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Seismoving App: Development of an early warning system for earthquakes

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Abstract

This work presents the development of an early warning system for earthquakes using the school seismograph network created by the Geodynamic Institute of the National Observatory of Athens. This work was conducted under the scientific oversee of Dr. Gerasimos Chouliaras, Research Director of the Geodynamic Institute of the National Observatory of Athens and the educational supervision of Prof. Dr. Norbert Frank, Professor in Physics and Earth Sciences at Heidelberg University.

Keywords
Earthquakes; early warning; triggering; seismograph; network

Introduction
Earthquakes are natural phenomena that causes awe but also many disasters at the same time. That is the reason why the science of seismology is very important and its systematic study may possibly develop a method so that earthquakes can be predicted. In this context, four years ago the Geodynamic Institute of Athens installed a seismograph in the school I used to study, Ellinogermaniki Agogi. Being a student in the 10th grade at the time, this event fueled my curiosity and soon I took part in the Seismology Club of our school. Today there are 65 seismographs installed in schools all over Greece and abroad, enabling many more school students to discover the wonders of seismology.

To be precise, in this work, an early warning system for earthquakes is developed. An earthquake can be detected by seismographs before its arrival in a big city giving the authorities an early warning. The use of the few seconds between the alarm and the arrival of a large earthquake is extremely important and it is enough to save lives and mitigate damages in densely populated areas. In my opinion such a mechanism would be of great value to the corresponding institutions.

In this work, the evolution of such an early warning system is presented, that uses the data from the 65 school seismographs. The coding language used is Python.

Theoretical Background

According to the Institute of Anti-seismic Design of the Greek Ministry of Infostructure and Transportation, an earthquake is “the vibration of the earth, that originates by the disturbance of the mechanical equilibrium of the stone, due to natural causes in the earth. The movement of the ground is caused by the breaking of rock and is the spontaneous result of a long procedure of potential energy accumulation, in damaged areas of the Lithosphere.” Most of the earthquakes are described as tectonic, but there are also volcano-tectonic, degenerate, cryogenic and man-made/artificial earthquakes. In this work only tectonic earthquakes will be considered.

Tectonic Earthquake

The earth’s crust is not a solid piece of rock. It consists of various pieces; we call them tectonic plates. A tectonic earthquake occurs, when two or more of these tectonic plates collide with each other, move apart or parallel to one another. The result of these movements is a set of energy waves we call tectonic earthquake and whose energy is usually measured through the Richter magnitude scale.

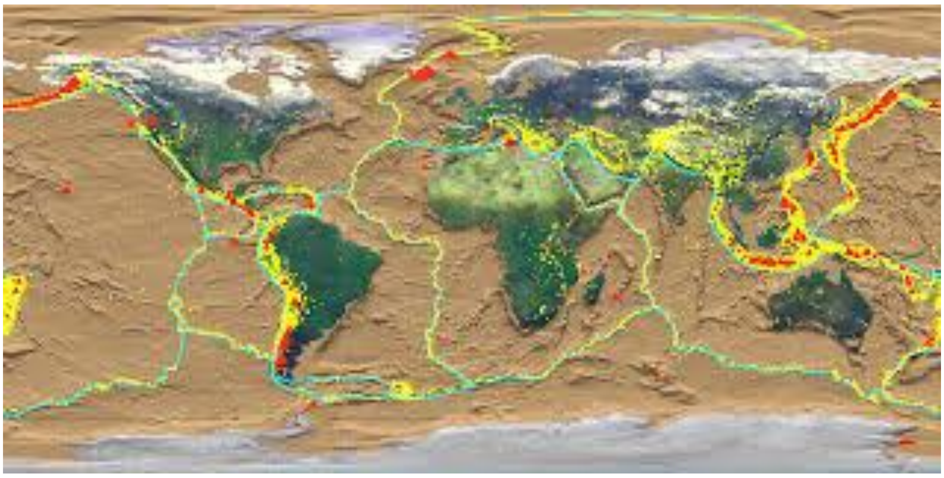

Figure 1: Map of the tectonic plates

The tectonic earthquake consists of many waves, that each move in a different way and with a different velocity. The two main types of waves are the body waves and the surface waves.

The body waves move towards every direction in the earth, while the surface waves move along the along the surface. Earthquakes release their seismic energy as body waves, as well as surface waves. and are of higher frequency than the surface waves.

Body waves are emitted from the epicenter of the earthquake. Due to their movement inside the earth, body waves are detected by seismographs before surface waves.

Body waves come in 2 pulses; the primary P-waves and the secondary S-waves.

The P-waves are longitudinal waves that run through the whole earth. They are the fastest types of seismic waves, with an average speed of about 6 km / s and are therefore the first to be recorded by seismometers. Longitudinal waves can move

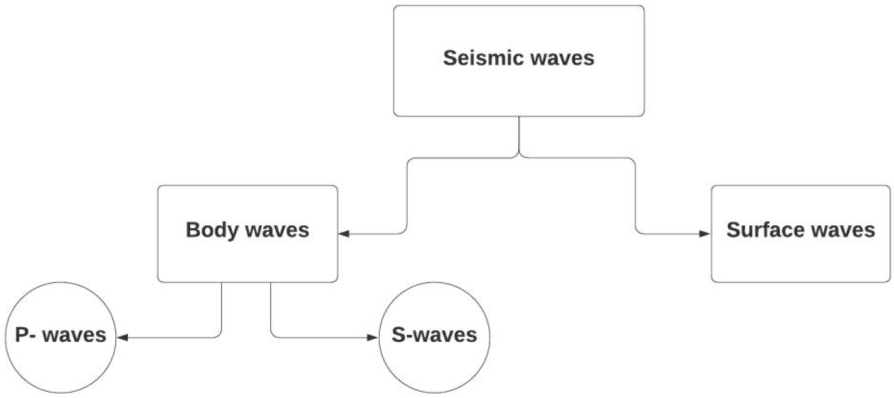

Figure 2: Different kinds of seismic waves

through the solid rocks of the earth and liquids, such as water or the liquid layers of the earth. P-waves push and pull rocks that move just like air in sound waves and for this reason they are also called compression waves.

The next waves to reach the seismographs are the transverse S waves. They are slower, but more powerful and destructive than the longitudinal P-waves. During the propagation of transverse waves, the material points of the rock oscillate perpendicular to the direction of propagation of the wave, causing a change in the shape of the rock. The S-waves travel with an average speed of about 4 km / s and due to their large width, they are the ones that cause strong ground movement, characteristic of large earthquakes.

Finally, surface waves move on the Earth's crust, are of lower frequency than body waves, and are easily distinguished in seismograms. Although they arrive after body waves, they are almost entirely responsible for the damage and destruction associated with an earthquake. The damage they cause is reduced to deeper earthquakes. In this paper, however, we will not deal with surface waves.

Figure 3: Seismic waves in a seismograph

Methods

Using the first parts of the P-waves, the earthquake is detected by stimulating a seismograph. Afterwards the system checks if a second seismograph is stimulated in order for it to be sure, that the events is an actual earthquake and not noise or a coincidental local event.

In order to develop a program for the detection of earthquakes and the early warning of corresponding authorities and the general population, it is important to create a program, which includes a triggering condition between 2 different seismographs. In this research the 65 school seismographs installed by the Geodynamic Institute of the National Observatory of Athens in an equal number of schools in Greece and abroad are used.

Triggering Condition

Coincidence is a method of detecting validity in experimental sciences. It is based on the principle that the stimulation of a sensor may be due to some real or accidental external factor. Triggering, then, requires that more than one condition be met at the right time in order to distinguish between valid and invalid data.

In seismology we use triggering to detect earthquakes. In other words, we consider that if two or more different seismographs are excited at a suitable time frame, then there has been acceptable seismic activity and so the signal they record is real and not a random event.

For the program to detect real-time earthquakes, there must have been two coincidence events within a specific time window.

This is achieved by measuring the amplitude of every seismograph's pendulum. The program reads the amplitude value of every seismograph of the network. If a seismograph is stimulated, then a timer of 5 sec starts counting in reverse. This time window was chosen, so that an earthquake's P-wave has enough time to reach a second seismograph of the network. In case of a second stimulation within this time window, these two coincidence events create our trigger and we are informed about an upcoming earthquake. If this is not the case, the stimulation indicator of the first seismograph is deactivated, the timer is reset and the process begins anew.

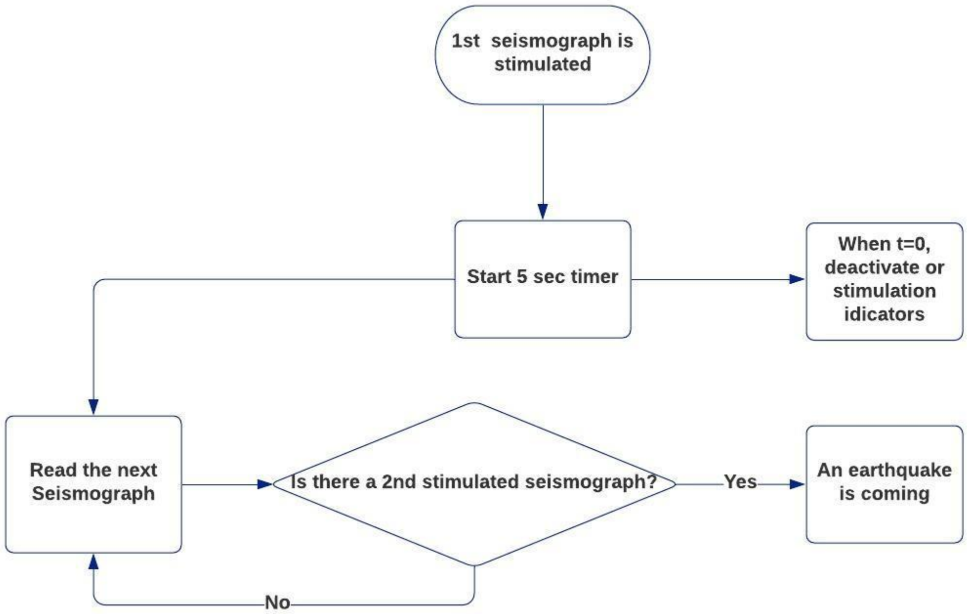

Figure 4: Triggering condition

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Time differences

Apart from the valid information about an upcoming earthquake, it is equally important to know how early we are informed about it and especially in case of a large earthquake. For this reason, the program includes an internal clock, which "runs" in parallel with the main program, using the method of threading. This allows us to find the time of the first (t1) and the second (t2) coincidence events that make up the trigger and to calculate the time (t) from the moment we are informed that an earthquake is coming until the earthquake reaches the main seismograph of Athens (Geodynamic Institute). The reason for this is that the S-wave will arrive in a little less time than t, as it is the second fastest wave.

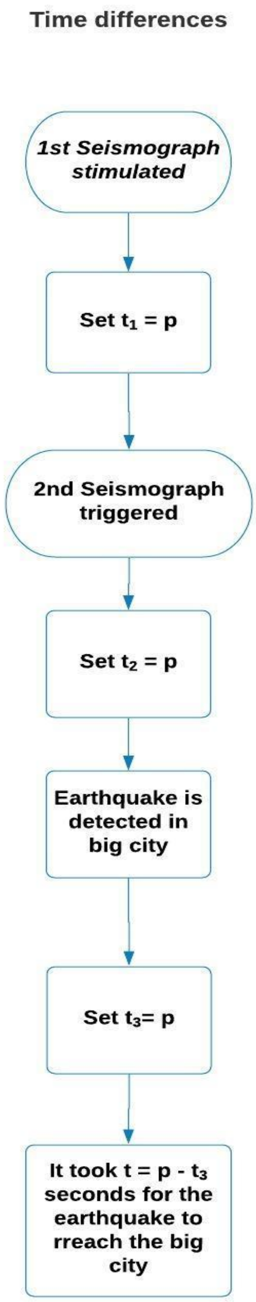


Figure 5: Time differences chart

Testing the real time program with experimental data

The program was tested with variables that change over time to confirm that it is "running" in real time.

Real earthquake files were then tested to determine if the program was working in actual earthquake conditions. At this point the problem of data arrays appeared, which Python could not process in the way required by the program. That is, it could not cut, reverse, and put the arrays on a new list. For this reason, a second code was developed (code - verification assistant), which is not to be used in a real time earthquake, however it allows the verification of the main code.

Thus, taking into account the frequency of seismographs and the inability of python to run multiple programs at the same time, the threading method was used to enable the triggering condition of the main code to be applied to each seismograph separately, and to simulate simultaneous reading of data (seismograms) and verify the results of the main code.

Knowing that the components of the "verification assistant code" have some effect on the results, mainly due to the nature of threading, the triggering time increased from 5 to 7 sec, while a delay of 0.055 sec was included in all seismographs, in order for the program not to run faster than the system would run in real time. It should be noted here that for computing reasons the main code was checked, running the earthquake files with the help of the "verification assistant code" in which the data of up to four seismographs i.e. two for triggering plus one random plus Athens (seismograph of the Geodynamic Institute) were used each time.

Examples and results

Earthquake Zakynthos 25/10/2018

For the triggering the seismographs in Argostoli-Kefalonia (ca 285 km from Athens) and Logga-Messinia (ca 203 km from Athens) were used.

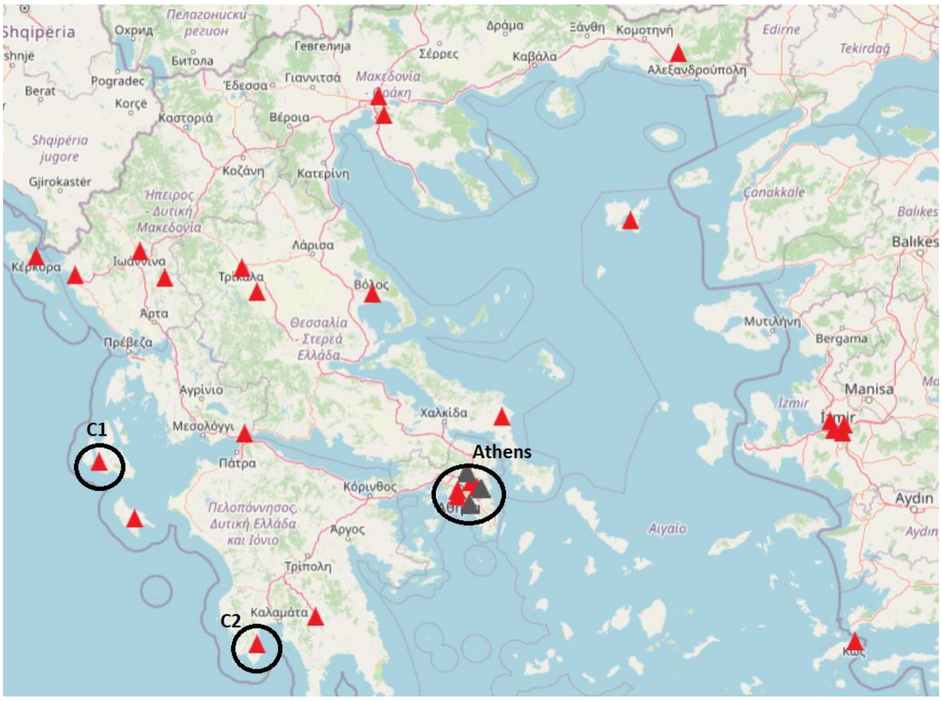


Figure 6: Map, C_1 first stimulated seismograph in Argostoli, C_2 second stimulated seismograph in Logga, target: Athens

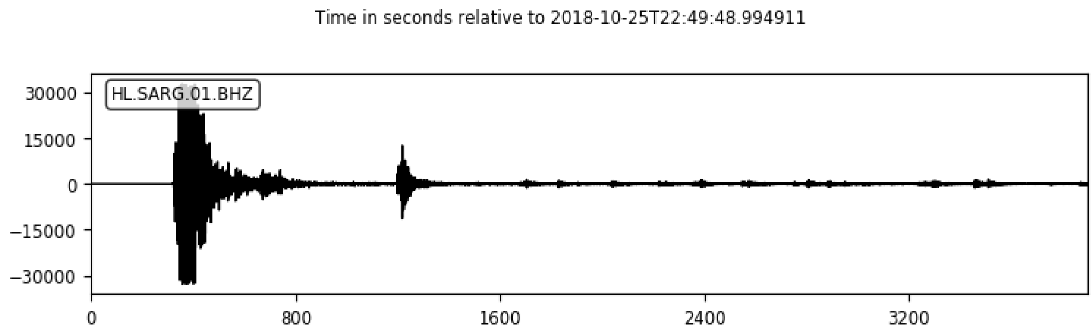


Figure 7: Seismogram in Argostoli

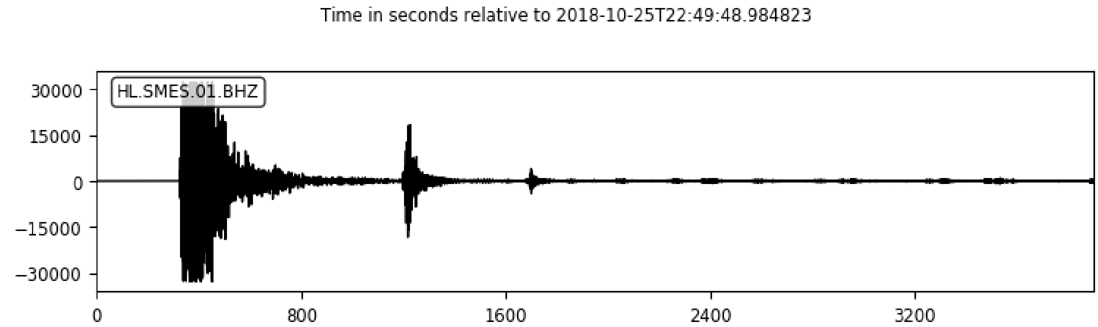


Figure 8: Seismogram in Logga

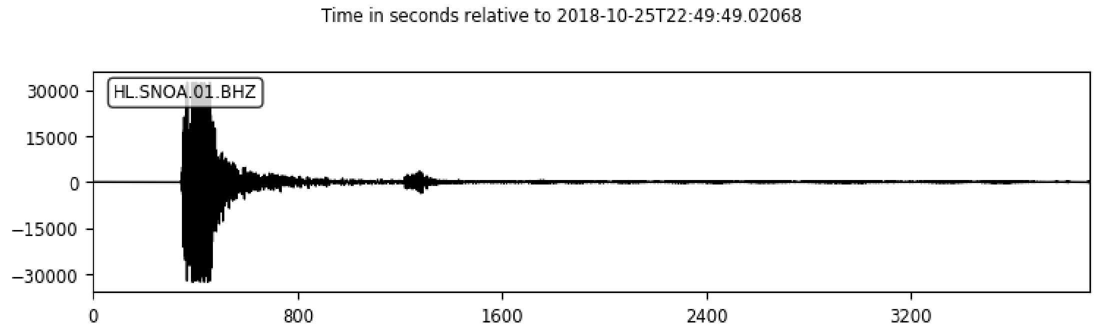


Figure 9: Seismogram in the Geodynamic Institute of Athens

Time of the earthquake arrival in Argostoli since the start of the program (s)	Time of the earthquake arrival in Logga since the start of the program (s)	Time passed between triggering and the arrival of the P-wave in Athens (s)	Time passed between triggering and the arrival of the S-wave in Athens (s)
249	251	15.7	23.55 (+7.85 sec from the P-wave)

Using this system Athens can be warned 15.7 sec before the P-wave's arrival and thus we can calculate that the S-wave will arrive approximately after 7.85 sec.

Earthquake Attica 19/07/2019

Due to the epicenter of this earthquake being in the general vicinity of Athens (Athens is a city in Attica), the seismographs in this example will attempt to give an early warning for the village Avlonari on the island of Evoia (ca 130 km from Athens). For the triggering the seismographs in Athens (Geodynamic Institute) and Pallini (ca 130 km from Avlonari) were used.

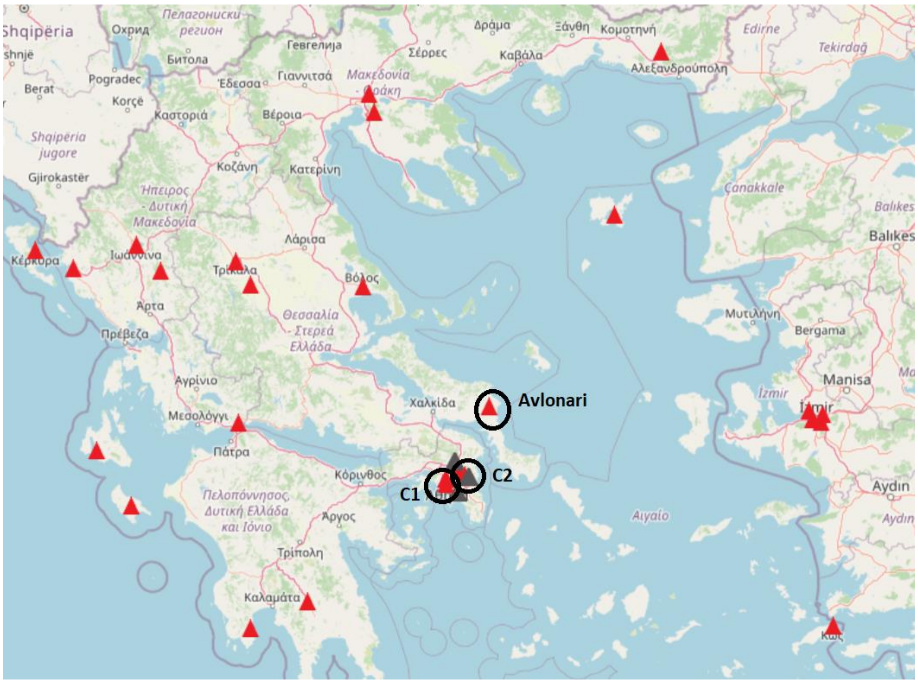


Figure 10: Map, C_1 first stimulated seismograph in Athens (Geodynamic Institute), C_2 second stimulated seismograph in Pallini, target: Avlonari

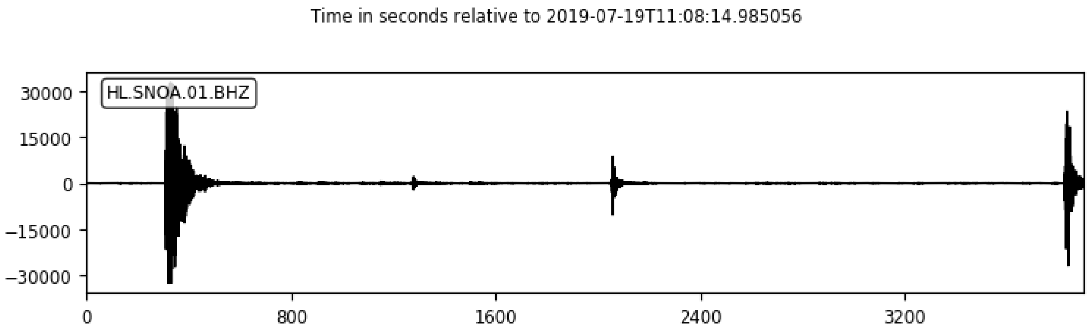


Figure 11: Seismogram in the Geodynamic Institute of Athens

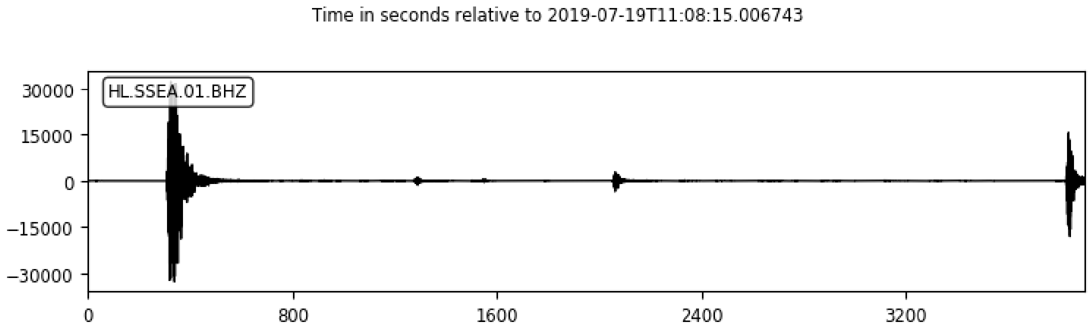


Figure 12 Seismogram in Pallini

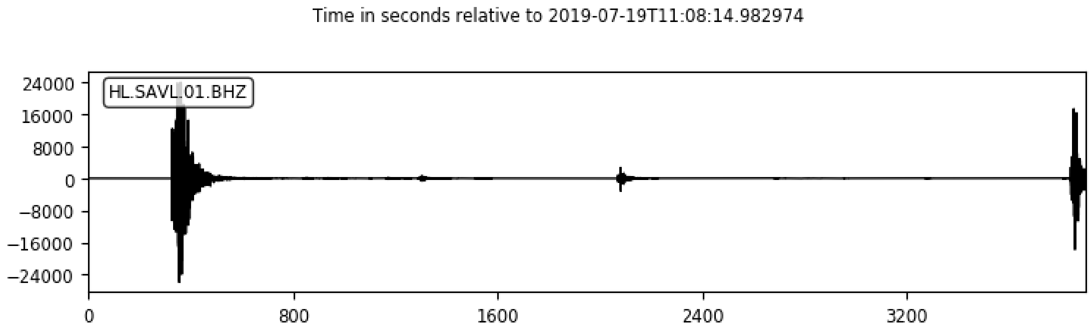


Figure 13: Seismogram in Avlonari

Time of the earthquake arrival in Athens since the start of the program (s)	Time of the earthquake arrival in Pallini since the start of the program (s)	Time passed between triggering and the arrival of the P-wave in Avlonari (s)	Time passed between triggering and the arrival of the S-wave in Avlonari (s)
346.4	346.6	4.1	6.15(+2.05sec from the P-wave)

Using this system Avlonari can be warned 4.1 sec before the P wave's arrival and thus we can calculate that the S wave will arrive approximately after 2.05 sec.

Earthquake Erateini 04/04/2020

For the triggering the seismographs in Nafpaktos (ca 170km from Athens) and Karditsa (ca 220 km from Athens) were used.

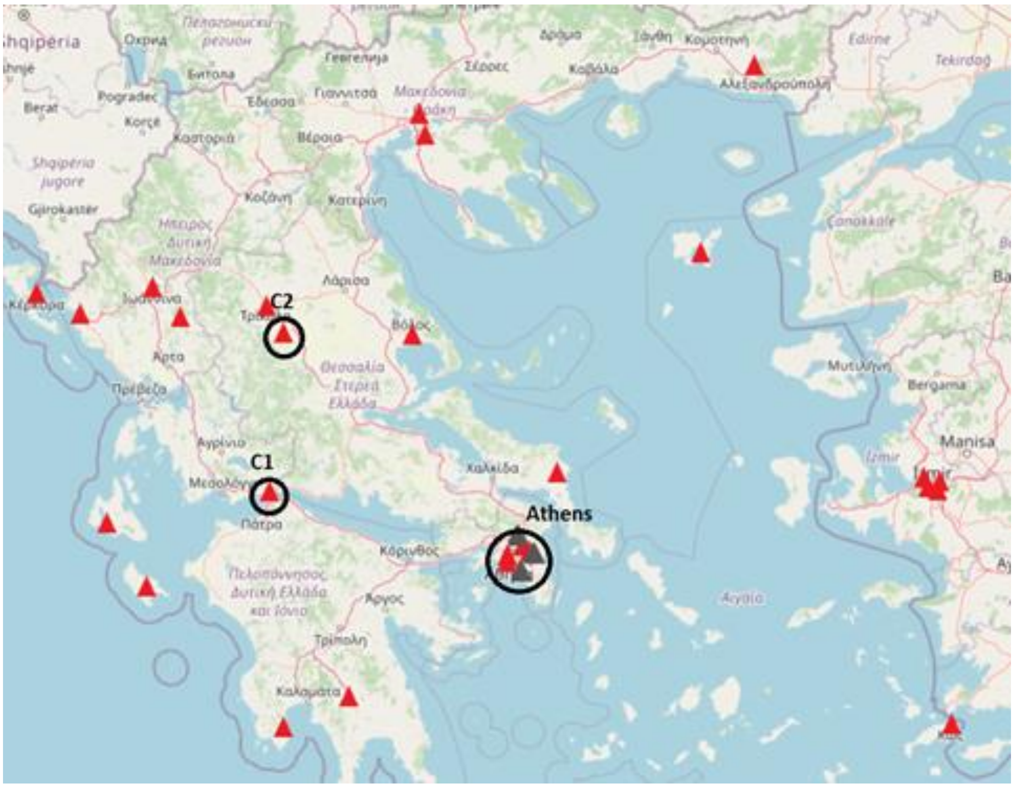
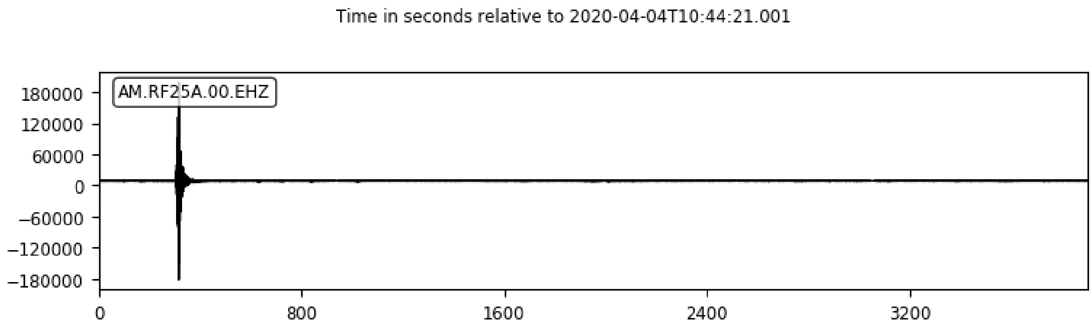


Figure 14: Map, C_1 first stimulated seismograph in Nafpaktos, C_2 second stimulated seismograph in Karditsa, target: Athens



4.3.2: Seismograph in Nafpaktos

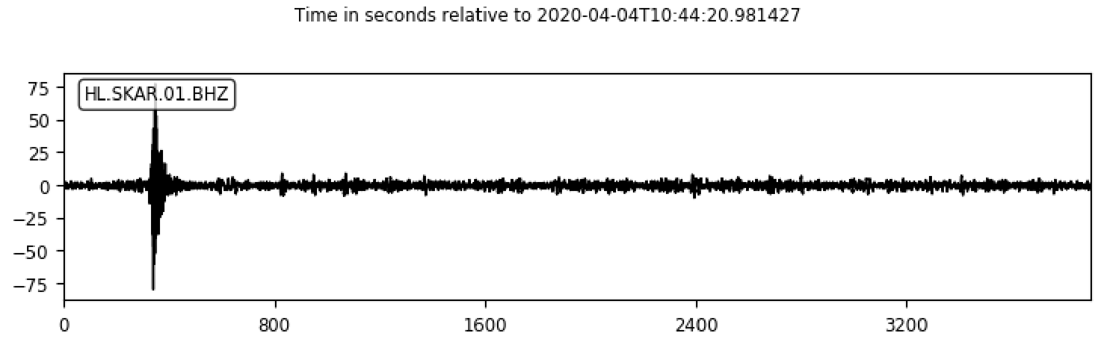


Figure 15: Seismograph in Karditsa

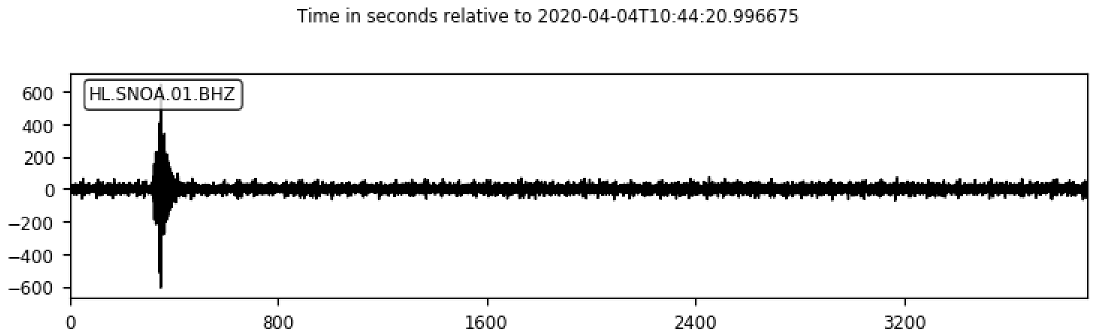


Figure 16: Seismograph in the Geodynamic Institute of Athens

Time of the earthquake arrival in Nafpaktos since the start of the program (s)	Time of the earthquake arrival in Karditsa since the start of the program (s)	Time passed between triggering and the arrival of the P-wave in Athens (s)	Time passed between triggering and the arrival of the S-wave in Athens (s)
53.1	57.3	3.5	5.25(+1.75 sec from the P-wave)

Using this system Athens can be warned 3.5 sec before the P-wave’s arrival and thus we can calculate that the S-wave will arrive approximately after 1.75 sec.

Discussion

Through the real-life examples, one can understand, that when there is a dense network around the epicenter of an earthquake, the authorities can get an early warning, giving them a head start in preparations in order to mitigate damages. The time it takes from the stimulation of the two seismographs until the arrival of the P-waves in the big city, is about the order of 3.5-15.7 sec. After that, the authorities have a time window about the order of 1.75-7.85 sec until the arrival of the destructive waves (S- and surface waves). All in all, by the use of this system the authorities have a total of 5.25-23.55 sec to prepare.

Additionally, such an early warning system would urge the Civil Protection Services to create earthquake preparation protocols. In 3.5 sec, one may not be capable to inform all the authorities, but there is enough time to turn off the electrical grid and natural gas supply in areas of high danger.

Finally, by connecting this system with the 112 Security Services all hospitals, police and firefighter precincts would be informed and all rescue personnel would be in high alert, decreasing their response time.

Conclusion

It is clear that the aim of this research is to create an application that will protect the population from the big catastrophic earthquake. The early warning system, presented here, looks forward to recognizing and taking advantage of the time between earthquakes and the average person hears the sound of an earthquake (P-wave) and the moment-peak that the ground shakes from the earthquake (S-wave).

It should also be noted that this system's downside is that there are not enough seismographs to cover every single possible epicenter and that the performance of this system is directly corelated with the number of seismographs in the vicinity of the earthquake. Having that in mind and knowing that schools are everywhere, where people live, it is easy to assume, that the installation of more school seismographs or the merging of the school and scientific seismograph networks, would create a dense network capable of protecting civilians is plausible.

Appendix

```
t = 5
i = 0
p = 0
B = [False for i in range(5)]
import time
import threading
# In real time we should define the varibles a,b,c,d,e,..... in the list A in order to change
def count_triggered(lst):
   return sum(lst)
def countdown():
   global B
   time.sleep(5)
   B = [False for i in range(5)]
def timepass():
   global p
   while True:
      p = p + 1
      time.sleep(1)
P = threading.Thread(target=timepass,name= 'thread1')
T = threading.Thread(target=countdown, name='thread2')
P.start()
while True:
   time.sleep(0.8)
   a = 1
   b = 2
   c = 3
   d = 4
   e = 5
```

```
A = [a,b,c,d,e]
for i, item in enumerate(A):
 if count_triggered(B) == 2:
     print("An earthquake is coming")
     t2 = p
     # In ath we difine the real time Athens seismograph
     ath = 8
     ATH = abs(ath)
     ####
     if ATH >= 10:
       t = p - t2
       print("It took",t,"seconds for the earthquake to reach Athens")
       print("Moment of 1st Stimulation:",t1)
       print("Moment of 2nd Stimulation:",t2)
       time.sleep(60)
   K= abs(item)
   if K>= 10 :
     B[i]=True
     if count_triggered(B) == 1:
       Check = threading.Thread(target=countdown,name='')
       Check.start()
       t1 = p
```

References

Figure 1: Website of the Geodynamic Institute of the National Observatory of Athens

Acknowledgments

At this point, I would like to thank the people who helped me and contributed to the elaboration of my current research practice.

At first, I want to thank my professor Dr. Norbert Frank who honored me with his trust, giving his approval and support to a student of the first semester of the Department of Physics at the University of Heidelberg to conduct his first scientific research, as part of his studies.

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