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When Smart Cities Get Smarter via Machine earning: An In-Depth Literature Review

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Abstract: The manuscript represents a comprehensive and systematic literature review on the machine learning methods in the emerging applications of the smart cities. Application domains include the essential aspects of the smart cities including the energy, healthcare, transportation, security, and pollution. The research methodology presents a state-of-the-art taxonomy, evaluation and model performance where the ML algorithms are classified into one of the following four categories: decision trees, support vector machines, artificial neural networks, and advanced machine learning methods, i.e., hybrid methods, ensembles, and Deep Learning. The study found that the hybrid models and ensembles have better performance since they exhibit both a high accuracy and low overall cost. On the other hand, the deep learning (DL) techniques had a higher accuracy than the hybrid models and ensembles, but they demanded relatively higher computation power. Moreover, all these advanced ML methods had a slower processing speed than the single methods. Likewise, the support vector machine (SVM) and decision tree (DT) generally outperformed the artificial neural network (ANN) for accuracy and other metrics. However, since the difference was negligible, it can be concluded that using either of them is appropriate.

Key words: Smart city, big data, machine learning, ensemble, articial intelligence, deep learning, data science, smart grid.

I. INTRODUCTION

Due to abundance of resources, facilities, and welfare, half of the world's population lives in cities [1]. The lack of a specific definition of what makes a smart city smart [2] led to many cities around the world tagging themselves smart [3]. In this paper, we define the smart city as a city that utilizes the various Information and Communication Technologies (ICT) [4], [5] to improve the lives of its citizens, to solve problems (e.g., pollution, traffic, crime, etc.) [6], and to preserve its natural resources [7]. Conceptually, smart cities might be the answer to goals such as improving living standards, provisioning more services and facilities, and attaining social sustainability [4], [6], [8], [9]. Consequently, numerous technologies, such as the Internet of Things (IoT) [7], Big Data, and Cloud Computing technologies [10] have been among the tools used to support smart cities and the goals behind constructing them [11]. IoT-based devices help to optimize the decisions to enhance the performance of the city services to citizens [12]. However, adopting IoTs in smart cities can have its toll on lifestyles and undesirable impacts such as the increase in energy consumption [13], and the increase in the pollution levels in the air, soil, and water resources [14]. As a result, several studies emerged to mitigate such cons. For example, Ghahramani et al. evaluated an intelligent technique for routing recommendations in an IoT-based waste management complex [15]. Alsamhi et al. [17], in a study, proposed Green IoT as an environmentally friendly solution for the future use of IoTs. Almalki et al. [18] also presented a low-cost platform to monitor environmental parameters by employing flying IoT of real-time applications. The literature is rich with studies investigating the role of AI and ML-based techniques in smart city applications. For example, Ullah et al. [19] reviewed recent trends in the application of AI techniques in smart cities but limited their analysis to ML and reinforcement learning and a selected set of applications (i.e., transportation, cyber-security, smart grids, unmanned air vehicles, and healthcare). The study lacks a comparison between the performance of the different ML techniques. Shafiq et al. [21] presented a survey on the applications of data mining and single ML techniques to have sustainable smart cities. The study discussed the performance of these techniques against complex datasets.

II.RELATED WORK

This paper introduces a novel taxonomy that focuses on the type of ML algorithms and approaches rather than the type of applications in smart cities. The proposed taxonomy may help researchers, policy makers, and practitioners to enhance the living standards in smart cities by leveraging the right ML tools. The rest of the manuscript is organized as follows. Section II explains the methodology we used to carry out this literature review. Section III surveys the literature, describes the role of state-of-the-art ML algorithms in solving problems in smart cities and presents the taxonomy of the AI and Ml-based techniques for application in smart city concepts. Smart city networks involve many applications that impose specific Quality of Service (QoS) requirements, thus representing a challenging scenario for network management.

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Solutions aiming to guarantee QoS support have not been deployed in large-scale networks. Traffic classification is a mechanism used to manage different aspects, including QoS requirements. However, conventional traffic classification methods, such as the port-based method, are inefficient because of their inability to handle dynamic port allocation and encryption. Traffic classification using machine learning has gained research interest as an alternative method to achieve high performance. In fact, machine learning embeds intelligence into network functions, thus improving network management. In this study, we apply machine learning algorithms to predict network traffic classification. The evaluation results indicate that the decision tree algorithm provides the highest average accuracy among the evaluated algorithms.

III. LITERATURE SURVEY

A. A. Omar, A. K. Jamil, A. Khandakar, A. R. Uzzal, R. Bosri, N. Mansoor, and M. S. Rahman, A smart city ensures quality maintenance in diverse sectors, namely citizen safety, security, healthcare, transportation, and energy. Besides, data privacy and security have become an uprising concern for Electronic Health Records (EHR) in smart cities. This is because the EHR platforms are constantly getting cyber threats from cybercriminals. On the other hand, health insurance companies offer certain specific policies that require the association of patients' financial data with EHRs. Thus, additional security concern arises as fraudulent entities can alter these insurance policies. An extra challenge is triggered as patients need to validate their identities separately while communicating with different smart healthcare entities. This is because these healthcare facilities and insurance companies ought to ensure authenticity before offering any service for an individual. Hence, we have implemented a blockchain framework to safeguard patients' personal information and insurance policy. In this paper, we propose a solution for the healthcare system that provides data privacy and transparency. Furthermore, in the proposed system, insurance policies are incorporated in blockchain via the Ethereum platform and data privacy is shielded with cryptographic tools.

Ref.	Highlights	Database information	Systematic review	Statistical analysis	Probable gap
[19]	Recent trends in the application of artificial intelligence techniques in smart cities	N.A.	☒	☒	Database information and subject review interval
[21]	A survey on the applications of data mining and single ML techniques against complex datasets	The most cited methods and datasets	☒	☑	Evaluation interval
[22]	The use of ML and DL techniques in smart cities for prediction, planning, and uncertainty analysis	Database from web of science (WoS) and Scopus	☒	☑	Subject review interval
[23]	IoT-based ML techniques in healthcare, smart grids, and vehicular communications	N.A.	☒	☒	Database information and subject review interval
[23]	ML and internet-of-thing-(IoT) techniques used in healthcare, and smart grids	N.A.	☒	☑	Database information
[24]	ML data mining techniques in smart city applications	Database from web of science (WoS) and Scopus	☑	☒	Evaluation and comparison interval
[25]	The relationship between AI and smart cities	N.A.	☒	☒	Database information and subject review interval
[26]	Big data in smart city applications from an ML techniques point of view	N.A.	☒	☒	Database information and evaluation interval
[27]	Qualitative analysis of DL-based techniques for smart city applications	N.A.	☒	☒	Database information and evaluation interval
[28]	Deep reinforcement learning and clustering in smart city applications	N.A.	☒	☒	Database information and evaluation interval

Table 1. The description of the conducted survey studies.

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O. B. Mora-Sanchez, E. Lopez-Neri, E. J. Cedillo-Elias, E. Aceves-Martinez, and V. M. Larios, the use of Internet-of-things (IoT) applications (solutions) in the real world has increased exponentially. In smart cities, networked IoT devices are collecting data from the physical medium to optimize the decisions to improve city services to citizens. One way to evaluate this services solution is the use of the living labs, shown as a good option to evaluate previous real applications. However, when this is implemented in the real-world cases, most of them are no scalar to the complexity of the city. One of the factors is that it is assumed an IoT infrastructure designed to meet the properties of the scalability for a smart city. This article proposes a validation methodology for the scalability compliant infrastructure: modularity, interoperability, and resiliency properties. The proposed methodology is based on the best practices achieved during a living lab of the Smart Cities Innovation Center in the Universidad de Guadalajara implementation.

J. Desdemoustier, N. Crutzen, and R. Giffinger, Description: The Smart City is a fuzzy concept, which integrates numerous characteristics, components and dimensions. These characteristics are challenged in the academic literature, especially the technocentric approach and the central position of private companies. Moreover, the lack of proper conceptualisation pushes cities to claim themselves ‘smart’. Finally, there are few rigorous analytical or statistical analyses of the concept and its application to territories.

Therefore, this paper studies how Belgian municipalities understand the concept of Smart Cities in 2016. Based on the groundwork of literature on Smart Cities and the results of a survey of 113 Belgian municipalities, a typology of four understandings of the Smart City (technological, societal, comprehensive and non-existent) is elaborated. The results also show that municipalities with no understanding of the Smart City concept or with a technical understanding are mostly located in small and rural municipalities. This could be a sign of rejection of the phenomenon in this context. Conversely, medium and large-sized municipalities mostly develop a societal or comprehensive understanding. Therefore, this study highlights a dichotomy of understanding and acceptance of the concept of the Smart City between peripheral (rural and small size municipalities) and central municipalities (urban, medium and large size municipalities).

R. S. Farias, R. M. de Souza, J. D. McGregor, and E. S. de Almeida, the software architecture community has played a crucial role in the development of mobile software. Many of the ideas used in the design of these systems came from traditional software architecture and those ideas have contributed to mobile computing becoming ubiquitous. Mobile applications in the context of smart cities are very challenging since they need to operate within the power, processor, and capacity limitations of mobile devices, the exacting demands of life critical smart city requirements, and the constantly changing and exposed environment which may not always be trusted.

Since there are no widely accepted design models for this type of software, developers must resort to primitive design decisions to meet all the needs of these applications, which takes additional time and expertise. For this reason, the goal of this study is to investigate the design process for mobile applications in the context of smart cities. In order to address the lack of verified information about designing mobile apps, we conducted a multi-case study with 9 applications from 4 different development groups to build a grounded theory. The applications were reverse engineered to expose the architecture of each application. Given this data, interviews were conducted with developers who created the apps being studied. Based on all the data, an initial grounded theory was constructed to explain how the selected design process produces an app with the desired characteristics.

The resulting theory offers explanations for how software engineering teams design mobile apps for smart cities. This knowledge will serve as a basis to further understand the phenomena and advances towards more effective design and development process definitions.

J. Edelenbos, F. Hirzalla, L. van Zoonen, J. van Dalen, G. Bouma, A. Slob, and A. Woestenburg, this chapter develops a research agenda for big and open data in smart cities based on a thorough literature discussion of Actor Network Theory and the key concepts of urban governance and complexity. We argue that much of the smart city data discourse is highly modernist and restores an ideal of control and central steering that is thoroughly at odds with the complex multi-actor environment of smart cities. Against this background, we propose new research directions for the policy aspects of smart cities, asking in particular about the possible contradictory interests of city governments and the ICT sector on the one hand, and of city governments and hyperinformed citizens on the other; the data and analytic aspects of smart cities, raising the question of the quality and implicit values in big data, as well as the analytic challenges to collect, analyze and apply them, including the issue of data literacy for the citizenry of the smart city; the legal and social aspects of smart cities, which concern particularly issues of data ownership and privacy, and the new inequalities that may emerge as a result of smart city and big data developments; and the spatial aspects of smart cities, in particular the material and spatial repercussions of the movement to online, digital public and private services, and the reworking of spatial boundaries..

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IV.PROPOSED SYSTEM

In this section, we discuss ML methods used in smart cities from different perspectives. Based on our survey, we analyze how these methods compare to each other for efficiency (processing time), reliability (accuracy of results), and other performance aspects. We can notice that hybrid models and ensembles are the best performers since they exhibit both high accuracy and not-costly complexity.

On the other hand, and despite that the DL techniques had higher accuracy than the hybrid models and ensembles, but they demanded relatively higher computation power. Moreover, all these advanced ML methods had a slower processing speed than the single methods. Likewise, the SVM and DT generally outperformed the ANN for accuracy and other metrics. However, since the difference is negligible, we can conclude that using any one of them is appropriate.

METHODOLOGY

It is challenging to search and identify all studies in which ML algorithms have supported smart cities due to the abundance of such algorithms and their variations. The simple search queries for ``smart city'' and ``machine learning'' may not provide a comprehensive list of relevant literature. The search phrase ``smart city'' is not the only one that we would solely bank on because other search phrases that bear close semantics, such as ``intelligent city,'' ``smart urban planning,'' ``smart urban mobility,'' etc., should not be neglected. The complexity notably increases when we compound the query with the names of many ML algorithms. We relied on the main algorithms discussed in textbooks and in surveys such as [30] for the names of the ML algorithms. In this research, the Scopus database has been used as the primary repository as it indexes the major authenticated publishers.

Our review ultimately aims to identify, organize, and classify the ML techniques that have been used to serve smart cities into one of the four architecture categories: single models, hybrid models, ensemble models, and DL. Figure 2 depicts our review methodology which consists of four stages. In the first stage, an initial set of relevant articles is identified based on the search queries: ``smart city'' and ``machine learning methods''. For each ML method, we applied a new search query taking into consideration the specifics of each ML method and its variations.

In the second and third stages of the review methodology, we analyzed and classified the ML algorithms based on how each algorithm was applied in smart cities, the datasets used, and the results attained. Finally, in the fourth stage, the ML models are classified into the four aforementioned categories. Overall,our search has generated more than 430 relevant documents. During the second stage, we have carefully analyzed these documents to discern the most relevant ones (i.e., those belonging to the fields depicted in Figure 2) and thus we narrowed the search pool down to 100 relevant papers. In the third stage, the papers pool was further refined so that we ended up with 80 core papers to review. There was a considerable increase in the number of articles that used ML methods over the last ten years.

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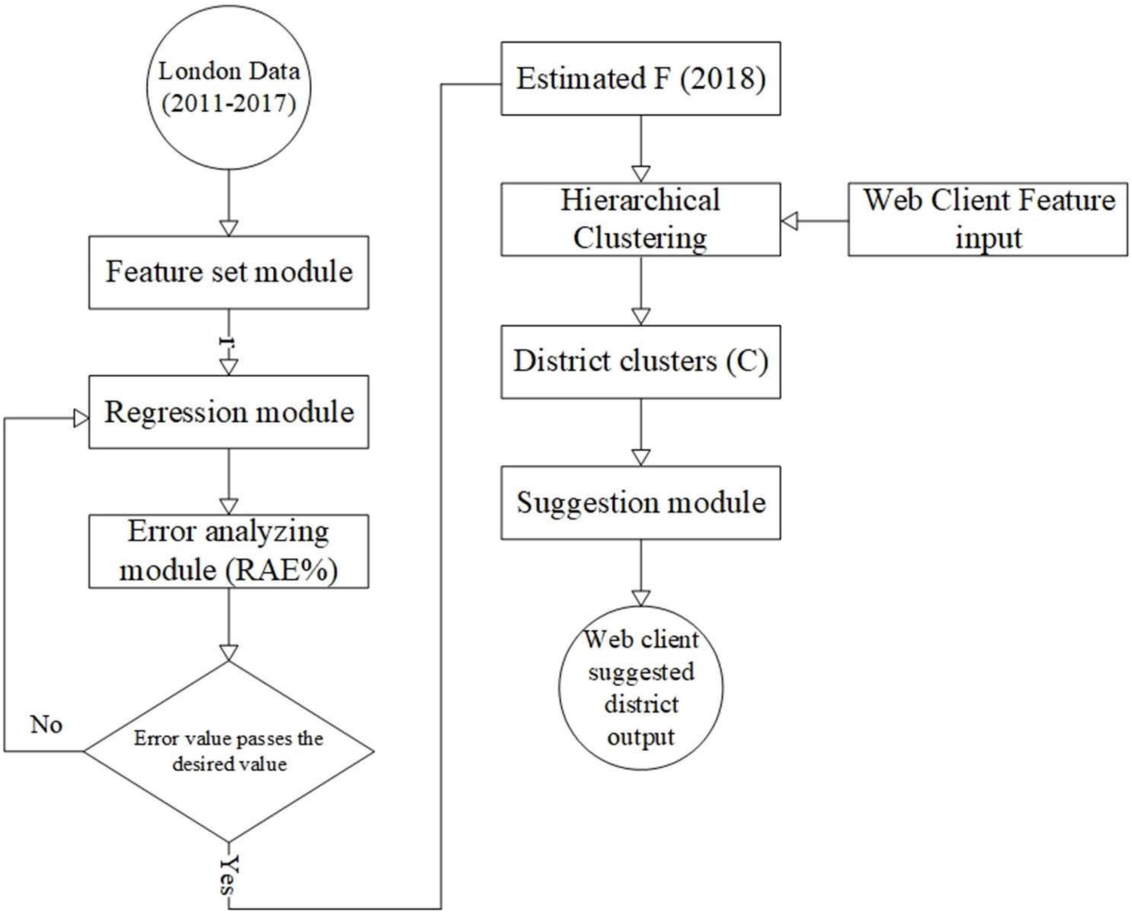

Figure 4. An algorithm to estimate business locations in smart cities.

V.DESCRIPTION OF THE WORK

Smart city applications have been faced with ML-based techniques as a new paradigm in this area. ML-based techniques are introduced as the vital element of smart cities, but the developed studies have not sufficiently and comprehensively considered these techniques. This part of the study discusses some open issues and challenges that can be targeted for future studies. For example, smart-city-based datasets are big and used by time-sensitive applications that demand real-time or semi-real-time analytics.

This highlights the need for a new analytic platform that supports big data analytics with fast/streaming data analytics. Furthermore, in applying the ML-based methods for smart city applications, the system's validity is closely related to the accuracy and precision of the data. On the other hand, data availability is a major challenge from the point of view of copyright issues and ethics. Furthermore, due to the nature of the data required for smart city applications, many performance domains can be easily rendered inaccessible if the results with large volumes of data for simulation are not confirmed. Therefore, the success of ML-based techniques in smart city applications depends on overcoming these challenges and excelling over them. Furthermore, due to the real-time applications of smart cities, the need for an ML-based technique that can provide high accuracy while providing a high operating speed and light platform can improve system reliability, stability, sustainability and availability.

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References	Year	Description of Machine Learning Approach	Smart city applications
[42]	2021	ML methods for IoT applications in smart cities, smart homes, and smart healthcare	Prediction and clustering for enhancing the IoT applications
[43]	2021	ML-based techniques for the prediction of Energy consumption in smart cities	Estimation of the Energy consumption
[44]	2021	ML-based techniques for handling the nanogenerators towards smart cities	Trend recognition
[45]	2020	ML-based techniques for enhancing the unmanned aerial vehicles efficiency	Process optimization
[46]	2020	Supervised and unsupervised ML-based techniques for handling electric vehicles in a smart city	Charging behavior analysis
[32]	2019	RBM technique for handling Distributed Denial of Service attacks related to smart cities	Detection of distributed denial of service
[33]	2019	RF algorithm used in IoT-based systems for detecting compromised IoT devices	Intelligent anomaly detection
[34]	2019	RF-based approach for estimating global solar radiation in comparison with other ML techniques	Estimation of global solar radiation
[35]	2018	MLP and MLR techniques for detecting and estimating the location of a business	Estimation of business location
[36]	2018	ML based-IoT system for waste management as a case study in smart cities	Waste management
[37]	2018	ML techniques for detecting the criminal patterns in the presence of historical data	Detection of criminal patterns
[38]	2018	IoT-based SVM for classification of vehicular traffic in smart cities as a case study	Classification of vehicular traffic
[39]	2018	RF, k-NN, and Bagging ML techniques for forecasting air pollution in smart cities	Forecasting air pollution
[40]	2018	ML techniques in combination with IoT devices for prediction of air pollution in smart cities	Forecasting air pollution
[41]	2017	ML-based IoT system used to develop personalized services by leveraging weather data	Developing personalized services

Table 2. Notable ML methods used in smart-city studies.

Model	Complexity	User-Friendliness	Accuracy	Processing Speed
DT	Reasonably high	Low	Reasonably high	Reasonable
SVM	Reasonably high	Low	Reasonably high	Low
ANN	Reasonable	Reasonable	Reasonable	High
Hybrid	High	High	High	High
Ensemble	High	Reasonable	High	High
DL	High	Reasonable	High	Reasonable

Table 3. Comparative analysis of ML models applied in smart cities.

Model	Advantages	Disadvantages
DT	Successfully applied in various smart city contexts	Moderate-to-high complexity and low user-friendliness
SVM	Frequently exploited for control-related applications	Low processing speed and user-friendliness
ANN	Successfully applied in smart cities with moderate-to-high accuracy	Low reliability in managing huge datasets
Hybrid	High accuracy, reliability, and user-friendliness	High complexity and moderate-to-low processing speed
DL	Very high accuracy and reliability and suitable to manage huge datasets	High complexity and low user-friendliness
Ensemble	High accuracy, reliability, and user-friendliness	High complexity and moderate-to-low processing speed

Table 4. Summary of advantages and disadvantages of ML-based models applied in smart cities.

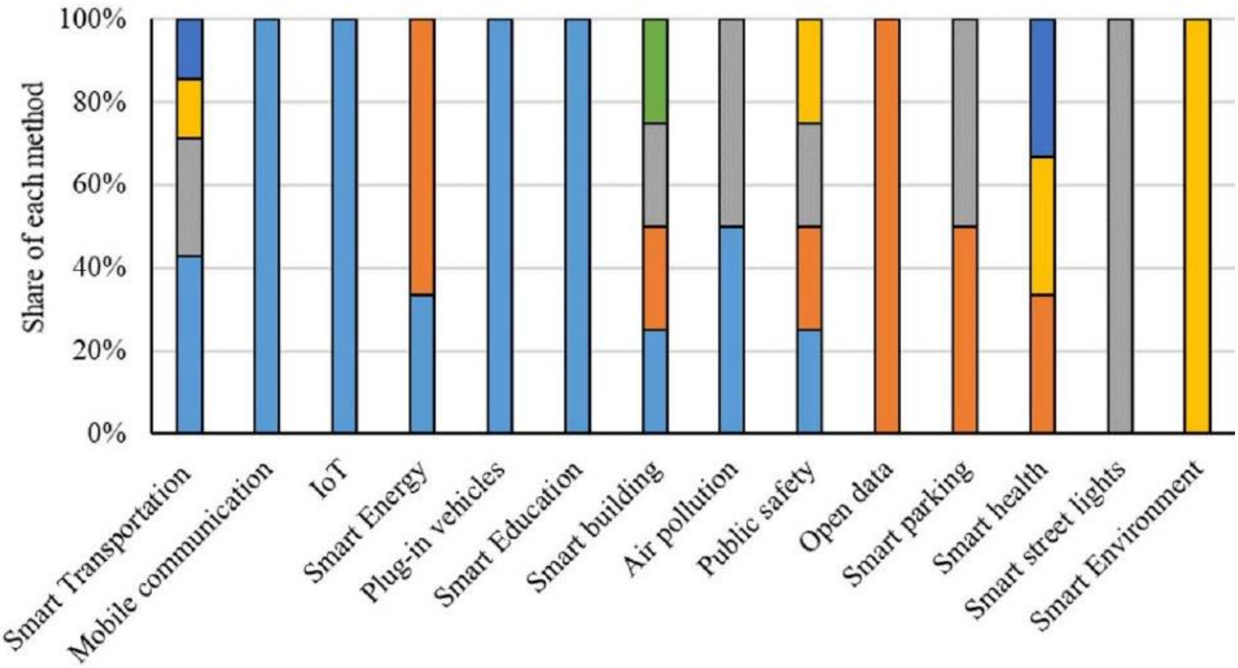

Fig 2. Share of each ML method under different types of smart city applications.

VI.TECHNIQUE USED OR ALGORITHM USED

Decision Tree (DT): In classification, the model predicts the class label, which is a predefined categorical output. In regression, a continuous output is predicted. Supervised learning involves training and testing. Here, we compare the results of the DT algorithm against other studies with similar approaches. For instance, proposed a method relying on the DL method with five hidden layers and 10 hidden nodes targeting the same dataset. Our proposed model achieved higher performance results than the DL method, reaching high accuracy compared with other. Moreover, the proposed algorithm outperformed evaluation results. Decision trees use multiple algorithms to decide to split a node into two or more sub-

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nodes. The creation of sub-nodes increases the homogeneity of resultant sub-nodes. In other words, we can say that the purity of the node increases with respect to the target variable. The decision tree splits the nodes on all available variables and then selects the split which results in most homogeneous sub-nodes.

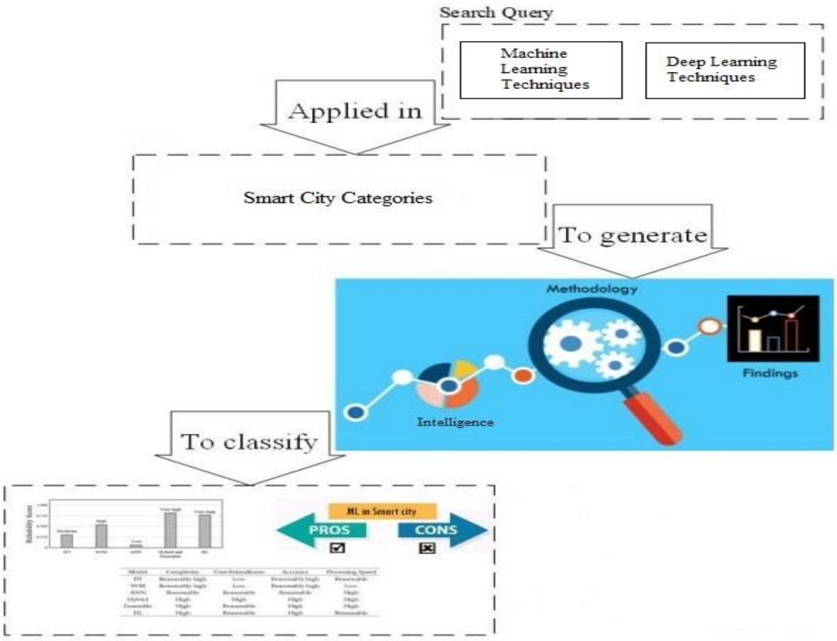

Fig 3. System Architecture

VII.PROPOSED TECHNIQUE USED OR ALGORITHM USED

SVM is one of the most frequently used supervised ML algorithms and employs the related learned model to handle both classification and regression tasks. In detail, the SVM represents the training samples as points in the feature space to find a set of hyperplanes that provide the best class separation, whereas new points are classified or predicted according to the portion of space they belong.

The ANN is an initial and simple way to design an intelligent learning system inspired by the biological neurons that constitute brains. This system uses a training stage related to a certain task that extracts knowledge from a training dataset without the need to be programmed by task-specific rules. Indeed, the basic idea of ANNs is performing tasks without any prior knowledge about the nature of phenomena. The DT algorithm is a supervised learning method that can be employed for classification and regression tasks. More specifically, a DT leverages a tree-based data structure in which the samples are recursively partitioned based on the selected feature whose values most effectively split to maximize a purity measure.

VIII. CONCLUSION

In this work, we present a comprehensive, systematic review of machine learning algorithms in smart city applications. As a result, we can conclude that the ML algorithms can fall into one of the following four categories: decision trees, support vector machines, artificial neural networks, and advanced machine learning methods (i.e., hybrid methods, ensembles, and Deep Learning techniques). We give a theoretical description for each ML algorithm and demonstrate how it was used across many applications in the smart city context. Furthermore, we evaluate all reviewed ML algorithms concerning efficiency (computational speed), reliability (accuracy of the output), and the pros and cons of each. Among the many important observations we encountered through our analysis, we found that hybrid methods, ensembles, and deep learning techniques can outperform single methods at the cost of higher complexity and processing time. With this analysis and comparisons, we hope to guide researchers, practitioners, and policymakers to select the appropriate ML tool for the right problem. Coupling of IoT with more powerful and reliable ML algorithms that can process a massive amount of data collected from the sensors will be the trend in the coming years. This might result in solutions for important problems typically associated with urban cities such as traffic, healthcare, pollution, education, etc.

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