Insanely Accurate Clock May Predict Earthquakes

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Earthquakes take a lot of lives and have a huge impact on economic activities. Japan, in particular, has been hit by numerous earthquakes, including the Great East Japan Earthquake, which hit the Tohoku area in March 2011 and took the lives of over 10,000 people[1]. As long as we live on the earth, not just in Japan, we cannot escape this crustal movement.

However, if we can predict earthquakes, we are able to reduce the damage and protect human lives. Currently, in Japan, the Earthquake Early Warning System allows us to

[1] https://www.data.jma.go.jp/svd/eqev/data/2011_03_11_tohoku/index.html

prepare for earthquakes seconds or even tens of seconds before they occur. If we can predict earthquakes for an hour, a day, or even longer, we should be able to reduce the death toll to zero.

Then, how can we predict an earthquake in the long term? First of all, currently, there is an overwhelming lack of data on crustal movement before an earthquake occurs. Global Positioning System (GPS), which is currently used for car navigation systems, can accurately measure the position in the horizontal direction. Therefore, it is possible to collect data on horizontal crustal movement by GPS. However, GPS is unable to accurately detect vertical crustal movement.

If we can create a system that can precisely measure vertical crustal movement, by combining it with current systems such as GPS, we can collect precise data on crustal movement before an earthquake occurs. The data obtained in this way will reveal phenomena unique to the pre-earthquake period that have not been observed before, and may lead to earthquake prediction.

The optical lattice clock[2] can precisely measure such vertical crustal movement. In other words, the optical lattice clock may be a scientific invention that will be the first step toward realizing long-term earthquake prediction. You may wonder why clocks are useful for earthquake prediction. Let's see how the optical lattice clock works and how it detects vertical crustal movement.

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[2] Ushijima, Ichiro, et al. "Cryogenic optical lattice clocks." *Nature Photonics* 9.3 (2015): 185-189.

First of all, let me explain how clocks measure one second and how to make more precise clocks. Most of the clocks in daily use today are quartz clocks. Quartz has the property of vibrating a fixed number of times per second when an AC voltage is applied, so time can be measured by counting the number of times the quartz vibrates.

If you use a quartz watch, the time is off by about two seconds per month. This is because there is an error in the frequency of the quartz and the frequency of quartz is not precisely kept constant. Therefore, in order to make a more precise clock, it is necessary to keep the frequency used to measure time as accurate and constant as possible.

In order to keep the frequency precisely constant, it is necessary to measure the frequency precisely. We measure the frequency, and if it is off, we feed it back to keep the frequency constant. For example, the cesium atomic clock, which is currently used in the international definition of one second, measures the frequency and keeps it constant by using the property that cesium atoms subjected to a magnetic field absorb light with a very narrow range frequency. The error of the cesium atomic clock is estimated to be about one second per 100 million years.

The optical lattice clock measures the frequency of light much more precisely than the cesium atomic clock using the mechanism explained below, and has achieved an accuracy of 1 second in 30 billion years, about 1000 times higher than the cesium atomic clock.

On the one hand, in the cesium atomic clock, the cesium atoms can move around, and the Doppler effect produces an error in the measurement of frequency. When the atoms move, the frequency of the light emitted by the atoms is observed to be different from the actual frequency, just as an ambulance makes a constant sound when it passes in front of you, but it sounds high or low to us. On the other hand, in the optical lattice clock, the atoms are trapped in an optical lattice made with a laser to minimize this effect and improve the accuracy of the measurement.

Now let me explain how we can predict earthquakes using this precise optical lattice clock. The higher the altitude, the further it is from the center of gravity of the earth's sphere, so the gravity becomes slightly weaker. According to the general theory of relativity, time moves slower at a point where gravity is strong than at a point where gravity is weak. Therefore, we can measure the difference in elevation of the earth's surface, sea surface, and ocean floor by comparing the advance of the optical lattice clock at different points. This is a result of the precision of the optical lattice clock.

The optical lattice clock is excellent at detecting height differences. In fact, it is possible to precisely measure the height of the Tokyo Sky Tree with the error of 13 mm using two optical lattice clocks, one on the observation deck of the Tokyo Sky Tree and the other on the ground[3][4]. Since the optical lattice clocks can measure height differences of only 1 cm, they can detect small changes in height caused by a crustal movement that cannot be detected by GPS.

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[3] https://scienceportal.jst.go.jp/newsflash/20200407_01/

[4] https://www.shimadzu.co.jp/news/press/4nuik3hd982hefif.html

If a geodetic system combining an optical lattice clock and GPS is realized, it will provide detailed data on crustal movements associated with earthquakes and volcanic activities. These data will help us find a way to realize long-term earthquake prediction. In other words, the optical lattice clock is a scientific discovery that may save lives lost due to earthquakes.