IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

Saudi Real-Time Climate Monitoring System: An Integrated Solution for Enhanced Weather Alerts and Visualization

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Abstract

The Saudi real-time climate monitoring system (SRTCMS) is the complete advanced geographical pictorial weather alert platform for monitoring critical weather conditions in Saudi Arabia. This platform effectively provides immediate and valuable weather information in English and Arabic with live updates every five seconds to government executives, serving sectors, citizens, and investigators. The key components of this monitoring system include a cloud-based data source, temperature, humidity-based alert system, and specified city data markers, enabling targeted, efficient communication and visualization. This proposed study integrates OpenWeatherMap API for climate data collection, folium, geopy for geospatial visualization, text-to-speech, and sound for real-time weather alerts to communicate potential hazards. It furthermore depicts the architecture and working principles of the system, and its efficacy, detailing its data integration, mapping functionalities, and user-friendly interface with Python packages and libraries: Tkinter, Pygame, and Pyttsx3. The findings emphasize the Saudi Real-Time Climate Monitoring System as a scalable, accessible enhanced model delivering timely alerts against extreme weather circumstances in arid regions.

Keywords: Climate change, Monitoring system, Temperature, Humidity, Saudi Arabia

1. Introduction

An effective real-time weather monitoring system is vital for forewarning the public and helping sectors with harmful climate conditions. Conventionally, Saudi Arabia depends on meteorological services, addressed by the climate monitoring system that connects API-driven weather statistics collection, topographical visualization, and multimedia alert broadcasting to bring up-to-the-second weather insights in real-time across various Saudi cities. People, agriculture, infrastructure, and transportation in Saudi Arabia are usually disturbed by risky heat changes and weather irregularities [13,16] In addition, weather changes initiate sandstorms, flash floods, and high temperatures in Saudi Arabia, requiring a real-time climate monitoring system to prevent

hese effects [10]. The current weather-related services do not support localized real-time information, preventing immediate action for local populations, especially in rural areas in Saudi Arabia [3,6,11].

The limitations of traditional climate monitoring systems in Saudi Arabia are delayed update intervals, lack of real-time climate management, specific city monitoring, multiple data visualization, and timely warning mechanisms [3,4,1]. Moreover, conventional monitoring systems are based on regional forecasts without focusing on detailed essential climates in high-risk specific cities and densely crowded areas [6]. Additionally, the non-existence of friendly approachable applications and multimedia warning software made slow transmissions of crucial threads to populations, and private public authorities [9,7]. The intelligent tools, such as OpenWeatherMap API, folium, and geopy of the new Saudi Real-Time Climate Monitoring System (SRTCMS), encounter these challenges and simplify them by gathering, picturing, and publishing original weather data. The SRTCMS offers live updates every five seconds that upgrade the common existing systems [10].

The instant alertness of current climate data in SRTCMS for Saudi cities improves situational awareness and fast reactions to remarkable weather facts. Python-based libraries like Tkinter in the new SRTCMS ensure easy access to different users. Besides, the audio and text-to-speech alerts advance conventional climate monitoring systems. The city-specific markers method enhances the ability of SRTCMS to expose high heat, moisture, and precise warnings to specific affected Saudi cities. Moreover, the scalable integration of speedy live updates, accessible localized visual data, hypermedia alarms, and precise efficient essential broadcasts of climate threats in Saudi Arabia fill the research gap with the current weather monitoring systems.

2. Literature Review

Previous Studies have shown that they played a significant role in weather data collection and creating real-time climate applications using graphical representation techniques. The integration of the meteorological application programming interface and visualization tools enhances the retrieval of data and the making of decisions according to present weather conditions. This integration needs to develop a system that should be flexible for monitoring various geographical climatical conditions [19,20]. The European Climate Assessment Dataset and National Oceanic and Atmospheric Administration institutions designed a large climate data platform to provide valuable information for arid regions, even though they failed to provide data for specified areas which is important for efficient decision-making processes [3,5].

The research highlighted the importance of developing inexpensive and simple deployable meteorological graphical systems for developing localities, insisted people use these systems in their gorgeous operation, and addressed the unique challenges faced by certain weather-changeable sectors [10]. An IoT system integrated several weather data sources to offer accurate and timely climate information and improve the availability and readability of climate forecasts [18]. The mobile application implemented a weather monitoring system that underlined the importance of user-friendly interfaces to help improve public awareness of severe climate conditions [6]. These key features are fundamental to the design of the proposed SRTCMS. Moreover, the comparative study of the previous weather monitoring systems emphasized significant research gaps in terms of specific locality and well-timed data revises. These studies assist the require for systems designed for the unique climatic conditions of zones like Saudi Arabia, which help justify the advancement of the SRTCMS.

The various current systems address the different weather patterns of arid regions which is essential for localized weather data [8]. This surveillance reinforces the prominence of a supervising system that focuses on these unusual climatic challenges.

The effectiveness of audio and visible notifications enhanced public responses to climate-related threats by integrating multimedia signals [2]. The SRTCMS offers the latest approach to meteorological conditions alert using this concept.

Finally, the current studies by [12,15] emphasize the impact of real-time data distribution and the necessity for accessible results that can adjust to changing climatic conditions. These studies assist in framing the targets of the SRTCMS to provide a comprehensive, real-time weather monitoring key for Saudi Arabia. As a group, much of the associated work grants a strong foundation for the invention of SRTCMS. It directs analytical gaps in presented approaches by increasing real-time red alerts, extending geographical customization, and supporting user-friendly interfaces designed explicitly for weather challenges in arid regions like Saudi Arabia.

3. Methodology

The Saudi Real-Time Climate Monitoring System (SRTCMS) is an efficient real-time management system compared to current monitoring systems in Saudi Arabia.

- **Real-Time Data Procurement Regularity**: SRTCMS provides live updates at more rapid intermissions (every 5 seconds) while several traditional systems offer updates at prolonged interludes (every 10 minutes). Users get severe weather events for appropriate decision-making through this rapid regularity.
- **Comprehensive Statistics Incorporation**: The SRTCMS utilizes the OpenWeatherMap API for the integration of various real-time meteorological data acquisition over previous systems which lack integration of current weather access and work with inadequate datasets [3,5].

- **Higher Geospatial Visualization**:

  The SRTCMS works with folium and geopy tools to enhance geographical visualization abilities for user awareness of meteorological conditions displays and alerts. The static maps and fewer desirable graphics climate alerts are given by conventional systems [7,14].

- **Multimedia Alert Integration**: The SRTCMS uniquely incorporates sound and text-to-speech alerts to communicate potential hazards. This multimedia approach ensures that alerts are accessible to a broader audience, including those with visual impairments or communication barriers, that are missing in usual systems [17].

- **User-Centered Interface**: Most of the existing systems may not prioritize ease of approachability, and user experience to relate with systems, and increase the diversity of users such as including residents, researchers, and government officials [6]. The proposed SRTCMS is designed with Tkinder and many Python-based libraries to focus on serviceability and interact with the platform effectively, which conflicts with the existing systems.

- **Specific Saudi City Data Markers**: The targeted weather communication is required to Saudi Arabia [10]. The city-specific data markers achieve this feature in SRTCMS to climate information and alerts in specific Saudi cities.

- **Cloud-Based Setup**: Some traditional climate monitoring systems rely on permanent and regional servers [8]. The SRTCMS facilitates cloud-based infrastructure to provide continuous weather updates to Saudi citizens, leading to scalability and accessibility.

- **Extreme Weather Attentiveness**: The SRTCMS establishes awareness against risky meteorological conditions and provides focused solutions to address the unique extreme climatic challenges of the region in Saudi Arabia which are missing in the current specialized systems. [9].

The SRTCMS is established for its high-frequency cloud-based extreme weather updates, innovative data integration, user-approachable development, and multimedia alert competencies, predominantly in Saudi Arabia. This individual considers the SRTCMS the ideal model for live weather monitoring systems in arid and quickly varying Saudi cities.

3.1 Hardware and Software Requirements

With the various Python packages, the SRTCMS has been implemented enhancing the limitations and functionalities of conventional monitoring systems.

The hardware requirements comprise:
- **System model:** HP ENVY X360 laptop
- **System type:** x64 based PC
- **Processor:** Intel Core i7
- **Operation System:** Microsoft Windows 11 Home
- **RAM:** 2 GB

The software requirements consist of:
- **Tkinter**: For the user interface, providing a user-friendly and intuitive experience.
- **Folium**: For map rendering, allowing the display of real-time weather data on interactive maps.
- **Geopy**: For location services, enabling geographical coordinate retrieval and enhancing map accuracy.
- **Pygame**: By audio alerts, ensure timely communication of weather warnings through sound.

In addition to hardware and software requirements, the system necessitates an active internet connection to access accurate, real-time reliability weather from cloud-based OpenWeatherMapAPI for specific risky cities across Saudi Arabia.

3.2 System Architecture

The SRTCMS architecture illustrated in “Fig. 1” consists of three modules that rely on their functionalities:
1. Data retrieval
2. Data processing
3. Alert display

Data Retrieval: The data retrieval module utilizes OpenWeatherMap API as a data source to dynamic essential meteorological weather data access every five seconds and weather parameters for retrieving specific localized temperature, humidity(moisture), and weather information for Saudi cities. This module ensures local people and servicing sectors get the most recent climate information for selected cities sent to the data processing module.
Data Processing: The data processing module analyses the gathered live weather data, determining alert levels (low, moderate, and high) by threshold processing and detecting extreme conditions and quick climate changes with Hazard detection. This module sends the established alerts and the grouped temperature information to the alert display module.
Alert Display: The alert display module represents the processed data on a dynamically generated HTML geographical map displaying Saudi cities using the Python package folium (map render). It incorporates visual markers color-coded blue: low, orange: medium, and red: high on the map according to live readings of risky heat levels every five seconds for selected Saudi cities. Furthermore, this module detects extreme weather or high-risk temperatures, using Python pygame (audio alert) and

pyttsx3 (text-to-speech) to create audio alert notification spoken messages like “High-risk temperature in Celsius at selected cities” ensuring that residents and agents are informed rapidly about feasible weather threats.

Finally, the SRTCMS alters locals and government agents of weather hazards in their particular risky Saudi cities every five seconds with friendly, real-time, visual, and audio-spoken messages.

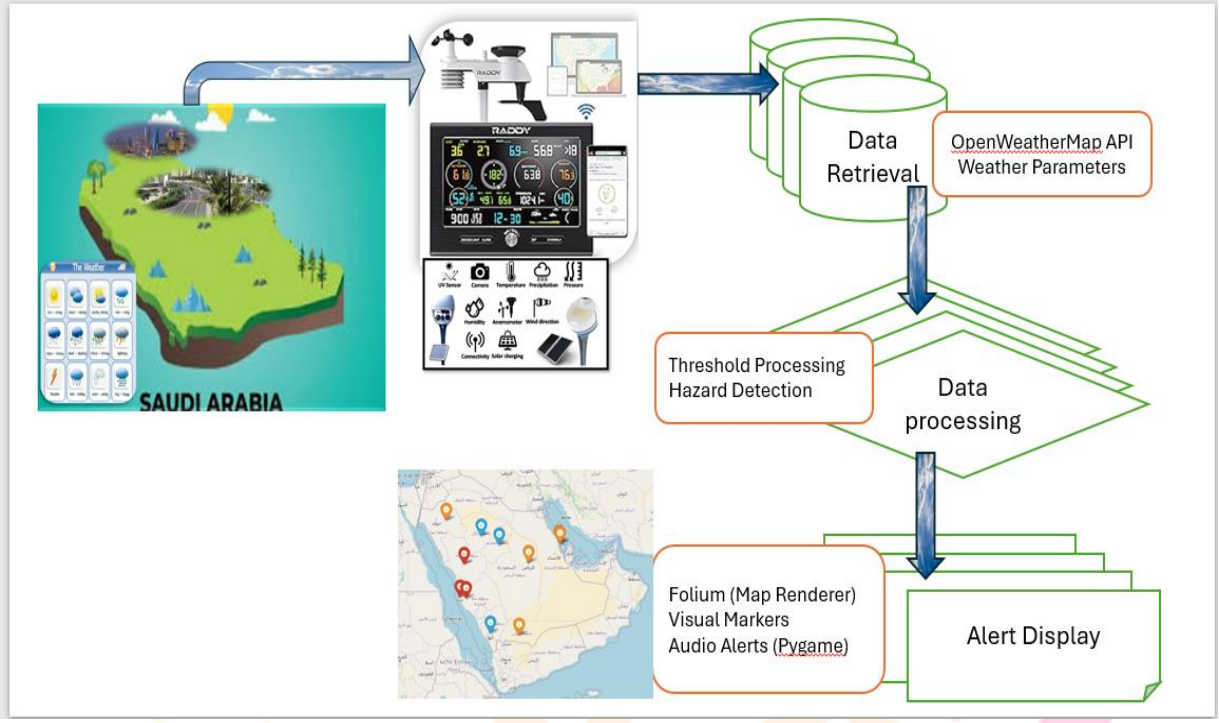

Figure 1. The SRTCMS architecture covered three primary modules: Data retrieval; Data processing; and Alert display.

3.3 Data Collection and Processing

OpenWeather model provides accurate weather data collected from various data resources through radar, satellite, and local and global weather agencies. The data collection process uses the Python OpenWeatherMap API accessing every five seconds to fetch dynamic weather information for a particular Saudi city within SRTCMS. The Geopy is employed to retrieve the geographical coordinates (latitude and longitude) necessary for accurate mapping or locating cities. A systematic color-coding approach categorizes temperature levels into three risk categories: (i) Safe weather (Blue: Low ≤19°C), (ii) Create attention (Orange: moderate 20–24°C), (iii) Triggering alert Red: High: ≥25°C).

3.4 Visualization and User Interface

The SRTCMS uses Python Tkinter, and Folium components to develop the user interface live map and alert windows, warning users of unusual weather conditions effectively. The auto-refreshing map is rendered as an HTML file using Folium updating weather data every five minutes for city-specific markers that exhibit crucial information: temperature, humidity, and current weather conditions. The enhanced SRTCMS fully attracts and ensures users of live weather conditions by triggering an audio-spoken alert with a warning message and a visual marker display on the dynamic Folium map when it detects a high-risk extreme temperature.

4. Results and Discussion

The efficiency and accuracy of the SRTCMS were evaluated across Saudi cities Riyadh, Jeddah, Mecca, Medina, Dammam, Khobar, Dhahran, Tabuk, Abha, and Hail, etc…, Initially, we tested the SRTCMS in delivering real-time weather across 15 cities, then extended it to 50 cities randomly at a time. The results show the following significant findings:

4.1 Accuracy and Responsiveness

The SRTCMS system effectively receives live climate data and displays precise weather conditions every five seconds for selected Saudi cities with the **OpenWeatherMap API**. The system established its ability to update and inform the users of real-time updated weather data during risky temperatures. When a high-risk heat wave is encountered in any specific Saudi city, the system successfully sends an alert threshold according to the categorized temperature levels. This responsiveness is significant for users, especially in cities with extreme weather changes.

4.2 Effectiveness of Visualization Tools

The color-coded visual markers in “Fig. 2” on the interactive dynamic map crucially enhanced users with temperature levels across Saudi cities. Users could easily identify high-risk areas immediately, with colors ranging from blue for low temperatures

(Low: ≤19°C) in “Fig. 3”, orange for medium temperatures (Moderate:20–24°C) in “Fig. 4,” and red for high-risk conditions (High: ≥25°C) in “Fig. 5”. This intuitive visual communication facilitated quicker decision-making and situational awareness among users. The integration of audio alerts proved system effective and user-friendly in capturing users' attention, particularly in scenarios involving extreme heat warnings. Feedback from users indicated that the audio alerts helped ensure that critical information was not overlooked, especially in busy or noisy environments.

Figure 2. Comprehension of temperature levels across different cities with color-coded markers: blue for low temperatures, orange for medium temperatures, and red for high-risk conditions.

Figure 3. Blue color marker (Low: ≤19°C) indicating safe weather conditions

Figure 4. Orange color marker (Moderate:20–24°C) suggesting caution may be warranted.

Figure 5. Red color marker (High: ≥25°C) triggering alerts due to potential health risks from extreme temperatures

4.3 User Experience and Feedback

Users reported a marked improvement in their situational awareness due to the combination of geographic visualization and real-time alerts as shown in “Fig. 6”. Many appreciations show the system's ability to visualize weather data spatially, which helped them better understand the implications of weather conditions concerning their specific locations. The user-friendly interface, built using Tkinter, received positive feedback for its ease of use.

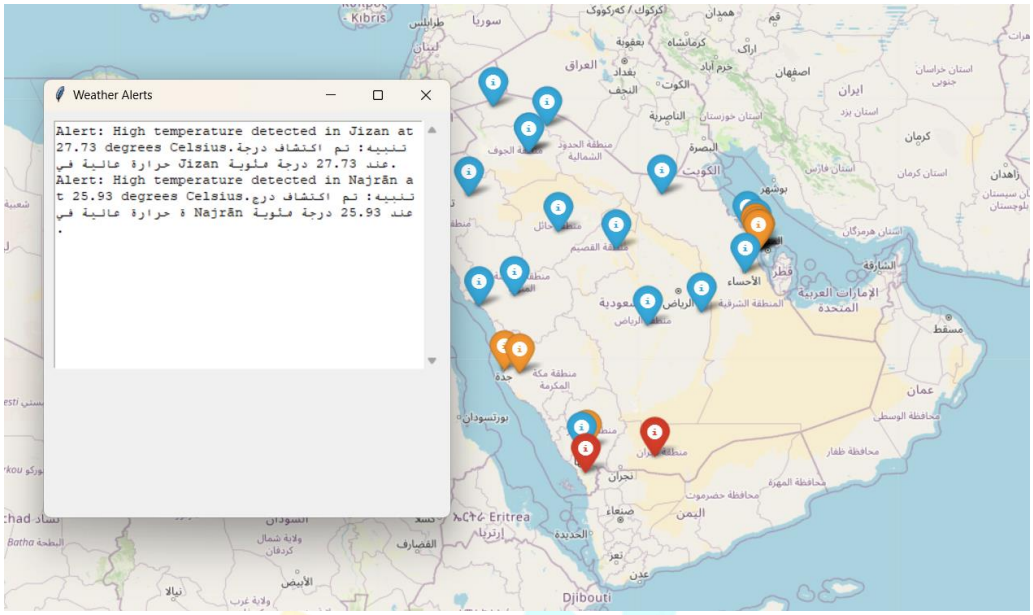

Figure 6. The combination of geographic visualization and real-time alerts.

4.4 Scalability and Integration Potential

The SRTCMS's scalable architecture can be easily adapted for various Saudi cities. Its design permits easy integration with local emergency organization systems, increasing the capacity to respond efficiently to weather-related disasters.

4.5 Limitations of the System

While the SRTCMS is a robust and scalable model for delivering timely, accurate, and user-friendly live weather conditions to public safety and emergency in desert areas across Saudi cities every five seconds, the system needs continuous internet access. Delays in geocoding requests lead to slower response times to retrieving the geographical coordinates of cities across Saudi Arabia.

4.6 Performance Analysis

A comparative assessment of SRTCMS and Global Weather Systems such as The Weather Channel, NOAA's National Weather Service, AccuWeather, Japan Meteorological Agency, India Meteorological Department emphasizing, and World Meteorological Organization key contrasts in update frequency, data sources, accuracy, geospatial resolution, alert methods, and system latency. SRTCMS advances quick updates every 5 seconds, city-specific tracking, and an advanced alert technique combining text-to-speech, sound, and color-coded markers. In contrast, Global Weather Systems combined data from various sources, incorporating satellites and IoT sensors, providing broader coverage with slow updates. The SRTCMS has a lower system latency of 28 seconds, its real-time abilities and localized focus make it a significant tool for urgent weather monitoring and society safety.

5. Conclusion

This study presented a robust, real-time climate monitoring system that addresses the need for immediate and accessible weather updates in Saudi Arabia. The Saudi Real-Time Climate Monitoring System (SRTCMS) effectively delivers timely and accurate weather information across multiple cities in Saudi Arabia, enhancing situational awareness and response to extreme weather conditions with the integration of folium mapping, real-time data updates, rapid data updates, intuitive geographic visualization, and multimedia alert features and Tkinter-based alerts enhance user experience and situational awareness, especially valuable in arid regions where climate conditions can change rapidly. The SRTCMS system successfully incorporates data vision with audio alert methods, announcing alerts in both English and Arabic languages, which is a robust tool for government interventions, investigators, and the community in Saudi Arabia. The SRTCMS will be enhanced in the future by increasing the number of cities around GCC countries and incorporating mobile applications to attract a wider audience and ease access, integrating with local weather services.

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