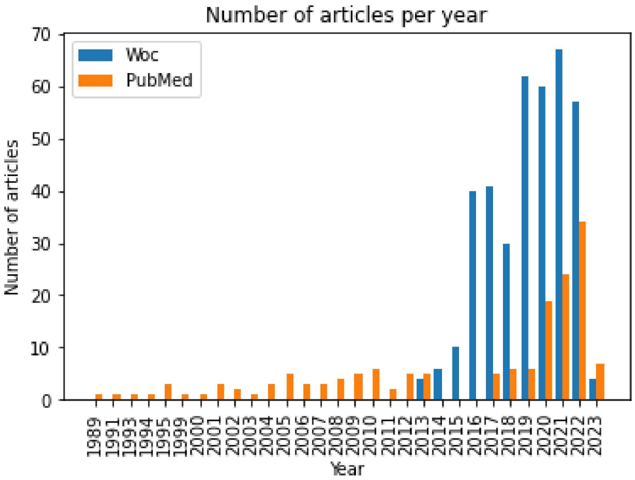

Figure 4: Temporal distribution of the articles fetched.

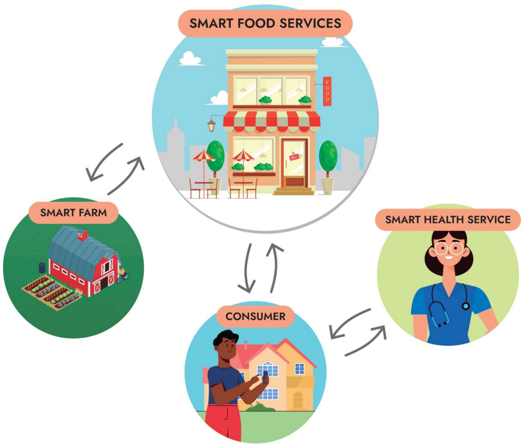

Figure 5: Illustration of the network interacting with future smart food services.

IV. Discussion

Analysis of Table II reveals that both searches were coincident on some topics - for example, optimization methods to design nutritional plans, WoS5 and Pubmed3 - but provide additional insights on others. This demonstrates that there is consistency between the methods and also complementarity. Furthermore, as both searches provide topics related to optimization methods to design nutritional plans, it is possible to conclude that nutritional plans using the help of artificial intelligence are likely to emerge in smart cities.

A thorough analysis of Table II provides important insights on how food services may evolve in smart cities. For instance, WoS1 emphasizes the importance of developing a direct connection between farms and consumers, to reduce food insecurity, which is especially relevant for fresh food options (a concern also highlighted in WoS3) and to promote sustainable city expansion and social-wellbeing. Therefore, food services creating a direct link between farms and the consumers' table could be perceived positively. In Figure 5, continuous interactions with farms allow smart management for storage and deliver. Food services interact with consumers providing suggestions on meals according to the information they receive from the consumer that is interacting with health services. The consumer send medical information through tools and sensors to the health services that will online monitor and prescribe the best nutritional plans.

Topics WoS5 and Pubmed1 highlight problems related to self-report food intake. Indeed, children and adolescents are unable to self-report food intake without caregivers [19] and even trained individuals have difficulties in estimating food portions accurately [20]. Solutions with sensors (body sensors, cameras, etc) and artificial intelligence could contribute to monitor and help control food intake, helping to develop better food prescriptions, better disease prediction, and improved prevention strategies.

Several diseases or health conditions could benefit from interaction with future food services. For instance, accurate food intake monitoring could help control obesity and diabetes (WoS5 and Pubmed1, Pubmed2 and Pubmed3). However, far-reaching outcomes could be achieved by combining biomedical parameters, nutrigenetic, nutrigenomic information, food mapping and consumer behavior (PubMed5).

This could have an impact in other diseases, such as hypertension, hypercholesterolemia, hepatic steatosis and real insufficiency, to mention only a few.

V. Conclusion and Future Work

This literature review provides an insight on how future smart cities, through the establishment of a network made of various participants interconnected with feedback loops, will facilitate the development of innovative food services.

Thanks to advancements in technology, consumers will be able to leverage sensors and apps to track their health status, customize their meal preferences with the help of online health professionals and bots, placing orders that align with their dietary requirements. Additionally, food services will prioritize resource optimization and encourage consumers to select options that reduce food waste.

Furthermore, food services can have a significant impact on the future farming, with automated kitchen inventory systems sending real-time storage updates to farms and facilitating the delivery of produce based on demand projections. This symbiotic relationship between food services and farms will improve the efficiency and productivity of both industries on a day-to-day basis.

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TABLE II: CONTENT TABLE FOR THE TOPICS OBTAINED.

Topic	Type of Solution	Example	Problem Addressed
WoS1	Urban agriculture	Human expansion into Asian highlands [4]	Food insecurity reduction, cities expansion, sustainability, social-wellbeing
WoS2	Blockchain for medical sector	Application of blockchain for drug traceability, remote patient monitoring and medical records management [5]	Security of records and quality improvement
	Big data for computer optimization method for the food nutrition formula	Computer optimization of food nutrition formula based on the consideration of adaptive genetic algorithm [6]	Nutrition formulas optimization
	Big Data for humidity sensors and automatic water irrigation scheduling	Smart water metering system sensor with new hybrid IoT [7]	Water resources optimization in agriculture
	Big Data for home	IoT based on automation and security systems [8]	Security at home
WoS3	Food conservation methods and food quality evaluation	Computer vision system that detect ammonia content in lettuce, discriminating the marketable samples from the waste [9]	Storage time increasion, food waste reduction and waste avoidance of the good quality food
WoS4	The second life of solid materials, food or water	Meal Matchup is an open source that give access to food closed to waste [10]	Resources optimization
WoS5	Application of AI in nutrition sector, such Predicting/managing diets for patients	Internet-based application for research on essential nutrients [11]	Health professionals work optimization
	Application of AI in nutrition sector, such body sensors that detect chewing or automated image processing	On-body sensor that detect chewing and connect to food intake [12]	Food intake collection with more accuracy
WoS6	Neural networks for prediction of intestinal absorption	Computational models for drug inhibition of the human apical sodium-dependent bile acid transporter [13]	Better drug and food prescription and health monitoring
PubMed1	Body sensors that detect chewing or automated image processing that recognize the food and their quantity	The goFOOD Lite App that, through a photo, detect the ingredient and the meal and convert into nutritional information of the food intake [14]	Food intake collection with more accuracy
PubMed2	Tools to manage glucose intake, glucose blood levels and insulin administration	PSECMAC - Positive evaluation of an intelligent insulin schedule to accurately capture the human glucose-insulin dynamics and manage glucose without meal announcement [15]	Glucose prediction and management in type-1 diabetic patients
PubMed3	Artificial intelligence personalised nutritional plans	Physical Activity and Diet Artificial Intelligence Virtual Assistant that detect moments of dietary intake, estimate nutritional intake and generate personalized/precision nutrition recommendations [16]	Health profissionals help to plan personalized nutritional plans and helps general people to have access a personalized nutritional plan
PubMed4	Machine learning algorithms	The case of generate a “food map” with potential anti-cancer properties [17]	Prediction, prevention and/or classification of various diseases or conditions (such malnutrition)
PubMed5	Analyses of nutrigenetic, nutrigenomic and consumption behaviour	Implementation of Nutrigenetics and Nutrigenomics Research and Training Activities for Developing Precision Nutrition Strategies in Malaysia [18]	Excess weight and obesity
PubMed6	Neural networks for prediction of intestinal absorption	Computational models for drug inhibition of the human apical sodium-dependent bile acid transporter [13]	Better drug and food prescription and health monitoring

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Augmented-Reality Optical Narrowcasting (ARON)

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***Abstract*—We introduce a new communications technology for consumers in Smart Cities, which we refer to as Augmented-Reality Optical Narrowcasting (ARON). This technology has the potential to significantly enhance mobile consumer communications by enabling information exchange between multiple transmitters and multiple receivers using free-space optical data transmission in the near infrared. A practical communication range of 400 meters in broad daylight is achievable with miniaturized optics transmitting HD video, for example, to smartphones and 1,000 meters to vehicles. An augmented-reality-style user interface, wherein visual representations of available information sources are overlaid on a live display of local video imagery allows users to conveniently manage transmissions from multiple parties. The new technology is envisioned to be installed in smartphones and other mobile devices and in vehicles, opening new vistas for commerce and social interaction. We have demonstrated key features of the technology using custom optical communications hardware and software developed especially for this purpose.**

Keywords- optical communication; augmented reality; smartphones; automobiles; nonimaging optics.

I. INTRODUCTION

In 1880, Alexander Graham Bell patented and demonstrated the world's first free space optical communication system, which he dubbed the Photophone. Bell achieved the first ever over-the-air voice transmission over a distance of 213 meters using meter-sized transmitter and receiver parabolic mirror dishes harnessing modulated sunlight. This achievement preceded by 19 years the first demonstration of radio by Marconi [1]. In his latter years, Bell stated that he believed this invention was "…greater than the telephone" [1].

In modern times, there have been several attempts, largely unsuccessful, to commercialize this technology. The Maxima Corporation published its operating theory in Science [2], and received $9 million in funding before permanently shutting down. No known spin-off or purchase followed this effort. In 2004, a Visible Light Communication Consortium was formed in Japan [3]. This was based on work from researchers that used a white Light Emitting Diode (LED)-based space lighting system for indoor Local Area Network (LAN) communications. Projected data rates and future data rate claims vary - a low-cost white LED (GaN-phosphor) which could be used for space lighting can typically be modulated up to 20 MHz [4]. Research published in 2009 used a system for traffic control of automated vehicles with LED traffic lights [5]. Increased security when working with narrow beams has also been demonstrated [6].

Our approach is conceptually and technically different from all previous commercialization attempts. We introduce a new type of communications channel, intended for the consumer in a Smart Cities environment. We refer to this technology as Augmented-Reality Optical Narrowcasting (ARON). ARON is a pioneering communications technology that transmits information locally using LED-generated beams of near-infrared light with tailored directionality. ARON offers a robust many-transmitters to many-receivers free-space optical communications channel for personal use with mobile devices (such as smartphones and automobiles). We envision the use of this localized optical communications channel as a means to enhance information flow, free-up overtaxed Radio Frequency (RF) bands, create a new class of mobile social networks, and provide a novel user experience.

In Section II, we discuss how the physics of optical communication differ from radio communication and how we can exploit these differences. In Section III, we discuss the underlying principles of our ARON architecture and how they significantly differ from prior work. In Section IV, we discuss the architecture of a new type of optical information processing chip, the Adaptive Communications Focal Plane Array (ACFPA), and how that design folds into our concept. In Section V, we present the assumptions and physics model for our signal to noise tradeoffs. In Section VI, we discuss our Technology Demonstration Unit (TDU) and real-life test results. In Section VII, we present conclusions and offer comments about how ARON can impact Smart Cities.

II. THE PHYSICS OF ELECTROMAGNETIC WAVE TRANSMISSION AND RECEPTION

RF waves are electromagnetic (EM) waves of frequency between 3 hertz (Hz) and 300 gigahertz (GHz). These waves readily reflect, refract and diffract. Due to their long wavelengths, radio waves can navigate around obstacles and also penetrate some types of materials. This is much less true of light waves which, due to their short wavelengths, require a line of sight to achieve a viable communications path and cannot penetrate most materials. These seeming limitations of light waves have until now stalled the development of free-space optical communications for use by the consumer - possibly because it was always considered an impractical proposition. Consequently, the only free-space optical

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device that has ever really achieved commercial success is the celebrated TV remote control.

EM waves propagating through the atmosphere obey the non-interference principle (i.e., EM waves originating from multiple transmitters do not exert force on each other). So, waves from multiple sources pass through each other unaffected. This occurs because Maxwell's equations are linear in the electric and magnetic fields, and in their sources, so the superposition of two solutions is also a solution. This is true of EM waves in both the RF band and the optical frequency band, but there is a major difference between the two types of waves which has to do with the physics of the intended receiver. Oscillating EM waves used in radio transmissions are designed to be detected via their interaction with a conducting antenna, in which an Alternating Current (AC) is induced with a frequency equal to that of the carrier EM wave. Consequently, if two EM waves utilizing the same carrier frequency and comparable strengths are transmitted in proximity to each other, the induced AC currents on the conducting antenna will superimpose and jamming will occur. This issue, associated with the detection of radio waves, has far reaching consequences requiring the strict allocation of broadcast transmission frequencies to different parties.

The authority for controlling the use of RF frequencies in the United States resides with the Federal Communications Commission (FCC). The FCC also regulates content and requires broadcasters (government, corporate and amateur) to be licensed. The RF spectrum, the total range of radio frequencies that can be used for communication in a given area, is a limited resource. Each radio transmission occupies a portion of the total bandwidth available. RF bandwidth is regarded as an economic commodity, which has a high monetary cost and is in increasing demand. Because it is a fixed resource which is in demand by an increasing number of users, the RF spectrum has become increasingly congested in recent decades, and the need to use it more effectively is driving many additional radio innovations, such as trunked radio systems, spread spectrum (ultra-wideband) transmission, frequency reuse, dynamic spectrum management, frequency pooling, and cognitive radio. The FCC, however, has no jurisdiction over the use of light waves for communication.

Light waves are also a form of EM waves but they differ from RF in one important aspect: because light photons are on the order of a million times more energetic than their RF counterparts, then instead of a conducting antenna, a different mechanism is employed for their reception. A carrier wave for optical transmission is not necessary (to induce an AC current on an antenna) and the receiver comprises a focal plane array of miniature photodiodes. High energy photons impacting the receiver focal plane detector array cause electrons to be emitted. This is a highly localized phenomenon (with low spatial crossover noise). Consequently, a focal plane array may receive (and process) multiple signals simultaneously without experiencing jamming or interference, as long as there is some spatial separation between the respective receiving array detectors. This mechanism offers us an opportunity to implement a novel receiver strategy of angular multiplexing which we can exploit to remediate the problem of potential obstructions to the optical transmission line of sight. In essence, our method will be to employ a redundant transmission of identical optical signals, narrowcast at the same frequency, containing the same identical data stream, but transmitted from spatially distinct origins.

Optical data transmission has no spectrum regulations attached to it. Additional loads to the RF spectrum introduced by Smart Cities, the Internet of Things, and now, the ubiquitous use of RF communications for the most mundane of tasks are already taxing the availability of clear channels in that spectrum. Unregulated optical alternatives are a simple way to relieve some of this stress and reduce the data collisions that will become more and more common in the future.

Some of the benefits of employing a free-space optical communication system vs RF are:

- Alternative optical many-to-many localized communications channel
- Independent of cell phone data plans or the Internet
- Unregulated, uncensored and free to use
- Capable of forming localized social networks between individuals/vehicles within visual range without login
- Receive educational and entertainment information in theme parks, museums and conferences
- Receive information from virtually generated electronic billboards both indoors (e.g., airports) or outdoors
- Universal international use without limitation or data plan
- Stress reduction for the already overtaxed RF spectrum
- Energy-efficient, low power
- Does not require geolocation
- Highly secure (if so desired) because optical data beams do not have leaking sidelobes

III. THE PRINCIPLES OF AUGMENTED-REALITY OPTICAL NARROWCASTING (ARON)

The augmented reality aspect of ARON (US Patent 9,747,503 [7]) provides the user with data overlaid over the field of view of the human eye, supplementing the experience of natural vision with information. Narrowcasting is distinguished from broadcasting in that the transmitted radiation field containing the optical signal is limited in range and in its projected solid angle.

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ARON provides a user experience like no other. The receiver (e.g., an ARON-equipped smartphone) is held vertically and the user views their surroundings through the wide angle camera function of a smartphone. ARON transmitters are similar to small inexpensive flashlights, can be installed outdoors and their data content is programmable. Since ARON does not require a cell plan, WiFi, Bluetooth or any kind of network login the usage is very simple and natural, and is intended to enhance the normal human vision experience.

ARON provides a many (transmitters) to many (receivers) network topology. ARON eliminates the need for the precise alignment of optical transmitters and receivers, due to its configurable narrowcast and wide receive angles, making optical communications at ranges of hundreds of meters practical and convenient for handheld use with mobile devices. Data received optically is automatically integrated with imagery from mobile-device cameras, thereby providing a user-friendly AR experience without the need for complex AR software and inputs from additional sensors.

To prevent obstruction of the line-of-sight optical signals and ensure robustness of use we implement a 3-step mitigation process:

1) We employ a robust forward error correction algorithm (i.e. data and retrieval buffering) of the signal which compensates for short term obstructions (Fig. 1).

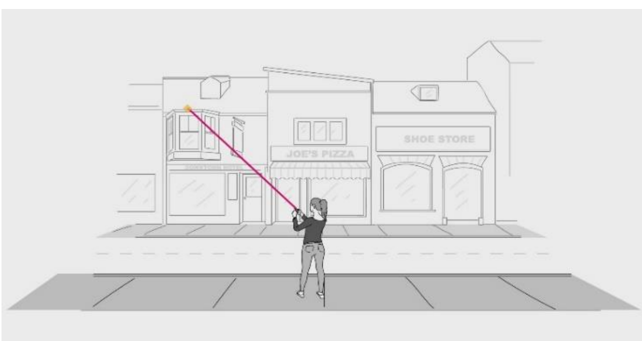

Figure 1. Forward error correction algorithm compensates for temporary obstructions.

2) We expand the emission beam from a pencil-like beam to a uniform, configurable, broad beam using nonimaging optics [8] so that the receiver does not need to be accurately aligned with the beam (Fig. 2) and multiple users can receive the data from any transmitter.

3) We employ multiple emitters, which through spatial separation, and angular multiplexing at the receiver's focal plane array, coupled with an AI-style adaptive processing algorithm achieve a photonic cross-fire mode, ensuring with very high probability that at least one of the transmissions of interest will always reach the receiver (Fig. 3).

Figure 2. Expanding the transmitter beam into a uniform swath.

Figure 3. Combining transmitter swaths to achieve photonic cross-fire and a many-to-many network topology.

ARON provides a secure optical communication channel with capabilities that complement, rather than replace, Wi-Fi and other RF technologies. Our patented Adaptive Communications Focal-Plane Array can also function as an ultra-high-data-rate replacement for conventional RF-based Wi-Fi systems and can also be used for Li-Fi communications.

As an optical, rather than RF, communication channel, ARON is not subject to regulation by the FCC. Its directional, localized characteristics provide a unique capability to securely send and receive information in a manner that is difficult to achieve using RF channels, such as interacting with mobile emitters. ARON provides a natural, user-friendly method of exploring a local environment (e.g., a shopping district) using an intuitive, visually-oriented AR interface (Fig. 4). For social media applications, ARON provides a convenient means of automatically attaching relevant additional information in an AR format to shared photos and videos. The ARON user can remain anonymous if desired.

ARON can fuse information transmitted via infrared light with video data from cameras in smartphones and other mobile devices to create dynamic AR imagery in real time, without reliance on cellular networks, Wi-Fi, the Internet, or other radio-frequency (RF) communication technologies.

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Figure 4. ARON-equipped smartphone receiving outdoor optical signals.

ARON is also intended to augment sensor fusion in the digital vehicle platform (Fig. 5). It can operate in locations where no cellular signals or other RF-based communications are available. Optically beamed information can be detected by vehicles at ranges on the order of 1 km. ARON's directional, localized characteristics provide a unique capability to tailor the delivery of information, allowing ARON to easily communicate with moving vehicles. Multiple small ARON receivers providing 360^0 coverage could be mounted on vehicles, with no beam steering necessary due to the wide-angle field of view afforded by the optics. Received data can be selectively displayed on the vehicle console and/or stored in the vehicle central computer and filtered and forwarded as desired.

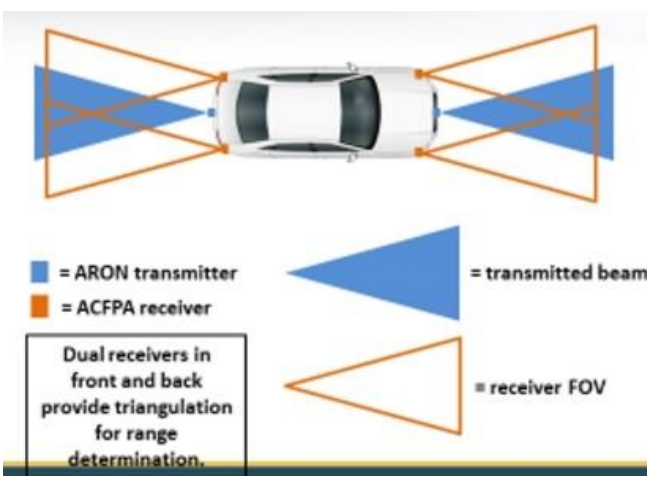

Figure 5. Vehicle equipped with ARON transmitters and receivers.

The solid angle tailoring of the data beam, i.e. directing the projection of the radiant energy only to where it is expected to be required, into a predefined area, allows us to reduce energy consumption by a factor of as much as 300, as compared to Wi-Fi, for an equal data rate of transmission. By tiling multiple transmitters and pointing them with angular separation, we can form a combined transmission beam that covers a zone of interest (for example, we can form a beam exclusively illuminating a zone along a street where reception coverage might be desired).

Multiple data streams are detected and processed by the focal plane array but if one of the redundant streams is interrupted then an adaptive (AI-style) algorithm which continuously analyzes the receiver data identifies which of the streams is being interrupted and switches the data processing to an alternate stream. Using this data processing algorithm it is straightforward to accommodate the simultaneous processing of 100 or more such streams on the focal plane array with a modest number of detectors (e.g., 100-1,000).

IV. THE ADAPTIVE COMMUNICATIONS FOCAL PLANE ARRAY (ACFPA)

Our Optical Narrowcasting System (ONS) utilizes Optical Receiver Modules (ORMs) to detect and receive optical data transmitted by Optical Transmitter Modules (OTMs). An ORM must include at least one Optical Beacon Receiver (OBR) and one Optical Signal Receiver (OSR). OBRs are designed to detect the presence of, determine the angular position of, and receive information from beacons, which are modulated optical beams transmitted by OTMs. Beacons contain information identifying entities (e.g., businesses, organizations, or private individuals) associated with OTMs. Once an OBR has detected, located, and received identifying information from a beacon, an OSR may be used to receive data from a signal beam transmitted by the same OTM that transmitted the beacon. A signal beam is a modulated optical beam that transmits data other than identifying information and typically utilizes a much higher average data rate than beacons.

In most cases it is desirable for an OBR to have a relatively wide field of view (FOV), because its purpose is to search for OTMs in situations in which little, if any, information will be available regarding their horizontal and vertical angular locations. A video camera is a suitable choice for use as a sensor for an OBR. Such a camera consists of an imaging lens with a focal-plane array (FPA) in its focal plane. The FPA is a 2D array of optical detectors designed to sequentially capture multiple frames of imagery at a frame rate usually on the order of a few tens of Hz. A narrowband optical filter will generally also be included in the optical train to improve the signal-to-noise ratio (SNR) by suppressing incident background radiation outside the beacon waveband. With the appropriate choice of imaging lens and FPA, such a video-camera-based OBR can have a sufficiently large FOV to provide a convenient means of searching for, detecting, and receiving data from beacons. The bit rate at which identifying information can be received from beacons by such a camera is limited by the Nyquist-Shannon sampling theorem to no more than half its frame rate. Since the information content of the identifying information is typically quite small (e.g., several bytes), this is not a serious limitation.

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Although a conventional video camera is a suitable choice of sensor for use in an OBR, it turns out not to be suitable for use in an OSR. In most cases, an OSR must be capable of receiving data from signal beams at much higher average data rates than OBRs will typically receive data from beacons. Typically, data rates on the order of 1 Mb/s or higher may be required. A video camera used as a sensor in an OSR operating at a data rate of 1 Mbit/sec would have to have a frame rate of at least 2 MHz. The highest frame rates provided by conventional video cameras are on the order of 240 Hz, which is much too low. The ARON focal plane array (ACFPA, Fig. 6) differs from a video-style FPA in that it exploits the sparseness of the positioning of the communication signals on the FPA. So for example, in contrast to a typical 10 megapixel video FPA with a full frame sampling rate of 240 Hz, such as may employed by imaging cameras, ARON will employ a 100 element FPA array of detectors which is sampled at 2 megahertz. The total throughput of the receiver chip in pixels per second is comparable in both cases.

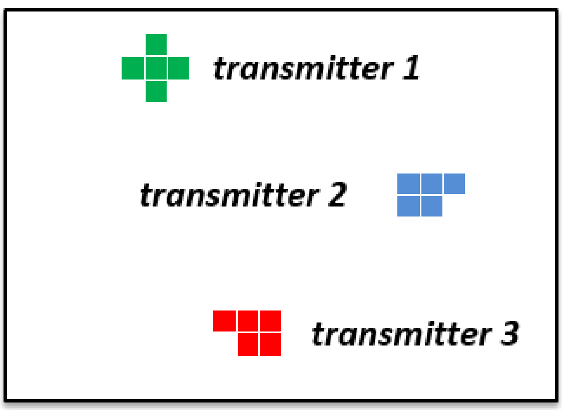

Figure 6. Multiple transmitter signals captured by the ACFPA.

Our Adaptive Communications FPA (ACFPA) provides the capability of receiving signal beams from OTMs at the required data rates. An Optical Communications Camera (OCC) consisting of an imaging lens with such a ACFPA in its focal plane will be capable of serving as both an OBR and an OSR, as long as the beacons and signal beams received from a given OTM do not overlap in time. As discussed above with regard to OBRs, a narrowband optical filter would most likely be included in the optical train of an OCC to suppress out-of-band background radiation. The ACFPA is designed to take advantage of the fact that the number of OTMs found within the FOV of the OCC will, in practice, be very small relative to the number of its detectors. The rate at which data is required to be output by the CFPA can therefore be substantially reduced by only outputting data from detectors that are actually receiving signal beams from OTMs, or from a subset of such detectors.

Detailed information describing the ACFPA chip design and the method of data processing is provided in US Patent 9,853,740 [9].

V. PERFORMANCE MODEL AND VALIDATION

To support our device design studies and provide a working physics tradeoff model for free-space optical communication, we composed a comprehensive signal to noise model to approximate the communications characteristics of an ARON-like device. The Technology Demonstration Unit (TDU) was then designed and fabricated using these modeled parameters to validate this model under real life test conditions. The methodology for the model and the detailed physics formulas are described in detail in the RCA Electro-Optics Handbook [10].

The model inputs are driven by the TDU system required capabilities. The outputs of the model flow into the hardware design parameters. In Section VI, we discuss the actual tested performance results of the TDU in comparison with the model.

The top-level requirements that drove our demo unit design are:

- A small IR transmitter with low power (under 5W total dissipation), using an LED source.
- Receiver to be integrated into smartphone Rx's case area near that of existing cell camera.
- Robust, no signal loss in communications to / between handheld phones with inherent physical jitter and occasional gross signal loss.
- Communication range up to 400 meters under ideal conditions passing HD video signals at rates higher than that required to watch in real time (i.e., able to quickly buffer excess error-free data).

The model assumptions are:

- Number of transmitter optics used, with 8° horizontal tilt difference between adjacent optics: 5.
- Output horizontal beam width produced by combined transmitter optics: $\Theta_{trans,horiz} = 40°$.
- Output vertical beam width produced by combined transmitter optics: $\Theta_{trans,vert} = 8°$.
- Peak optical output power (during transmission of a 1-bit) of infrared emitting diode used in each transmitter optic: $P_{src,max} = 1.4\,\mathrm{W}$.
- Center wavelength, for both transmitter and receiver: $\lambda_c = 850\,\mathrm{nm}$.
- Optical bandwidth, for both transmitter and receiver: $\Delta\lambda = 75\,\mathrm{nm}$.
- Bit rate: $BR = 1\mathrm{MHz}$.

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- Maximum allowable bit-error probability: $P_{error} = 10^{-9}$.
- Modulation scheme: return-to-zero (RZ) on-off keying (OOK).
- Duty cycle of signal pulse, defined as the duration of a transmitted signal pulse representing a binary 1-bit in units of integration times: $\eta_{mod} = 0.85$.
- Optical efficiency of transmitter optics, due to reflection and transmission losses: $\eta_{trans} = 0.80$.
- In-band atmospheric extinction coefficient: $\alpha_{atmos} = 0.1\,\text{km}^{-1}$. (This value is based on Figure 7-3 of the RCA Electro-Optics Handbook, which shows horizontal clear-air attenuation coefficient as a function of wavelength. Atmospheric transmittance as a function of range r from transmitter to receiver is $T_{atmos}(r) = \exp(-\alpha_{atmos} r)$.)
- In-band spectral background radiance for use in computing photon noise produced by background radiation: $L_{back} = 500 \dfrac{\text{W}}{\text{m}^2 \cdot \text{sr} \cdot \mu\text{m}}$ (assumption of sun-illuminated background during daytime operation) or $L_{back} = 5 \dfrac{\text{W}}{\text{m}^2 \cdot \text{sr} \cdot \mu\text{m}}$ (assumption for nighttime operation).
- Optical efficiency of receiver optics: $\eta_{rec} = 0.8939$ (assuming uncoated polycarbonate lens).
- Full width of square field of view of receiver optics: $FOV_{rec} = 3.6°$.
- Refractive index of medium in which each detector in the receiver is immersed: $n_{det} = 1.00$.
- External quantum efficiency of each detector in the receiver: $QE_{det} = 0.7402$.
- Specific detectivity of each detector in the receiver: $Dstar = 4.06 \times 10^{12} \dfrac{\text{cm} \cdot \sqrt{\text{Hz}}}{\text{W}}$.

The output intensity in the center of the beam produced by the five transmitters (with 8° horizontal tilt difference between adjacent optics) is 43.9 W/sr, assuming the optical output of each infrared emitting die is 1.4 W and neglecting reflection and transmission losses. When optical losses are included, this becomes 35.12 W/sr, where we have assumed each transmitter has an optical efficiency of 0.80. The maximum range for daytime operation is 415 m. The irradiance at this maximum range is:

$$E_{max,range} = \frac{35.12 \frac{\text{W}}{\text{sr}}}{(415\,\text{m})^2} \cdot T_{atmos}(415\text{m}) = 2.039 \times 10^{-8} \frac{\text{W}}{\text{cm}^2} \cdot 0.959 = 1.956 \times 10^{-8} \frac{\text{W}}{\text{cm}^2}.$$

The primary model output data included:

- Minimum transmitter exit pupil diameter, based on étendue conservation (~260 mm^2).
- Minimum signal Irradiance at entrance pupil – the minimum required optical power at input aperture of the receiver (2e^{-8} W/cm^2).
- Day and Night maximum operational range based upon bit rate (see Fig. 7 and Fig. 8)
- Day maximum operational range based upon Rx aperture (see Fig. 9).

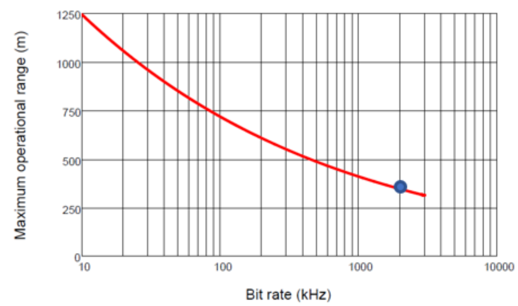

Figure 7. Maximum range vs bit rate (day).

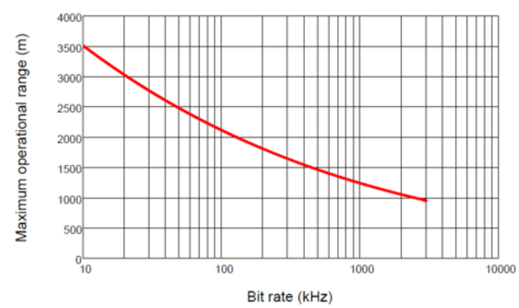

Figure 8. Maximum range vs bit rate (night).

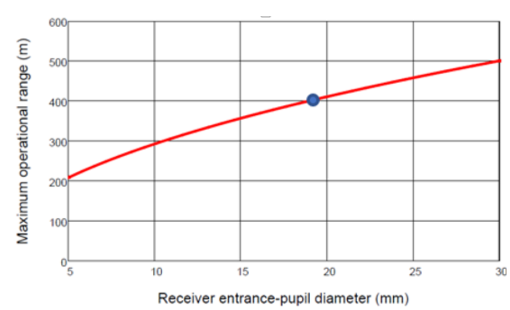

Figure 9. Maximum range vs aperture (day).

VI. TECHNOLOGY DEMONSTRATOR UNIT

To demonstrate the feasibility and functionality of the ARON concept, we have developed and fabricated a Technology Demonstration Unit (TDU) [11] that provides a communication channel in the 810-890 nm near-infrared (NIR) wavelength band, with a data rate greater than 1 Mbit per second and an operational range tested to work in excess of 200 meters in broad daylight. The unit consists of an optical transmitter (OT) and an optical receiver (OR), depicted in Figs. 10 and 12, respectively. This unit can transmit and receive HD video (and other digital files).

An ARON receiver's OBR measures the horizontal and vertical angular positions of ARON transmitters detected within its field of view (FOV) and then creates visual representations of the locations of the transmitters, including the identities of entities operating the transmitters. These representations comprise icons and text overlaid at the positions of these transmitters within live imagery produced by a video camera collocated with each ARON receiver. For example, the availability of information transmitted from a pizza restaurant may appear in the form of an iconic representation of a pizza accompanied by the name of the pizza restaurant, where the icon and text are overlaid at the location of the actual restaurant within the live video imagery. Controls are provided for allowing users to opt to receive high-bandwidth information of interest to them from the pizza restaurant's ARON transmitter or from additional ARON transmitters that may also be viewable in the FOV.

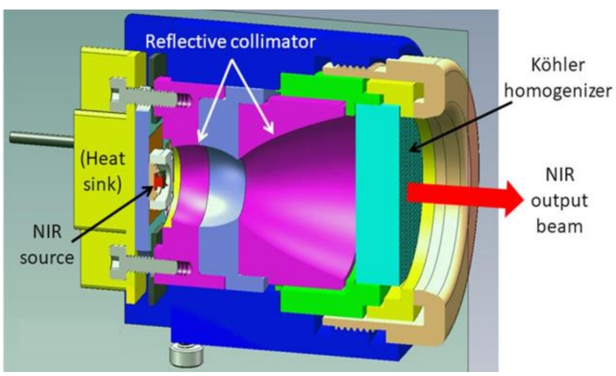

Figure 10. Cross-sectional perspective view of optical transmitter assembly for technology demonstration unit employing a nonimaging wineglass collimator.

The TDU's OT design comprises OT electronics, an incoherent solid-state NIR emitter, and a nonimaging beamforming optic. Our transmitter requires a mere 4 W of electrical power and has an exit-pupil diameter of 18 mm. The ARON system requires each OT to simultaneously transmit two types of modulated optical beams. The first type, referred to as a beacon, provides the means for an OR to: (1) detect the presence of OTs, (2) identify entities operating OTs, and (3) determine the positions of OTs within the FOV of the OR's visible-light camera. The second type of modulated beam, referred to as the signal, provides the actual information the operator of the OT wishes to send. Typically the average data rate transmitted by an OT in the form of signals will be much higher than that transmitted in the form of beacons. Temporary obstructions of the beam path that may occur due to moving obstacles are handled effectively using forward error correction algorithms.

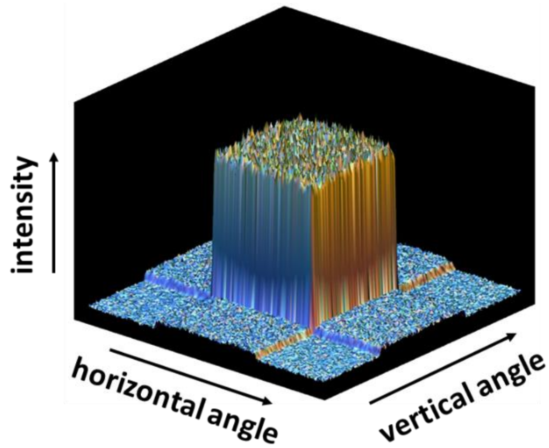

Figure 11. ARON transmitter forming a uniform 8°–square data beam.

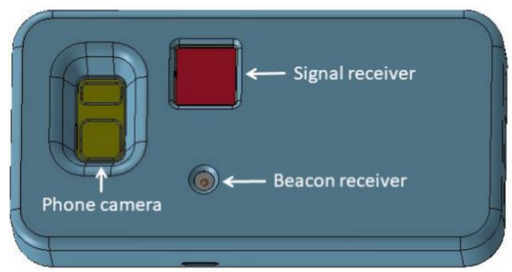

Figure 12. Optical receiver assembly of technology demonstration unit, mounted in a smartphone case.

To simultaneously transmit beacons and signals, the TDU uses a double-modulation scheme, in which a beacon having a data rate of 10 bits per second modulates a signal having a data rate greater than 1 Mbit per second. (ARON systems having far higher bit rates are feasible.) The double-modulation scheme has the advantage of allowing it to utilize a single NIR source and beamforming optic to simultaneously transmit both beacons and signals.

Fig. 10 depicts a cross sectional view of the NIR source and beamforming optic for the TDU's OT. The efficient, highly compact nonimaging optical design of the beamforming optic utilizes an advanced reflective collimator followed by a Köhler homogenizer to transform the output of the source into a NIR beam that is highly uniform within an 8°-square angular region (Fig. 11). The uniform square output beam allows copies of this optic, each with its own emitter, to be combined as modules to produce a customized tiled beam swath consisting of multiples of the 8°-square, arranged horizontally and/or vertically. A wide beam swath enables widely separated receivers to be able to simultaneously tune in to the transmission. The beamforming optical design used in the TDU is representative of a design that could be used for an OT mounted at a fixed installation (e.g., outside or inside a building) or on a vehicle. The wineglass collimator optic achieves a volume reduction factor of 2.5 compared to a conventional parabolic reflector.

The TDU OT electronics (not shown) consists of a smartphone interfaced via USB on-the-go (OTG) to a Universal Asynchronous Transmitter/Receiver (UART) which converts the byte-wise transmit data into a proprietary return-to-zero serial data format with a high level of embedded forward error correction. A current driver is used to modulate the solid-state NIR LED emitter with this data.

The OR design for the TDU comprises OR electronics, a beacon receiver, and a signal receiver, all mounted within a smartphone case and interfaced with a smartphone by means of a USB connection. An ARON app installed in the receiver smartphone provides the capability of combining beacon information received from OTs with live imagery produced by the phone's camera to create and display AR presentations.

The TDU's beacon receiver is a monochrome NIR video camera, which serves the purpose of detecting beacon data transmitted by the OT and using this data to determine the angular position of the OT within the FOV of the visible-light camera. The beacon receiver also receives and decodes identifying information encoded in transmitted beacons, allowing the OR to identify the entity operating the OT. Once a beacon has been detected, the processor determines its horizontal and vertical position within the visible-light camera's FOV and generates and overlays an augmented reality icon with identifying text at the correct location on the live video imagery, where the icon and text represent the identity of the detected OT obtained from its beacon. Multiple beacons can be handled. These functions could easily be integrated with a cell phone's existing camera if the OR is also integrated into the phone, as opposed to being in a cell phone case for the TDU.

The TDU's signal receiver uses a 6x6 array of square-aperture lenslets to concentrate flux onto a 6x6 array of silicon photodetectors. The outputs of all 36 detectors are summed, amplified, filtered and digitized to produce the signal output. The signal receiver has a 3.6°-square FOV within which it can receive signals. Since this FOV is much smaller than the FOV of the beacon receiver and the phone's visible-light camera, in order to receive a signal from a detected OT, the TDU user needs to manually tilt the phone until the OT is within the signal receiver's FOV.

Fig. 13 depicts the display screen of the receiver smartphone after the ARON app has been activated, showing the live video feed, overlaid with a central box representing the FOV of the signal receiver and an icon and text representing a detected OT. To receive a signal from the detected OT, the phone is tilted manually until the icon is located inside the box, at which time signal data will begin to be received. Receipt of signal data will continue as long as the icon is kept within the box. Once received, the app allows the user to view the signal data in various ways.

This section has described the elements of our technology demonstrator unit. In its planned production configuration, as an integrated internal component within a smartphone, an ARON receiver and optical assembly will ultimately occupy a footprint no larger than a conventional video camera. In this consumer configuration, employing an ACFPA chip, the phone will not require tilting to receive signals.

Figure 13. Display produced by augmented-reality optical narrowcasting app in technology demonstration unit's receiver smartphone.

The TDU's transmitter uses a single LED emitting into a wineglass collimator through a pair of micro-lens homogenizers, with dimensions and parameters very similar to those of the model. The TDU receive aperture was chosen to be ~19mm and bit rate at 1.1Mbit/s (good HD video transmission speed) was selected, both to support the 400m modeled maximum range goal. The TDU's receiver uses 36 fixed micro photodiodes in a 6x6 array, illuminated by 36 micro-lenslets also in a 6x6 array. These provide a large aperture while maintaining a very short system depth and are very close to those used in the theoretical model. The micro-lens array, an optical bandpass array and the detectors are mounted on a small circuit board along with the necessary support electronics. All are mounted in a case containing a smartphone used for the processing and display of the received information.

Results of outdoor tests with the Technology Demonstrator Unit hardware showed that actual daylight performance matched closely with that predicted by the theoretical model. Demonstrated maximum range was in excess of 200 m versus the desired 400 m.

Two known issues explain a large part of this range difference. The modeled receiver optics loss did not include additional attenuation in the band-pass filter, which has a pass-through limited to about 85% at our wavelength. Amplifier choice in the front-end electronics limited trans-impedance gain to about 75% of that desired for optimum signal to noise. In all, signal at the receiver was down at least 64%. Both of these losses can be mitigated easily in the future.

Finally, a commercial smartphone implementation would use a much smaller detector size than our TDU, and with an AFCPA chip architecture we estimate that the resulting detector noise could be lower by a factor of 4, which would lead to a realistic achieved signal reception range of 400 m for transmitted HD video.

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VII. CONCLUSION AND FUTURE WORK

The availability of clear RF channels is fading. The yearly growth in demand for data bandwidth is fueled by the needs of IOT and Smart Cities. An open, unrestricted optical communications channel can provide space for at least some of this growth and enable a novel path for information expansion.

ARON's use of its tailored, configurable transmit areas for narrowcasting to desired locations, its ACFPA chip for angular multiplexing and detection of signals over a wide area, and its error correction and photonic cross-fire to solve the problem of obstruction, make it a new and novel platform to support this alternate data channel. ARON is intended to complement, rather than replace, the use of RF communications and to help ease future bottlenecks in a useful and elegant fashion.

Our main conclusion is that free-space optical communication using incoherent light sources is a much more practical proposition than has been believed to date.

Future work will entail the design and fabrication of the ACFPA chip and the integration of ARON into smartphone platforms and automobiles.

ARON is the subject of 21 US Patents.

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Demonstration of Free-Space Optical Communications

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***Abstract*—We introduce a new communications technology for consumers in Smart Cities, which we refer to as Augmented-Reality Optical Narrowcasting (ARON). This technology has the potential to significantly enhance mobile consumer communications by enabling information exchange between multiple transmitters and multiple receivers using free-space optical data transmission in the near infrared. A practical communication range of 400 meters in broad daylight is achievable with miniaturized optics transmitting HD video, for example, to smartphones and 1,000 meters to vehicles. An augmented-reality-style user interface, wherein visual representations of available information sources are overlaid on a live display of local video imagery allows users to conveniently manage transmissions from multiple parties. The new technology is envisioned to be installed in smartphones and other mobile devices and in vehicles, opening new vistas for commerce and social interaction. We have demonstrated key features of the technology using custom optical communications hardware and software developed especially for this purpose.**

***Keywords-** optical communication; augmented reality; smartphones; automobiles; nonimaging optics.*

I. INTRODUCTION

To demonstrate the feasibility and functionality of the Augmented-Reality Optical Narrowcasting (ARON) concept [1], we have developed and fabricated a Technology Demonstration Unit (TDU) that provides a communication channel in the 810-890 nm Near-Infrared (NIR) wavelength band, with a data rate greater than 1 megabit per second and an operational range tested to work in excess of 200 meters in broad daylight. The unit consists of an Optical Transmitter (OT) in Fig. 1 and an Optical Receiver (OR) in Fig. 2. This unit can transmit and receive HD video and other digital files.

II. THE TECHNOLOGY DEMONSTRATOR UNIT

An ARON Optical Beacon Receiver (OBR) measures the horizontal and vertical angular positions of ARON transmitters detected within its Field Of View (FOV) and then creates visual representations of the locations of the transmitters, including the identities of entities operating the transmitters. These representations comprise icons and text overlaid at the positions of these transmitters within live imagery produced by a video camera collocated with each ARON receiver. For example, the availability of information transmitted from a pizza restaurant may appear in the form of an iconic representation of a pizza accompanied by the name of the restaurant, where the icon and text are overlaid at the location of the actual restaurant within the live video imagery. Controls are provided for allowing users to opt to receive high-bandwidth information of interest to them from the pizza restaurant's ARON transmitter or from additional ARON transmitters that may also be viewable in the FOV.

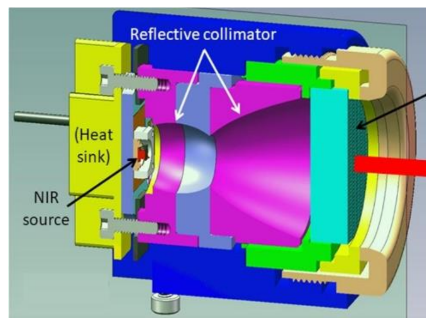

Figure 1. Cross-sectional perspective view of optical transmitter assembly for technology demonstration unit employing a nonimaging wineglass collimator.

The TDU's OT design comprises OT electronics, an incoherent solid-state NIR emitter, and a nonimaging beamforming optic. Our transmitter requires a mere 4 W of electrical power and has an exit-pupil diameter of 18 mm. The ARON system requires each OT to simultaneously transmit two types of modulated optical beams. The first type, referred to as a beacon, provides the means for an OR to: (1) detect the presence of OTs, (2) identify entities operating OTs, and (3) determine the positions of OTs within the FOV of the OR's visible-light camera. The second type of modulated beam, referred to as the signal, provides the actual information the operator of the OT wishes to send. Typically, the average data rate transmitted by an OT in the form of signals will be much higher than that transmitted in the form of beacons. Temporary obstructions of the beam path that may occur due to moving obstacles are handled effectively using forward error correction algorithms. To simultaneously transmit beacons and signals, the TDU uses a double-modulation scheme, in which a beacon having a data rate of 10 bits per second modulates a signal having a data rate greater than 1 megabit per second (ARON systems having far higher bit rates are feasible). The double-modulation scheme has the advantage of allowing it to utilize a single NIR source and beamforming optic to simultaneously transmit both beacons and signals.

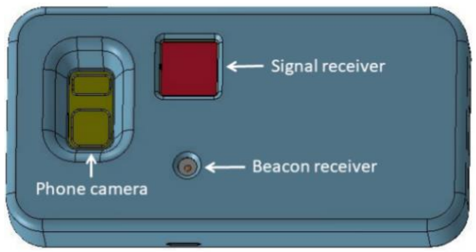

Figure 2. Optical receiver assembly of technology demonstration unit, mounted in a smartphone case.

Fig. 1 depicts a cross sectional view of the NIR source and beamforming optic for the TDU's OT. The efficient, highly compact nonimaging optical design of the beamforming optic utilizes an advanced reflective collimator followed by a Köhler homogenizer to transform the output of the source into a NIR beam that is highly uniform within an 8°-square angular region. The uniform square output beam allows copies of this optic, each with its own emitter, to be combined as modules to produce a customized tiled beam swath consisting of multiples of the 8°-square, arranged horizontally and/or vertically. A wide beam swath enables widely separated receivers to be able to simultaneously tune in to the transmission. The beamforming optical design used in the TDU is representative of a design that could be used for an OT mounted at a fixed installation (e.g., outside or inside a building) or on a vehicle. The wineglass collimator optic achieves a volume reduction factor of 2.5 compared to a conventional parabolic reflector. This is because the wineglass collimator is an aplanat and therefore experiences much less étendue dilution when collecting light from an extended source than the parabolic reflector.

The TDU OT electronics shown in Fig. 3 consist of a smartphone interfaced via USB On-The-Go (OTG) to a Universal Asynchronous Transmitter/Receiver (UART) which converts the byte-wise transmit data into a proprietary return-to-zero serial data format with a high level of embedded forward error correction. A current driver is used to modulate the solid-state NIR LED emitter with this data.

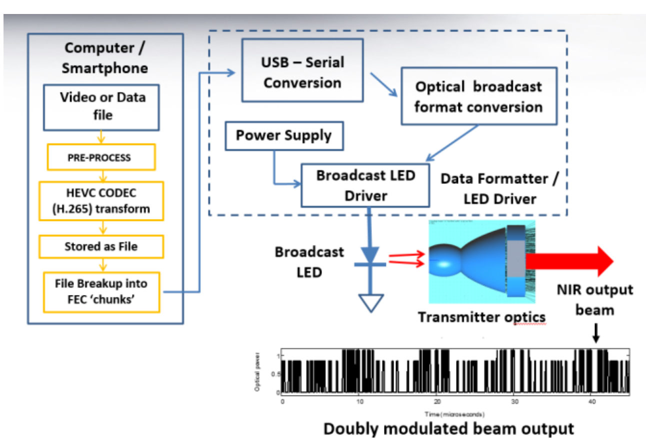

Figure 3. Technology Demonstrator Unit transmitter block diagram.

The OR design for the TDU (Fig. 4) comprises OR electronics, a beacon receiver, and a signal receiver, all mounted within a smartphone case and interfaced with a smartphone by means of a USB connection. An ARON app installed in the receiver smartphone provides the capability of combining beacon information received from OTs with live imagery produced by the phone's camera to create and display AR presentations.

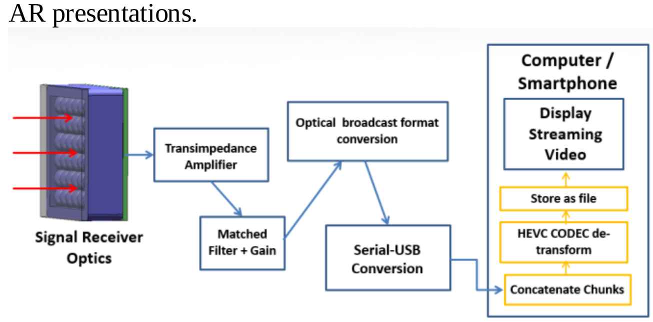

Figure 4. Technology Demonstrator Unit signal receiver block diagram

The TDU's beacon receiver is a monochrome NIR video camera, which serves the purpose of detecting beacon data transmitted by the OT and using this data to determine the angular position of the OT within the FOV of the visible-light camera. The beacon receiver also receives and decodes identifying information encoded in transmitted beacons, allowing the OR to identify the entity operating the OT. Once a beacon has been detected, the processor determines its horizontal and vertical position within the visible-light camera's FOV and generates and overlays an augmented reality icon with identifying text at the correct location on the live video imagery, where the icon and text represent the identity of the detected OT obtained from its beacon. Multiple beacons can be handled. These functions could easily be integrated with a cell phone's existing camera if the OR is also integrated into the phone, as opposed to being in a cell phone case for the TDU.

The TDU's signal receiver uses a 6x6 array of square-aperture lenslets to concentrate flux onto a 6x6 array of silicon photodetectors. The outputs of all 36 detectors are summed, amplified, filtered and digitized to produce the signal output. The signal receiver has a 3.6°-square FOV within which it can receive signals. Since this FOV is much smaller than the FOV of the beacon receiver and the phone's visible-light camera, in order to receive a signal from a detected OT, the TDU user needs to manually tilt the phone until the OT is within the signal receiver's FOV.

Fig. 5 depicts the display screen of the receiver smartphone after the ARON app has been activated, showing the live video feed, overlaid with a central box representing the FOV of the signal receiver and an icon and text representing a detected OT. To receive a signal from the detected OT, the phone is tilted manually until the icon is located inside the box, at which time signal data will begin to be received. Receipt of signal data will continue as long as the icon is kept

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within the box. Once received, the app allows the user to view the signal data in various ways.

Figure 5. Display produced by augmented-reality optical narrowcasting app in technology demonstration unit's receiver smartphone.

III. CONCLUSION

In this work, we have described the elements of a technology demonstrator unit that provides an optical communication channel in the 810-890 nm near-infrared (NIR) wavelength band, with a data rate greater than 1 megabit per second and an operational range tested to work in excess of 200 meters in broad daylight. In its planned production configuration, as an integrated internal component within a smartphone, an ARON receiver and optical assembly will ultimately occupy a footprint no larger than a conventional video camera. In this consumer configuration, the phone will not require tilting to receive signals.

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Hotspot Prediction of Severe Traffic Accidents in the Federal District of Brazil

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***Abstract*—Traffic accidents are one of the biggest challenges in a society where commuting is so important. What triggers an accident can be dependent on several subjective parameters and varies within each region, city, or country. In the same way, it is important to understand those parameters in order to provide a knowledge basis to support decisions regarding future cases prevention. The literature presents several works where machine learning algorithms are used for prediction of accidents or severity of accidents, in which city-level datasets were used as evaluation studies. This work attempts to add to the diversity of research, by focusing mainly on concentration of accidents and how machine learning can be used to predict hotspots. This approach demonstrated to be a useful technique for authorities to understand nuances of accident concentration behavior. For the first time, data from the Federal District of Brazil collected from forensic traffic accident analysts were used and combined with data from local weather conditions to predict hotspots of collisions. Out of the five algorithms we considered, two had good performance: Multi-layer Perceptron and Random Forest, with the latter being the best one at 98% accuracy. As a result, we identify that weather parameters are not as important as the accident location, demonstrating that local intervention is important to reduce the number of accidents**.

Keywords-traffic accident; machine learning; forensic sciences; accident reconstruction; hotspots.

I. INTRODUCTION

Traffic accidents are a pervasive problem in modern cities worldwide. In response, the World Health Organization (WHO) has created an ambitious agenda to reduce accidents by 2030 [1]. In Brazil, traffic accidents are a major public health concern, with the government spending significant amounts of money on addressing their consequences [2]. However, instead of reacting to accidents after they happen, prevention is key. Machine Learning (ML) [3] is a rapidly advancing technology that can predict outcomes based on features and provide valuable insights into their causes. These methods can be useful tools for accident analysis and align with the concepts of Safe Smart Cities [4].

The increasing number of traffic accidents creates an opportunity to study them and get a better perspective on their causes. The knowledge derived from the reason behind traffic accidents can help authorities make better decisions regarding public policies or infrastructure to prevent future cases.

This paper focuses on data collected by crash reconstructionists from the Brazilian Federal District Civil Police. In Brazil, every accident with injuries requires a forensic team to collect evidence and analyze the scene, providing a forensic report to police investigators and justice authorities [5, p. 9]. Since 2019, the forensic team has been collecting data in a digital format, creating an archive of accident data and information. In practice, accidents that resulted in minor injuries or the ones that could not be isolated by the police (for safety reasons, or to relieve traffic congestion, for instance) are not examined on-site, but instead, they have the vehicles removed for analysis at a police station. Here, we define severe accidents as the ones where at least one person was taken to the hospital or died.

The motivation for this research came from a previous visualization tool that identified three hotspots and analyzed their causes based on forensic reports [6]. This work demonstrated the importance of studying crash concentrations and their causes. Forensic analysts typically focus on individual cases, but this paper aligns with the concept of "Forensic Intelligence" by exploring the broader law enforcement knowledge that can be gained from analyzing the rich database collected from many accidents [7]. Therefore, we demonstrate the opportunity forensic analysts have to provide intelligent data by studying the general behavior of accidents, abstracting hidden patterns, and consequently creating supportive knowledge to prevent new cases.

A prediction analysis was conducted based on the data collected on-site in conjunction with weather parameters in the Federal District of Brazil, where the capital of the country sits. ML algorithms such as Random Forest and Multi-layer Perceptron, demonstrated to have good performance to predict the number of accidents in different regions, therefore, identifying hotspots of accidents. Furthermore, a feature importance analysis based on the evaluated parameters was conducted and described.

The remainder of this paper is structured as follows. Section II provides an overview of similar and related work. Section III summarizes the primary objectives of our research, outlining the research questions we aim to address. In Section IV, we present the dataset used for this study and detail the preprocessing steps undertaken to ensure its suitability for our objectives. Section V explains the methodology employed in this project, while Section VI provides a comprehensive discussion of the main findings. Additionally, in Section VI, we acknowledge the limitations of this work and outline our plans for future research. Finally, the article concludes with Section VII, where we present our conclusions, followed by an acknowledgement section.

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II. RELATED WORK

The study of traffic accident causes is not new, as well as the prediction of accident hotspots. Nevertheless, the literature is diverse in the way the analysis is conducted. Authors usually use case studies to state their points of conclusion [8]. Identifying the main reasons behind an accident is hard, subjective, and likely to be dependent on several features. The heterogeneity of the results is corroborated by the research of many authors exploring the subject in different datasets from different angles. We will focus on related literature that uses ML in traffic accident datasets on a city level. Also, we are interested in previous work that aimed to detect hotspots of accidents. It was not part of our review literature scope, papers that address accident prediction for autonomous vehicles purposes.

Regarding the related literature that uses machine learning as a supporting technique to predict future accidents, they mainly follow two approaches [9-10]. The first one is the prediction of the accident itself. They mainly follow a simple supervised approach of using a dataset to be trained, where the output is binary classification into accident or not-accident. However, the data used only have information about when the accident happened (positive samples). Therefore, a common technique required is to generate negative random samples in order to have information on non-accident cases [11-15]. This is not a trivial task, and its foundation is somewhat controversial. Most of the studies generate negative samples in an arbitrary way, which can be questioned. They usually have labeled non-accident data as an expansion of the real accident information. For instance, Hébert, et al. [12] present that for each accident, there are three non-accidents, based on the combinations of time and day for non-positive cases. Although there is a reasonable explanation for the generation of negative samples, it is unsure if this technique can be expanded for every city and any dataset. To avoid this issue, other works focus not on the prediction, but on the level of severity of an event [16-18]. These are multiclass classification problems, where the output goal is a scale of how severe an accident can be. Nevertheless, the results of this approach are important for public policies, someone can argue that severity can be quite subjective, as the definition of severity may vary within regions. In contrast, this research provided an analysis using only objective data, without creating fictional information, by targeting the number of accidents in an area.

As for the prediction of hotspots, we have less research. Here, the outcomes are treated as a regression problem, instead of a classification. Lu et al. used Linear Regression to check whether certain regions of Beijing were considered hotspots of accidents based on data from the road, environment, vehicle, and driver information [19]. Mansourkhaki et al. presented a hybrid model of accident prediction combining a prediction analysis with statistics functions and previous knowledge to filter out outliers in big sets of accident data [20]. Ren et al. used the deep learning technique of Long Short-Term Memory (LSTM) to predict traffic accident risk by analyzing the Spatio-temporal characteristics of accidents in Beijing [21]. Yuan et al. created a similar analysis, but predicted the number of accidents in real-time by training the past seven days of data from Iowa, using ConvLSTM (Convolutional Long Short-Term Memory) [22]. Fawcett et al. presented the prediction of the number of accidents in the city of Halle (Germany) using the Bayesian approach [23]. Al-Omari et al. used GIS and Fuzzy Logic to identify hotspots in Irbid City, Jordan [24]. Lin et al. proposed the prediction of real-time accidents based on the Frequent Pattern tree (FP-tree) on Virginia's I-64 highway [25]. Here again, we see how diverse the research in the field is, with different algorithms providing solutions tailored to the studied city and dataset.

As for a similar work regarding data from Brazil, only one case was found using machine learning to study the causes of road accidents on a highway south of the country [26]. To the best of our knowledge, this is the first time a prediction analysis is conducted from Brazilian data at a city level with data from traffic reconstruction analysis.

Our goal is to use ML to predict the number of accidents, based on data from crash scenes and weather data. We aim to contribute to the diverse literature, with a novel dataset and location, adding more knowledge to the study of causes behind vehicle accidents. More importantly, we want to provide local authorities with supporting information on how ML can be used to help decisions to prevent new collisions in future intelligent cities. Finally, it is also our goal to demonstrate how crash forensics teams can use their data to extract important high-level information, expanding their work to a collective perspective, instead of just individual investigations.

III. RESEARCH DESIGN

To achieve high steps of insights it is interesting to study the intersection between distinct domains or datasets [27]. In our research, we do this, by connecting our accident data with weather information and trying to check possible correlations.

We are mostly interested in the following research questions:

1. Is it possible to the predict number of accidents in defined regions (i.e., hotspots) with traffic accidents and weather information?
2. If yes, what are the main features involved in the prediction outcomes?

We will first present our datasets, give an overview of the preprocessing phase, and a brief analysis of heatmap visualizations that are more useful for our purposes. Then we will proceed to the ML algorithms, with the resulting performances. Then, we will provide an analysis of the correlation between the predictions and the features involved. Finally, we will discuss the results and how the current work can aid government authorities in strategies to prevent future accidents.

IV. DATASET AND PREPROCESSING

Two datasets were used for this research. The first one was the severe accident data originating from the Federal District Civil Police (*Polícia Civil do Distrito Federal*), regional police situated in Brasilia, the capital of Brazil. The data was provided by a non-profit organization that fosters research in forensic sciences, *Fundação de Peritos em Criminalística Ilaraine Acácio Arce*, which is formed by forensic scientist officers. It contained information from the accident scene, such as the topography of the street, road conditions, vehicle information, and damages, collected in the years 2020 and 2021. The total number of severe accidents presented was 3,846, with almost half each year. For the purpose of this work, we focused on objective data only, i.e., numbered information such as GPS coordinates (latitude, longitude), date, time, and road speed limit. The second dataset is the weather information, which came from the National Meteorology Institute (Instituto Nacional de Meteorologia). It contained instant values of temperature, humidity, pressure, wind, solar radiation, and rain precipitation from five different stations in the Federal District.

The first step was to preprocess the data in order to filter out null information and mistaken outliers (when the coordinates were situated outside the limits of the Federal District, for instance). Then, we needed to merge the accident dataset with the weather into one. The weather information came from five stations spread out in the district. To this objective, it was necessary to match each accident with information from the closest meteorologic station, according to the time it happened. For each accident location, we measure the distance from each of the five stations and merge the weather information with the closest one. Our weather dataset provided hourly measurements, so we matched the hour of the accident with the hour of the collected meteorology information (this generalization is understandable, since in a tropical country like Brazil, the temperature has low variance within the hour). One important consideration is that our accident data does not provide the time when the accident actually happened, but only when the forensic team got to the scene. However, in previous research, it was possible to generalize that on average the forensic team gets to the scene about one hour after the accident really happened [6].

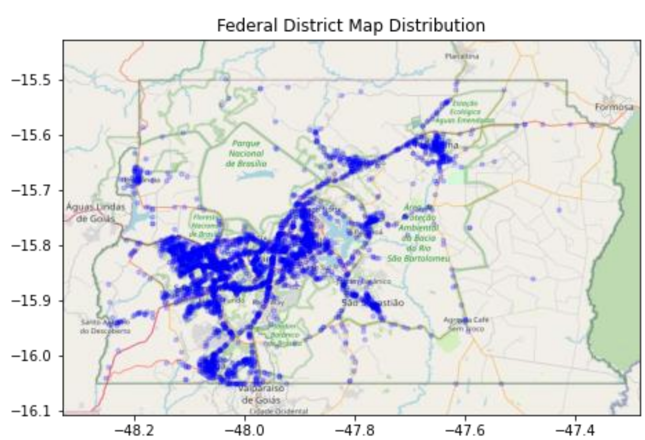

Figure 1. Scatter plot of accidents in 2020 and 2021. It can be seen that there is a contraction of accidents in urban areas. Python and Matplotlib were used to generate this map and the axes represent latitude and longitude coordinates.

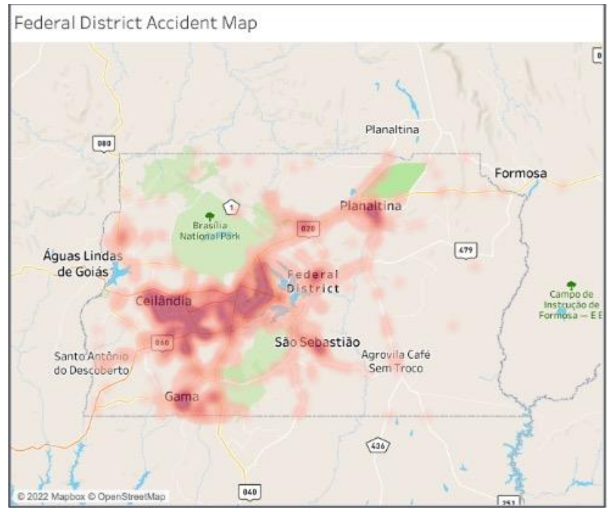

Figure 2. Density map of accidents in 2020 and 2021. The darker color represents hotspot areas of crashes. Tableau was used to generate this map.

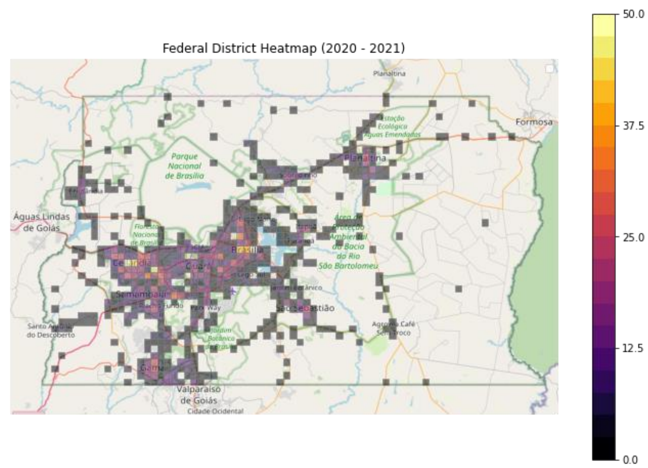

Figure 3. Density gridded map of accidents in 2020 and 2021. Colors close to yellow correspond to higher numbers of accidents. Python and Geopandas were used to generate this map.

Figures 1 and 2 represent the location of accidents as a scatter plot and density map, respectively. We want to predict the number of accidents in defined regions; therefore, it is important to divide our map into grids and count the number of accidents in each grid. Figure 3 shows this representation, using a colormap to visualize "hotcells" based on the number of accidents in each grid. The map was divided into 80 regions, which gives us a grid with dimensions of 4.6 miles by 6.0 miles. This representation is more likely to be used by the police or authorities to identify problematic regions since it provides exact boundaries of these regions. While scatter plots and density maps also provide some insights into the concentration of events, it is hard to accurately identify the limits of each hotspot location. Moreover, the width and length of the grids can be set accordingly to how authorities want to look at the problem. For instance, they can set the cells at a road intersection level or a neighborhood level.

V. Methodology

Machine Learning algorithms are mostly used to solve regression or classification problems. Since we are trying to predict the number of accidents, we are dealing more with a regression situation, but we tested both approaches with the main algorithms. As it will be detailed later, Random Forest, Multi-layer Perceptron demonstrated to be an efficient model for the task in question. Other algorithms, such as Support Vector Machine [28], Linear Regression [29], and Neural Networks [30] were also tested, but performed poorly or took too long to provide the prediction. To keep it short, we will not describe their details.

As mentioned, we combined information from traffic accident data and climate data, having the following inputs: Longitude, Latitude, Street Speed limit, Year, Month, Workday, Hour of the day, Temperature, Humidity, Pressure, Wind, Solar Radiation, Rain Precipitation. The output of the model was the number of accidents in boundary regions. We set these regions, divided our map into grids, and counted the number of accidents in each cell. For each accident, we added this value as a target prediction. We trained our model with data from 2020 and tested it on the 2021 dataset, in order to check the correlations between consequent years. We used Python along with the Scikit-learn library to implement the models.

After preprocessing the data, it is time to build the algorithm to be trained. Basically, what these techniques are trying to do is solve an optimum way to classify (or reduce) the output based on the given input information. Random Forest achieves the solution by creating several decision trees and averaging the results of each ramification. Multi-layer Perceptron Classification does the same task by having an artificial network of neurons that sets different weights to the nodes that closely fit the output. For this technique, we used 3 hidden layers, with 21 neurons each, and the ReLu (Rectified Linear Unit) default as the activation function. Performance and results are discussed in the next section.

VI. Results and Discussion

Table I provides the accuracy of the tested algorithms, both treating the problem as regression or classification.

TABLE I. Algorithms Comparison

Model	Type	Accuracy
Random Forest	Regression	98.8 %
Multilayer Perceptron	Regression	79.6 %
Random Forest	Classification	94.1 %
Multilayer Perceptron	Classification	88.2 %

As can be observed, Random Forest performed really well in both situations, achieving almost 99% of the right predictions. This can be explained by looking more deeply into the data and observing that the locations of accidents do not differ much from one year to another. This information already reveals that from 2020 to 2021 not much was done to change the traffic scenario.

The good performance of both models can be explained by their capability to reveal a pattern behavior with non-linear features. However, as we increase the number of grids, the accuracy decreases. This makes sense since with more regions on the map, it would be harder for the model to correctly predict the number of accidents. Moreover, we saw a greater decrease in the accuracy of the classification models when the number of grids raises. This is somewhat expected since the classification model treats the number of accidents as categories, making it hard to predict for a wider range of labels. The classification would be suitable for authorities to predict levels of accident concentration (for instance, on a scale of low to high). The developed model has been demonstrated to be efficient for a certain number of grids in the map and thus could be easily adapted to fit the prediction into hotspot categories. The regression approach treats the values as a continuum parameter, and it is suitable in case authorities want to predict the actual number of accidents in a given area. This technique has demonstrated good results even with a different set of grids. However, more data is important to give stronger support to decision-makers.

Figure 4 shows the features extracted from the Random Forest technique in terms of importance to the model's output. It can be seen that the location attributes (latitude and longitude) are the main features contributing to the prediction. We can deduct from the figure that weather conditions do not influence severe accidents in a significant way. When taking out latitude and longitude from our model, Random Forest returns a poor accuracy of only 0.04%. Even the pressure attribute, a weather parameter, can be said to be related to location since this value changes according to the altitude level.

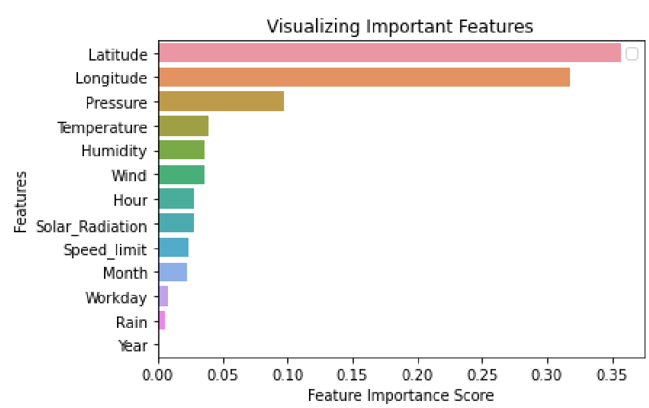

Figure 4. Density Histogram of ranked features used in the Random Forest algorithm. To each feature, it is assigned the proportion of which each contributes to the outputs.

The non-correlation with weather conditions actually aligns with related research [31-32]. This may be explained because the weather in tropical places is almost the same throughout the year and the same result may not apply to regions where the seasons are more well-defined. Another interesting result is that the hour and month of the accident are also less important features when predicting the number of accidents. This infers that rush hours may be an important factor to predict hotspots, but not as much as the location of the accident itself.

Based on our findings, we can conclude that if we want to understand more about the causes of the accidents, we need to study deeper the characteristics of the location of the accident rather than looking at other variables, such as the climate conditions. In the end, hotspots' identification and understanding are key factors to act in the direction of traffic accident prevention.

VII. LIMITATIONS

For the purposes of this research, we used all the data available from traffic reconstructionists. However, it is important to state that our dataset is considered small for prediction purposes. Only about 1,600 points were used to train the models. This also explains the high accuracy result. More data means more information, consequently providing more realistic outputs, and possibly a lower performance is expected. This research worked as a proof of concept to the claim of automatically predicting hotspots of accidents, providing a powerful tool to support knowledge regarding accident prevention. Moreover, as mentioned before, the number of grids can be set, according to how big the authorities need the region to be. Naturally, the accuracy of the results tends to decrease as the number of grids rises (another issue that can be resolved by having a bigger dataset).

Also, as mentioned in the Introduction, data used to feed the algorithms were from severe accident cases that had an on-scene examination. Thus, it does not contemplate the overall traffic accident cases.

VIII. CONCLUSION AND FUTURE WORK

The present work is a case study of a real-world dataset about severe traffic accidents collected from the Federal District Police in Brazil. The data were analyzed along with weather information such as temperature and rain precipitation. After prepossessing the data, we first visualized some of its content to get a sense of the accident panorama. We were particularly interested in predicting the number of accidents in defined regions and, thus, identifying intelligent hotspots based on past evidence. For this work, we tested traditional machine learning algorithms, analyzing the performance as regression and classification problems. Random Forest and Multilayer Perceptron outputted high accuracies, with the former outperforming the latter.

Random Forest model also revealed that location attributes, such as longitude and latitude, were considered more important features to predict the number of accidents than the meteorology parameters, such as rain and temperature, and time parameters, such as hour and day. In other words, the place where the accident happened is a key factor contributing to the identification of hotspots. Public authorities and researchers need thus to focus their studies primarily on the site characteristics, for example, suggesting road infrastructure interventions. Overall, we demonstrate how density maps and machine learning are powerful tools to generate insights for high-level decisions in the direction of accident prevention.

To the best of our knowledge, this is the first work with machine learning in traffic accidents in the Federal District of Brazil. Thus, we add new insights to this diverse research area, which attempts to understand the root causes of vehicle collisions. Moreover, we demonstrated that data from forensic teams can be used not only for traditional one-by-one investigations but also to understand patterns and associations in the big picture, delivering useful information for public policies. This work aligns with the new era of Forensic Intelligence, where data science plays a key role.

For future research, beyond more points, we will add to the model's discrete variables collected from the traffic reconstruction forensic team. As a result of this work, it will be interesting to observe the performance considering location attributes, such as topography, cross intersections, junctions, street lighting, and road conditions.

ACKNOWLEDGMENT

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Driving the Future

A Comparative Analysis of Electric Vehicle Trends in Norway and Spain

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***Abstract*—This paper compares the Electric Vehicle (EV) situations in Spain and Norway by looking at policy frameworks, infrastructural growth, adoption rates, financial incentives, and environmental effects. In contrast to Spain, which has suffered due to limited charging infrastructure, and a complex regulatory environment, Norway has been successful due to strong government support, financial incentives, and well-developed charging infrastructure. The carbon footprint of EVs is smaller in Norway thanks to the country's emphasis on renewable energy sources, whereas Spain is having trouble making the switch to clean energy. The comparison allows us to draw some conclusions. It also emphasizes the significance of a favorable policy environment, financial incentives, and a reliable charging infrastructure in promoting EV adoption. The paper suggests creating a national plan for Electric Vehicles (EVs) in Spain, increasing the availability of charging stations in urban and rural regions, and encouraging collaborations between the public, private entities, and utility companies. Norway should prioritize assuring the accessibility of charging infrastructure in rural locations, encouraging the use of second-life batteries, and resolving issues with electricity demand. By sharing experiences and adopting the necessary measures, both nations may hasten the transition to sustainable transportation.**

Keywords-electric vehicles; charging infrastructure; adoption; incentives.

I. INTRODUCTION

Norway has the highest adoption rate of Electric Vehicles (EVs) per capita worldwide [1]. Spain has recently launched several initiatives to promote electric car adoption [2]. In this paper, we compare the adoption of EVs in Norway with the adoption in Spain. Spain is adopting some of the incentives shown to be effective in Norway. At the same time, Norway is removing some of its incentives due to the high adoption rate of EVs.

An EV is a vehicle that utilizes one or more electric motors for propulsion. It can run autonomously using a battery that can be charged using various techniques, including solar panels, fuel cells, or generators, or it can receive power from an external source through a collector system.

Battery Electric Vehicles (BEVs) are powered entirely by electricity. A BEV has no Internal Combustion Engine (ICE), fuel tank, or exhaust pipe. Instead, it has one or more electric motors powered by a large battery, which must be charged through an external outlet. Due to their lack of exhaust emissions, BEVs are regarded as the most ecologically beneficial form of electric car. However, they have a constrained driving range because the battery must be recharged. Several general advantages apply to EVs:

- Environmental benefits: EVs do not contribute to air pollution or the release of greenhouse gases because they do not have tailpipe emissions. Even when fossil fuels are required to produce the energy needed to power the EV, it still produces less pollution than a conventional gas-powered vehicle [3].
- Lower operation costs: EVs require less maintenance since they have fewer moving parts than gasoline or diesel vehicles and are generally less expensive than those fuels. Electric motors frequently have longer lifespans due to their superior durability to internal combustion engines [4].
- Efficiency: The power plant's efficiency will impact the well-to-wheel (WTW) efficacy. The overall WTW productivity of gasoline vehicles ranges from 12% to 28%, whereas that of diesel cars ranges from 26% to 38%. In contrast, EVs driven by natural gas-powered plants vary in WTW efficiency from 14% to 30%, while EVs powered by renewable energy sources exhibit up to 70% total efficiency [5].
- Energy independence: EVs might be powered by renewable energy sources like solar or wind energy. This reduces dependency on fossil fuels and could improve energy consumption sustainability [5].

The EV market differs from the typical Internal Combustion Engine (ICE) industry in many respects, which makes expanding EV service operations more challenging. Problems like the charging infrastructure make the EV market less convenient and less accessible than traditional gas stations, which presents difficulties for EV drivers, particularly when traveling large distances or in rural locations. Variations in charging interface standards and battery recharging rates make infrastructure development more difficult. Also, the related public policies, since the EV industry is still in its infancy, and public sector policies play a crucial role in encouraging EV adoption. Different taxation, carbon emissions, infrastructure for public

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charging, incentive, and support for research and development policies are implemented by governments: EV-specific market dynamics and uncertainty present decision-making issues. Business strategies are a challenge too. Innovative ownership models, such as battery swapping and EV sharing, aim to address range anxiety and high upfront costs. These models have been implemented in various cities, providing cost-effective access to EVs. A thorough examination of the business models is necessary for their successful implementation.

The following section defines provides an overview of policies and regulations on EVs in Europe. Sections III and IV discuss electric vehicles in Norway and Spain, respectively. Section V compares the findings from the two countries, while Section VI concludes the paper.

II. Policies and Regulations on EVs in Europe

The European Commission (EC) has proposed cutting emissions by at least 55% by 2030, with plans to increase the current 1.4 million EVs to 30 million by 2030 through regulations, targets, and initiatives such as encouraging low-emission vehicle production and developing charging infrastructure. The EU's EUR 750 billion stimulus package includes 20 billion euros for clean vehicle sales and plans for 1 million charging stations by 2025. This reflects the EU's commitment to promoting electric mobility and transitioning to sustainable transportation [6].

The European Union (EU) policy highlights the importance of renewable energy and smart grids for energy system decarbonization. A vital element of this policy is the Renovation Wave strategy, which focuses on integrating various sectors instead of treating them separately, enhancing the efficiency of future electrification projects.

The EU recognizes that transportation contributes to almost a quarter of Europe's greenhouse gas emissions. Thus, promoting electric mobility (E-mobility) is crucial in achieving climate objectives. Therefore, efforts are underway to align the expansion of charging infrastructure with these targets.

In her State of the Union speech, EC President Ursula Von der Leyen emphasized this need for integration and expansion, where she proposed investing one million electric charging points as part of the Next Generation EU initiative [6]. This policy indicates the EU's holistic and integrative approach to decarbonization and sustainable energy use. Some examples of recent and upcoming legislation in the EU are:

Energy Efficiency Directive (EED): By 2030, the EED [7] aims to reduce the EU's overall energy consumption by at least 32.5% through energy efficiency advancements. This includes the transition to cleaner EVs and the enhancement of the efficiency of existing ones. Member states have introduced emission targets and awards to expedite the shift to e-mobility. All member states are encouraged to adopt ambitious transportation measures aligned with the EU's 2030 energy efficiency target.

EU Taxonomies: This classification scheme lists economically viable and ecologically sustainable activities vital to implement the European Green Deal and scaling sustainable investments. It mandates businesses seeking financing to document their emissions management [8].

The Energy Performance of Buildings Directive (EPBD): EPBD [9] necessitates installing charging stations or ducting infrastructure in new or significantly renovated buildings. It also suggests that charging stations should be "smart," i.e., responsive to grid signals, offering long-term economic benefits for consumers and property owners.

Electricity Directive (ED): ED, amended in 2022, [10] encourages member states to use smart metering technologies for power utilization and smart charging systems to ensure consumers can use, produce, store, and sell energy without extra charges, aiding in grid stability and flexibility.

A strong message is being sent to the real estate industry by the Clean Energy Package and other approaching EU regulations: electric vehicle charging is a solution that addresses several issues at once. Aside from complying with legal standards, real estate companies must also meet the enormous demand for EV charging services among tenants and consumers. M. Kumpula-Natri, a Finnish member of the European Parliament, recently expressed [11]:

"*I think that now there is momentum to create a comprehensive and smart EV charging infrastructure with these many legislative proposals. I just introduced to you, that will be based, as much as possible, on renewables, clean energy and supports the demand response of the smart grids. So, we need smart systems and digital solutions to cut emissions and now the opportunities are great – there is finance, there is political will. Now we need everyone on board to make this happen*."

III. Electric Vehicles in Norway

A. History and development

In 2016 the number of EVs reached 100,000. In 2017 the Norwegian Parliament decided on a national goal that all new cars sold by 2025 should be zero-emission. In 2022 the number of pure EVs reached 500,000. Norway has the highest adoption rate per capita worldwide [12].

B. Charging infrastructure

In Norway, the number of electric car charging stations has increased in recent years, reaching just under 19,300 for roughly 647,000 electric and plug-in hybrid cars registered as of 2021. The Type 2 or standard charger has been the most popular in the country. In 2021, there were about 12,900 of this charging type in the country. In comparison, the number of Tesla Superchargers amounted to 1,200 that year. The Supercharger was introduced by Tesla to make fast-charging cars accessible exclusively to their models, such as Tesla Model S and Tesla Model X. Both were among the best-selling EV models in Norway [13].

The "charging right" for residents of apartment buildings was established by a parliamentary act in 2015. Still, EV owners believe it is crucial to have the option to fast charge when necessary, even if they charge at home and seldom need the fast charge alternative.

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A well-planned charging network must be in place for more extended travels. In Norway, fast charging stations have been successfully installed on all major routes. By the end of 2022, they were trying to have more than 5,600 cars that can fast charge simultaneously. Customers are willing to pay more for the rapid charging service. On average, they spend three times as much on power than they do at home. Figure 1 shows the deployment of public EV charging stations by type from 2011 to 2021 [13]. According to nobil.no, the current number of public charging stations is 26,258 [14].

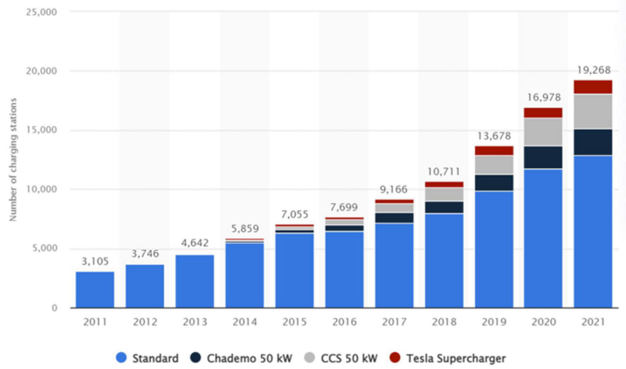

Figure 1. Deployment of public EV charging stations (Norway).

C. *Energy and fuel price*

Norway's average wholesale electricity price dropped to 83 euros per megawatt-hour in March 2023, a 60% decrease from December 2022's record high of over EUR 246. The surge in 2021 and 2022 prices was due to factors like widespread electric heating, irregular rainfall affecting power plant production, new cable connections with the UK and Germany, and the EU market's relationship with fluctuating natural gas prices.

Despite Norway's high cost of living, electricity was an exception until recent years. Peak demand times occur around 6:00 and 14:00, particularly in cold weather due to reliance on electric heating. Lower rainfall in the south in 2022 affected power plant profits, while the operation of two new international cables in 2021 contributed 10-25% to the price hike. The EU's advanced bidding system and rising natural gas prices, influenced by COVID-19 and the Ukraine war, also increased electricity prices [15].

As shown in Figure 2, fuel prices increased in 2022 due to the Russian invasion of Ukraine and a hike in Norway's CO_2 taxes on fossil fuels [16]. In April 2023, gasoline and diesel prices stood at EUR 1.90/L and EUR 1.73/L, respectively. Despite these increases, EV sales have risen rapidly, with over 800,000 units sold by the end of 2022.

D. *Sales and adoption of EVs*

"*Eight out of ten people choosing fully electric instead of combustion engines is a considerable step towards Norway reaching its climate goal of 100% BEV sales in 2025. This proves beyond doubt that affordable BEVs are the number one choice for new car owners*", said Christina Bu, Secretary General of The Norwegian EV Association. One-fifth of the Norwegian population has EVs.

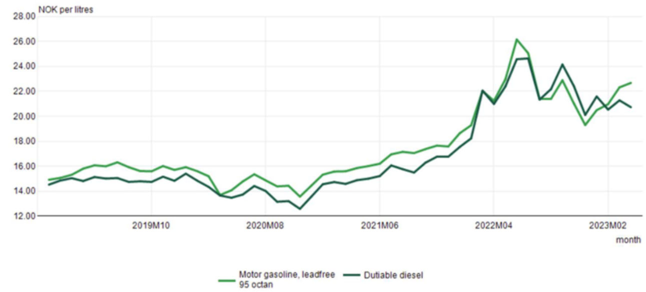

Figure 2. Gasoline and diesel prices through the last years (Norway).

"*Our message to the rest of the world is crystal clear: Now there is no excuse for the internal combustion engines' unnecessary pollution when the climate crisis is so urgent to solve*," she said in a statement [17].

Table I shows the number of registered vehicles by energy sources in 2020 [18].

TABLE I. REGISTERED VEHICLES 2022

	Petrol	Diesel	Electricity	Gas	Petrol hybrid	Diesel hybrid
Cars	822,133	1,135,538	599,169	195	333,765	14,975
Buses	153	12,771	840	755	0	165
Vans	18,931	466,490	21,657	457	591	535
Lorries	1,962	65,056	455	813	0	11
Total	843,179	1,679,855	622,121	2,220	334,356	15,686

E. *Government incentives and support programs*

The high adoption rate results from a comprehensive set of incentives encouraging the market adoption of zero-emission automobiles. Since the early 1990s, the incentives have been steadily added to speed up the transition by several governments and large coalitions of parties.

All new cars sold in Norway must be zero-emission (electric or hydrogen-powered) by 2025, according to a national target established by the Norwegian Parliament. More than 20% of Norway's registered cars by the end of 2022 were Battery Electric Vehicles (BEVs). In 2022, BEVs held a 79.2% market share. Policy tools and various incentives are crucial in determining how quickly the transformation occurred.

Weight, CO_2, and NOx emissions are combined to determine the purchase tax for all new cars with emissions. Since the tax is progressive, big vehicles with significant emissions are expensive. The purchase tax has steadily changed over the last few years to place more emphasis on emissions and less on weight.

EVs have long been excluded from VAT and Norway's high new-car purchase tax. But Norway will begin charging a 25 percent VAT on purchases costing NOK 500,000 or more in 2023. A new weight tax will also be in effect for all EVs.

"*We are unable to predict how these additional EV taxes would impact EV sales*," adds Christina Bu. She argues that the Norwegian government has to be reminded of the

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importance of these incentives if they are to succeed and continue to demonstrate to the rest of the globe that a cold environment and inaccessible infrastructure are not reasons to switch to 100% electric transportation [17].

The following list shows incentives offered to Norwegian EV owners [12]:

- No purchase or import tax on EVs until 2022, with a new purchase tax based on weight for new EVs starting in 2023.
- Exemption from 25% Value-Added Tax (VAT) on EV purchases until 2022, but from 2023, a 25% VAT will apply for the amount exceeding NOK 500,000.
- No annual road tax until 2021, but reduced tax rates were introduced from 2021 onwards, and full tax is in effect from 2022.
- EVs were previously exempt from toll road charges until 2017, and from 2018 to 2022, a maximum of 50% of the total toll amount was charged for EVs. This increased to 70% from 2023.
- Similarly, EVs enjoyed no charges on ferries until 2017, and from 2018, a maximum of 50% of the total ferry fare was charged for EVs.
- Free municipal parking was provided for EVs until 2017.
- EVs had access to bus lanes since 2005, although new rules implemented in 2016 allow local authorities to restrict access to EVs carrying one or more passengers.
- Various reductions in company car tax have been in place, such as a 25% reduction until 2008, a 50% reduction until 2017, a 40% reduction from 2018 to 2021, and a 20% reduction from 2022 onwards.
- Leased EVs have been exempted from 25% VAT on leasing payments since 2015.

The Norwegian Parliament set a national goal in 2017 for all new cars sold by 2025 to be zero-emission (electric or hydrogen).

"Charging rights" were established in 2017 to ensure access to charging infrastructure for residents in apartment buildings.

Public procurement rules require Zero-Emission Vehicles (ZEVs) for cars starting in 2022 and city buses starting in 2025.

IV. ELECTRIC VEHICLES IN SPAIN

A. *Charging infrastructure*

One of their biggest drawbacks is the need for more driving range in EVs compared to internal combustion vehicles. EVs can only become a substantial part of the market if their use aligns with people's normal movement patterns. For a vehicle to cover at least 80% of the daily driving profiles of regular customers in various countries, a range of roughly 50–60 km is required, which led to a battery's nominal size of 16 kWh. Therefore, the driving distance should be within the battery's operating range, or parking arrangements should permit recharging. Regarding the average daily driving distance in Europe, three groups of nations can be distinguished [19]: the first group includes countries that are over 70 km or even 80 km (Poland and Spain), the second includes nations that are around 40 km (UK), and the third includes countries that are between 50 and 60 km (Example: France, Germany, and Italy). In this regard, if current driving habits are maintained, Spain has better prospects for EVs in urban areas.

Looking through the last few years, we can see the evolution of Spain's charging infrastructure.

Starting with the charging points of public access in 2021, this year, 4,866 points were installed, a growth four times less than necessary to keep pace with market growth. Additionally, this growth occurs at power levels associated with slow charging, with a maximum power of 22 kW. Just 12% of the charging infrastructure for public access in Spain corresponds to loads with power greater than 22 kW [20].

Of the total points installed in 2021, 2,234 were in urban areas, which makes a total of 7,685 points in this type of area. On the other hand, 2,632 points were in interurban regions, leaving a total of 5,726 points. Table II shows the 2021 distribution of charging points based on region and charging capacity [20].

TABLE II. SPANISH PUBLIC CHARGING POINTS (2021)

Region	P < 22 [kW]	22 < P < 50 [kW]	50 < P < 150 [kW]	150 < P < 250 [kW]	P < 250 [kW]	Total
Andalucía	1,194	32	89	2	10	1.327
Aragón	337	11	33	2	6	389
Asturias	191	22	24	0	2	239
Balears, Illes	862	9	15	0	2	888
Canarias	691	14	23	0	0	728
Cantabria	131	7	12	0	0	150
Castilla y León	573	52	102	2	8	737
Castilla-La Mancha	212	28	50	1	4	295
Cataluña	3,190	110	234	1	14	3,549
Ceuta	6	0	0	0	0	6
Comunitat Valenciana	1,435	79	135	6	6	1,661
Extremadura	146	33	23	2	2	206
Galicia	398	20	28	0	8	454
Madrid, Comunidad de	1,427	65	92	1	16	1,601
Melilla	9	0	0	0	0	9
Murcia, Region de	284	19	31	0	4	338
Navarra, Comunidad Foral de	171	12	31	0	4	218
Pais Vasco	488	12	41	0	6	547
Rioja, La	60	3	6	0	0	69
Total	11,805	528	969	17	92	13,411

84% of the intercity charging points have powers less than 22 kW, which means long recharge times and a very important barrier for the consumer. Long-distance charging should focus on high powers as recharging points below 22

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kW are unacceptable in intercity routes since using these points assumes a minimum recharge time of 3 hours.

The recharge points of 250 kW (less than 15 min) were almost doubled throughout the year, going from 50 to 92. These figures are far from the forecasts, which they were aiming for approximately 150 points to yearend. The 92 existing public access charging points are 350 kW and 400 kW spread over 33 stations. Canary Islands, Cantabria, La Rioja, Ceuta, and Melilla don't have any charging point high power public access. 95% of public access charging points high power responds to projects of automobile manufacturers. The administrative difficulties associated with the development of these projects are one of the major barriers. Because of this, many projects have stopped.

Moving forward with this study of the evolution of the charging infrastructure, in the last quarter of 2022, it increased by 1,563 recharging points (the pace of deployment continues to be lower than desired).

Eight hundred ninety-three charging points have a power of up to 22 kW. In other words, 79% of the points of public access recharge are low power (up to 22 kW). This makes 14 387 low power points (recharge time 19 - 3 hours). Long-distance charging must focus on high power since 72% of the intercity points have power up to 22 kW.

Only 52 load points between 22 and 50 kW have been installed. This leaves 823 points with this power (recharge time 3 - 1:20 hours).

And in the last quarter of 2022, 400 recharge points between 50 kW and 150 kW of power compared to the 177 installed in the third quarter (recharge time 27 - 40 min). This number represents 25% of the growth of the quarter. This makes a total of 2,220 points. Finally, between 150 kW and 250 kW, there are 227 points (recharge time 15- 27 min), 442 in total [20].

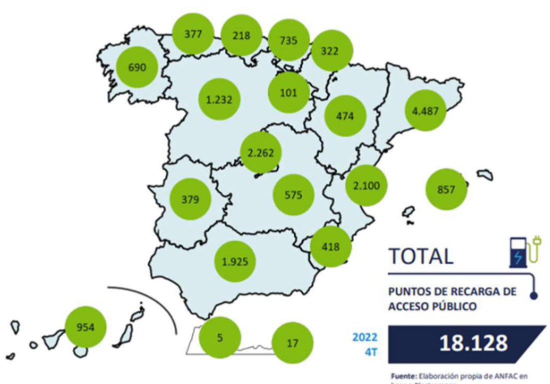

Figure 3. Charging points for each region (Spain).

The deployment of this type of infrastructure high power, which allows recharges like the refueling experience of an internal combustion vehicle, is essential for the proper growth of the electrified vehicle, even more considering that current technology of light-duty vehicles batteries already presented with power load exceeding 100 kW and shall rapidly increasing with the introduction of new models. It is also necessary for mobility associated with heavy vehicles that are from load powers of 150 kW already at present.

Figure 3 shows the number of public charging points for each region in 2022 [21].

B. *Energy and fuel price*

Currently, at EUR 70-80/MWh, energy prices are rising rapidly due to increasing gas prices, low renewable energy use, higher energy demand, and CO_2 emission costs. Gas price hikes, especially caused by the instability in Ukraine and Russia, directly impact electricity costs. Spain's heavy reliance on imported energy and the resurging global economy has exacerbated this issue, escalating gas prices from EUR 10/MWh in 2020 to over EUR 100/MWh in 2022. Additionally, the EU's measures to reduce CO_2 emissions are increasing consumer electricity bills. Figure 4 shows the increase in Spanish average energy prices since 1998 [22].

Energy peaks occur around 8:00 and 22:00, aligning with the highest demand periods. Currently, gasoline and diesel prices in Spain are EUR 1,637 and 1,611, respectively, influenced primarily by oil costs and taxes. Figure 5 shows the daily energy demand in Spain [23].

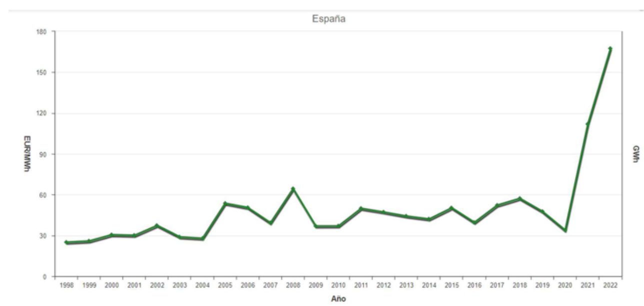

Figure 4. Average energy price since 1998 (Spain).

Factors impacting oil prices include OPEC's production limits, Russia's role in energy exports, and the conflict with Ukraine. Taxes account for 50% of the fuel price, with fixed logistics and distribution costs making up another 12%.

Despite a 17.1% growth in the EV market in 2022, the total sales volume remains low at 9.63% of the general market, indicating the need for urgent measures to promote renewable energy adoption and emission reduction targets.

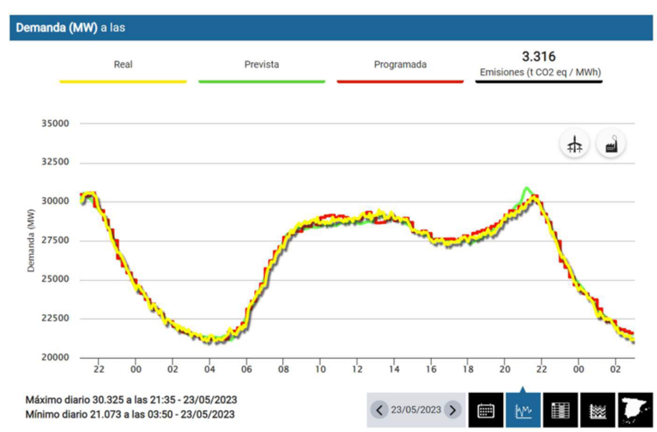

Figure 5. Daily energy demand (Spain).

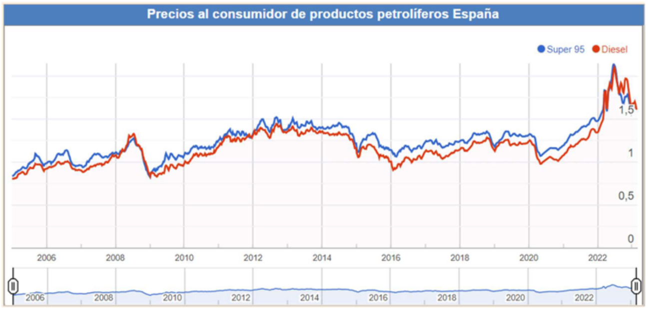

Figure 6. Consumer prices of petroleum products (Spain).

The current price of gasoline (blue line) is EUR 1.637, and diesel (red line) is EUR 1.611, with the corresponding taxes added. If we look at their evolution over the years, in Figure 6, we see how they have also been increasing [24].

C. Sales and adoption of EVs

Table III shows the numbers of registered vehicles by energy sources at the end of 2021 and 2022 [25]. While the total registrations in December 2022 decreased slightly compared to the previous year, the overall registrations from January to December 2022 increased. Gasoline vehicles had the highest number of registrations in 2022 (346281 registrations), followed by diesel vehicles. However, electric vehicles (EVs) showed a significant increase in registrations, indicating a growing interest in sustainable transportation options. Within the EV category, Battery and Extended-Range Electric Vehicles (BEV and E-REV) and Plug-in Hybrid Electric Vehicles (PHEV) experienced an increase. Hybrid vehicles remained popular, with Hybrid Electric Vehicles (HEVs) dominating the category (with 243,267 registrations). Hydrogen vehicles had minimal representation. These trends suggest a shift towards cleaner and more sustainable mobility choices, with EVs gaining traction in the market, going from being 30.17% of the market to 35.84% [25].

TABLE III. REGISTERED VEHICLES BY ENERGY SOURCES

	December				From January to December			
	2022		2021		2022		2021	
	Total	%	Total	%	Total	%	Total	%
Total	88,591	100.00	98,901	100.00	962,020	100.00	1,037,255	100.00
Gasoline	29,854	33.70	33,345	33.72	346,281	36.00	392,076	37.80
Diesel	25,191	28.44	29,258	29.58	270,915	28.16	332.245	32.03
Hydrogen	1	0.00	2	0.00	11	0.00	11	0,00
EVs Total	33.545	37.86	36,296	36.70	344,813	35.84	312,923	30.17
BEV + E-REV	4,140	4.67	4,203	4.25	36,452	3.79	27,767	2.68
PHEV	4,641	5.24	4,833	4.89	48,193	5.01	43,311	4.18
Gas Hybrid	2,058	2.32	2,067	2.09	16,901	1.76	18,459	1.78
HEV	22,706	25.63	25,193	25.47	243,267	25.29	223,386	21.54

D. Government incentives and support programs

Boosting EVs is essential for achieving zero-emission mobility by 2050. To this end, the Spanish Government has created a series of incentives that make purchasing EVs and installing charging points more feasible. Currently, incentives for electric mobility in Spain are included in Moves II Plan and Moves III Plan.

The Moves II Plan was introduced in June 2020, and in March 2021, 20 million euros were added as several communities distributed all their aid. This program currently coexists with the Moves III Plan, which was introduced in April 2021 as an improved continuation of the previous one. The Moves III Plan will last until 2023 and aims to improve support for charging infrastructure for individuals and small and medium-sized enterprises, as well as for fast and ultra-fast charging infrastructure.

1) Moves II

The program Moves II provides a set of incentives to promote EV adoption [26]. They depend on the engine and vehicle category, from EUR 600 for light electric quads to EUR 15,000 for purchasing trucks and electric buses. Aid for the purchase of EVs can reach, depending on the type of beneficiary, up to EUR 5,500 with scrapping, and in the case of commercial vehicles, up to 3,500 kg, up to EUR 6,000, also with scrapping.

In the case of purchasing passenger cars for disabled people with reduced mobility, the amount of aid shall be increased by EUR 750, provided that the adaptation is indicated on the technical data sheet of the vehicle purchased.

Regarding e-bike loan systems, the aid will be around 30% of the eligible cost, with a ceiling of EUR 100,000.

For the establishment of measures of Transport Plans to Workplaces and of measures to be carried out by Municipalities in urban centers to adapt mobility in a scenario of new demands arising from the post-COVID-19 period, the aid will be 40% or 50% of the eligible cost, depending on the type of beneficiary, with a ceiling of EUR 500,000.

2) Moves III

The program Moves III provides a new set of incentives [27]. For individuals, self-employed or administration, in the case of commercial up to 3,500 kg, this aid can reach up to EUR 7,000 (EUR 9,000 with scrapping) and up to EUR 4,500 (EUR 7,000 with chargeable) in the case of passenger cars.

The above aid amounts may be increased by 10% (not cumulative) in the following cases:

- Purchases of passenger cars by recipients who are disabled persons with reduced mobility. Also, in the case of the acquisition of light commercial vehicles by self-employed persons with disabilities with reduced mobility.
- Vehicle purchases by persons registered in municipalities of less than 5,000 inhabitants (registration must be maintained at least two years from the date of registration of the application).

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- Purchases of passenger cars by persons with economic activity (self-employed) intended for the use of taxis and services of transport vehicles with driver.

The amount of aid in the charging infrastructure for EVs may be up to the following percentage of the eligible cost:

- Up to 70% for self-employed individuals, communities of owners, and administration without economic activity (in the case of Municipalities <5,000 inhabitants, it will be 80%).
- Companies and public entities with economic activity (public access recharge $P \geq 50$kW): up to 35% (45% for medium-sized enterprises or 55% for small businesses). But in the case of municipalities with less than 5,000 inhabitants, it will be up to 40% (50% for medium-sized enterprises or 60% for small businesses).
- Companies and public entities with economic activity (public access recharge $P<50$kW): up to 30% (in case of Municipalities <5,000 inhabitants, it will be up to 40%).

The five main differences between the two programs are:

- Maximum help: The Moves III Plan offers a higher maximum help than the Moves II Plan.
- Support for recharging infrastructure: The Moves II Plan offers 30 to 40% (up to a maximum of EUR 100,000) of the cost of purchasing and installing public and private chargers, while the Moves III Plan offers up to 80%.
- 10% extra in three incentives: Unlike the Moves II Plan, the Moves III Plan offers 10% more aid for people with disabilities, self-employed using EVs as work tools, and holders registered in municipalities with less than 5,000 inhabitants.
- List of eligible vehicles: The Moves III Plan does not offer aid for electric trucks, buses, or gas vehicles.
- Vehicle purchase date: The Moves III Plan focuses on acquisitions made as of 9 April 2021. Therefore, vehicles purchased before this date can only apply to Moves II aids.

E. Challenges and obstacles

The Spanish Association of Automobile and Truck Manufacturers (ANFAC) proposes the three challenges that must be faced immediately to make the mobility ecosystem's development possible [2].

1) Decarbonization and air quality

Environmental concerns and stringent EU regulations on vehicle emissions drive manufacturers to reduce emissions. They've made significant technical advancements, reducing NOx and particle emissions by 85% and 90%, respectively, over 15 years, and aim for future vehicles to be carbon neutral.

However, 80% of global emissions come from older vehicles, with the average vehicle age in 2018 being 12.4 years, among the oldest in Western Europe. Regulations at various levels could promote fleet renewal, contributing to environmental goals.

2) Deployment of infrastructure

Implementing future vehicle infrastructure requires a focus on four areas:

- Traffic management infrastructure: Incorporating smart signage, intelligent traffic systems, and 5G networks for autonomous vehicles.
- Daily network infrastructure: Expanding the charging grid and redefining service stations due to longer recharge times.
- Smart materials: Incorporating self-control, interactive features in roads and bridges, and photosensitive paint in pavements.
- Fleet management: Modifying current parking infrastructure and dealership business models.

3) Intelligent regulation

Intelligent regulation must address mobility needs, ensure progress, propose a realistic timeline for transformation, and attract automotive sector investment. This requires legal certainty, investor and user confidence, and support for the sector committed to new mobility, thus creating a conducive framework for vehicle production and market strengthening.

F. Roadmap for 2040

To continue playing a relevant role in the international context, a framework that helps the industry to enhance its strengths and to devise appropriate strategies to overcome the challenges looming on the horizon is essential.

This scheme [2] is presented in four temporary moments to advance in an orderly transition to respond to the need to rationalize efforts, resources, and capacities of the industry that will allow maintaining the competitive position of Spain. The Administration, at all levels, must accompany the industry to make this path possible, and there will be six pillars that must generate the necessary ecosystem for its development focus:

1) industry and companies,
2) the environment and energy,
3) mobility,
4) people,
5) the vehicle and
6) public-private collaboration.

Figure 7 elaborates on the details of the roadmap. As it shows us, the action plan for the EV market in Spain from 2020 to 2040 aims to unify the messages of all sectors and stakeholders involved, establish a stable regulatory framework, and optimize existing assets. By 2025, the objective is to attract investments, increase productivity, and encourage innovation-related activities, particularly in low-emission and alternative vehicles. By 2030, the goal is to align the production mix with demand, adopt new business models, and occupy distinct market niches. By 2040, the

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plan aims to fully deploy the Spanish mobility ecosystem, digitalize production and sales processes, become information managers, and capture value within the mobility ecosystem.

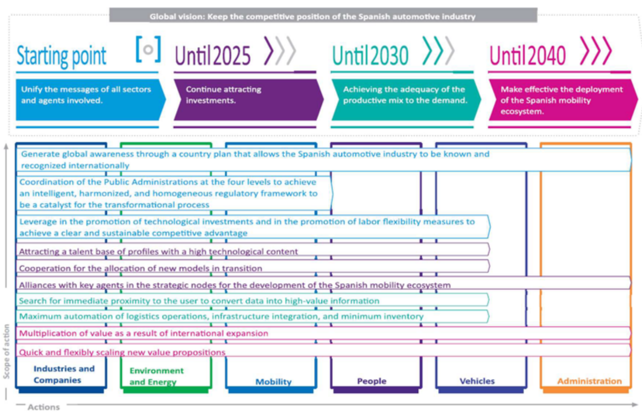

Figure 7. Plan 2020-40 scheme by ANFAC (Spain).

G. Spanish owners experience

To know if all the incentives and efforts are working, let us see what the owners say by checking the official forum of the Electric Vehicles Users Association (AUVE).

One of the most common topics is "Trips, routes, and experiences." For traveling with an EV is essential to have a good plan, decide where and when to stop and charge the vehicle, following the next steps:

Organize the route: Some apps will help, like ABRP (A Better Route Planner), used to calculate approximately where you must stop. Also, you can check all the available recharging points and their respective managers (Ionity, Endesa, Iberdrola, Wenea, etc.).

Check the recharging points: The drivers check the charger's condition with apps like ELECTROMAPS, which also include comments from other users.

Choose the cheapest rate: The ABRP app will show the price of kWh for each charging station and makes it possible for the user to select the best alternative (like Ionity, Kia charger, Juicepass or Endesa, Iberdrola, etc.). Payment can be made by an app or, alternatively, by card.

This shows us all the planning needed to go on a trip. Other topics on the website are news, charging information, sports with EVs, and purchase and selling. You can also talk with the rest of the users to share information, ask questions, etc.

Joana, an EV owner for six months and forum user, has shared with us her experiences where she tells us that for her daily life, it is perfect.

"*It is very efficient (I live 40 km from my work). When you have to consider longer distances, things get complicated. At the moment, I have always gone well, but it requires much more planning.*"

Regarding the difficulties that can be found with EVs, she tells us that they would be the purchase price and the complication of having a charging point at home if you do not have a parking space on your property; it is very common in Spain to have a community garage which can make even more difficult to install chargers. Nevertheless, Joana highlights the remarkable convenience of charging an EV at home. She describes it as a seamless process comparable to charging at work. Joana explains that this is inconsequential despite the slow charging speed since the vehicle remains parked for several hours, making it imperceptible when the charging is taking place. Home charging enables EV owners to integrate charging into their daily routines and eliminates the need for frequent visits to public charging stations. Since she also highlights the difficulties associated with public charging infrastructure, especially when using free charging stations. She emphasizes that these stations are often fully occupied, making it arduous for other EV owners to find an available spot. Furthermore, Joana expresses disappointment over the lack of empathy from some users who fill their batteries for as long as they need, disregarding the fact that public charging is a shared service.

"*Charging it at home is very comfortable, just as if you can at work, even if it is slow charging, the car is stopped for many hours, so you don't even notice when it's charging. But charging it on the public infrastructure is a horror. If it's free, it's always full and people aren't empathetic at all, they fill their batteries for the hours they need, without taking into account that it's a public service.*"

An important concern raised by Joana is the issue of overnight charging and the need for regulations. She observes that in her town, the only regulation is not staying for more than 4 hours. Consequently, many EV owners leave their vehicles charging overnight, taking advantage of the lenient guidelines. To ensure fair usage of public charging infrastructure, it is crucial to implement clear guidelines, such as limiting charging times or introducing penalties for prolonged stays. So, she recounts having a more positive experience with fast charging points provided by electric companies. These fast chargers offer quicker charging times, making them useful when immediate charging is required. However, Joana notes that the need for fast charging is rare, indicating that slow charging options are generally sufficient for her daily driving needs.

"*There is not much regulation about leaving it overnight. In my town, they only ask that you please not stay for more than 4 hours, so people leave it at night. I have had a better experience with fast charging points from electric companies, although electricity is almost the same price as diesel, but you rarely really need it.*"

In conclusion, it is imperative to recognize the need for continuous improvement in public charging infrastructure. This includes increasing the number of charging stations, implementing smart charging solutions to optimize usage, and promoting a culture of empathy and responsible charging behavior among EV owners. These improvements will provide a more seamless and accessible charging experience for all.

V. Comparison of the Evolution of EVs in Spain and Norway

Charging Infrastructure: There are some contrasts between Norway's and Spain's charging infrastructure expansion efforts. The implementation of high-power charging infrastructure has been limited in Spain, where the growth of charging points has lagged behind the expansion of the market. On the other hand, Norway has a well-established network of charging stations, including AC and DC fast chargers, providing quicker and more practical charging. This has aided in Norway's broad adoption of EVs.

Energy and Fuel Price: Energy prices in Spain have been rising rapidly due to increasing gas prices, low renewable energy use, higher energy demand, and CO_2 emission costs. In contrast, Norway has a significant share of renewable energy, mainly hydropower, which helps keep electricity prices relatively stable and lower than Spain. This has made EVs more cost-effective for Norwegian consumers.

Sales and Adoption of EVs: Electric vehicle acceptance and sales have increased in Spain and Norway. In contrast to Spain, Norway has achieved a far higher market penetration of electric automobiles. With a market share of more than 80% in 2022, EVs represented an essential percentage of new car registrations in Norway. Spain's market share of EVs remained low in 2022, representing just 9.63% of all recent car sales.

Government Incentives and Support Programs: Spain and Norway have implemented incentives and support programs to promote electric vehicle adoption. Moves II and III in Spain offer financial incentives for purchasing EVs and installing charging infrastructure. In contrast, Norway offers tax exemptions, toll discounts, free parking, and a comprehensive charging infrastructure until 2023. These incentives and infrastructure developments have played a key role in driving the high adoption rate of EVs in Norway.

Challenges and Obstacles: The necessity for effective regulation, the decarbonization of the vehicle fleet, and adequate infrastructure present issues for Spain. 2040 plan tries to deal with these problems. Norway must maintain charging stations and ensure the energy grid can handle the rising demand. It is crucial to control the market's impact on the nation's finances and maintain its continuing growth and prosperity.

VI. Conclusions

Recap of key findings: Spain and Norway have made efforts to promote electric vehicle adoption, but Norway has achieved a significantly higher market penetration of EVs due to government incentives, charging infrastructure availability, and energy prices. Spain has faced challenges in expanding its charging infrastructure, particularly in deploying high-power charging points, while Norway benefits from a stable and relatively low-cost renewable energy supply. This disparity can be attributed to government incentives, charging infrastructure availability, and energy prices.

Lessons learned and recommendations: The findings have led to lessons being learned, and suggestions can be made to enhance the EV industry and charging infrastructure in both nations. To make EVs more appealing and accessible, Spain should take a page from Norway's strategy and prioritize constructing high-power charging infrastructure, boosting government subsidies, and raising its investment in renewable energy sources. To achieve a smooth transition to electric mobility, public-private cooperation should be encouraged in both nations, utilizing the knowledge of diverse EV ecosystem stakeholders. Dispelling EV myths and misconceptions, addressing range anxiety issues, and emphasizing the advantages of electric mobility for the environment and the economy can all be accomplished through education and awareness campaigns.

Potential areas for improvement in each country: To bolster the EV market, nations need targeted strategies. In Spain, quickening the rollout of high-power charging infrastructure across all regions, boosting government incentives, and lowering energy prices can make EVs more affordable. In contrast, Norway must focus on expanding and upkeeping its charging network due to rising EV demand, vigilantly track the financial implications of EV incentives, and devise innovative solutions for surging electricity demand.

By implementing these recommendations, Spain and Norway can foster the development of their respective EV markets and promote sustainable transportation methods. These actions can significantly contribute to their national goals of reducing greenhouse gas emissions. A collaborative effort involving the government, private sector, and citizens is crucial to facilitate the transition toward electric mobility. This transition, in turn, could bring about substantial long-term environmental benefits and help both countries meet their commitments under international climate agreements.

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