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# Signal processing in the "Zhang Heng Seismograph" for remote sensing of impending earthquakes

Dr Jan Pajak
Wellington Institute of Technology,
Petone, Wellington, New Zealand
pajakjan@yahoo.co.nz

## Abstract

This paper explains principles of operation of an instrument for remote detection of impending earthquakes. The only prototype of this instrument was constructed in 132 AD by a Chinese mathematical genius named Zhang Heng. It is probably the reason why this device is presently called the Zhang Heng seismograph. But the original Chinese name for it was the "houfeng didongy yi", meaning "the instrument for inquiry into the fluid and earth movement." The first and the only historically well recorded prototype of this instrument operated successfully until the death of Zhang Heng in 139 AD. It carried out an analog processing of signals that are emitted by impending earthquakes, and raised alarms before these earthquakes were to strike. This paper elaborates also how the analog signal processing of this device could be converted into modern state-of-the-art digital processing and implement on present computer technology.

**Keywords**: earthquake, remote sensing, history, Zhang Heng seismograph, "houfeng didongy yi"

## 1 Introduction

The entire present system of detection of earthquakes is based on the principle of inertia. In this principle an earthquake shakes a frame of an instrument, so that this frame is displaced in relation to an inertial pendulum, while this displacement is registered as the indication of an earthquake. Unfortunately for us, the sole use of this one principle only, introduces a whole range of drawbacks. In turn, these drawbacks effectively cripple our defences against earthquakes. The most significant of these drawbacks is that in the current earthquake sensing technology an earthquake cannot be detected before the shockwaves arrive to a sensing instrument.

Much better solution would be if our civilisation develops a principle and a device, which would allow for a remote sensing of impending earthquakes. After all, before any earthquake strikes, powerful stresses must build up in the Earth's crust, which for sure sends various early-warning signals. If we only consider the piezoelectric effect and principles of electricity generation, it already indicates that when any earthquake is brewing up, powerful electromagnetic signals must be emitted by it. And we must remember, that electromagnetic phenomena are not the only ones, which could carry warnings about impending earthquakes. Since many animals and various psychic people are able to sense remotely the incoming earthquakes, there must also be a way to build a technical device for the same purpose.

At the moment we do not have such a working device yet. However, the historic sources indicate that there was one constructed almost 2000 years ago, and it has proven that it has been feasible. This historic device for remote sensing of impending earthquakes is currently known under a popular (although rather misleading) name of the "Zhang Heng seismograph". However, the original Chinese name for it was much more meaningful. It reads "houfeng didongy yi". This translates into the present scientific terminology approximately as "the instrument for inquiry into the fluids and earth movement." (Note: the term "fluid" is used here in the understanding of hydromechanics – i.e. it encompasses all "non-solids".)

The thesis of this paper states that "**it is possible to work out principles involved in the analog operation of the Zhang Heng's apparatus, and then convert these principles into modern digital (computer) technology, thus obtaining a robust information system for remote sensing of impending earthquakes.** "

The goal of this paper is to explain a practical manner of testing this thesis.

## 2 The Zhang Heng Seismograph

Earthquakes remote detection apparatus originally named the "houfeng didongy yi", was constructed in 132 AD by a Chinese mathematician and technical genius named Zhang Heng. Only a single working prototype of this apparatus was ever built. It was

installed in the palace of Chinese emperor, at that time located in the capitol city Luoyang (present Nanyang city) of the Henan province of China. Historic records indicate that this device was so sensitive, that it remotely detected an earthquake on 1 March 138 AD which destroyed the city of Longxi from western Gansu Province. This city was situated approximately 500 kilometres from the device. Unfortunately, in order to operate, the apparatus required constant maintenance and fine-tuning. Furthermore, only the constructor knew how to do this. So when Zhang Heng died in 139 AD, the apparatus ceased to work and fell into disuse. Soon afterwards it was shifted to the tomb of Zhang Heng. Later it was destroyed during a raid of Mongolian army. In the last century archaeologists managed to excavate remnants of it.

## 2.1 The description of this apparatus

Not many technical details of the Zhang Heng apparatus are available today. These details mainly describe the general appearance of this device and effects of its operation. However, the principles and phenomena utilised in the operation of this extraordinary apparatus, till now remain only a subject of various speculations. Written **historic records** describe the external appearance of this device. So we know this appearance for sure. It is shown here in Figure 1. The "houfeng didongy yi" took the shape of a bronze round "antenna chamber", around 3 meters tall and 1.9 meter in diameter (when measured in the widest cross-section). The side walls and the top of this rounded "antenna chamber" were curved into a parabolic shape, very similar to that of our present satellite dishes. Around peripherals of this chamber, in the half of its height, 8 dragon heads were attached in equal distances from each other. (In the original version of this apparatus, only dragon heads were used – NOT whole dragons as this is visible on the ornamental replica from Figure 1. Actually my own analyses suggest that the use of whole dragons would introduce an unnecessary dissipation of earthquake input signals, thus decreasing the sensitivity of this apparatus.) In the mouth of each of these dragons was placed a metal "pearl". Around the round "antenna chamber" and under each dragon's head was situated a bronze bell which was shaped like a frog. There were 8 of these bells.

**Historic records** also describe results of the operation of this apparatus. Namely, when an impending earthquake was detected, a single metal "pearl" dropped down from a dragon's head to a frog's mouth. (Note that this frog was actually a bronze bell.) The impact of this "pearl" onto the surface of the bronze bell shaped like a frog, produced a loud ringing noise. This noise constituted an earthquake alarm. According to historic records, the ringing alarm raised was loud enough to wake up an entire court of the Chinese emperor.

**Figure 1:** The external appearance of the apparatus for remote sensing of impending earthquakes, popularly called the "Zhang Heng Seismograph" (originally named "houfeng didongy yi"). The model of this device shown above is exhibited in the "Te Papa" museum of Wellington, New Zealand (http://www.tepapa.govt.nz).

The Chinese **verbal tradition** states, that the "houfeng didongy yi" worked in the Emperor's palace like an ornamental fountain. From the mouth of each dragon a steady stream of water flowed. This character of flow of water is called by present hydromechanics as the "**laminar flow**". The flowing water was washing around a metal "pearl" placed in a labile balance in the mouth of each dragon. Then the water flowed gently into the open mouth of a frog below. The highly intriguing detail which emerged from **archaeological excavations**, is that the intakes of water to pipes which forwarded it to the mouths of the dragons, were arranged around the "focal point" of the parabolic "antenna chamber" (means at the very centre of this chamber – not at the wall to which these dragon heads were attached). This detail is intriguing, as it needed to have a justification in the principles of operation of this device. After all, a precise arrangements of these almost a meter long pipes imposed additional constraint on workmanship, not mentioning that each long pipe needed to be continually cleared and maintained.

When an earthquake was approaching, a single "pearl" in the dragon's mouth was put out of balance by the flow of water disturbed by the incoming earthquake signal. This affected pearl was located on the side of the instrument, from which side the earthquake was arriving. Thus, the instrument dropped only this one pearl. The heavy metal pearl dropped onto the mouth of the frog, making a loud

ringing sound. After the alarm was raised, people checked the flow of water pouring from the dragon's mouth located on the side of the impending earthquake. When this flow of water indicated that a powerful earthquake is coming, people still had enough time to escape from the danger zones.

In spite that it was constructed around 132 AD, i.e. almost 2000 years ago, the Zhang Heng device even now exceeds the present level of our knowledge and technology. Practically until today no one managed to re-construct a working model of it. Even worse, the present level of our scientific knowledge apparently does not give an indication of phenomena which would allow to explain how this device really worked. The existing official explanation for the operation of this extraordinary instrument, based on the phenomenon of inertia, does not "hold water". Also no working prototype was ever built to prove that this inertial explanation is feasible

This present lack of knowledge as to how the "houfeng didongy yi" really operated, is the main reason why the analog principles of this extraordinary apparatus are still not re-utilised in modern digital versions of the same instrument. So it is worth to put our effort into finding out what went wrong with the understanding of principles involved in remote sensing of impending earthquakes implemented in this device. After all, if we manage to re-build this device, in practical terms this would mean saving countless human lives.

## 2.2 The conventional explanation of principles of this apparatus based on forces of inertia

The present official explanation of the operation of the "houfeng didongy yi" was developed by an Englishman named Dr John Milne, who himself was an inventor and builder of an inertial seismograph. He suggested that the Zhang Heng's device works on inertia forces, means very similar to his own inertial seismograph. He claimed that inside the bronze "antenna chamber" of this apparatus, a large inertial pendulum was hanging. When an earthquake stroke, this pendulum moved in relationship to the chamber, thus triggering a set of levers which opened the dragons mouths. In turn the opening of the dragon's mouth through the push of these levers caused a "pearl" to drop which then raised an acoustic alarm.

There is a lot of inconsistencies and problems with this official explanation. Some of these are listed on the web page [1]. For example, in order to implement the Milne's principles, the instrument did not require to have the parabolic outlines of the "antenna chamber" similar to present parabolic (satellite) antennas – which for sure was extremely difficult to manufacture in antiquity. A cylindrical shape, which is incomparably easier for manufacturing, would do the same job equally well. It also does not explain why the apparatus worked as a fountain, and why the outlets of the water were at the half-height of the chamber, not at the bottom of it. (A fountain with outlets/dragons at very bottom of the chamber would build up a higher pressure, thus would work much better.) It does not explain why an earthquake caused a single "pearl" to drop from a single dragon mouth – any swing of an inertial pendulum should cause two "pearls" on opposite sides of the chamber to drop. Finally, all attempts to-date to construct a working replica according to Milne's principles, have always failed. So even a single working replica of this wonder device was not constructed in modern times.

## 2.3 An alternative explanation of the operation of this apparatus based on hydromechanics

Because of the obvious infeasibility of the Milne's inertial explanation, I have come up with an alternative explanation for the operation of the same apparatus. My explanation utilises the phenomena of laminar and turbulent flow of water, known from hydromechanics, plus principles of focusing of input signal by parabolic walls of the "antenna chamber".

According to my explanation, the parabolic shape of the chamber of this apparatus was actually designed that way on purpose. It is to deflect signals incoming from the earthquake zone, like a parabolic mirror would deflect them, and to focus these input signals on the inlet of a selected pipe. The pipe forwards the flow of water to the mouth of the dragon positioned on the side of the chamber from which the signal arrived. Therefore the input signal arriving to the inlet of this pipe modifies the property of the water flow, allowing the apparatus to work. Let us now analyse what actually happens during the operation of this remote sensing device.

## 2.4 Analog signal processing in the alternative (hydraulic) explaination of the operation of this apparatus

The first situation which we need to consider is the situation when there was no earthquake brewing up. So no input signal was being transmitted to this apparatus. In such a situation, the apparatus worked like an ornamental fountain. The water of this fountain was accumulated in the parabolic "antenna chamber" where it stabilised itself. Because of the action of gravity, it was entering the inlet pipes, from which it was forwarded to mouths of 8 dragons. It flowed almost statically through these mouths. The nature of flow that the water then displayed in hydromechanics is called the **laminar flow**. The characteristic attribute of this flow is, that it produces a very low friction. Therefore, in spite that the water was washing around the pearls that were kept in a labile balance, the low friction of this water was unable to dislodge the pearls out of the dragon

mouths. So only water was pouring down from the mouths of the dragons to the mouth of the bronze frogs, or more strictly, bronze bells shaped like frogs.

Let us now consider a different situation, when actually a powerful earthquake was initiated somewhere within the detection range of this device. The powerful radiation generated by phenomena that were unleashed by this earthquake arrived to the apparatus from the direction of that earthquake. The radiation was deflected by the inner walls of the parabolic "antenna chamber" in the same way like satellite signals are deflected by modern satellite dishes. Thus this radiation was focused at one particular inlet to a pipe. The water entering this inlet was disturbed by the energy contained in this radiation. The previous laminar flow of water is now converted into a **turbulent flow**. From hydromechanics we know that turbulent flows of water display very high friction. Therefore the "pearl" in a labile position, which is being washed by this water, this time is moved from the dragon's mouth. The "pearl" follows water and drops down to the frog's mouth making a ringing noise and this acts as an earthquake alarm.

The above explains that the "houfeng didongy yi" apparatus was designed to convert energy contained in the radiation generated by an earthquake into a turbulent flow of water, thus forcing a metal "pearl" to fall out of the dragon's mouth. The fall of this pearl caused the apparatus to generate an acoustic alarm.

## 3 An experiment to confirm the hydraulic operation of the Zhang Heng device

I designed an experiment, which I hope one day may confirm that the "houfeng didongy yi" apparatus actually did operate in the manner described above. Here is a general idea of this experiment (technical details will have to be worked out and implemented).

The research station on which this experiment could be carried out is shown in Figure 2. This station is composed of a rectangular glass aquarium (A) filled with water. In the centre of a side wall of this aquarium a smooth pipe (P) is inserted which allows water from the aquarium to pour out as a stream (W). Near the aquarium, on the same side as this pipe (P), a generator (S) of electric sparks is placed. It would be desirable if this generator allows for the regulation of sparks intensity and/or frequency. Electrodes of an electric welding machine, or a working spark plug from present cars, can be used to generate this. Between the pipe (P) and the spark generator (S) a removable steel screen (H) can optionally be placed. On the other side of the aquarium, which is opposite to the spark generator (S), a hemispherical metal mirror (M) is placed. The curvature of this mirror (M) is so selected, that it allows the radiation (O) emitted by sparks (S) to be focused on the inlet to pipe (P).

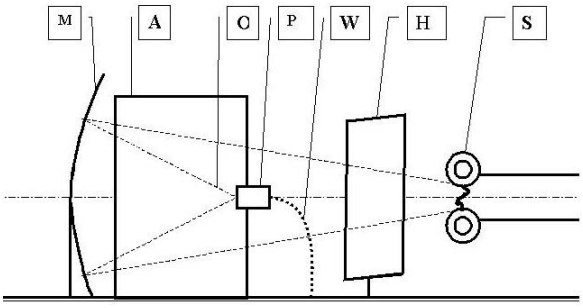


**Figure 2:** An illustration of the research station which allows to carry out a hydraulic experiment capable of confirming the operation of the "houfeng didongy yi" apparatus in a hydraulic manner described here.

Of course, as this is the case with all other experiments, there are various requirements imposed on subsequent components of this working station. For example, dimensions and the inner surface of the pipe (P) must be such, that if water in the aquarium is stationary, the flow (W) of this water through the pipe (P) should be minimal possible, but still maintaining a laminar flow. Furthermore, the curvature and the positioning of the mirror (M) must be such that any radiation incoming from sparks (S) and deflected by (M) must be focused exactly on the inlet to pipe (P).

Let us now consider what should happen in the first phase of the experiment. This phase is to be carried out without the steel screen (H). After the aquarium is filled up with water, we allow this water to flow out through the pipe (P). Since no additional phenomena is generated that would interact with the flow of water, the flow (W) in this first stage must have a laminar character. We can notice this by observing that the flowing water (W) has a smooth surface, deprived of ripples and bubbles. It also flows down uniformly. (If we do not obtain a laminar flow, parameters of the pipe (P) are wrongly selected.)

Now let us consider what could happen when we switch on the generation of spark by (S). The radiation (O) emitted by these sparks is deflected by the mirror (M) and focused at the inlet to the pipe (P). The energy of this radiation is changing the behaviour of water (W) flowing out from the pipe. If the sparks produced by (S) have a sufficient power in relationship to the throughput of water (W), the stream of water (W) should now flow in a turbulent manner. We can see it from a changed (whitish) colour of water, from uneven, bubbly flow of it, and also from ripples on the surface of flowing water.

Although the experiment described here may appear to be simple, in reality it requires a well equipped laboratory. Let us hope, that I will be able to complete it soon, and present the outcome during a next ICST conference. If it is successful, it is expected to demonstrate, that the focusing of radiation emitted by electric sparks is changing the behaviour and properties of the flow of water. In turn the change in

this behaviour can be utilised in an analog or digital processing system described here, for the detection of a signal that is emitted by an impending earthquake.

The additional attribute of this experiment is that it is able to verify whether the emission sent out by sparks (S) and influencing the flow of water (W) has an electromagnetic or a different character. If we repeat this experiment but after placing a steel screen (H) between the spark generator (S) and the mirror (M), the energy of sparks is only able to pass through the screen, if the radiation which carries it has a different character than an electromagnetic waves. (As it is commonly known, an electromagnetic (radio) waves typically are unable to pass through a steel screen.)

## 4 Application potentials after converting the analog signal processing into a digital (computerised) information system

There is a possibility to accomplish the same general purpose of the device described here, if the analog processing of incoming earthquake signals is replaced by a digital processing of the same signals. A computerised information system received in this way would also generate alarms in advance of impending earthquakes to allow for safe evacuation from danger zones. Such a computerised system should additionally be able to estimate the magnitude of an impending earthquake and the amount of time before it strikes.

The general principle on which this system would work is based on the digital interception and on software recognition of subtle signals emitted during the development of conditions leading to an earthquake. The latest developments in voice recognition and image recognition should enable the development of an advance warning system that can sense and isolate these warning signals from background environmental noise. Since these signals incoming from impending earthquakes were already perceived and processed by analog principles of the Zhang Heng seismograph, it paves the way for working out a computerised system that would accomplish the same goal but in a digital manner

The simplest manner of converting the Zhang Heng's principles from analog into digital ones, is to translate these principles into parameters compatible with the present capabilities of computer technology and remote sensing devices, and then to implement them on state-of-the-art computer hardware and software. The essential hardware component most crucial to the successful implementation of this system would be a remote earthquake sensor that could produce advanced warning signals. So far I have experimented with three types of sensing apparatus (1) salt solution in distilled water, (2) optical resonance cavity, and (3) industrial quartz crystal (please see my paper [2] entitled "Thought Recognition Interface"). As demonstrated in the aforementioned paper, the most promising type of sensing apparatus seems to be the quartz crystal, as it appears to be simplest in use and has a high threshold of sensitivity. With the use of digital technology, also the parabolic "antenna chamber" from the "houfeng didongy yi" could be replaced by appropriate system of parabolic antennas (similar to the ones used in modern satellite TV). Such system of antenna dishes would increase the accuracy of the device and could cover a more selective area of seismic activities.

The practical development of the digital equivalent to the Zhang Heng seismograph would require a minimum of two stages of implementation. The first stage would consist of the development of a remote sensing device, which would require the development of not only software, but also the hardware mechanism of such a sensor. In the second stage, specialized software would need to be developed to identify the specific attributes of the signals generated by the conditions of an impending earthquake, and isolate those warning signals from the background environmental noise. The software should also be able to estimate the magnitude of an impending earthquake and the amount of time before it strikes.

## 5 To conclude

Although I have developed the earthquake early warning system as an idea rather than an existing device, in case it is developed technically it has enormous potential for human and social benefit and inestimable potential of commercial value. For example, after appropriate miniaturization, such advanced earthquake detection systems could be built into mobile phones, thus providing personal warning systems instantly providing the individual of warning of an impending earthquake, its approximate magnitude, and the amount of time before it strikes. Such technology would give an enormous commercial advantage to enterprises within the telephone industry. For human and social benefits, the success in the development of this innovative research field could help save many lives.

## 6 References

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