Anomaly detection in atomic clocks using machine learning and time series approach

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Atomic clocks (ACs) are the most vital devices used by national standard agencies of a nation in order to maintain a continuous and stable time scale. Errors in the prediction of time by the ACs are caused by external factors called anomalies. Monitoring atomic clocks and detecting anomalies is essential for them to serve their purpose. The present study proposes a machine learning-based time-series approach for detecting anomalies in Indian AC data. A point anomaly has been simulated in the AC data, and a prediction has been made. The anomalies have been inserted into the 52-day phase data from August–September 2019 at the National Physical Laboratory, New Delhi. Development has been done in Jupyter Notebook using Python. Based on the analysis, the outcomes showed that precision was achieved at 0.9643, accuracy at 0.9310, recall score was 0.9643, and F1-score was 0.9643, denoting that the obtained results are higher in the 7th and 8th clock, which proves that the developed model is a good fit.

Keywords: Anomalies, atomic clocks, detection, machine learning, time series

A standard time or a frequency based on the resonance of atoms is referred to as an atomic clock (AC). The microwave oscillator stabilisation obtains extreme frequency stability with hyperfine atom transition of alkali metals. An AC is a standard frequency derived from an atom's transition frequency and is used in high-end systems, such as base stations and satellites, due to its outstanding stability and accuracy. ACs must be organised into a small end system with greater frequency uncertainty, given the strength and consistency of the communication network's adjustment. The alkali atom's transition frequency is employed as a standard frequency in the AC[1]. The evolution of ACs brings new creativity to fundamental physics, global positioning system (GPS) techniques, and metrology. ACs are employed not only on satellites but also on terrestrial stations, where they can coordinate clocks in orbit and illustrate the time system. ACs in orbit face anomalies, including temperature fluctuations, radiation, relativistic effects, ageing, and sudden power outages. Detecting anomalies that affect atomic clocks is important for applying sufficient corrections for positioning. The GPS uses ACs of caesium and rubidium[2]. The general block diagram of an AC is shown in Figure 1.

In Figure 1, the atoms first pass through the vacuum chamber of the AC. The movement of atoms is slowed gradually using six lasers by cooling them to near '0' and compressing them into a spherical cloud at the intersection of the laser beams. Then, the two lasers toss the ball upward through a cavity filled with microwaves. Next, the six lasers are turned off. After that, gravity pulls the atom ball back through the microwave cavity. The microwave cavity partially changes the energy levels of atoms[3]. An AC is a device that uses the electromagnetic transition at the resonance frequency between two energy levels in an atomic system to count the number of times between two consecutive seconds. The ACs are categorised into either passive or active, depending on whether the standard frequency results from the radiation of an electromagnet directly or is derived from the radiation of an electromagnet from an exterior oscillator. ACs are important tools of GPS, where the satellites comprise numerous ACs. The receivers of GPS decode the signal by coordinating every receiver to atomic clocks. ACs are used to coordinate signals from various instruments to achieve greater precision[4]. ACs are emerging as a new tool for measuring the local geoid on Earth. The best type of clocks to map date alters the earth's geoimportance with an accuracy of 1 cm over a period of integration of hours. ACs rival the accuracy of differential GPS, which can estimate ground uplift. Clocks provide a separate measurement that is complemented by GPS receivers. ACs estimate the gradual changes in Earth's geoimportance on a sub-centimetre level. The ACs are also used to estimate Earth's tidal response at the local level. The accurate estimation of tide uplift addresses alterations in crustal deformability, which is a feasible precursor to earthquakes[5]. The natural oscillation of atoms performs like a pendulum in a grandfather clock in an AC. Although ACs are more accurate than conventional clocks, the swinging of atoms has a greater frequency and is more stable. The working of an AC is shown in Figure 2.

The AC working process is classified into three steps: heat, pack and sort; count irradiate; and tune and measure.

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