Experimental Analysis of Metronome Synchronization

Aris Kanellopoulos, Nick-Marios T. Kokolakis, Filippos Fotiadis

Nonlinear Dynamics and Chaos

Outline

Outline

Outline

Outline

Outline

1. Introduction
2. Experimental setup
3. Measurement setup
4. Result analysis
5. Conclusion and future work

Introduction

- Synchronization of coupled oscillators $\Rightarrow$ Two or more systems interact and move together.

Introduction

- Synchronization of coupled oscillators $\Rightarrow$ Two or more systems interact and move together.
- Accidentally discovered by Christiaan Huygens when observed pendulums hanging from beam.

Introduction

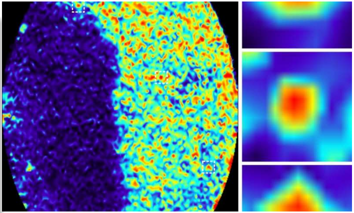
- Synchronization of coupled oscillators $\Rightarrow$ Two or more systems interact and move together.
- Accidentally discovered by Christiaan Huygens when observed pendulums hanging from beam.

Applications

- Biology:

  Firefly synchronization.

  Neural/Pancreatic/Pacemaker cell synchronization.



Introduction

- Synchronization of coupled oscillators $\Rightarrow$ Two or more systems interact and move together.
- Accidentally discovered by Christiaan Huygens when observed pendulums hanging from beam.

Applications

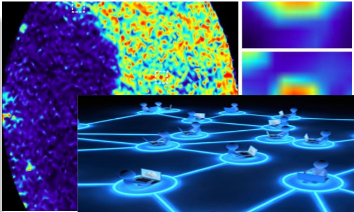
- Biology:

  Firefly synchronization.

  Neural/Pancreatic/Pacemaker cell synchronization.

- Computer science:

  Distributed power grids.



Introduction

- Synchronization of coupled oscillators ⇒ Two or more systems interact and move together.
- Accidentally discovered by Christiaan Huygens when observed pendulums hanging from beam.

Applications

- Biology:

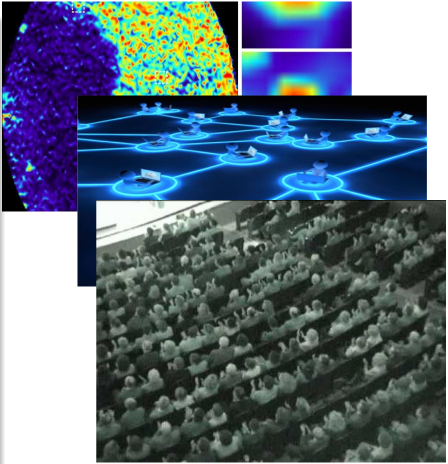
  Firefly synchronization.

  Neural/Pancreatic/Pacemaker cell synchronization.
- Computer science:

  Distributed power grids.
- Social science:

  Opinion formation.

  Audience applause synchronization.

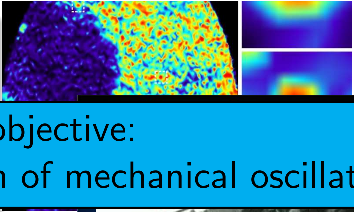


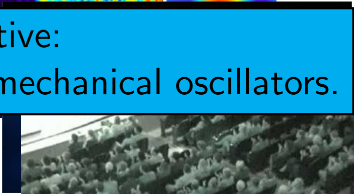
Introduction

- Synchronization of coupled oscillators $\Rightarrow$ Two or more systems interact and move together.
- Accidentally discovered by Christiaan Huygens when observed pendulums hanging from beam.

Applications

- Biology:





Project objective:
Investigate synchronization of mechanical oscillators.

- Computer science:
  Distributed power grids.
- Social science:
  Opinion formation.
  Audience applause synchronization.

Experimental setup

- Coupled mechanical oscillator system $\rightarrow$ Metronomes on moving platform.

Experimental setup

- Coupled mechanical oscillator system → Metronomes on moving platform.

Experimental equipment

- N number of metronomes → subsystems that oscillate at specific frequencies.

Experimental setup

- Coupled mechanical oscillator system $\rightarrow$ Metronomes on moving platform.

Experimental equipment

- N number of metronomes $\rightarrow$ subsystems that oscillate at specific frequencies.
- Light platform made of foam acting as coupling between the metronomes via inertial force transfer.

Experimental setup

- Coupled mechanical oscillator system $\rightarrow$ Metronomes on moving platform.

Experimental equipment

- N number of metronomes $\rightarrow$ subsystems that oscillate at specific frequencies.
- Light platform made of foam acting as coupling between the metronomes via inertial force transfer.
- 2 soda cans, acting as a base that is able to move in one dimension.

Experimental setup

- Coupled mechanical oscillator system $\rightarrow$ Metronomes on moving platform.

Experimental equipment

- N number of metronomes $\rightarrow$ subsystems that oscillate at specific frequencies.
- Light platform made of foam acting as coupling between the metronomes via inertial force transfer.
- 2 soda cans, acting as a base that is able to move in one dimension.
- Camera-equipped smartphone, used to measure positions of the metronomes.

Experimental setup

- Coupled mechanical oscillator system $\rightarrow$ Metronomes on moving platform.

Experimental equipment

- N number of metronomes $\rightarrow$ subsystems that oscillate at specific frequencies.
- Light platform made of foam acting as coupling between the metronomes via inertial force transfer.
- 2 soda cans, acting as a base that is able to move in one dimension.
- Camera-equipped smartphone, used to measure positions of the metronomes.

- For educational purposes, we employed $N = 3$ metronomes to learn how to gather data and develop the required code.

Measurement setup

Measurement equipment

- Used camera phone to capture video of metronomes.
- 2 sets of markers were used for position tracking.

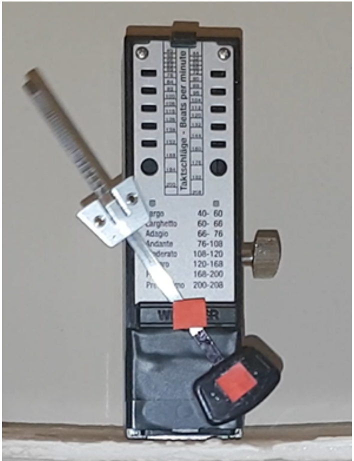
Measurement setup

Measurement equipment

- Used camera phone to capture video of metronomes.
- 2 sets of markers were used for position tracking.

Measurement process

- Metronomes were initialized by random initial positions → Mechanical energy input via spring winding.



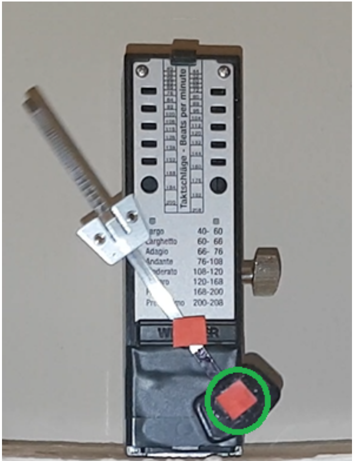
Measurement setup

Measurement equipment

- Used camera phone to capture video of metronomes.
- 2 sets of markers were used for position tracking.

Measurement process

- Metronomes were initialized by random initial positions → Mechanical energy input via spring winding.
- Marker was placed on the edge of the pendulum, used to measure position wrt point of reference.



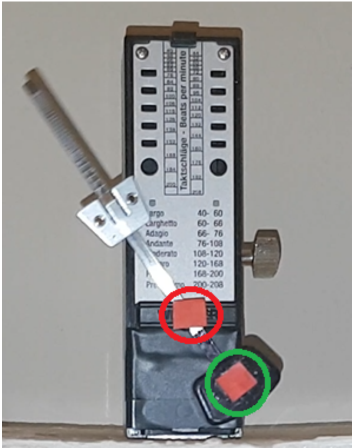
Measurement setup

Measurement equipment

- Used camera phone to capture video of metronomes.
- 2 sets of markers were used for position tracking.

Measurement process

- Metronomes were initialized by random initial positions → Mechanical energy input via spring winding.
- Marker was placed on the edge of the pendulum, used to measure position wrt point of reference.
- Marker was placed on the center of metronome, used as point of reference.



Measurement setup

Video analysis

In order to derive trajectories from video, we developed a Matlab script for motion capture.

Measurement setup

Video analysis

In order to derive trajectories from video, we developed a Matlab script for motion capture.

- Load video to Matlab using *VideoReader* object.

Measurement setup

Video analysis

In order to derive trajectories from video, we developed a Matlab script for motion capture.

- Load video to Matlab using *VideoReader* object.
- Read frame and save as RGB matrix.

Measurement setup

Video analysis

In order to derive trajectories from video, we developed a Matlab script for motion capture.

- Load video to Matlab using *VideoReader* object.
- Read frame and save as RGB matrix.
- For $i = 1, \ldots, N$ metronomes,

Measurement setup

Video analysis

In order to derive trajectories from video, we developed a Matlab script for motion capture.

- Load video to Matlab using *VideoReader* object.
- Read frame and save as RGB matrix.
- For $i = 1, \ldots, N$ metronomes,
  - Determine corresponding positions and reference points.

Measurement setup

Video analysis

In order to derive trajectories from video, we developed a Matlab script for motion capture.

- Load video to Matlab using *VideoReader* object.
- Read frame and save as RGB matrix.
- For $i = 1, \ldots, N$ metronomes,
  - Determine corresponding positions and reference points.
  - Determine x_i, y_i positions of reference point and edge of pendulum.

Measurement setup

Video analysis

In order to derive trajectories from video, we developed a Matlab script for motion capture.

- Load video to Matlab using *VideoReader* object.
- Read frame and save as RGB matrix.
- For $i = 1, \ldots, N$ metronomes,
  - Determine corresponding positions and reference points.
  - Determine x_i, y_i positions of reference point and edge of pendulum.
  - Compute i-th angle $\phi_i = \arctan(x_i, y_i)$.

Measurement setup

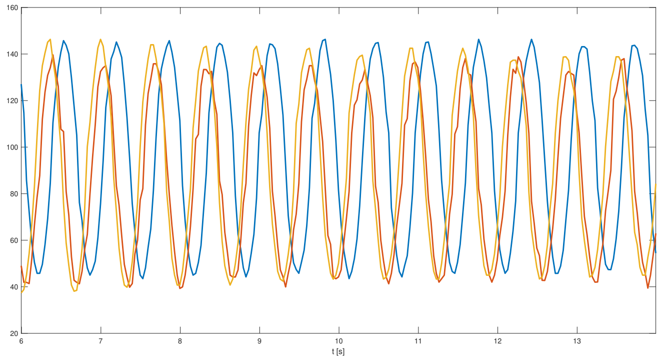
Video analysis

In order to derive trajectories from video, we developed a Matlab script for motion capture.

- Load video to Matlab using *VideoReader* object.
- Read frame and save as RGB matrix.
- For $i = 1, \dots, N$ metronomes,
  - Determine corresponding positions and reference points.
  - Determine x_i, y_i positions of reference point and edge of pendulum.
  - Compute i-th angle $\phi_i = \arctan(x_i, y_i)$.
- Find trajectories of angles for the N metronomes.

Result analysis

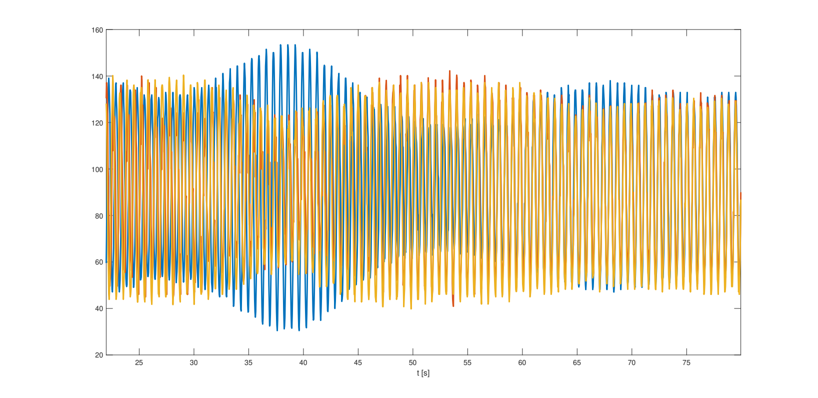
Observed trajectories – Initial phase



- Metronomes are initialized from random angles.

Result analysis

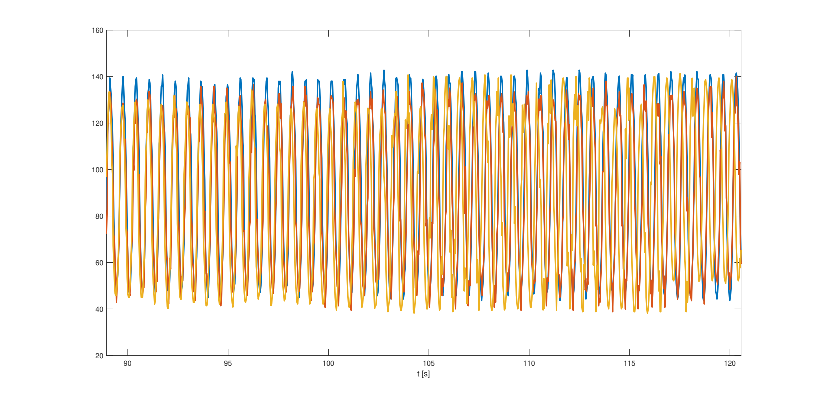
Observed trajectories – Transience



- During $\sim 30, 45$ sec. we observe anti-phase synchronization of one metronome.
- Eventually, all metronomes achieve synchronization.

Result analysis

Observed trajectories – Synchronized phase



- Metronomes are moved off the base – mechanical coupling is lost.
- Synchronization is lost due to perturbations from movement.

Result analysis – Theoretical analysis

- Need to evaluate theoretical models against experimental results.

Result analysis – Theoretical analysis

- Need to evaluate theoretical models against experimental results.
- Develop code to compare evolution of metronome synchronization in simulation and experiment.

Result analysis – Theoretical analysis

- Need to evaluate theoretical models against experimental results.
- Develop code to compare evolution of metronome synchronization in simulation and experiment.

Theoretical model

- Employed model by Bennett et al (2002), Kapitaniak et al (2012).

$$\ddot{\phi}_i + b\dot{\phi}_i + \frac{g}{l}\sin\phi_i + \frac{1}{l}\ddot{x}\cos\phi_i + \bar{F}_i = 0,$$

$$(M + nm)\ddot{x} + B\dot{x} + Kx + ml\sum_{j=1}^{N}\sin\phi_i = 0.$$

Result analysis – Theoretical analysis

- Need to evaluate theoretical models against experimental results.
- Develop code to compare evolution of metronome synchronization in simulation and experiment.

Theoretical model

- Employed model by Bennett et al (2002), Kapitaniak et al (2012).

$$\ddot{\phi}_i + b\dot{\phi}_i + \frac{g}{l}\sin\phi_i + \frac{1}{l}\ddot{x}\cos\phi_i + \bar{F}_i = 0,$$

$$(M + nm)\ddot{x} + B\dot{x} + Kx + ml\sum_{j=1}^{N}\sin\phi_i = 0.$$

- N equations of motion (based on E-L).

Result analysis – Theoretical analysis

- Need to evaluate theoretical models against experimental results.
- Develop code to compare evolution of metronome synchronization in simulation and experiment.

Theoretical model

- Employed model by Bennett et al (2002), Kapitaniak et al (2012).

$$\ddot{\phi}_i + b\dot{\phi}_i + \frac{g}{l}\sin\phi_i + \frac{1}{l}\ddot{x}\cos\phi_i + \bar{F}_i = 0,$$

$$(M + nm)\ddot{x} + B\dot{x} + Kx + ml\sum_{j=1}^{N}\sin\phi_i = 0.$$

- N equations of motion (based on E-L).
- Equation of motion of platform.

Result analysis – Theoretical analysis

- Need to evaluate theoretical models against experimental results.
- Develop code to compare evolution of metronome synchronization in simulation and experiment.

Theoretical model

- Employed model by Bennett et al (2002), Kapitaniak et al (2012).

$$\ddot{\phi}_i + b\dot{\phi}_i + \frac{g}{l}\sin\phi_i + \frac{1}{l}\ddot{x}\cos\phi_i + \bar{F}_i = 0,$$

$$(M + nm)\ddot{x} + B\dot{x} + Kx + ml\sum_{j=1}^{N}\sin\phi_i = 0.$$

- N equations of motion (based on E-L).
- Equation of motion of platform.
- Coupling between metronomes via perturbation force due to $\ddot{x}$.

Conclusion and future work

Conclusion

- Set up the experiment to achieve synchronization of metronomes.
- Investigate the measurement environment to achieve position tracking.
- Developed Matlab code for visual position tracking.
- Studied the literature for appropriate mathematical models.

Conclusion and future work

Conclusion

- Set up the experiment to achieve synchronization of metronomes.
- Investigate the measurement environment to achieve position tracking.
- Developed Matlab code for visual position tracking.
- Studied the literature for appropriate mathematical models.

Future work

- Analyze the fit of the mathematical model.
- Conduct experiment with greater number of metronomes.

Thank you