A new approach for earthquake early warning: gravitational sensing

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An earthquake is a phenomenon in which the Earth's surface quakes. Human society has faced this disaster many times, and the tragedies with the disaster have been passed down from generation to generation. Helike, an ancient Greek city, was hit by an earthquake followed by a destructive ocean wave in 373 BC and sank into the ocean. In 1556, The deadliest earthquake in human history struck Shaanxi and either hurt or claimed over 800,000 people. The great Tohoku earthquake in 2011 devastated many things including nuclear power plants and killed about 16,000 people. Aftershocks (earthquakes that happen after a larger earthquake) of this earthquake are still being observed to this day, and some of them are reported to have dead people. As earthquake is the result of underground phenomena, this disaster will continue to threaten humanity until the time comes when we stop living on Earth.

Because of the critical consequence of the disaster, people have tried to know an occurrence of an earthquake. Unfortunately, the scientific prediction of earthquakes has not been successful to this day. In other words, there is no way to know precisely when and where an earthquake will strike in advance. Instead, people succeeded in developing the earthquake warning system that detects the occurrence of an earthquake then alerts human society. This system consists of multiple seismometers (devices that respond to ground tremble) and computers. When an earthquake happens, the system detects the fastest earthquake wave then immediately analyzes the source of the quake and the power of other destructive earthquake waves such as S-waves. This system is vital in areas where earthquakes occur frequently. For example, "Earthquake Early Warning" provided by Japan Meteorological Agency has been available in Japan since 2007.

Recently, a new approach is proposed to detect the occurrence of an earthquake. In this approach gravitational detectors, instead of seismometers, will sense a slight modulation of gravitational field caused by an earthquake. When an Earthquake happens, the underground mass is redistributed, thus the gravitational field changes. General relativity tells that the gravitational effect propagates at the speed of light, about 300,000 km/s. This speed is far faster than earthquake waves, as the fastest earthquake wave propagates at ~10 km/s. Therefore, this way of detection will issue earthquake warnings earlier than current seismometer-based systems. The earlier we know about an imminent earthquake, the more we can save lives and prevent secondary disasters. A good example of the benefits of an earlier warning is evacuation from a tsunami: a tsunami is an intense ocean wave triggered by an earthquake and can arrive as fast as a few minutes after the earthquake. Therefore, an earlier warning system can save lives by providing people sufficient time.

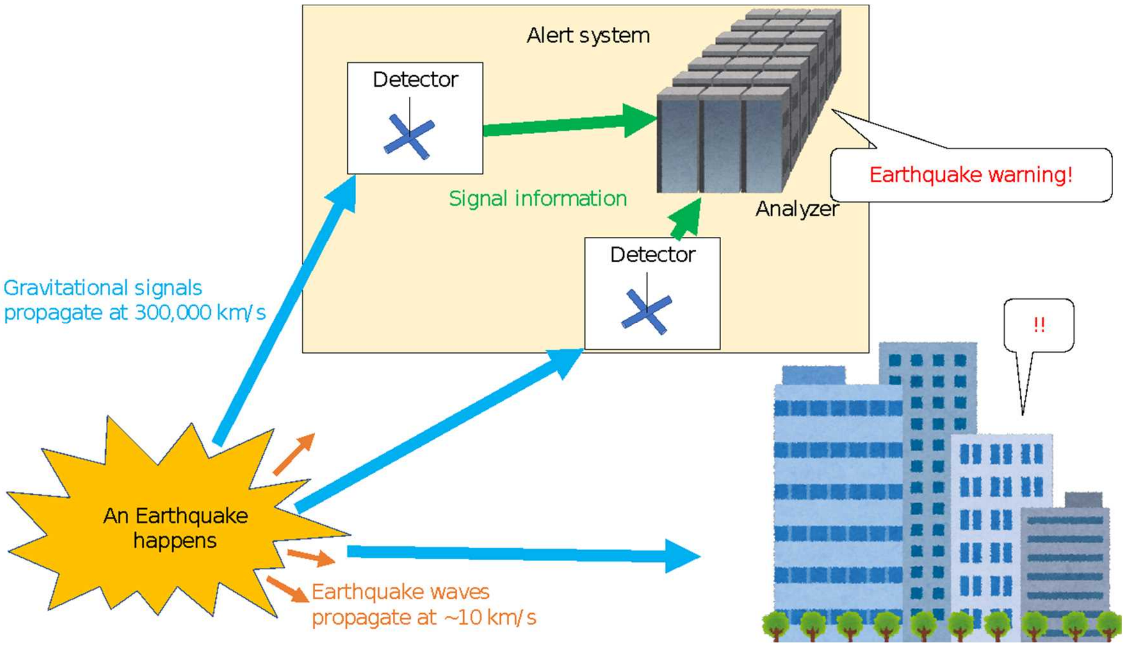
However, it is difficult to sense a modulation of the gravitational field induced by an earthquake because of the tiny amplitude. It is not until 2016 since the gravitational modulation caused by an earthquake was reported [1]. Subsequently, the gravitational signals associated with the great Tohoku earthquake in 2011 are discovered in several locations [2]. The amplitudes of the signals were on the order of nm/s^2($= 10^{-9}$ m/s^2) several thousand kilometers away from where the earthquake occurred. The discovery showed both the possibility and the difficulty to find the earthquake by gravitational signal. Since we feel the gravity of 9.8 m/s^2, The detection system with gravitation must react about 10^{-10} or an even more slight change of gravitation. Such a microscopic modulation requires both high sensitivity and suppression of irrelevant noise to detect.

Some plans of detector use torsion pendulums to face this challenge. A torsion pendulum consists of a mass suspended by a torsion wire. When the mass rotates, the wire twists and reacts to restore its untwisted state, but its tiny restoring force is suitable for subtle force measurement.

TOBA, TOrtion Bar Antenna, is a candidate detector for a new early earthquake warning system, while this scheme initially aimed to detect the gravitational wave (subtle wave of spacetime disturbance) [3][4]. Most current gravitational wave detectors, including LIGO, use laser interferometry, which detects the arrival of a gravitational wave as laser interference due to relative changes in the optical length; it is this method that enabled the first observation of a gravitational wave at LIGO. On the other hand, TOBA uses two bars and locates them orthogonally. If gravitational disturbance happens, the bars start differential rotation. In other words, they rotate with individual angular velocities. Thanks to this structural difference, TOBA can sense low-frequency (below 1 Hz) fluctuation of the gravitational field where interferometers cannot. These low-frequency gravitational waves may be emitted from the very beginning of the universe: the inflationary universe or even the Big Bang. Moreover, such a low-frequency modulation can be caused by a transient earthquake. Thus, the detector may find the signal from the earthquake.

To measure the earthquake with TOBA, the developers estimate that the required sensitivity is $10^{-15}\ /\sqrt{Hz}$ at 0.1 Hz. Since the sensitivity of prototypes was $10^{-8}\ /\sqrt{Hz}$ at 0.1 Hz, noise suppression is essential to achieve the target sensitivity. The developers state that a principal target of the reduction is thermal noise, which originated from the random motion of the component of the system. Since this noise increases in proportion to the system temperature, the researchers will place the device in a cold environment of -269 °C. In addition, they will use silicon or sapphire as the suspension wire because these materials can contribute to the suppression of thermal noise. Combined with other noise-reduction mechanisms, the device will achieve the goal, which will be a big step toward realizing a gravitation-based warning system.

In summary, the earthquake warning system is vital because we cannot avoid the strike of earthquakes. The new approach for earthquake early warning will issue warnings far faster than the current one because of the difference in propagation speed. Researchers found the earthquake signals in gravitation and are constructing a detector prototype. It may not be long before gravitational sensing saves our lives from earthquakes.



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