



SMART INTEGRATED URBAN SUSTAINABLE SYSTEM:DYNAMIC TRAFFIC, RENEWABLE ENERGY AND WASTE SEGREGATION.

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ABSTRACT:

Urbanization has created major challenges in traffic congestion, waste management, and energy demands. This paper presents an integrated IoT-based smart city infrastructure to address these issues efficiently. A density-based traffic signal system is implemented using infrared sensors and Arduino to automatically adjust signal timings based on real-time vehicle density, improving traffic flow and reducing idle time. A smart garbage bin system monitors bin fill levels using ultrasonic sensors and performs waste segregation into wet and dry categories using IR and moisture sensors. This enables timely collection and helps maintain urban cleanliness with minimal manual effort. Additionally, a road hump power generation system is introduced using a rack and pinion mechanism to convert vertical motion from passing vehicles into rotary motion, which is then used to generate electricity. The harvested energy can power streetlights and traffic systems. Together, these systems promote automation, energy efficiency, and sustainable urban development for smarter cities.

Keywords :- Arduino, Infrared Sensor, Ultrasonic Sensor, Moisture Sensor, LCD Display, Waste Segregation, Smart Bin System, Smart Traffic Control, Power Hump, Kinetic Energy, Non-Conventional Energy, Smart City Infrastructure

INTRODUCTION

Modern cities are facing growing challenges in managing traffic congestion, waste accumulation, and increasing energy demands due to rising population and rapid development. Traffic congestion, in particular, has become a serious concern as static, time-based traffic signal systems struggle to adapt to fluctuating vehicle volumes. These inefficiencies lead to increased idle time, fuel wastage, and air pollution. To address this, smart systems that dynamically respond to traffic density are essential. In our approach, infrared (IR) sensors are deployed at intersections to detect real-time vehicle density, enabling automatic adjustments to signal timings for improved traffic flow.

At the same time, waste management in public spaces remains a persistent issue. Overflowing garbage bins due to inconsistent collection schedules contribute to environmental pollution and health risks. Our system incorporates real-time bin monitoring and automated waste segregation using IR and moisture sensors to differentiate between wet and dry waste, enabling efficient collection and promoting urban cleanliness.

In addition to traffic and waste concerns, the growing energy demand has emphasized the need for alternative power sources. A practical and sustainable solution is implemented using a rack and pinion-based road hump mechanism that converts the kinetic energy of moving vehicles into electricity. This energy can be stored and used to power infrastructure such as traffic signals and streetlights, reducing dependence on conventional energy sources.

Together, these systems form an integrated framework that leverages automation and smart technology to create cleaner, more efficient, and sustainable urban environments.

LITERATURE REVIEW

Density Based Traffic Signal Controller Using IoT (May 2024)

Aishwarya Tingare, Pooja Babar, Ruchita Saindane, Prof. Sanjiwani Deshmukh

This paper presents a smart traffic signal controller that adjusts signal timings based on real-time traffic density. The system uses IR (Infrared) sensors placed on poles to detect the number of vehicles in each lane. These sensors are connected to a NodeMCU (ESP8266) microcontroller, which processes the data and decides the duration of green lights dynamically. When traffic is heavier in one direction, that lane gets a longer green signal. This eliminates the inefficiency of fixed-time traffic signals and improves road usage efficiency, especially during peak hours. The system also sends data to a cloud server, enabling remote monitoring and data analysis for smart city planning.

Density Based Traffic Light Control Using IR Sensors and Arduino (2023)

Km Manisha Rai, Dr. S. Vijayalakshmi

This work focuses on solving traffic congestion by implementing an intelligent traffic light system. IR sensors detect how many vehicles are present in each lane. These readings are sent to an Arduino microcontroller, which compares the data from all lanes and assigns green lights accordingly. The most congested lane receives the green light for the longest time, while others wait. This system is simple yet effective and suitable for smaller intersections or towns. The prototype showed that adaptive timing helped reduce average wait times and improved vehicle movement at junctions.

Smart Bin Using IoT (2022)

Arindam Ghosh, Debajyoti Sarkar, Aditya Kumar Jha, Saikat Banerjee, Sujoy Barui, Biswanil Ghosh, Tapas Kumar Nandi

The main objective of this work is to design a smart garbage bin that can efficiently manage waste collection by integrating IoT-based monitoring and waste segregation. The system uses an ultrasonic sensor to detect the fill level of the bin and a moisture sensor to classify the waste as wet or dry. Once the bin is almost full, the system triggers an alert through a Bluetooth module for real-time monitoring and communication. This helps optimize waste collection schedules by notifying the concerned authorities. The prototype aims to enhance urban cleanliness by promoting timely waste disposal and automation of segregation at the source. The use of Bluetooth for local connectivity and mobile-based interaction makes the system user-friendly and energy-efficient.

Smart Dustbin Monitoring System Using Arduino UNO (2023)

Rajendra P. Singh, Sandeep Kumar, Shubham Gupta, Vishal Yadav, Amit Kumar, Priya Mehta

This research presents a smart dustbin system designed to automate waste management using IoT. The system is based on an Arduino UNO microcontroller and incorporates two key sensors: an ultrasonic sensor and a moisture sensor. The ultrasonic sensor is responsible for measuring the fill level of the dustbin. Once the bin reaches a certain threshold, the system triggers an alert, ensuring timely waste collection. The moisture sensor plays a crucial role in differentiating between wet and dry waste, allowing the system to segregate the waste into appropriate compartments. A servo motor is used to guide the waste to the correct section, ensuring effective waste sorting. Moreover, the system is equipped with an LCD display that provides real-time updates about the dustbin's status. This setup is designed to increase the efficiency of waste management processes, reduce human intervention, and ensure cleaner, more organized urban environments by facilitating automatic segregation and timely waste disposal.

Modelling and Design of an Auto Street Light Generation Speed Breaker Mechanism (2023)

Olugboji, O. A., Abolarin, M. S., Ohiemi, I. E., Ajani, K. C.

This study presents the modeling of a speed breaker that converts mechanical energy into electrical energy using a spring-based compression mechanism. As vehicles pass over the speed breaker, they apply force that compresses the system and rotates a generator. The generated power is used to control LED-based street lights, which are further optimized using an automatic light sensor. This sensor ensures that the street lights only turn on when it's dark, thus reducing unnecessary power usage. The model emphasizes mechanical reliability, ease of maintenance, and automation, offering a sustainable solution to energy generation and lighting in developing regions.

Roadside Power Harvesting for Auto Street Light (2023)

Md. Saiful Islam, Abdul Razzak Pathan, Shakun Asthan

This paper explores different mechanical systems such as rack-and-pinion, roller mechanisms, and linear gear systems embedded under speed breakers to extract energy from vehicle pressure. As vehicles pass, their weight moves mechanical parts that drive a small generator. This harvested energy is stored and then used to light up street lights through a microcontroller that operates the lights based on ambient light. The paper emphasizes affordability and scalability of the system in cities with high traffic density, making it suitable for areas aiming to transition to smart energy practices without high investment.

PROBLEM STATEMENT

As urban populations continue to expand, traditional city infrastructure systems face increasing challenges in meeting the demands of sustainability, efficiency, and responsiveness. Existing systems for traffic management, waste disposal, and energy consumption are often disconnected, leading to inefficiencies, increased environmental pollution, and a lower quality of life for residents. To address these challenges, there is a pressing need for an integrated smart city infrastructure that leverages emerging technologies like IoT and data analytics.

The primary goal of this research is to design and implement a cohesive smart city infrastructure that integrates intelligent systems for traffic management, waste management, and energy optimization. By utilizing advanced sensors and real-time data processing, the smart infrastructure aims to reduce traffic congestion, optimize waste collection, and efficiently manage energy usage, ultimately leading to a more sustainable, livable, and cost-effective urban environment.

IV.METHODOLOGY

To address critical urban challenges, this research proposes a smart city framework integrating three modules: density-based traffic signal control, smart garbage monitoring and segregation, and non-conventional energy generation using road humps. All three systems are implemented using Arduino Uno microcontrollers, which serve as the central control units to process real-time data from various sensors and actuate necessary outputs.

4.1 Density-Based Traffic Signal Control System

This system is designed to regulate traffic flow based on real-time vehicle density using Infrared (IR) sensors. These sensors are placed at the entry points of each road leading to a junction. An IR sensor emits infrared light, which gets reflected by nearby objects (in this case, vehicles) and is detected by a photodiode receiver.

- When a vehicle passes in front of the sensor, the IR light is reflected back and detected, signaling the presence of a vehicle.
- The system counts the number of vehicles detected in a specific time interval and sends this data to the Arduino Uno, which processes the density data for each lane.
- Based on the count, a decision-making algorithm prioritizes the signal for the lane with the highest vehicle density, dynamically adjusting the green light duration.
- This real-time switching replaces fixed-timer signals, improving vehicle flow and reducing waiting time and fuel wastage.
- The system resets and repeats the cycle after every signal rotation, ensuring continuous adaptation to traffic variations.

4.2 Smart Garbage Bin System with Waste Segregation

This module aims to automate the monitoring of garbage levels and enable the segregation of waste into wet and dry categories.

An Ultrasonic sensor is installed at the top of the garbage bin. It emits sound waves and measures the time it takes for the echo to return after hitting the surface of the garbage.

- The shorter the echo time, the fuller the bin.
- This data is sent to the Arduino, which calculates the fill level and displays it on an LCD screen.
- A Moisture sensor is used to detect the presence of water content in the waste.
- If moisture is present, the waste is classified as wet.
- An IR sensor detects objects that do not have moisture, typically identifying dry waste.
- When waste is thrown in, these sensors work together to route it into either a wet or dry waste compartment within the bin.

Additionally, once the bin reaches a predefined fill threshold, the Arduino can be programmed to trigger a notification system (e.g., via Wi-Fi or SMS module) alerting collection authorities for timely waste removal. This system significantly reduces manual monitoring, prevents bin overflow, and supports cleaner urban spaces.

4.3 Road Hump Power Generation using Rack and Pinion Mechanism

This system captures the kinetic energy generated by moving vehicles over speed breakers and converts it into electrical energy:

- A rack and pinion mechanism is installed underneath a specially designed speed breaker.
- When a vehicle passes over, it applies a vertical force on the speed breaker, pushing the rack (a linear gear) downward.
- The rack is connected to a pinion (a circular gear), which rotates as the rack moves linearly.
- This rotational motion is transferred to a DC generator, converting mechanical energy into electrical energy.
- The generated electricity is stored in a rechargeable battery and can be used to power local infrastructure such as traffic lights and streetlights.

This method utilizes energy that is otherwise wasted, making it a highly effective solution for power generation in high-traffic areas. Over time, a series of such units can contribute significantly to energy savings.

4.4 System Integration

Each of the three modules is independently controlled by an Arduino board, ensuring modularity and ease of implementation. The sensors used are cost-effective, energy-efficient, and suitable for real-time applications. Collectively, these systems automate three major urban infrastructure components—traffic flow, waste disposal, and energy usage—making them ideal for future smart city deployments.

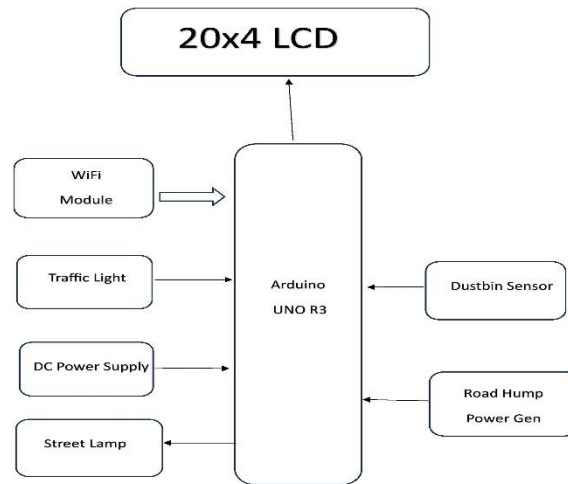


Fig 1 Block diagram

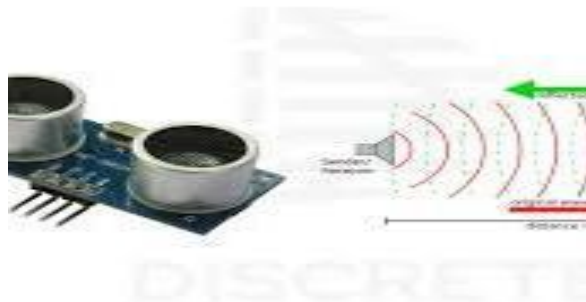
V COMPONENTS USED

Ultrasonic Sensor (HC-SR04)

The Ultrasonic Sensor is used to measure the distance between the sensor and the surface of an object using sound waves. It consists of:

Transmitter: Emits ultrasonic pulses (typically at 40kHz).

Receiver: Detects the echo signal reflected from the object.

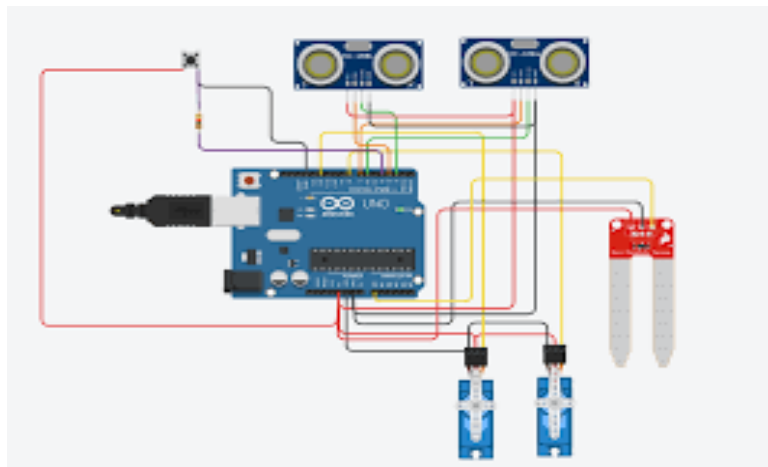


Moisture Sensor

A Moisture Sensor is used to detect the presence of water content in a substance. It works based on the conductivity between two probes:

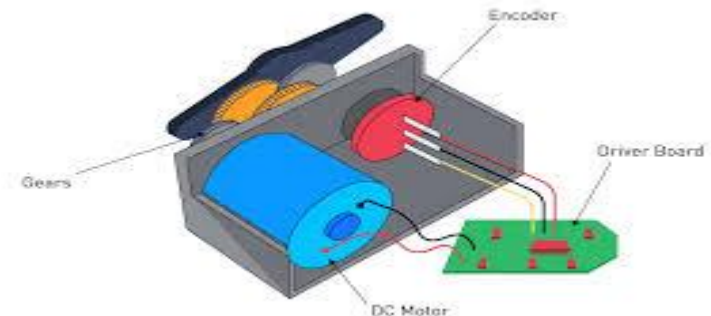
Wet material allows more current to flow (higher conductivity).

Dry material allows less or no current to flow (low conductivity).

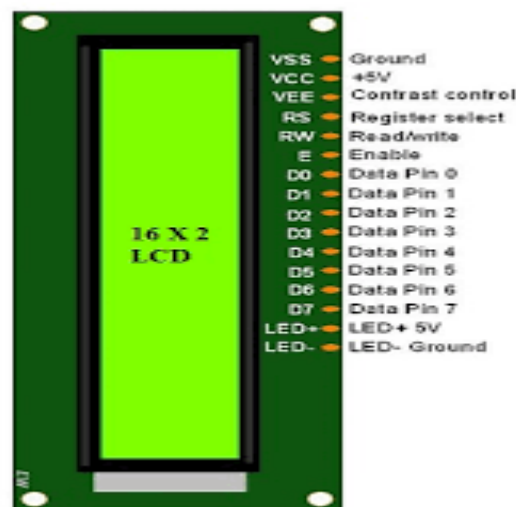


Servo Motor:

A servo motor is a type of electric motor that can precisely control the angular position of a shaft. It consists of a motor, a gear mechanism, and a control circuit that ensures the motor rotates to the required position. The operating voltage of a typical servo motor is between 4.8V to 6V. Servo motors are widely used in applications requiring precise movement, such as robotics, RC (remote-controlled) vehicles, and automation systems. They are capable of both continuous rotation and controlled movements, with the angle of rotation determined by the signal pulse width sent to the motor's control circuit.

**LCD DISPLAY**

A liquid-crystal display (LCD) is a level panel display or other electronically adjusted optical gadget that uses the light-tweaking properties of liquid crystals. Liquid crystals don't discharge light straightforwardly, rather utilizing a backlight or reflector to deliver images in shading or monochrome. LCDs are accessible to display subjective images (as in a universally useful PC 24 display) or settled images with low information content, which can be displayed or covered up, for example, present words, digits, and 7-segment displays, as in an advanced clock. They utilize a similar fundamental innovation, with the exception of that self-assertive images are comprised of countless pixels, while different displays have bigger elements.

**VI. IMPLEMENTATION:**

Ultrasonic Sensor HC-SR04 and Arduino Tutorial

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* Crated by Dejan Nedelkovski,

* www.HowToMechatronics.com

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*/

```
#include <LiquidCrystal595.h> // include the library
```

```
LiquidCrystal595 lcd(4, 3, 2);
```

```
const int trigPin = 5;
```

```
const int echoPin = 6;
```

```
const int Ir1 = 7;
```

```
const int Ir2 = 8;
```

```

long duration;
int distanceCm, distanceInch;

void setup()
{
  Serial.begin(9600);
  lcd.begin(16, 2);      // 16 characters, 2 rows
  lcd.setLED2Pin(HIGH);
  lcd.clear();
  lcd.home ();
  pinMode(trigPin,OUTPUT);
  pinMode(echoPin,INPUT);
  pinMode(Ir1,INPUT);
  pinMode(Ir2,INPUT);
}
//*****
void loop()
{
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  duration = pulseIn(echoPin, HIGH);
  distanceCm= duration*0.034/2;
  distanceInch = duration*0.0133/2;
  Serial.println(distanceInch);

  lcd.setCursor(0,0); // Sets the location at which subsequent text written to the LCD will be displayed
  lcd.print("Distance: "); // Prints string "Distance" on the LCD
  lcd.print(distanceCm); // Prints the distance value from the sensor
  lcd.print(" Cm  ");
  delay(300);

  if((distanceCm > 0) && (distanceCm <= 3))
  {
    lcd.setCursor(0,1); // Sets the location at which subsequent text written to the LCD will be displayed
    lcd.print("Bin:Full  ");
  }

  else if((distanceCm > 3) && (distanceCm <= 6))
  {
    lcd.setCursor(0,1); // Sets the location at which subsequent text written to the LCD will be displayed
    lcd.print("Bin:Med   ");
  }

  else if((distanceCm > 6) && (distanceCm <= 9))
  {
    lcd.setCursor(0,1); // Sets the location at which subsequent text written to the LCD will be displayed
    lcd.print("Bin:Empty ");
  }

  else if(distanceCm >= 10)
  {
    lcd.setCursor(0,1); // Sets the location at which subsequent text written to the LCD will be displayed
    lcd.print("No range");
  }

  //-----
  if(digitalRead(Ir1) == HIGH && digitalRead(Ir2) == HIGH)

```

```

{
  lcd.setCursor(10, 1); lcd.print("Normal");
}
else if(digitalRead(Ir1) == LOW && digitalRead(Ir2) == HIGH)
{
  lcd.setCursor(10, 1); lcd.print("Medium");
}
else if(digitalRead(Ir1) == LOW && digitalRead(Ir2) == LOW )
{
  lcd.setCursor(10, 1); lcd.print("Heavy ");
}
}
//-----
}

```

VII.RESULT:

The proposed smart city system was successfully developed and tested in a controlled environment. The integration of traffic control, smart waste management, and energy harvesting systems resulted in a functional prototype capable of performing real-time automation using embedded hardware.

The density-based traffic signal system demonstrated effective control of traffic signals based on vehicle presence detection. IR sensors placed at junction lanes accurately identified whether a vehicle was present, allowing the Arduino Uno to dynamically assign green signals to active lanes. This approach prevented unnecessary delays on empty lanes, improving the responsiveness of the signal flow. Signal switching occurred reliably, and the system was able to adapt to multiple test scenarios with varying traffic presence across lanes.

In the smart garbage bin system, the ultrasonic sensor accurately detected the garbage level inside the bin. The use of moisture and IR sensors enabled the classification of waste as wet or dry based on its material and moisture content. The LCD display successfully indicated the current fill level and waste type in real-time. When the bin reached a predefined threshold, the system triggered an alert through the display and LED indicators. This ensured timely waste collection and helped reduce overflow, promoting better sanitation.

The road hump power generation system using a rack and pinion mechanism successfully converted the vertical force applied by passing vehicles into rotational motion. This rotation was coupled to a DC generator, which produced measurable electrical energy. The generated energy was stored in a rechargeable battery and used to power an LED-based streetlight during the prototype demonstration. The system showed consistent energy output under repeated vehicular passes, indicating its potential for practical use in high-traffic urban areas.

Overall, the prototype fulfilled its intended objectives, with each module functioning independently and in coordination. The implementation demonstrates the potential of integrating embedded systems and sensor-based automation to address urban infrastructure challenges in a cost-effective and sustainable manner.

VIII.CONCLUSION:

This project successfully demonstrates the design and implementation of an integrated smart city infrastructure using embedded systems and real-time sensing technologies. The system consists of three core modules—density-based traffic signal control, smart garbage bin monitoring with segregation, and road hump energy generation—each addressing critical challenges in urban management.

The use of IR, ultrasonic, and moisture sensors enabled efficient detection, automation, and response in each module. The Arduino Uno served as a reliable and flexible controller for all systems. The prototype was tested in a controlled environment and functioned as expected, showing the feasibility of using low-cost microcontrollers and sensors to automate urban processes.

This work provides a scalable and modular approach toward smart city development, supporting cleaner, safer, and more energy-efficient environments. Future enhancements may include wireless communication, centralized data monitoring, and solar-powered integration for complete smart infrastructure solutions.

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