Intelligent and Flexible Home Automation System

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***Abstract*—The increasing demand of energy has urged many researchers to closely work together in order to create technological solutions for optimal energy consumption. Due to inadequate electricity issues in Pakistan, there is a need to develop a mechanism to utilize home appliances efficiently while keeping electricity cost to the minimum. This paper describes an intelligent, flexible and low-cost solution for better energy management and conservation in the context of smart homes. The developed system focuses on making intelligent decisions and expanding its existing knowledge; specific to user actions, to achieve load balancing among different categories of appliances as per user needs. A client server based web application is developed that provides front end to the user whereas centralized control unit is based on Seeheim Model. Furthermore, an android based smart-phone application is developed to monitor/control/configure/notify all connected sensors/appliances. The adaptive behavior of the presented system was evaluated by incorporating artificial intelligence algorithms i.e. Fuzzy Logic (with 79% accuracy) and Support Vector Machine (with 71% accuracy).**

I. Introduction

One can improve his/her living style and home environment by moving towards the smart technology. Traditional homes can be revolutionized into smart homes by integrating variety of existing connected devices such as sensors, home appliances etc., if devices are able to communicate with each other without interacting home residents. Smart home are those homes which use state of the art technology in them and can be communicated by the resident whenever needed. They also provide information regarding the home condition to have a safer and comfortable environment [1].

Till date, many researchers have contributed their work with research community and industry in the context of smart home automation. However, most automated systems are unable to extend their ability to current demands of society due to rapid changes in technology. Todays home automation paradigms eliminate many problems [2]. Moreover, in developed countries where electricity load-shading is one of the problems which increases the demand of developing such systems which are not only smart but intelligent enough to guide residents in terms of effective operational timings of home appliances.

Major communication technologies being used by today's smart homes include LAN, Bluetooth, Wireless LAN, Zigbee, GSM etc. GSM based home automation systems were presented by [3]–[5]. Usually, GSM based systems use SMS messages to communicate the commands issued by the user to the main control system. This system offers the ability to control the appliances from all over the world. Such type of system cannot be used as a real time system. Some locations such as hospitals, airplanes and Military organization require cell phones to be turned off. In countries like Pakistan, government can turn off mobile service whenever there is security threat.

A Bluetooth based systems, as presented by [6]–[8], may use either a mobile phone or a PC as the receiver. The Bluetooth system can offer comprehensive control to the home appliances as long as the user is at home. It can function as a real time system. Advantage of this system is to offer remote access from anywhere in the world. The drawback of such system is that it limits the number of possible devices to the number of possible DTMF tones.

Similarly, [9], [10] conducted experimentation using ZigBee. ZigBee communication protocol is similar to Bluetooth. This system can also be used to operate a real time system. The only thing that may affect such systems is the cost of the systems and the possibility of termination. It implements the basic methods to switch status, set device level, receive device events, and ask for device information. It is also a way to detect device faults such as disconnections or malfunctions. It is a future work project. The Cost of all these devices is very high. Each technology is system dependent and they do not interact with other technology.

Wireless networks generally deliver slower internet speeds than wired ones. Connections can also be blocked by everyday obstacles, such as walls, doors, and furniture. Connections are also usually less secure. It can require extra costs and equipment to set up. Setting up a wireless network can sometimes be difficult for people who are not experienced with computers. Wireless communication has quality transmission speeds and mobility. Wireless networks and devices allow the user to move from place to place with their device while still acquiring a signal. Some wireless networks are also self-configuring, for ease of use [11], [12].

Existing automation systems are so intricate and difficult for common user to operate and understand. For the ease of common user, the system should be intelligent and flexible with simple application interface to operate it without any exertion. In conclusion, early systems developed with limited user interface (UI) but now the systems are developed by keeping in mind that how the end user will interact with

system. The motivation behind the presented work is about to take advantage from different technologies like smart-phone and desktop PC. By developing problem-specific algorithm, and incorporating Artificial Intelligence (AI) techniques, the domain of automation could generate new better solutions. Thus, the goal of this project is to make such system, which is easy to operate and intelligently control home devices, moreover provides the details of daily electric power consumption.

This can be done by changing the home into an Intelligent & Flexible Home Automation System. By integrating such automation system, traditional homes can be turned into comfortable place to be live in. An automated home can be controlled via any of the android supportive devices, Laptops and PCs. By using an intelligent & flexible home automation system one can feel much safer and can also help in catering the present energy crisis. Such system which is easy to deploy, able to learn from previous knowledge and also predict user activities, will provide more intelligent way of handling homes [13].

While keeping in mind the problem statement, the objective is to design a system which is:

Smart: The intelligent controller is able to increase its knowledge during time by learning from users specific action.

Adaptive Nature: To provide consumer a control to manage and reduce energy usage, while adapting to their everyday needs, preferences and schedules.

Efficient to Electrical Power Consumption: Design & implement an algorithm which helps users to optimize their electricity consumption.

The system is designed by keeping in view that it should provide a reliable solution to reduce electric consumption and to enhance automation in homes. The developed system is user friendly with customization features; easy to manage and to operate. Application interface of the system kept simple and attractive so that a common user can operate it easily.

Intelligent & Flexible Home Automation System incorporates technologies to improve living standards. By using smart phone or desktop application, the user can not only control home appliances/sensors but also get an overview of all connected appliances/sensors home. The developed system is scalable and extendable to both large and small size home. The basic function of the system is to control home appliances/sensors and to create operating schedule according to user requirements. It also provides the daily electricity consumption details which are helpful for user to reduce his/her electricity bill.

The rest of the paper is organized as follows: In Section II, we provide an overview of the proposed system design and developed system features. The developed algorithm, based on AI techniques, of the system is discussed in section III.In Section V, we describe that how system is implemented and its prototype testing which is based on AI techniques. Finally, in Section VI, we provide our conclusions.

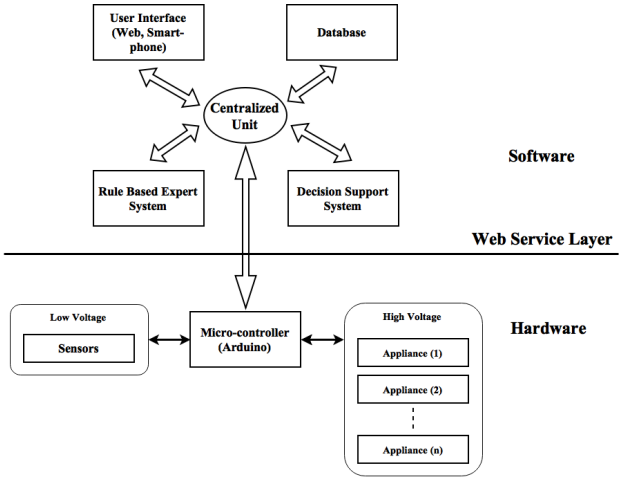

Fig. 1. The proposed system overview

II. Proposed Methodology

The main purpose of this system is to make smart decision without effecting user preferences to reduce electric consumption. The methods, based on the conventional mathematical approach, must have a precise information. In real control problem, we don't have the precise information. For this reason we select fuzzy logic and support vector machine. In order to run system from scratch, we initially developed a rule based system to get intelligent results using fuzzy controller, as it is the best option to be implemented. Later on it is upgraded to decision support system using support vector machine. Its adaptive in nature, as it gets trained on the rule set and adapts accordingly for increased number of sensors. So system first run on the fuzzy controller gathered data and that data was then used by fuzzy and support vector machine to get training. We used fuzzy logic methods because it is more accurate than interval arithmetic. Fuzzy logic is a rule based approach accepting imprecise information. It have ability to model the reasoning of an experienced human being, for example the thinking of a house owner when he knew that if load (consumption) stay like that he must have to pay this certain amount of bill, which works on the basis of approximate reasoning for different situations. There is no doubt that the introduction of fuzzy logic was a major milestone for computer science. SVM is one of the most robust and accurate algorithm among the other classification algorithms. It is optimal margin based classification technique in machine learning. It is binary classifier which suits for sensors data. Though Neural Network, Multi regression, ID3, Adaboost, Decision trees can also be used but can give low accuracy on system dataset. Support vector machine gives best result when number of features (variables) and number of training data is very large (as it was gather by using fuzzy controller). So, when fuzzy controller prepared data is provided to SVM it gives high accurate result.

Initially, the following features were considered while designing the system:-

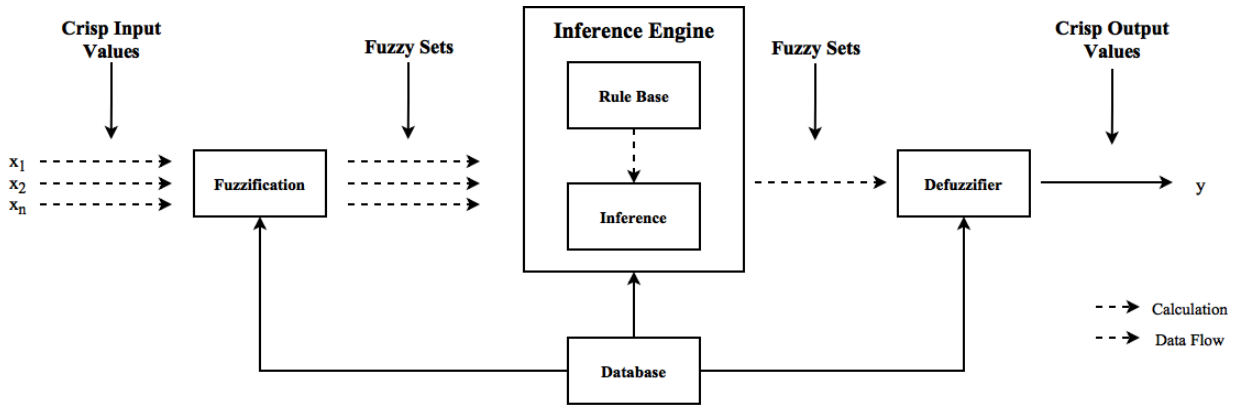

Fig. 2. Mamdani Framework.

- Controlling home appliances wirelessly and scheduling it for efficient energy consumption.
- Load balancing and managing home appliances by setting rules and regulations.
- Provide power consumption information to the user and which can automatically turn off appliances causing load and wastage of energy.
- Continuous monitoring of different sensors data.
- Generate consumption report of (day, week and month) and predict month billing.
- Automatically monitor home against smoke. In case of fire, the system automatically it switch off all home appliances immediately and notify user on the web application and smart-phone.
- Automatic scheduling of appliances.

The proposed system is composed of two major components, as shown in Fig. 1.

- Software
- Hardware

The hardware component consists of micro-controller (Arduino UNO), acting as main hub to all devices. The devices, specifically the sensors or appliances, can be of either low-voltage (5V) sensors such as fire, smoke, light, temperature etc. or high-voltage (220V) appliances such iron, washing machine, laundry machine, air-conditioner etc.

The software component consists of centralized control unit. The purpose of this unit is to coordinate with web service layer to gather current status of connected devices and transfer information to other software components; which includes Rule Based System, Database, User Interface and Decision Support System.

III. Proposed Algorithms

Rule-based systems are used to influence and store knowledge to interpret information in a useful way. Two algorithms were implemented, which are:-

1) Fuzzy Logic
2) Support Vector Machine

A. Fuzzy Logic

Fuzzy logic is an approach to compute based on *degrees of truth* rather than the usual *"true or false"*; (1 or 0) Boolean logic, on which the modern computer is based. We aggregate data and form a number of partial truths which we aggregate further into higher truths. There are two frameworks of fuzzy Logic;

Takagi-Sugeno Type Fuzzy Logic controller: It is indirect adaptive type fuzzy controller where the system to be controlled is identified using fuzzy set, Fuzzy model and the controller is designed based on the identified system model.

Mamdani Framework: It is direct adaptive type controller where the controller is designed directly based on the fuzzy rule base system, as shown in Fig. 2. In this project Mamdani Framework is implemented.

Fuzzy objective is to design a fuzzy controller using information based on some physical intuition even if the exact system dynamics are not known. The main problem is of rules construction which requires a prior knowledge and expertise in the domain of system under consideration. Firstly, fuzzy controller objectives are sets, as shown in Fig. 3, which are prediction of output of appliance that was trained on the basis of user interaction. After that parameter to be controlled is selected which are appliances. Fuzzy set is selected on the bases of the domain knowledge considering failure state. Minimum number of variable is choose to input the fuzzy logic engine. Input and output relationship is deter- mine by typical output error and rate of change of error. This Fuzzy controller break control pattern down to series of if X and Y then Z rules that defines the desired controller output for a given input condition.

1) Fuzzification: In fuzzification, first step is to change input to fuzzy value. There is membership function which determines the crisp input and generates the fuzzy output value in terms of degree. There are different types of membership functions involve in fuzzification.

2) Singleton Fuzzifier: In singleton fuzzifier, the input is converted into fuzzy singletons elsewhere singleton fuzzifier simplifies calculations but cannot suppress noise in the input.

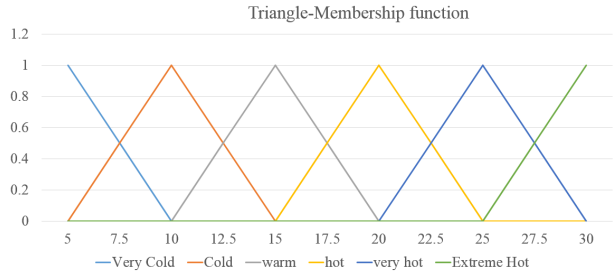

Fig. 3. Triangle membership function.

The singleton fuzzifier simplifies the computation involved in any fuzzy inference engine.

3) Gaussian Fuzzifier: In Gaussian fuzzifier, the input is converted into Gaussian fuzzy sets. It simplifies calculations if Membership Function (MF) are Gaussian it can suppress noise in the input. The Gaussian fuzzifier also simplify the computation in the fuzzy inference engine.

4) Triangular Fuzzifier: In triangular fuzzifier, the input is converted into triangular fuzzy. It simplifies calculations if MFs are triangular and it can suppress noise in the input. In this research we used triangular membership functions as shown in Fig. 3.

A fuzzy set is completely characterized by its membership function. A more convenient and concise way down the MF, to express as a mathematical formula. A triangular MF is specified by three parameters a, b, c, as shown in Eq. 1.

$$\mathbf{Triangle}(\mathbf{x}; \mathbf{a}, \mathbf{b}, \mathbf{c}) = \begin{cases} 0 & x \leq a \\ \frac{x-a}{b-a} & a \leq x \leq b \\ \frac{c-x}{c-b} & b \leq x \leq c \\ 0 & c \leq x \end{cases} \quad (1)$$

By using min and max, we have an alternative expression for the preceding equation as shown in Eq. 2.

$$\mathbf{Triangle}(\mathbf{x}; \mathbf{a}, \mathbf{b}, \mathbf{c}) = \mathbf{max}\left(\mathbf{min}\left(\frac{\mathbf{x}-\mathbf{a}}{\mathbf{b}-\mathbf{a}}, \frac{\mathbf{c}-\mathbf{x}}{\mathbf{c}-\mathbf{b}}\right), \mathbf{0}\right) \quad (2)$$

5) Inference Engine: The parameters a, b, c (with $a < b < c$) determine the x coordinates of the three corners of the underlying triangular MF. In Eq. 1, a triangular MF defined by triangle $(x; a, b, c)$. Reason using Membership function is that is has a simple formulas to implement, computational efficient and have been used extensively, especially in real-time implementations.

Crisp value becomes an input to triangle membership function, which converts that value to fuzzy value and is forward to inference engine for comparison against pre-defined fuzzy rules. A fuzzy rules consists of a set of linguistic *IF-THEN* constructions that have general form *IF A THEN B*, where *A* and *B* are collection of linguistic variables such as Very Cold, Cold, Hot, Very Hot etc.

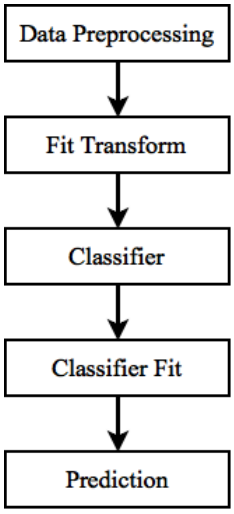

Fig. 4. SVM based algorithm.

In more explicit form, if there are *R* rules each with *k* premises in the system then R^{th} rule will have the following form.

$$IF\ a_1\ is\ A_{r,1}\ AND\ a_2\ is\ A_{r,2}\ a_3\ is\ A_{r,3}\ THEN\ B_r$$

where, a represents the crisp inputs and A, B are linguistic variables.

6) Defuzzifier: The output of the Inference Engine further passes to Defuzzifier, which converts fuzzy input to fuzzy output. The center average technique was selected among other techniques such as maximum, centroid etc. for defuzzification. The center average defuzzification formula is shown in Eq. 3.

$$\mathbf{y} = \frac{\sum_{\mathbf{i=1}}^{\mathbf{R}} \mu_{\mathbf{O^i}}^{\mathbf{i}} \quad \mathbf{y^{-i}}}{\sum_{\mathbf{i=1}}^{\mathbf{R}} \mu_{\mathbf{O^i}}^{\mathbf{i}}} \quad (3)$$

Where y^{-i} denotes the center value of region $\mu_{O^i}^{i}$ (cold, warm, hot etc.) and *R* is the total number of rules in the rule base.

B. Support Vector Machine

Support vector machine is a supervised machine learning technique in which dataset contains number of input data and labeled output data for training and testing the underling classifier. On the basis of classifier training, the developed algorithm, as shown in Fig. 4, is able to predict the output of an unknown input value.

The algorithm developed based on SVM classifier contains the following steps;

Data Pre-processing: The pre-processing is required on the acquired raw data from the sensors and other appliances in order to make it useful. Later, the input data is mapped to corresponding output label.

Fit Transform: In this, we scale the data. In other words we generate the binary for the labels and set that data into a matrix.

TABLE I
PREDICTED BILL SUMMARY

System Power Usage (Watt.)	Cost/6hr (Rs.)	Cost/12hr (Rs.)
192	34.6	69.2

Classifier: 1. Count Vectorizer: If we do not provide Apriori dictionary for feature selection and also we do not use analyzer then our number of features will be equal to the vocabulary size. That we come to know after analyzing the data. 2. Identity Transform: In this we scale down the impact of the tokens that have been frequently in the given data. Due to this, zero and low values are not ignored. 3. One Vs Rest: In this we classify one class with all of the other classes.

Classifier Fit: In this, there is the training of the data. And checks the confidence against the input to determine the output.

Prediction: Prediction takes the inverse transform of the labels so that different type of patterns must be removed and tests the output against the input.

IV. LOAD BALANCING APPROACH

Pakistan is facing worst energy crisis from last 10 years. Due to limited resources for generating power and bad economy we are not able to overcome this problem. As a part of long-term plan for sustainable energy use, it is important that we should learn to conserve energy and use it wisely. The energy demand of our country had grown at an annual consumption growth rate of 4.8% in the past five years but now it is expected to grow at 8 to 10% till the end of current decade. Load balancing is possible when people minimize heavy consumption of electricity during peak hour time. This method saves money because during these peak hour times the cost per kilowatt hour of electricity is higher than at other times during the day. The energy appliances are used simply for human comfort and convenience. If areas of a building are not being used by humans then there is no need of air conditioning and lighting. These cost saving methods measure the overall power usage of a building. For this purpose load balancing following load balancing approach is used.

A. Time Scheduling

User itself scheduled different appliance in order to control consumption. For Example air condition can be used for 30min then it turn off after 1 hour itself turn on and same goes on. Water pump is scheduled to be turn on based on the sensor data and as soon it is getting full it is turn on. By adding different appliances different time. User can reduce 20%-30% consumption.

B. Load Balancing Scheduling

User have given a table to check the load (consumption) of the appliance and if it stays like this for different hour what will be the predicted bill is shown in I. User itself scheduled appliances by checking the table and its billing.

The billing system is in $KWHr/Month$ (K means Kilo, W means Watt, Hr means Hour)so the predicted bill is calculated by using the formula:-

$$Power\ Usage\ (Watt.)\ x\ Time\ (Hours)\ =\ W\ Hr/Day$$

$$Watt\ Hr/Day/1000\ =\ KW\ Hr/day$$

$$KW\ Hr/day\ x\ Number\ of\ Days\ =\ KW\ Hr/day/Month$$

$$KW\ Hr/day/Month\ x\ Unit\ Price = MonthlyBill$$

For example;
192 x 12 = 2304 W Hr/Day
2304/1000= 2.304 KW Hr/Day
2.304 x 30 = 69.2 KW Hr/Day/Month
Lets suppose, Unit Price = 10, then
69.2 x 10 = Rs. 692

C. Load Balancing Priority

As in the previous case, user have given a table to check the load (consumption) of the appliance and if it stay like this for different hour what will be the predicted bill after an hour. So, user set the priority of the appliance if load increase to that limit which appliance should be shut down first. Appliance can be of different power consuming and might have different frequency in term of usage. This information will be used in fuzzy set and output is set under different rule. More than 50% bill can be reduced by applying these technique.

V. EXPERIMENTAL RESULTS

The system software application was built and tested in Enthought Canopy (in python language) under Microsoft Windows 7 environment. However, the hardware application was built using Arduino IDE. The system experimentation was conducted on dataset (sensors data obtained from hardware) by using techniques; Fuzzy Logic (Mamdani Framework) & Support Vector Machine.

In order to test the software algorithm i.e Fuzzy Logic and SVM, two different dataset were used which are explained below.

UCI Repository: This dataset was collected from a monitor system mounted in a demotic house settings. It corresponds to approximately 40 days of monitoring data. The data was sampled at every minute, computed and uploaded with 15 minute means [14]. UCI dataset was used during initial algorithm's accuracy and efficiency evaluation.

Custom-built Prototype Data: This dataset was collected from custom-built system prototype which consisted of 4 different rooms having different sensors such as temperature, motion, smoke, photo-resistor, light bulbs, fan and alarm. Furthermore instead of connecting high voltage (220V) appliances, three different high voltage load resistors were utilized. The simplified version of prototype is shown in Fig. 5. The dataset was collected for 5 days where new input data sample was collected at every second. The output data, if any, for each sensor and appliances was computed and uploaded to server within seconds.

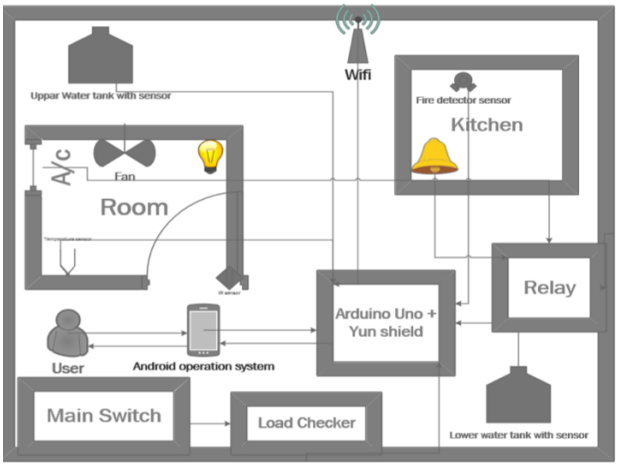

Fig. 5. Simplified System Prototype Overview.

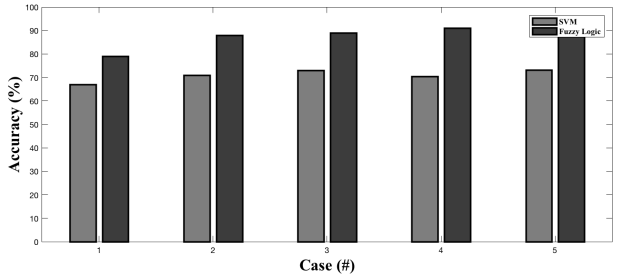

Fig. 6. Simulation results of achieved accuracy.

Under these settings, 5 different dataset, each containing 700 data samples, were gathered for algorithm's evaluation. Moreover, each dataset is based on different test case scenarios of how sensor and appliance will work.

The accuracy achieved with Fuzzy Logic algorithm, as explained in Sec. III-A, and SVM algorithm, as explained in Sec. III-B, for different test cases is shown in the Fig. 6.

VI. Conclusion

Based on all the systems surveyed, their advantages and drawbacks, this paper present the features to be possessed by an ideal Intelligent & flexible home automation with remote access. The adaptive nature has achieved by giving control to user to manage and reduce energy usage, while adapting to their everyday needs, preferences and schedules. To make the system efficient to electric consumption different algorithm has designed & implemented which help users to optimize their electricity consumption. Intelligent controller used to increase system knowledge during time by learning from users specific action which makes this system smart and intelligent. Simple and effective interface has designed both for web and mobile application. Accuracy achieved during testing; fuzzy logic 79% and support vector machine 71%, based on the gathered data.

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