Look What They've Done To My Shoes!

SCU_China Project 2016

Modeling Handbook

Look What They've Done To My Shoes!

Modeling

Part 0：Perface

At the very beginning, our modeling group planned to build an overall model to describe the whole system, including biochemical reactions induced by our reconstruction(VHb, aarC, etc), design of the insole, and population dynamics of floras(on the foot&inside the insoles).

Here are the initial plans for modeling.

Biochemical Reactions

1. VHb Enhancement
2. “Liv”-Leu-System
3. CH3COOH Absorption
4. Temperature Inducement

Insole Design

1. Human Gait
2. Mechanical Analysis
3. Design
4. 3D Modeling and Print

Population Dynamics

1. Temperature Conduction
2. Population of E.coli Inside the Insole
3. Population of the Floras on the Foot
4. Deodorizing Effects

In our work, numerical simulation softwares have been widely used for modeling, such as Matlab, Mathematica, Eclipse and COMSOL Multiphysics. And all of our program and code have been uploaded.

By now, **Biochemical Reactions** and **Insole Design** have been accomplished in the main. Besides, **Population Dynamics** has been partially completed as well. However, due to the lack of time and pertinent data, the majority of our modeling work is far from being optimized or verified yet. So we’ll choose and show the three models which have been verified and supported by experiment data, as follow.

Part 1. VHb Enhancement

In our biological design, VHb plays a great role in the enhancement of the growth and division of the engineering bacterias. Because of that, it is important and significative for us to make clear how the enhancement depends on related parameters, like the oxygen concentration.

Based on Hill Equation, the conservation of oxygen and energy, a model to simulate the division cycles of E.coli has been built.

By simulating and comparing the division cycles of different types of E.coli, the phenomenon that the one with VHb grows faster than the one without in low oxygen environment but the situation gets contrary in high oxygen environment, which is mentioned in a paper from China[1], can be explained and predicted perfectly. Furthermore, the existence of the best enhancement induced by VHb, which has been found by our experiment group, can be simulated with this model as well.

Part 2. Human Gait

The specific insole is designed not only to cultivate bacterias but also to bear the weight and pressure induced by a man. If the insole can't satisfy the basic mechanical requirements, it may lose its function and cause biological pollution. It is necessary to figure out how much pressure will be imposed on the insole when its user walks, jumps or runs.

Based on Newton's second law, we can calculate the pressure on the insole, as long as we measure the acceleration of the foot. Therefore, we designed and programmed a mobilephone software with Eclipse, which runs on Android platform and could record the accelerations in 3 directions (x,y,z) accurately. With the mobilephone tied on the foot, the acceleration data coule be measured easily, as a result, we could get the information about the pressure imposed on the insole, and know exactly the basic mechanical requirement that the insole must satisfy.

Part 3. Population of E.coli inside the Insole

Due to the temperature response promoter in E.coli, the increasing rate of the population would be acted upon by temperature changes. Therefore, before we simulate the population of E.coli inside the insoles, it is necessary for us to figure out how the temperature changes as the shoes get put on or taken off first.

Based on Newton's law of cooling, an model for the change process of temperature has been built and verified with experiments. Combined with the characteristics of temperature changes, we also build a model for the population of E.coli which contains cecropin with discrete Logistic model, and then analyse the population as well as the release of cecropin by simulating on Matlab.

The numerical simulation results show that the insole system could work continually as expected and have a huge potential to be optimized.

Part 1：VHb Enhancement

Goal:

To analyse and figure out how the growth of E.coli is effected by the oxygen concentration.

Introduction:

In our biological design, VHb plays a great role in the enhancement of the growth and division of the engineering bacterias. Because of that, it is important and significative for us to make clear how the enhancement depends on related parameters, like the oxygen concentration.

Based on Hill Equation, the conservation of oxygen and energy, a model to simulate the division cycles of E.coli has been built.

By simulating and comparing the division cycles of different types of E.coli, the phenomenon that the one with VHb grows faster than the one without in low oxygen environment but the situation gets contrary in high oxygen environment, which is mentioned in a paper from China, can be explained and predicted perfectly. Furthermore, the existence of the best enhancement induced by VHb, which has been found by our experiment group, can be simulated with this model as well.

Model：

Symbol:

Variable	Meaning
W	Diameter of a cell
L	Length of a cell
cc	Oxygen concentration outside the cell
c_{O_2}	Oxygen concentration inside the cell
t	Time
k	Strength of effect of VHb
n_{VHb}	Amount of VHb inside the cell
N_{VHb}	Number of gene express paths for VHb
α_{VHb}	Promoter strength for VHb

ξ_{VHb}	Promoter leakage of VHb
δ_{VHb}	Degradation of VHb
$c_{\text{M-VHb}}$	Turning point of VHb
m_{VHb}	Hill coefficient of VHb
$P_{\text{Anaerobic}}$	Power produced by anaerobic respiration
$P_{\text{Anaerobic-0}}$	Maximum power produced by anaerobic respiration
$\alpha_{\text{Anaerobic}}$	Strength for anaerobic respiration
$c_{\text{M-Anaerobic}}$	Hill coefficient for anaerobic respiration
$m_{\text{Anaerobic}}$	Hill coefficient for anaerobic respiration
n_{X}	Amount of product from plasmids inside the cell
N_{X}	Number of plasmids
α_{X}	Promoter strength for metabolism of plasmids
ξ_{X}	Promoter leakage of metabolism of plasmids
δ_{X}	Degradation of metabolism of plasmids
$c_{\text{M-X}}$	Turning point of metabolism of plasmids
m_{X}	Hill coefficient of metabolism of plasmids
n_{Target}	Amount of target protein inside the cell
N_{Target}	Number of gene express paths of target protein
α_{Target}	Promoter strength for target protein
ξ_{Target}	Promoter leakage of target protein
δ_{Target}	Degradation of target protein
m_{Target}	Turning point of target protein

$c_{\text{M-Target}}$	Hill coefficient of target protein
K_{VHb}	Oxygen expenditure for synthetic of VHb
K_{Target}	Oxygen expenditure for synthetic of target protein
K_{X}	Oxygen expenditure for metabolism of plasmids
K_L	Oxygen expenditure for growth of the cell
W_{VHb}	Energy expenditure for synthetic of VHb
W_{Target}	Energy expenditure for synthetic of target protein
W_{X}	Energy expenditure for metabolism of plasmids
W_L	Energy expenditure for growth of the cell

It is known that VHb plays an inportant role in low oxygen environment indeed but becomes an energetic burden when the oxygen is enough. Therefore, it is a very possibility that the rate of VHb synthesis is regulated by oxygen negatively, so we will take it as an assumption and describe it with Hill Equation.[2]

Synthetic of VHb:

$$\frac{\mathrm{d}n_{\text{VHb}}(t)}{\mathrm{d}t} = N_{\text{VHb}} \cdot \left\{ \frac{\alpha_{\text{VHb}} - \xi_{\text{VHb}}}{1 + \left[\frac{c_{\text{O}_2}(t) + \dfrac{k \cdot n_{\text{VHb}}(t)}{\pi \cdot \left(\dfrac{W}{2}\right)^2 \cdot L(t)}}{c_{\text{M-VHb}}} \right]^{m_{\text{VHb}}}} + \xi_{\text{VHb}} - \delta_{\text{VHb}} \right\}, \quad (1.1)$$

Note that $k \cdot n_{\text{VHb}}(t)$ is the total content of oxygen effected specificly by VHb, and $\pi \cdot \left(\frac{W}{2}\right)^2 \cdot L(t)$ is the volume of a cell. So $c_{\text{O}_2}(t) + \dfrac{k \cdot n_{\text{VHb}}(t)}{\pi \cdot \left(\frac{W}{2}\right)^2 \cdot L(t)}$ represents the real concentration of oxygen inside a cell and

controls the biochemical reaction .

Similar to the description of VHb, we also assume that the anaerobic respiration is regulated by oxygen negatively as well. Besides, the metabolic rate of plasmids and the synthetic rate of target protein are both regulated by oxygen positively. Here are the equations.

Anaerobic Respiration:

$$P_{\text{Anaerobic}}(t)=P_{\text{Anaerobic-0}}\cdot\frac{\alpha_{\text{Anaerobic}}}{1+\left[\frac{c_{O_2}(t)+\frac{k\cdot n_{\text{VHb}}(t)}{\pi\left(\frac{W}{2}\right)^2\cdot L(t)}}{c_{\text{M-Anaerobic}}}\right]^{-m_{\text{Anaerobic}}}},\ (1.2)$$

Metabolism of Plasmids:

$$\frac{\mathrm{d}n_{\text{X}}(t)}{\mathrm{d}t}=N_{\text{X}}\cdot\left\{\frac{\alpha_{\text{X}}-\xi_{\text{X}}}{1+\left[\frac{c_{O_2}(t)+\frac{k\cdot n_{\text{VHb}}(t)}{\pi\left(\frac{W}{2}\right)^2\cdot L(t)}}{c_{\text{M-X}}}\right]^{-m_{\text{X}}}}+\xi_{\text{X}}-\delta_{\text{X}}\right\},\ (1.3)$$

Synthetic of Target Protein:

$$\frac{\mathrm{d}n_{\mathrm{Target}}(t)}{\mathrm{d}t}=N_{\mathrm{Target}}\cdot\left\{\frac{\alpha_{\mathrm{Target}}-\xi_{\mathrm{Target}}}{1+\left[\frac{c_{\mathrm{O_2}}(t)+\frac{k\cdot n_{\mathrm{VHb}}(t)}{\pi\left(\frac{W}{2}\right)^2\cdot L(t)}}{c_{\mathrm{M\text{-}Target}}}\right]^{-m_{\mathrm{Target}}}}+\xi_{\mathrm{Target}}-\delta_{\mathrm{Target}}\right\},\quad(1.4)$$

It's obvious that, there are 4 directions of the flow of oxygen and energy:

1. synthetic of VHb

2. synthetic of target protein

3.metabolism of plasmids

4. metabolism and growth of the cell

we consider that the energy produced by anaerobic respiration and aerobic respiration, will be totally used for the 4 parts mentioned above, as well as the oxygen which diffuses in from outside.

Here are the conservation equations.

Conservation of oxygen:

$$\frac{\mathrm{d}c_{\mathrm{O_2}}(t)}{\mathrm{d}t}=\frac{1}{\pi\left(\frac{W}{2}\right)^2}\cdot\left\{\begin{array}{l}\left[\pi\left(\frac{W}{2}\right)^2\cdot L(t)\right]\cdot c_{\mathrm{O_2}}(t)\cdot\left[-\frac{1}{L(t)^2}\cdot\frac{\mathrm{d}L(t)}{\mathrm{d}t}\right]+\\ \frac{1}{L(t)}\cdot\left[\begin{array}{l}\frac{D_{\mathrm{O_2}}}{d}\left(cc-c_{\mathrm{O_2}}(t)\right)\cdot\left(\pi W\cdot L(t)+2\cdot\pi\left(\frac{W}{2}\right)^2\right)\\ -k\cdot n_{\mathrm{VHb}}(t)-K_{\mathrm{VHb}}\cdot\frac{\mathrm{d}n_{\mathrm{VHb}}}{\mathrm{d}t}-K_{\mathrm{Target}}\cdot\frac{\mathrm{d}n_{\mathrm{Target}}}{\mathrm{d}t}-K_{\mathrm{X}}\cdot\frac{\mathrm{d}n_{\mathrm{X}}}{\mathrm{d}t}-K_L\cdot\frac{\mathrm{d}L(t)}{\mathrm{d}t}\end{array}\right]\end{array}\right\},\quad(1.5)$$

Conservation of energy:

$$\begin{aligned}&\left[\frac{D_{\mathrm{O_2}}}{d}\left(cc-c_{\mathrm{O_2}}(t)\right)\cdot\left(\pi W\cdot L(t)+2\cdot\pi\left(\frac{W}{2}\right)^2\right)\right]\cdot W_{\mathrm{O_2}}+W_{\mathrm{Anaerobic}}(t)\\&=\frac{\mathrm{d}n_{\mathrm{VHb}}}{\mathrm{d}t}\cdot W_{\mathrm{VHb}}+\frac{\mathrm{d}n_{\mathrm{Target}}}{\mathrm{d}t}W_{\mathrm{Target}}+\frac{\mathrm{d}n_{\mathrm{X}}}{\mathrm{d}t}\cdot W_{\mathrm{X}}+\left[\pi W\cdot\frac{\mathrm{d}L(t)}{\mathrm{d}t}\right]\cdot W_L\end{aligned},\quad(1.6)$$

To compute the growth and division of a cell, we take $L(t)$ as the length of the cell and give it an initial value L_0. $L(t)$ represents the growth of the cell, and has a significant impact on the whole system. We assume that the cell will divide when $L(t)$ reaches $2L_0$, so we can computing the division cycle of cells by numerical simulation software.

Results:

The result of modeling is just the same as our experiment result of E. coli with VHb before the second critical point, which means the model has been proved strongly.

The simulation and experiment results are as below.

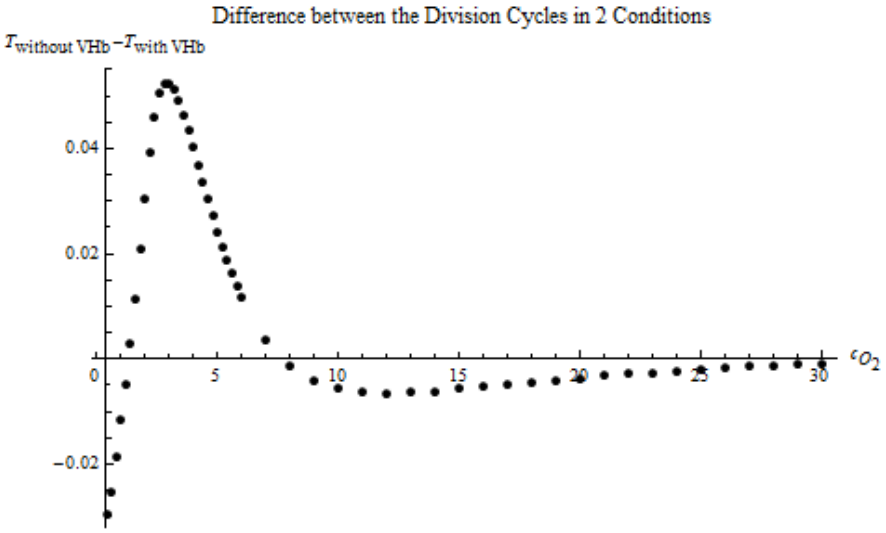

Figure 1.1 Difference between division cycles in 2 conditions

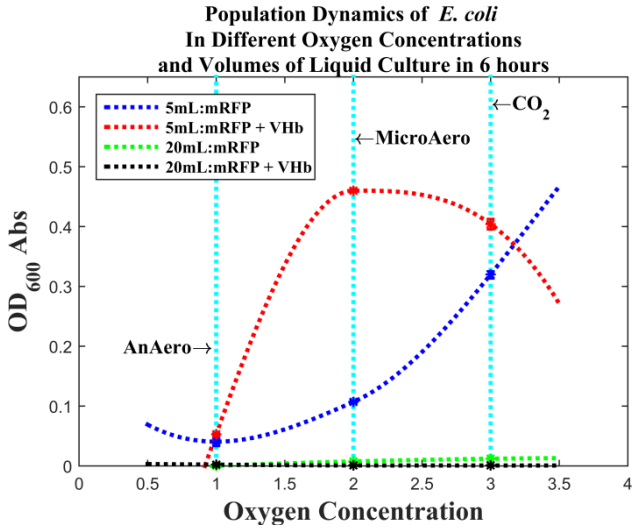

Figure 1.2 Population expriment results

Part 2：Gait Analysis

Goal：

To measure and analyse how much pressure will be imposed on the insoles in a man's daily life, so as to help set the material parameters and geometrical parameters of the insole appropriately.

Introduction：

The specific insole is designed not only to cultivate bacterias but also to bear the weight and pressure induced by a man. If the insole can't satisfy the basic mechanical requirements, it may lose its function and cause biological pollution. It is necessary to figure out how much pressure will be imposed on the insole when its user walks, jumps or runs.

Based on Newton's second law, we can calculate the pressure on the insole, as long as we measure the acceleration of the foot. Therefore, we designed and programmed a mobilephone software with Eclipse, which runs on Android platform and could record the accelerations in 3 directions (x,y,z) accurately.

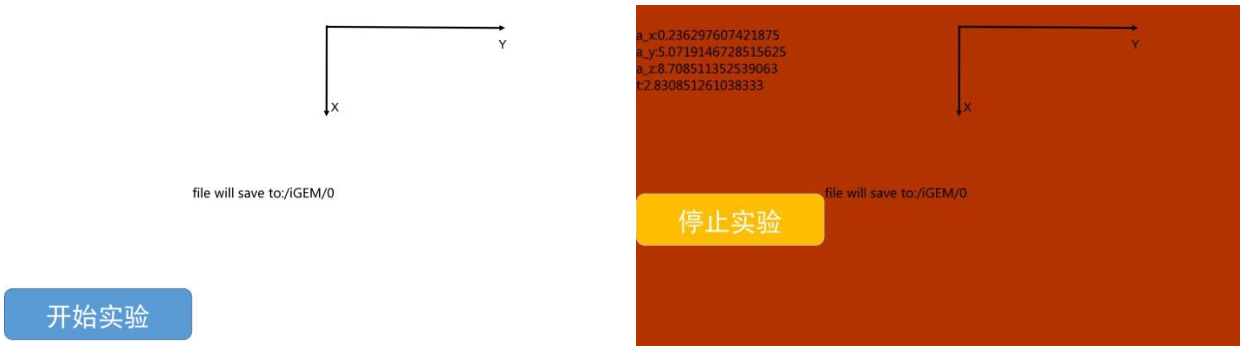

Figure 2.1 The operator interface of the software

With the mobilephone tied on the foot, the acceleration data coule be measured easily with the software. As a result, we could get the information about the pressure imposed on the insoles, and know exactly the basic mechanical requirement that the insole must satisfy.

Model：

Symbol:

Variable	Meaning
m	Acceleration of the object
$\vec{a}$	Force exerted on the object
$\vec{F}$	Pressure imposed on the insole

$N_{foot \to insole}$	Pressure exerted on the feet
$F_{insole \to foot}$	Acceleration of the feet in the forward direction
a_x	Acceleration of the feet in vertical direction
a_y	Acceleration of the feet to the right
a_z	Acceleration of the object

Newton's Second Law in Vector Form:

Newton's second law of motion states that the acceleration of an object is dependent upon two variables – the net force acting upon the object and the mass of the object. The acceleration of an object depends directly upon the net force acting upon the object, and inversely upon the mass of the object. Here is the mathematical expression.

$$\vec{F} = m\vec{a}, \quad (2.1)$$

Next, we'll take the feet and the insoles as the subjects investigated.

Newton's Third Law:

Newton's third law is stated states that action and reaction are equal and opposite. The acceleration of the feet is related to the force exerted to them by the insoles underneath, which is equal to the pressure imposed on the insoles. The relationship is as below.

$$N_{foot \to insole} = F_{insole \to foot} = ma_y, \quad (2.2)$$

Here, we take a_y as the acceleration in the vertical direction. As long as we measure and record the data of a_y under different gaits, the pressure imposed on the insoles could be calculated.

Results:

Walking:

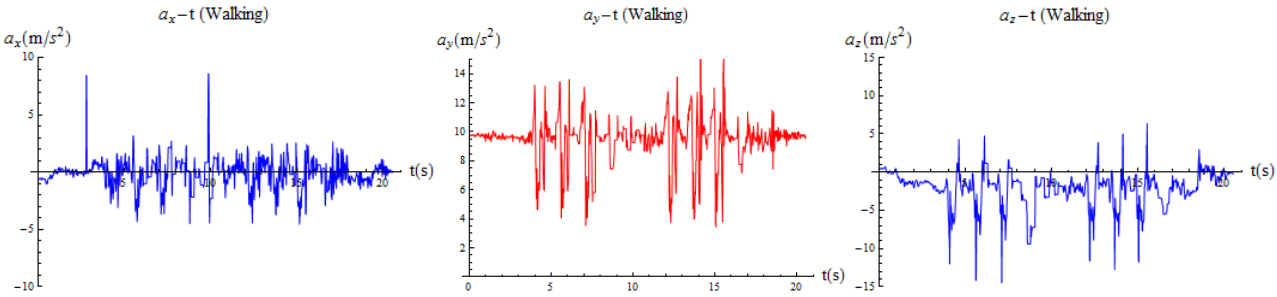

Figure 2.2 Accelerations in 3 directions (walking)

High Jumping:

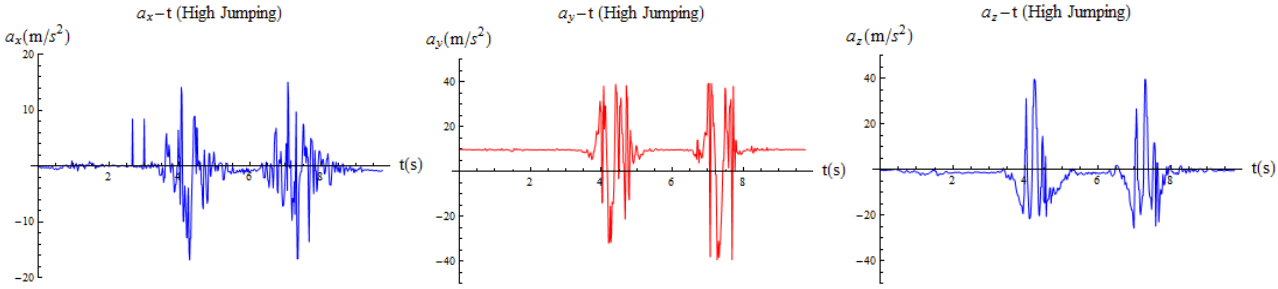

Figure 2.3 Accelerations in 3 directions (High Jumping)

High Knees:

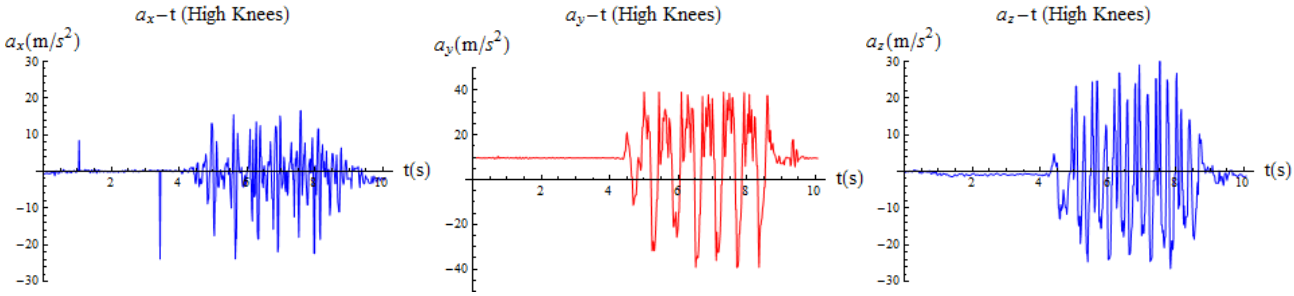

Figure 2.4 Accelerations in 3 directions (High Knees)

Acceleration in the vertical direction:

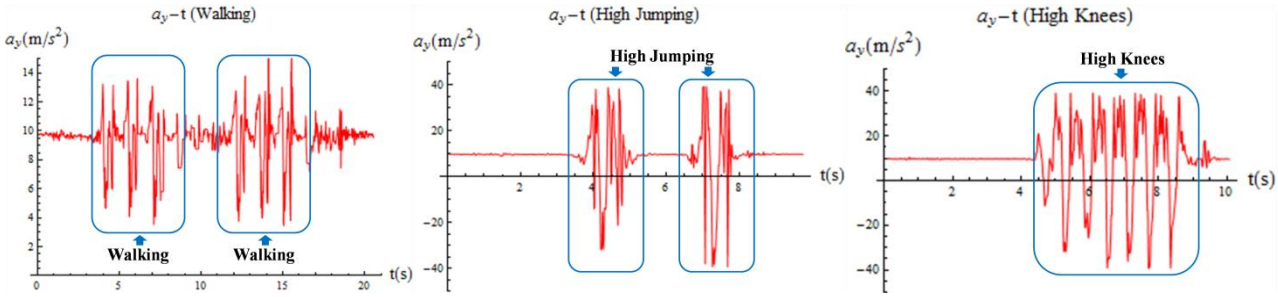

Figure 2.5 Acceleration in the vertical direction under different gaits

From the results above, there is obviously a very different between 3 types of gaits mentioned. When a human jumps, the maximum acceleration in the vertical direction could reach $40m/s^2$, which means the insole we design must be able to bear the pressure about $1300N$. (The experimenter is 65 kg.) And that is exactly what we need to take notice of.

Part 3：Population

Goal：

To simulate how the population of E.coli and the release rate of cecropin will change as the temperature of the insoles change periodically, and then analyse the efficiency, persistence, feasibility of the system.

Introduction：

Due to the temperature response promoter in E.coli, the increasing rate of the population would be acted upon by temperature changes. Therefore, before we simulate the population of E.coli inside the insole, it is necessary for us to figure out how the temperature changes as the shoes get put on or taken off first.

Based on Newton's law of cooling, an model for the change process of temperature has been built and verified with experiment. Combined with the characteristics of temperature changes, we also build a model for the population of E.coli which contains cecropin with discrete Logistic regression, and analyse the the population as well as the release of cecropin by simulating on Matlab.

The numerical simulation results show that the insole system could work continually as expected and have a huge potential to be optimized.

Model:

Symbol:

Variable	Meaning
T	Temperature of the object
c	Thermal capacity of an object
Q	Quantity of heat flowing through the object
t	Time
λ	Heat transfer coefficient
f	Heat production due to friction
v	Walking speed
μ	Friction Coefficient
$N_{foot \to insole}$	Pressure imposed on the insole

c_{insole}	Thermal Capicity of the insoles
T_{insole}	Temperature of the insoles
T_{foot}	Temperature of the feet
T_{room}	Temperature of the room
$\lambda_{\text{insole-foot}}$	Heat transfer coefficient between the isoles and the feet
$\lambda_{\text{insole-room}}$	Heat transfer coefficient between the isoles and the room
i	Generation Number
N_i	Population of E.coli
n_i	Quantity of death
K_i	Carrying Capacity of the insoles
k	Rate of nutrition expending
r_i	Increasing rate of the population
r_0	Division rate of the population
r_{D}	Death rate of the population

Thermal Capacity:

Heat capacity is defined as the ratio of heat absorbed by a material to the change in temperature. The formula is as below.

$$\Delta Q = c \cdot \Delta T \text{ , } (3.1)$$

In our modeling work, we'll choose the insoles as the subject investigated, and then discuss the heat flowing through as well as the temperature change of them.

Newton's Law of Cooling:

Newton's law of cooling states that the rate of heat loss of a body is proportional to the difference in temperatures between the body and its surroundings. As such, it is equivalent to a statement that the heat transfer coefficient, which mediates between heat losses and temperature differences, is a constant.

$$\frac{\mathrm{d}Q}{\mathrm{d}t} = \lambda \cdot \left(T_1 - T_2\right), \text{ (3.2)}$$

The formula above is simplified, for the reason that the rate of heat transfer would be decided by only one reduced parameter (λ), if the thermal system is established and invariant.

Heating Process:

When a man puts on a pair of shoes which is at room temperature, the insoles will start to be heated. The heat absoption is not only from the condution of heat caused by the difference of temperature, but also the heat production generated by friction, which is inextricably related to the man's walking speed, the friction coefficient between the insoles and the soles of his feet, and the pressure imposed on the insoles. Here, we simply take the rate of this kind of heat production as $f\left(v, \mu, N_{foot \to insole}\right)$. But the need to pay attention to is that the value of f is zero when the user of the insoles doesn't walk or run.

Here is the differential equation for heating process.

$$c_{\text{insole}} \cdot \frac{\mathrm{d}T_{\text{insole}}}{\mathrm{d}t} = \frac{\mathrm{d}Q}{\mathrm{d}t} = \lambda_{\text{insole-foot}} \cdot \left(T_{\text{foot}} - T_{\text{insole}}\right) + f \text{ , (3.3)}$$

$$T_{\text{insole}}\left(0\right) = T_{\text{room}}, \text{ (3.4)}$$

The solution of (3.3) (3.4) is as below.

$$T_{\text{insole}}\left(t\right) = \left(T_{\text{foot}} + \frac{f}{\lambda_{\text{insole-foot}}}\right) - \left(T_{\text{foot}} + \frac{f}{\lambda_{\text{insole-foot}}} - T_{\text{room}}\right) \cdot e^{-\frac{\lambda_{\text{insole-foot}}}{c_{\text{insole}}} \cdot t}, \text{ (3.5)}$$

Cooling Process:

When a man takes off the shoes, the insoles will start to be cooled, and the cooling process could be alos decribed similarly to the heating process.

$$c_{\text{insole}} \cdot \frac{\mathrm{dT}_{\text{insole}}}{\mathrm{d}t} = \frac{\mathrm{d}Q}{\mathrm{d}t} = \lambda_{\text{insole-room}} \cdot \left(T_{\text{room}} - T_{\text{insole}}\right), \text{ (3.6)}$$

$$T_{\text{insole}}\left(0\right) = T_{\text{foot}} + \frac{f}{\lambda_{\text{insole-foot}}}, \text{ (3.7)}$$

The solution of (3.6) (3.7) is as below.

$$T_{\text{insole}}\left(t\right) = T_{\text{room}} + \left(T_{\text{foot}} + \frac{f}{\lambda_{\text{insole-foot}}} - T_{\text{room}}\right) \cdot e^{-\frac{\lambda_{\text{insole-room}}}{c_{\text{insole}}} \cdot t}, \text{ (3.8)}$$

It is shown that the temperature of the insoles would approach the equilibrium temperature gradually in the

form of exponential function.

Discrete Logistic Model:

In the section, we would use the discrete logistic model to describe the growth of the population of E.coli. The relation between two generations is as below.

$$\frac{N_{i+1}-N_i}{N_i}=r_i\cdot\left(1-\frac{N_i}{K_i}\right), (3.9)$$

Then we have the iteration relation as (3.10) (3.11).

$$N_{i+1}=N_i\cdot\left[r_i\cdot\left(1-\frac{N_i}{K_i}\right)+1\right], (3.10)$$

$$K_{i+1}=K_i-k\cdot N_i, (3.11)$$

Moreover, the release of cecropin is equivalent to the quantity of death of the population.

$$n_i=N_i\cdot\left[\left(r_0-r_i\right)\cdot\left(1-\frac{N_i}{K_i}\right)\right], (3.12)$$

Before we simulate the population, it is necessary for us to test whether the system works properly, for the reason that the parameters we set must be appropriate and the growth of population should be in line with reality. Here, we set the parameters as below.

Variable	Value	Meaning
N_1	10^3	Initial population of E.coli
K_1	10^9	Initial carrying capacity of E.coli
k	10^{-2}	Rate of nutrition expending of E.coli
r_0	1	Division rate of the population

Next, the population in free condition is simulated with Matlab.

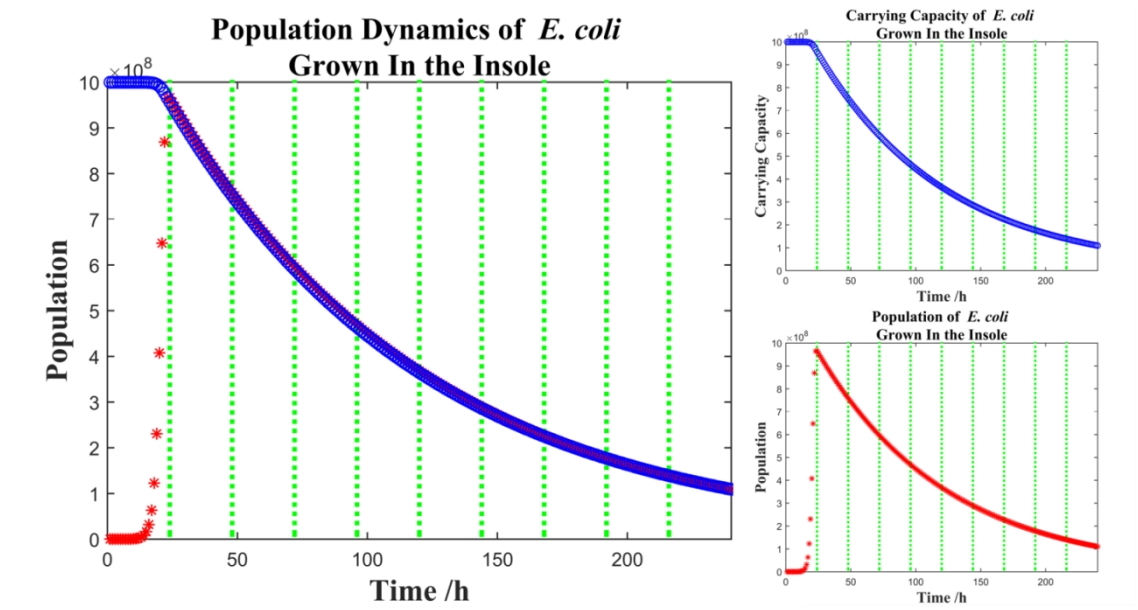

Figure 3.1 The free growth of E.coli

The simulation results show that the population would keep increasing continually under parameters given above. The population reaches the maximum value after about 24 hours, and then decreases gradually at a low speed. Besides, it can remain one tenth of the maximum value even after 10 days, which correspond to reality quite well. Therefore, the parameters is approapriate for the system we study on.

Based on the test above, we'll do more simulations under this set of parameters.

Results:

As is mention above, we need to figure out how the temperature changes as the shoes get put on or taken off before simulating. To prove the correctness of the model and figure out how fast the temperature change would be, an experiment was designed as follow.

Heating Process

1. Put a pair of shoes at room temperature for a long time. (temperature balance)
2. Put on the shoes.
3. Measure the temperature inside the shoes with an infrared thermometer every 20 seconds
4. Fit a curve and compose a graph with the data

Cooling Process

1. Put on the shoes for a long time. (temperature balance)
2. Take off the shoes at room temperature.
3. Measure the temperature inside the shoes with an infrared thermometer every 20 seconds
4. Fit a curve and compose a graph with the data

The experiment results are as below.

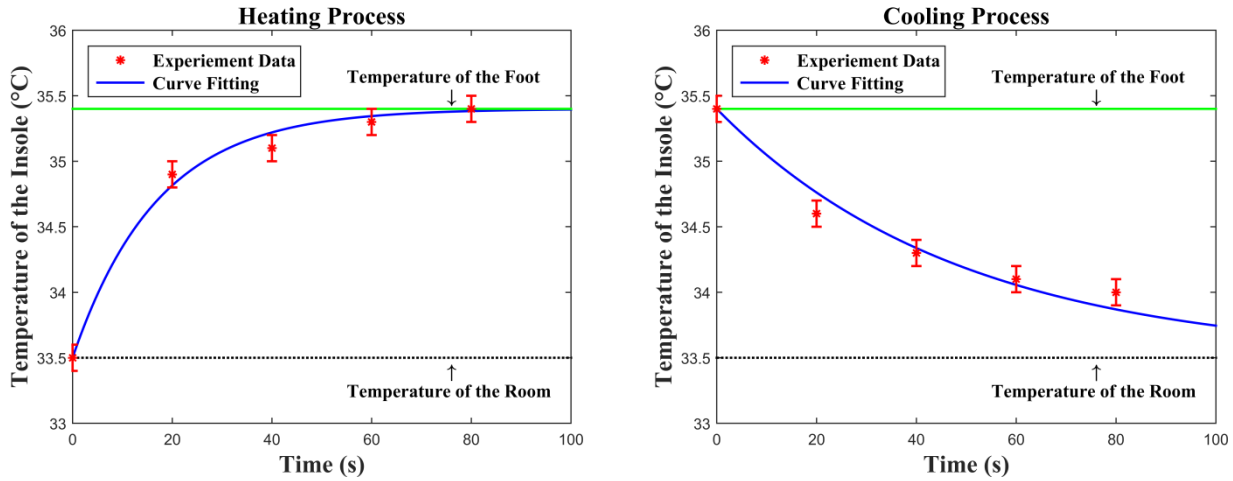

Figure 3.2 Temperature change process

The experiment results have proved the correctness of (3.5)(3.8), because the correlation coefficients are both bigger than 0.95, which meas the temperature would change according to the form of exponential function.

What's more, from the results, it is also discovered that the temperature of the shoes would take about 1 minute to reach the temperature balance, which is much shorter than the division cycle of E.coli (about 1 hour), no matter it is heating process or cooling process. Therefore, when it comes to the simulation on populations, temperature changes caused by putting on or taking off shoes could be regarded as instantaneous.

Next, we start to simulate the populations of E.coli under periodic excitation. As is mentioned above, at the different temperature, the increasing rate of population would be different as well. Let's assume that the increasing rate is 1 when the shoes are taken off, which means the temperature promoter is not working at room temperature. Then we take r as the increasing rate when the shoes put on and the temperature of the insoles reach a higher balance.

Now, we assume someone's life habit is as below.

06:00-12:00 Get up and start a day (put on the shoes)

12:00-14:00 Take a sleep (take off the shoes)

14:00-24:00 Keep on working (put on the shoes)

00:00-06:00 Sleep (take off the shoes)

Here are simulations on the population of E.coli, the carrying capacity and the release of cecropin when r takes different values.

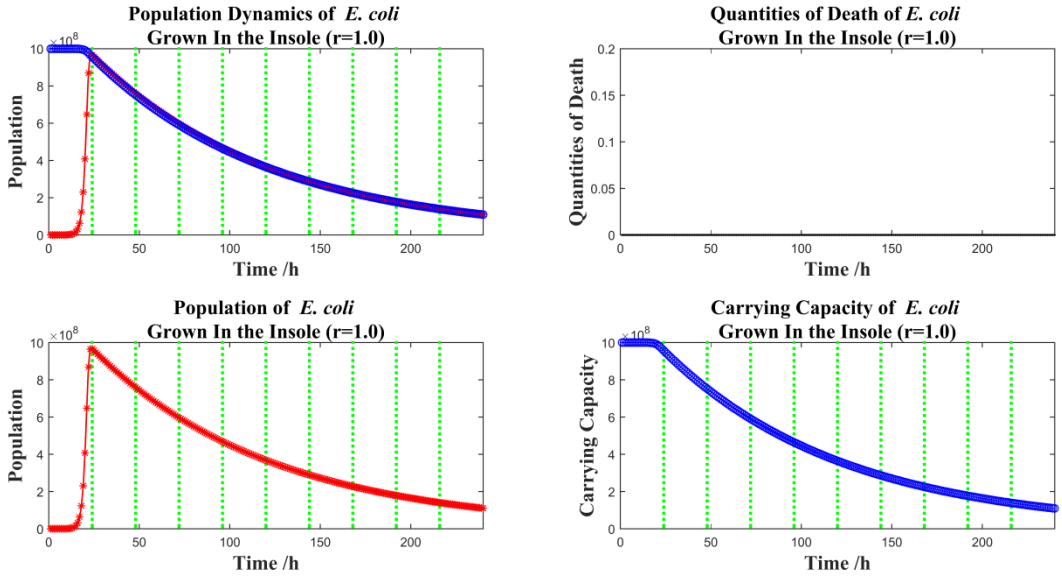

Figure 3.3 (a) Simulation results when r=1.0

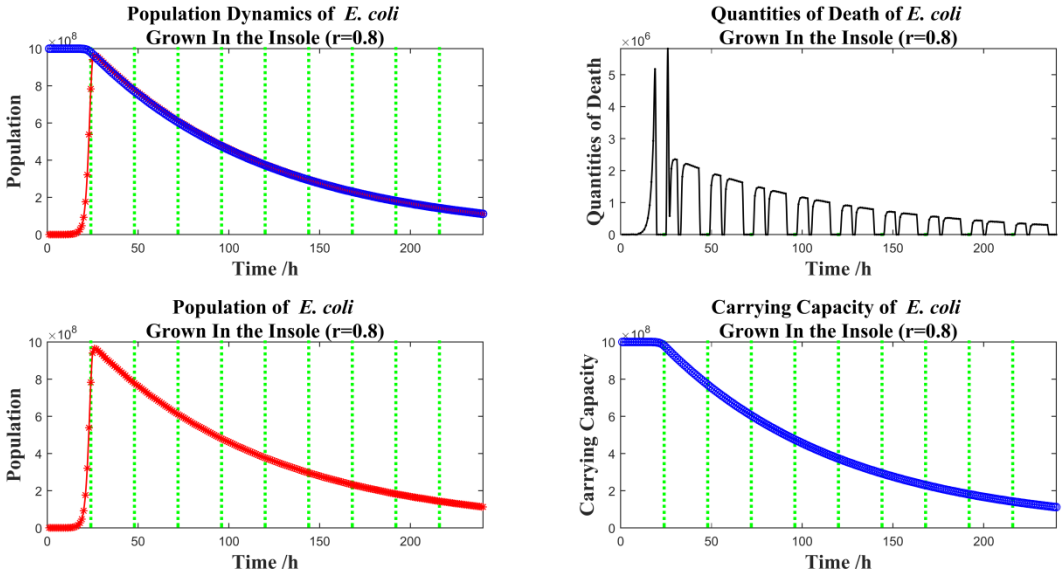

Figure 3.3 (b) Simulation results when r=0.8

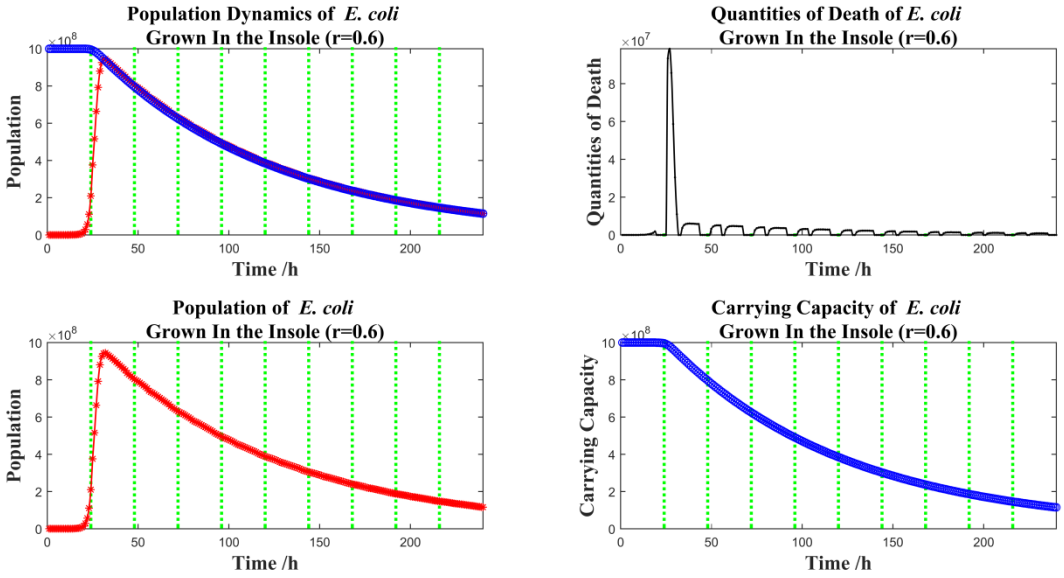

Figure 3.3 (c) Simulation results when r=0.6

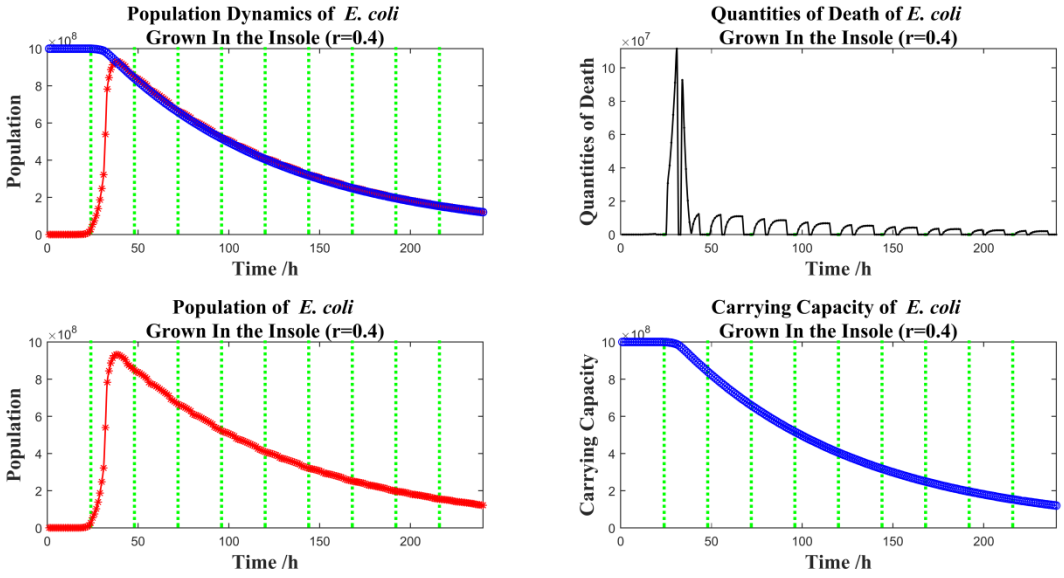

Figure 3.3 (d) Simulation results when r=0.4

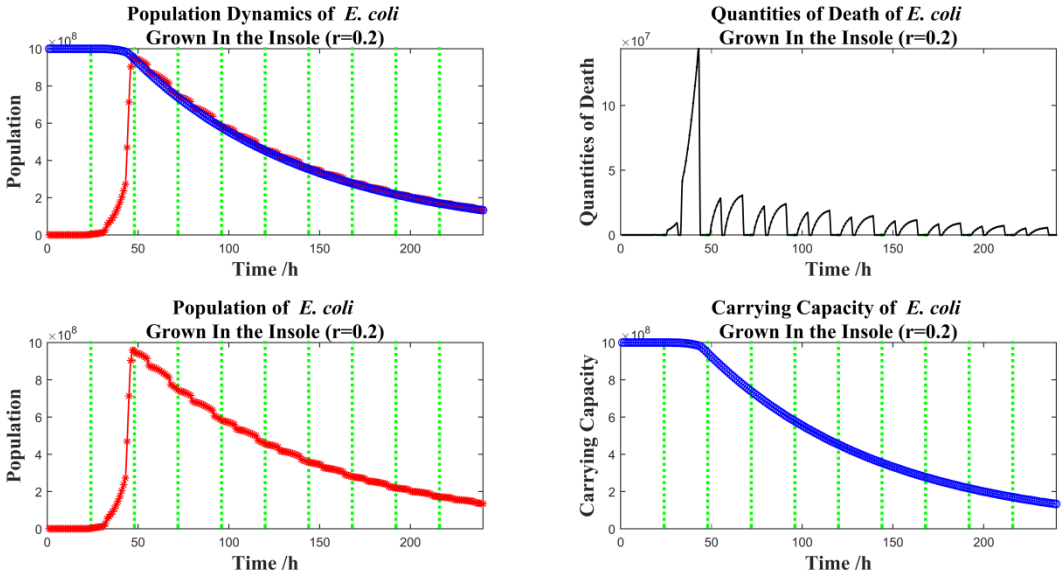

Figure 3.3 (e) Simulation results when r=0.2

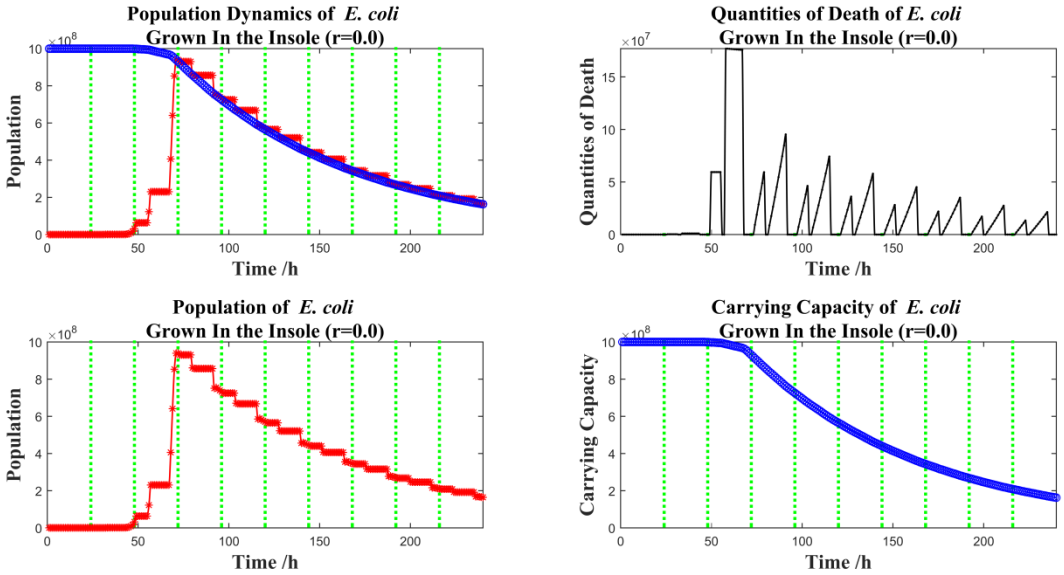

Figure 3.3 (f) Simulation results when r=0.0

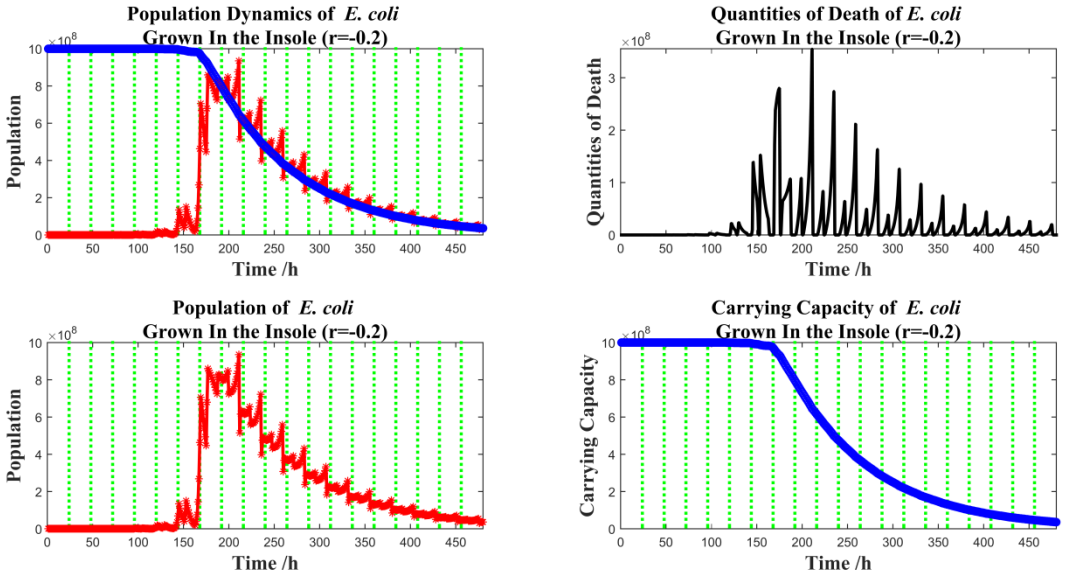

Figure 3.3 (g) Simulation results when r=-0.2

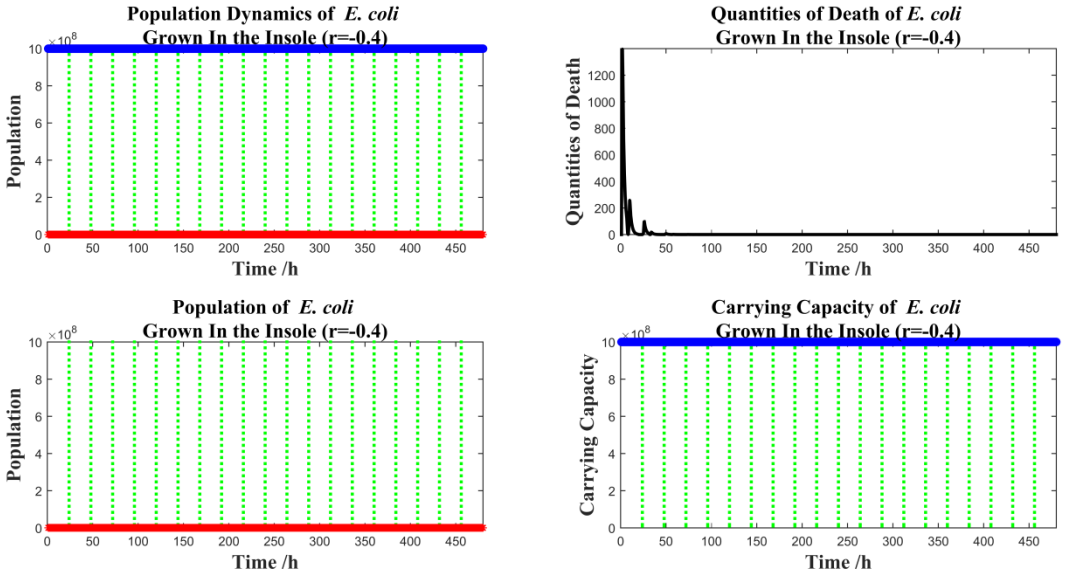

Figure 3.3 (h) Simulation results when r=-0.4

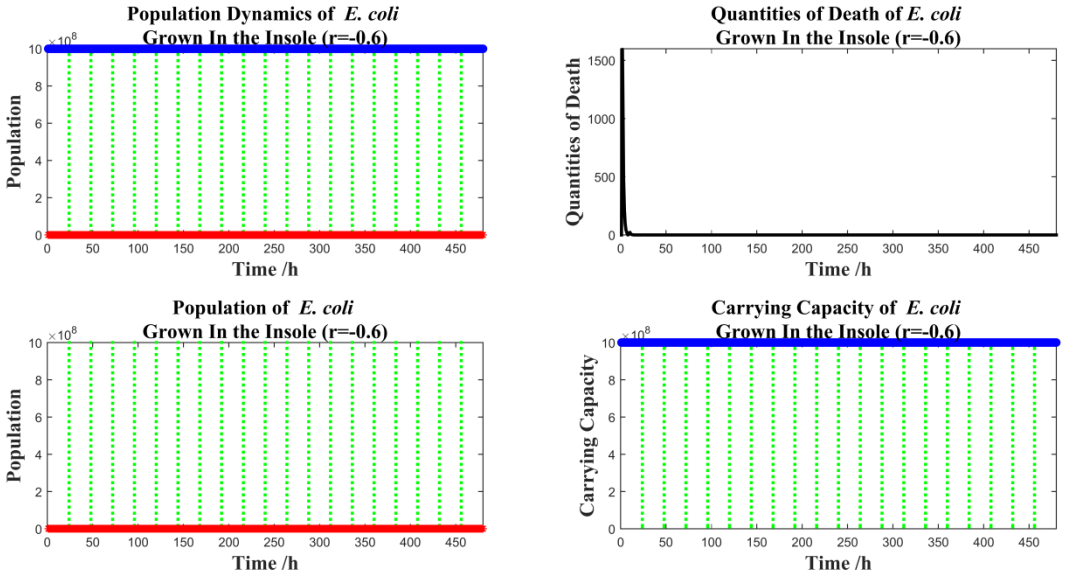

Figure 3.3 (i) Simulation results when r=-0.6

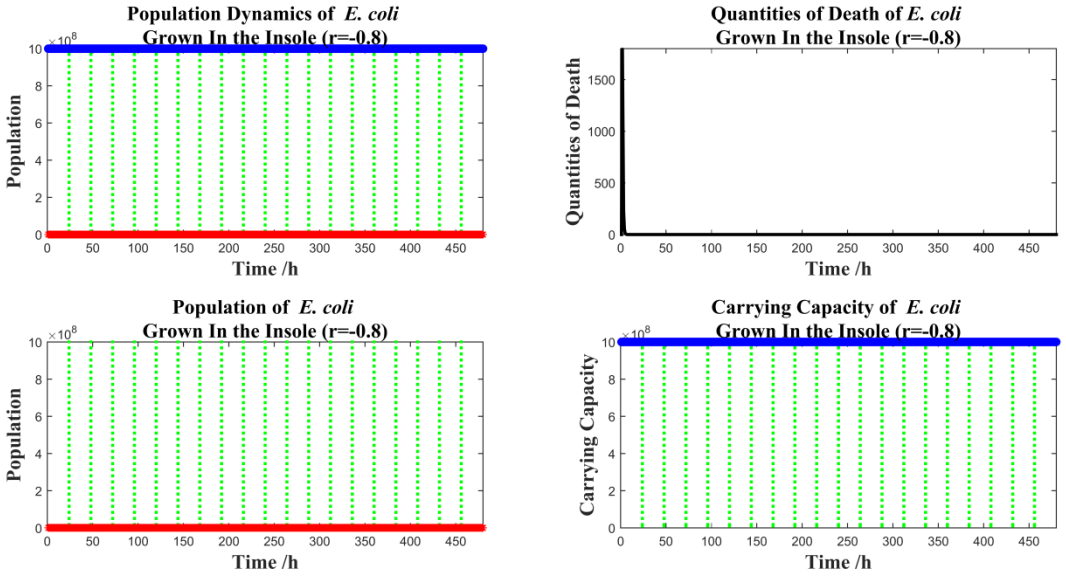

Figure 3.3 (j) Simulation results when r=-0.8

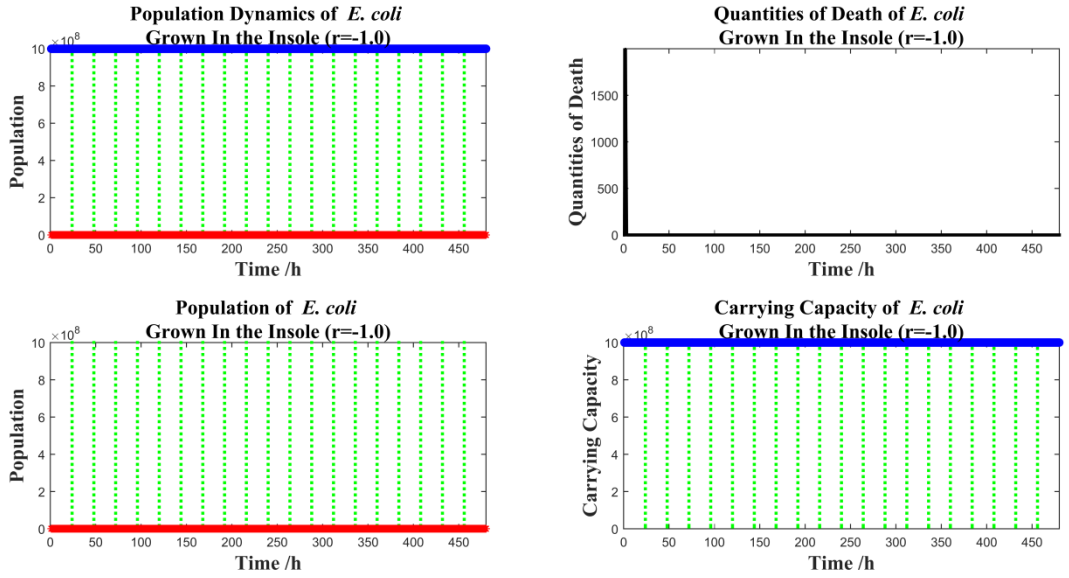

Figure 3.3 (k) Simulation results when r=-1.0

From the simulation results, we can come to a conclusion.

When r_D is small, the release of cecropin would reach a maximum value in a high speed, then decreases in a fluctuation. However, the relative amount of cecropin released is small.

As r_D gets bigger, the time when the release reaches the maximum gets longer as well. Besides, a number of secondary peaks appears, as a result, cecropin is released repeatedly, continuously and greatly. The system reaches its best state when r_D is about -0.2, with the effective working time for more than 20 days.

When r_D is too big, the population would decrease in a short time, which means the insoles can't work as expected.

In a word, the system of insoles can work with high efficiency under approapriate parameters.

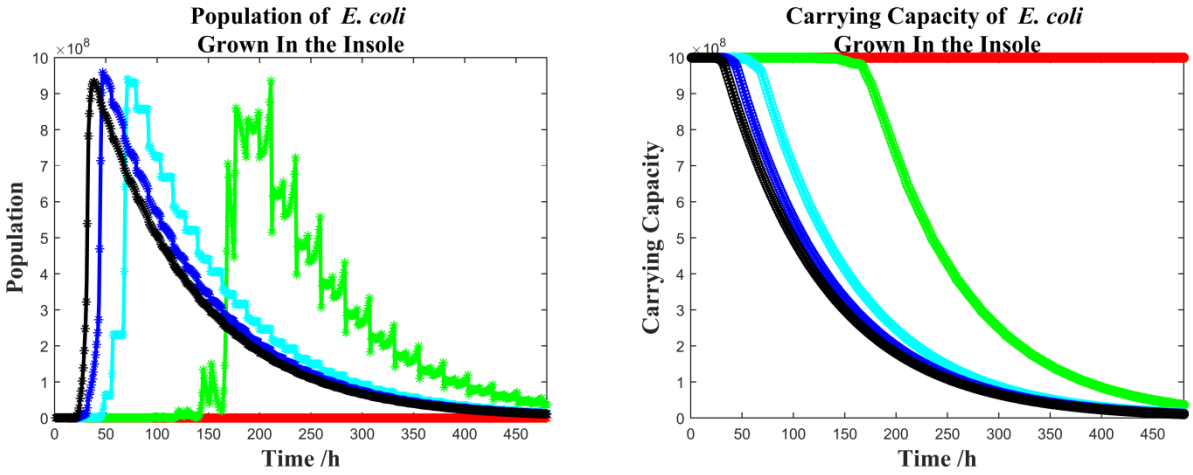

Figure 3.4 Simulation results when r=-0.4/-0.2/0.0/0.2/0.4

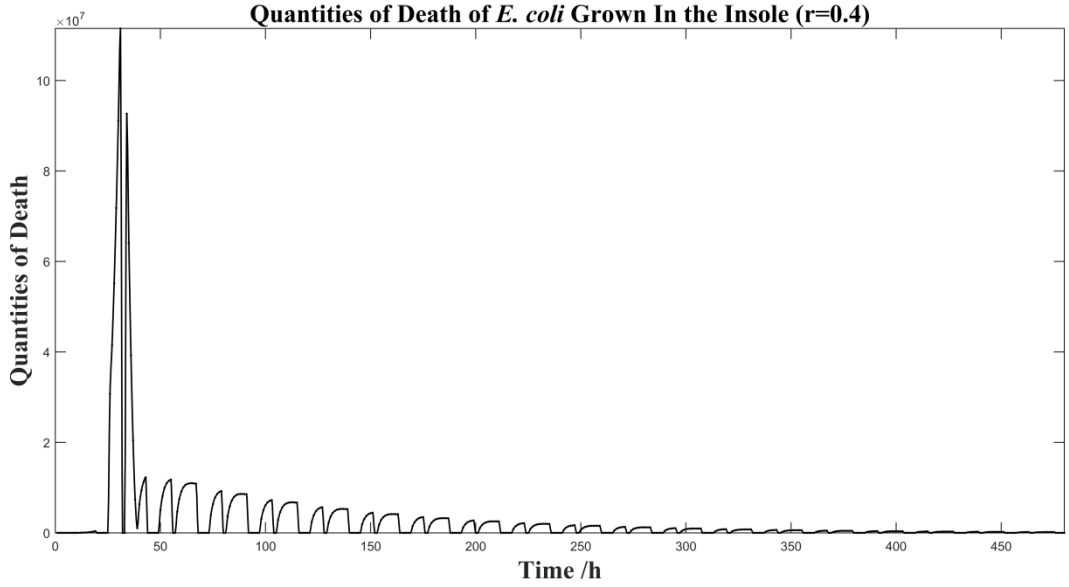

Figure 3.4 (a). Release of cecropin when r=0.4

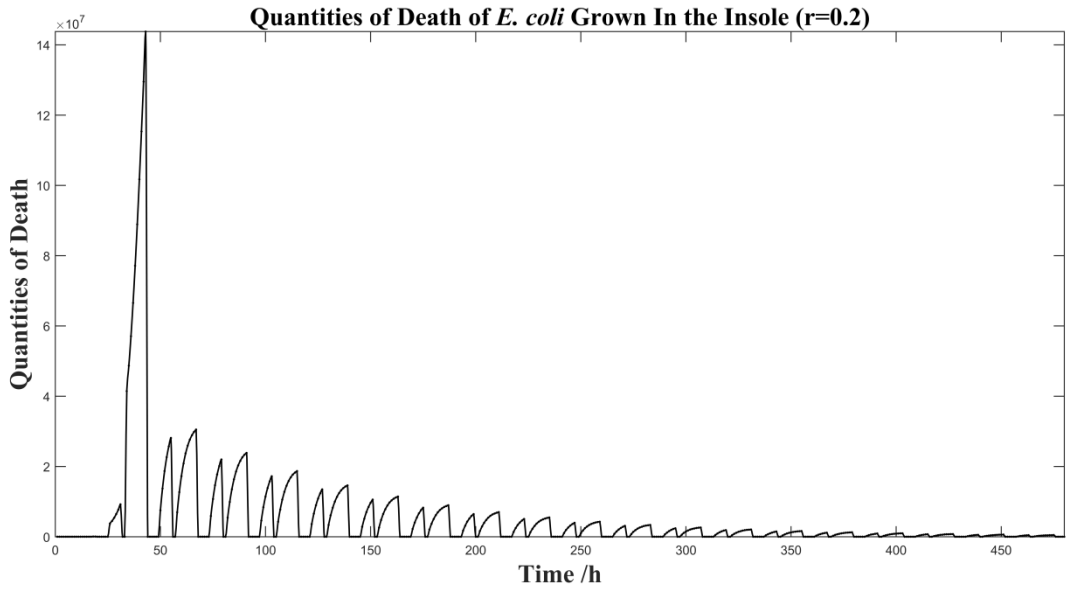

Figure 3.4 (b). Release of cecropin when r=0.2

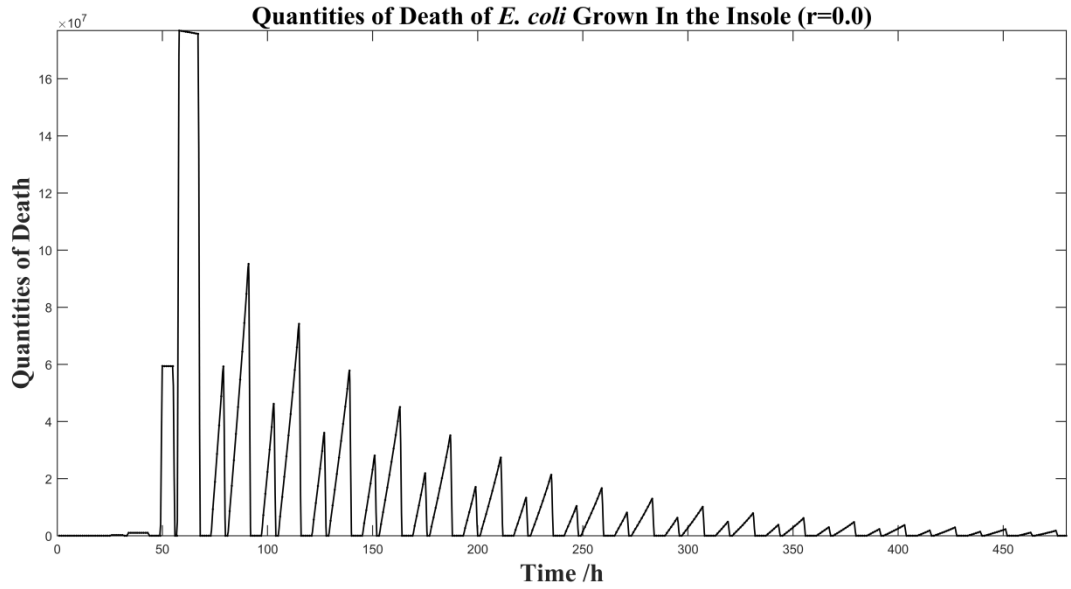

Figure 3.4 (c). Release of cecropin when r=0.0

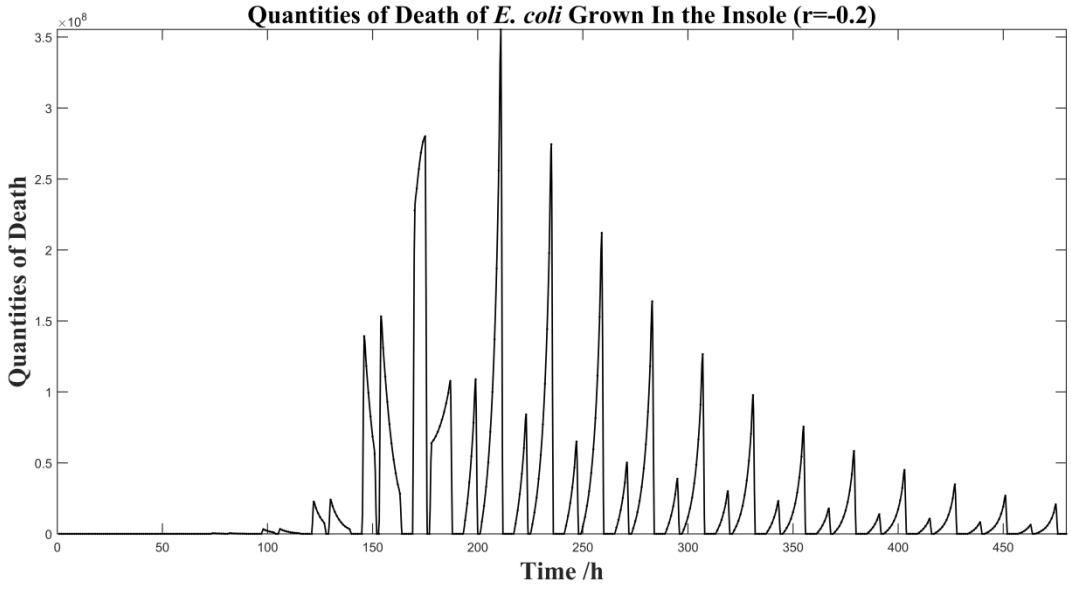

Figure 3.4 (d). Release of cecropin when r=-0.2

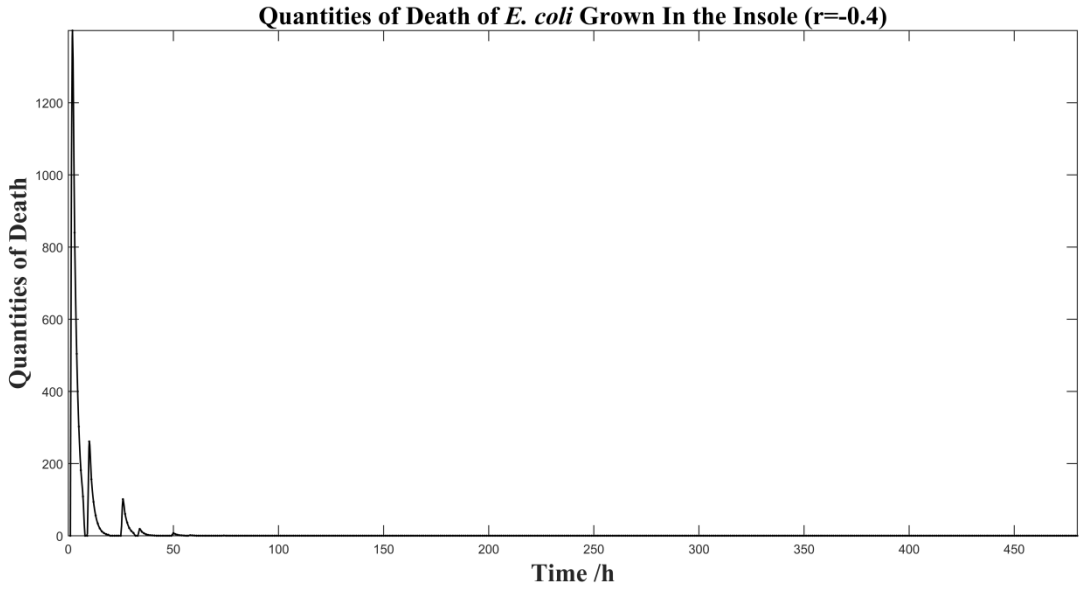

Figure 3.4 (e). Release of cecropin when r=-0.4

[1] Xiong Aisheng, et al. Studieson Synthesis of *Vitreoscilla* Hemoglobin Gene by PCR Technique and its Effcet in Prokaryotic Organism. *Acta Agriculturae Shanghai*, 16.3(2000):19-24.

[2] Song Kai. Introduction To Synthetic Biology. Science Press, 2010.