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On Experiments of Synchronization

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Abstract—Synchronization is ubiquitous in our world. We can see various synchronization phenomena in our daily life. In this article, we review several experiments on synchronization of metronomes, candle fires, PET (polyethylene terephthalate) plastic bottles, conducted in our laboratory. We also review that in 1988 synchronization phenomena have already occurred at the Toda Koen Ohashi, a long bridge in Toda city, Saitama, Japan, similar phenomena to the synchronization of the Millennium bridge in London.

1. Introduction

Synchronization is ubiquitous in our real world [1]. We often observe synchronization in various fields. For example, in biological systems, synchronization in a frustrated system of three frogs is observed and its mathematical model of the calling behavior has been proposed [2, 3, 4]. Another example from biological systems is synchronized flashes of fireflies [5, 6, 7].

We can also observe synchronization phenomena from non-biological systems: for example, in mechanical systems, metronomes on a suspended plate or on a moving plate [8], unbalanced rotors on a flexible structure, [9]; in sound vibrations, self-exited sound generated from two Helmholz Resonators [10]; in fluid dynamical systems, candle fires [11, 12], connected PET plastic bottles [13, 14, 15, 16] and two hoses connected to a water supplying pipe system [17] and so on.

In this article, we report experiments of synchronization that we have conducted in our laboratory. We also report that a big bridge, the Toda Koen Ohashi in Saimata, Japan, has experienced synchronization by crowd that steamed into the bridge in 1988. This phenomenon is similar to that has occurred at the Millennium bridge of London in 2000.

2. Metronomes

Metronome is one of the typical example of limit cycle oscillators. Two ways exist to observe synchronization of metronomes. The first one uses a board suspended by wires or equivalents, on which the metronomes are put. To fix the wires, we make two types of apparatus: a frame with 12 rods (e.g. Fig.1), and T-shaped stands (e.g Fig.3). The second one uses a board put on two (or more) cans or PET (PolyEthylene Terephthalate) plastic (empty) bottles, the vertical sections of which are circular.

We have already conducted experiments of metronome synchronization. The numbers of metronomes are from two to ten, 16, 24 and 32. Taking the above-mentioned first way, we constructed two kinds of apparatus in the experiments. The first one is a frame of 900[mm] width × 600[mm] height × 800[mm] depth, and it suspends a light board by four wires (Fig.1). The second one is a pair of T-shape stands, and each of them has 300[mm] width × 300[mm] height × 30[mm] depth (Fig.3).

Figure 1: A frame and a board used for experiments on synchronization of 32 metronomes.

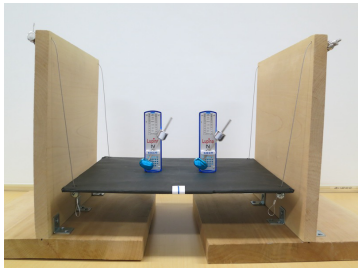
The metronome is called Lupina, manufactured by Nikko Seiki Co. Ltd (Fig.2). Its dimension is 110[mm] height, 32[mm] width and 51[mm] depth, and its weight is about 200[g]. Using these metronomes, we can observe not only in-phase synchronization, but also out-phase synchronization.

We have already uploaded movies of these experiments of synchronization with many metronomes to YouTube. We have many views for these movies. In particular, we have more than 2.5 million views for the synchronization of 32 metronomes [8]. Synchronization of many metronomes is very attractive. Motivated by our experiments, the synchronization of metronomes is used for contents of TV programs in Japan, recently [18, 19].

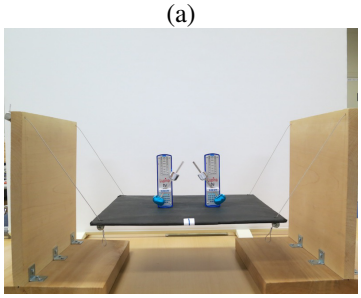
From a theoretical point of view, physical models are proposed to analyze these synchronization phenomena [20, 21]. In Ref.[20], Sato et al. analyzed synchronization phenomena of two metronomes on a board suspended by four wires. They show that a physical model of the experimental apparatus can predict results of the experiments quantitatively as well as qualitatively. In Ref.[21], Pantaleone examined synchronization of two metronomes on a moving board. They proposed a physical model for the experimental setting, and show that in-phase synchronization generally occurs but out-of-phase synchronization occurs under special conditions.

Figure 2: The metronome used for the experiments of synchronization.

In case of using a board-suspended type apparatus, we can observe a bifurcation between in-phase synchronization and out-of-phase synchronization. In Fig.3, we show two snap shots of the in-phase and out-of-phase synchronization. The parameter for observing the bifurcation is an angle between the wires and the vertical boards. Initially, we started the experiment with small angles to observe the in-phase synchronization (Fig.3(a)). Next, we separated the T-shaped stands outwards to make the angle large. Then, we can observe out-of-phase synchronization (Fig.3(b)).



(a)



(b)

Figure 3: (a)In-phase synchronization and (b) out-of-phase synchronization of two metronomes.

3. Synchronization in combustion of candles

The synchronization is also observed in the combustion of candles [11]. Using two candles and two aluminum boards, we conduct some experiments to observe their synchronization.

The candle is manufactured by Kameyama Co. Ltd., Japan. Its diameter and height are 10[mm] and 100[mm] (Fig. 4(a)). We put one of two candles onto the edge of each aluminum board and light the candles under the environment without external airflow. Figure 4(b) shows a schematic diagram of the setup of our experiments.

The distance l between two candles is sufficiently large in the initial condition such that they cannot interact. In this case, the candles burn in a resting state without oscillation. By moving one of two aluminum boards toward another one, the distance l gradually decreases, and then the distance l reaches around 4[mm] which is the minimum length in our experiments. After a few seconds, the candles start to oscillate and synchronize. Using a high-speed video camera whose frame rate is 240 fps (Xacti DMX-HD2000, SANYO Electric Co., Ltd, Japan), we recorded the synchronization of two candles [12]. The brightness of the candles oscillates in synchronization with each other. If we change the number of candles, we can also observe the synchronization. In the movie [22], using four candles, we put two of four candles onto the edge of each aluminum board and conduct the same experiments.

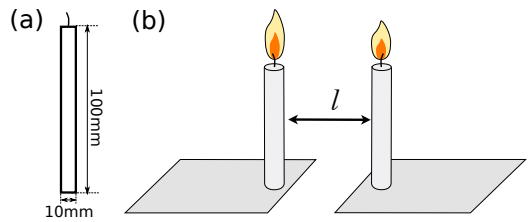


Figure 4: Schematic diagram of (a) the size of candle and (b) the setup of two candles.

4. Synchronization in connected PET plastic bottles

The synchronization of connected PET plastic bottles is also one of typical examples [13, 14]. We use two PET plastic bottles whose width and height are 105[mm] and 300[mm], and connect them by a silicone rubber hose whose external and internal diameters are 13[mm] and 10[mm]. We make a hole with the diameter 10[mm] in the center of the cap of PET plastic bottle whose diameter is 27[mm], and set the caps to the PET bottles. When we turn one PET plastic bottle filled with water upside down before we connect it to another one, drops of water fall from the PET plastic bottle periodically, and thereby we can obtain the PET bottle oscillator. In the experiments, the upside-down connected PET plastic bottles filled with water are put onto a wooden board which has two holes with the size 27[mm] in a manner such that each cap of the PET plastic bottles is attached on each hole of the wooden board (see also Fig. 5(b)). The drops of water initially fall from each PET plastic bottle independently, but the oscillation of

two PET plastic bottles affect each other because of airflow in the silicone rubber hose which connects them. After a few minutes, their timing of dropping of water gradually synchronizes [15, 16]. One might have an idea that the connection is not the silicone rubber hose, but the wooden board on which two PET plastic bottles are attached. However, these PET plastic bottles do not synchronize without the connection by the silicone rubber hose. Further, we can easily find that the internal diameter of the hose affects the synchronization and it might be an essential parameter in the synchronization.

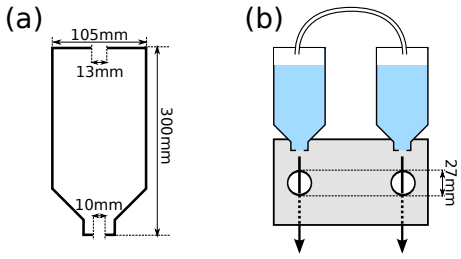


Figure 5: Schematic diagram of (a) the size of PET plastic bottle and (b) the setup of two PET plastic bottles.

5. Bridge

Many pedestrians streamed to the Millennium Bridge in London at the opening day of June 10, 2000. Then, the pedestrians on the bridge oscillated in the lateral direction [23]. Just after three days from its opening day, the Millennium bridge was closed. It took about 1 year and 8 months to fix the problem. In Ref.[24], the motion for the Millennium bridge was modeled by a weakly damped and driven harmonic oscillator, and it is now shown that this phenomenon is due to crowd synchrony.

The Toda Koen Ohashi, or the Toda Park Long Bridge if we literally translate it into English, is a bridge for pedestrians in Toda city, Saitama, Japan (Fig.6). Toda city is located at the southern area of Saitama, just faced to Tokyo Metropolitan area. The bridge connects the east building of the Toda boat race course and the bus terminals. The Toda Koen Ohashi is a cable-stayed-type bridge with two-span steel box girder (Fig.7). After its opening, pedestrians complained that they fell some unexpected lateral motion when many pedestrians are on the bridge.

In Refs.[25, 26], human-induced large-amplitude vibration in lateral direction of the bridge was reported. It is also reported that walking among 20 per cent or more of the pedestrians on the bridge was in synchrony to the girder vibration in the lateral direction. Until mid 1990's, a large number of boat race funs go to the Toda boat race course when the boat race is hold. When all the programmed boat races are finished, the funs go back to the bus terminal simultaneously. Then, the crowds go to the bridge and unexpected synchrony occurred. It is reported that when the crowd synchrony occurred, the number of pedestrians on the bridge is almost 2,000, and this situation continues for more than 20 minutes.

Now, to control the synchronization of the Toda Koen Ohashi, a large number of small tuned liquid dampers (TLD) are installed inside the girder. The TLDs work very well, so the synchronization does not occur presently [25].

Figure 6: Top view of the Toda Koen Ohashi. The photograph is taken from the roof on the east building of the Toda boat race course.

(a)

(b)

Figure 7: (a)Side view and (b) under view of the girder of the Toda Koen Ohashi. In the bottom part of the girder, many TLDs are installed.

6. Conclusion

In this article, we reported experiments of synchronization that we have conducted in our laboratory: metronomes, candle fires, and PET (polyethylene terephthalate) plastic bottles [27]. We also review that in 1988 unexpected synchronization has occurred at the Toda Koen Ohashi, a long bridge in Toda city, Saitama, Japan.

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