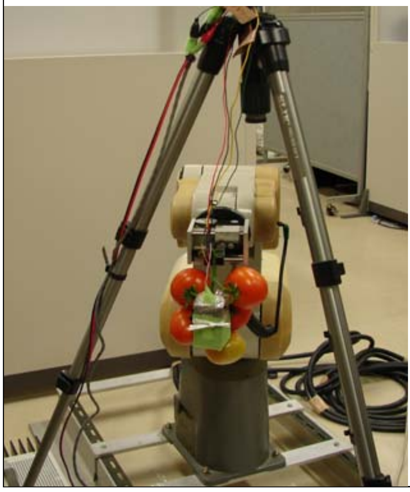
AN END-EFFECTER AND MANIPULATOR CONTROL FOR TOMATO CLUSTER HARVESTING ROBOT



Koichi Tanihara
Department of Mechanical Engineering
Ehime University

Thank you for your introduction chairman

Let me talk about AN END-EFFECTER AND MANIPULATOR CONTROL FOR TOMATO CLUSTER HARVESTING ROBOT
today

Research Background

- Tomato is being produced in large scale Dutch style green houses
- Dutch style green house is easy to be introduced automated devices
- They have problems such as
  labor shortage and monotonous working
- Tomato fruit cluster harvesting is popular

Research objective

- To develop a manipulator control method for preventing tomato cluster swinging during harvesting operation

Dutch style green house

Inner side view

You, know, we have many greenhouses for growing tomatoes in the world.

Recently large scale green houses are increasing even in Japan.

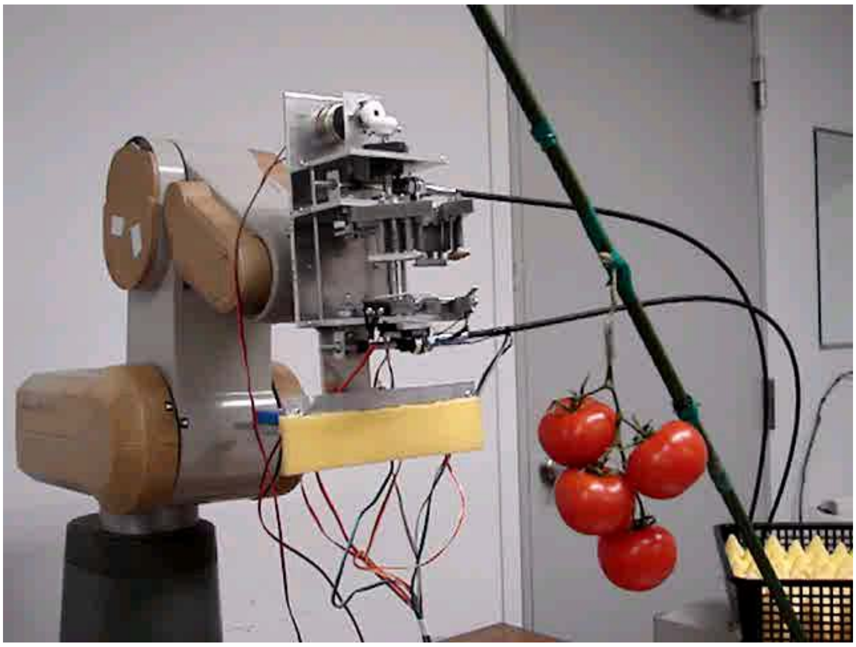
Most green houses are Dutch style, not only appearance but also internal equipments like this. This style green house is easy to be introduced the automated devices.

However, because of the large scale greenhouse *(and of very much equipped like this rail,) they have problems such as labor shortage and monotonous working.

From these reasons we are now researching tomato cluster harvesting robot

In this study research objective is to

End-Effecter



Pushing device is quite big and needs time, Here we are proposing another method to prevent fruit cluster from swinging by manipulator control.

The fruit clusters look to come out in various directions.

The end-effector needs to have a function to grasp and cut peduncle which exists in any direction.

Assuming this support pole is main stem. We hung this real fruit cluster like this.

Let me show you a movie file of the end-effector we developed.

The robot arm moves towards the main stem.

When a limit-switch touched the main stem right here, it stopped and the fingers closed.

Grasp and cut the peduncle like that.

The arm moved back keeping the fruit cluster.

The harvested cluster was held on the pushing device to prevent cluster vibration like this.

At last, the cluster was released at this container like this.

*we used this pushing device for preventing the cluster vibration.

*However this pushing device quite big here we are proposing another method to prevent swinging by manipulator control.

Here is the requirements of the manipulator control method

First one is to avoid swinging fruit cluster during transportation.

We need to realize a quick motion control and a vibration damping at a time to when transporting tomato cluster.

We used Input shaping method for this in this research.

*This blue vibration caused by Impulse A1 is cancelled by this red vibration caused by Impulse A2.

Input shaping method can cancel the vibration by a couple impulses like this

The manipulator acceleration depends on the natural frequency

For example, this method is used in operation of a crane or in flexible manipulator.

However, this method has less robustness against object parameter uncertainties.

As another requirement, adaptability to various objects, fruit clusters is added.

Here, we proposed a modified input shaping method considering individual fruit cluster parameters.

Modified Input shaping method

1. Peduncle diameter d, and length l ⟵ Machine vision

   Cluster weight m ⟵ Load sell

- These sensors are supposed to be installed in the harvesting robot

2. Natural frequency of 1st mode ω_e is estimated

$$\omega_e = f\,(d, l, m)$$

3. Control parameter (manipulator acceleration) of input shaping is adjusted based on estimated ω_e

Let me explain the modified input shaping method

*In this method we need peduncle diameter and length which ware measured by a machine vision.

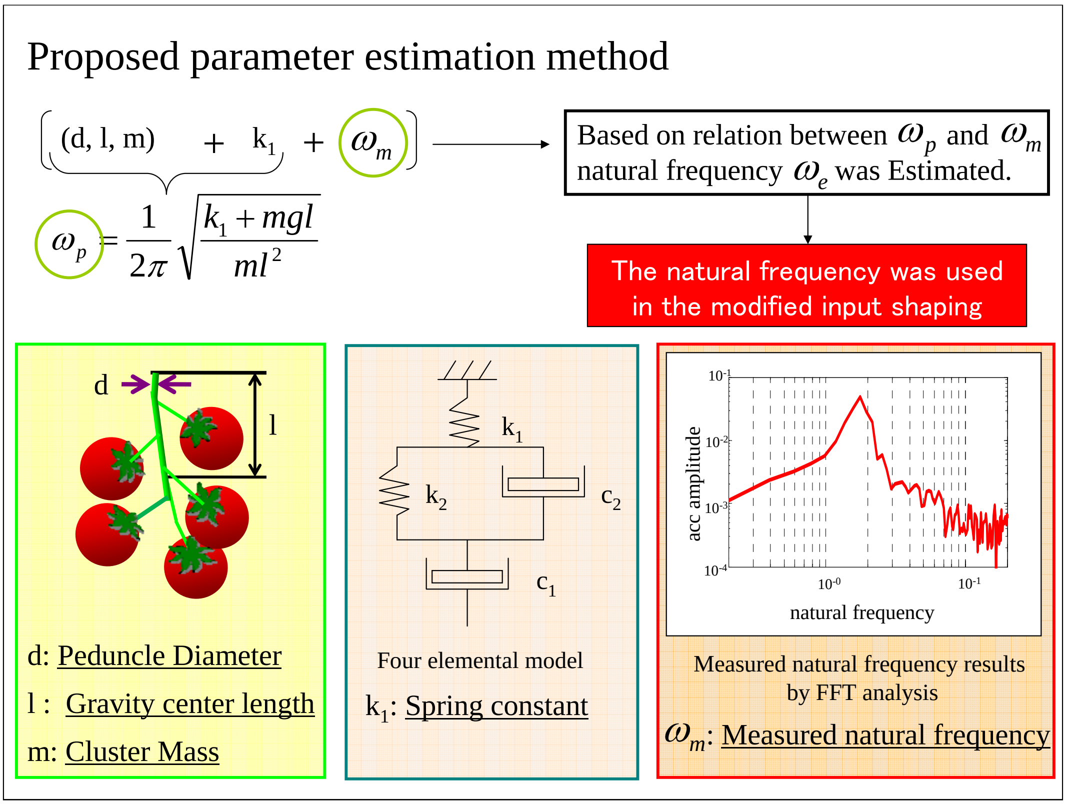
Cluster weight was measured by load sell

These sensors are supposed to be installed in the harvesting robot

Natural frequency of first mode oe should be estimated *in this method using d m and l like this equation

*Then control parameter that is (manipulator acceleration) of input shaping is adjusted Based on estimated oe

This oe is



Estimate like this

We need to consider these parameters to get omegae.

*These D,l,m are supposed to be measured by sensors but manually measured this experiment

Many of biological materials are expressed by 4 element model.

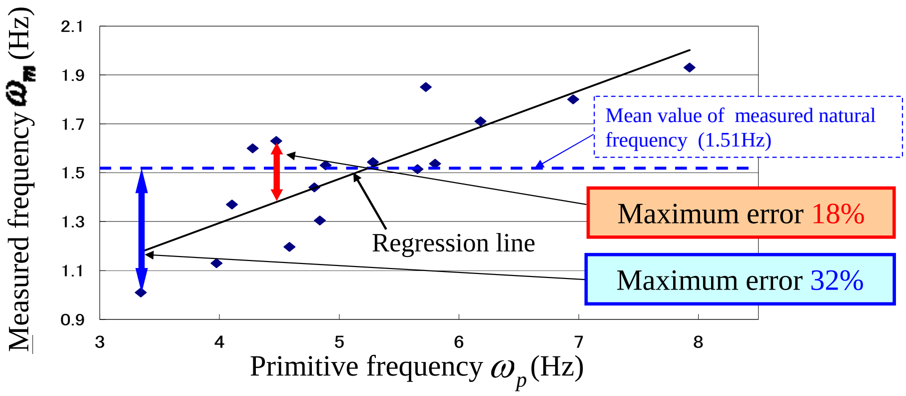
Here, spring constant k1 was obtained by a peduncle bending test.

Based on those parameter, wp was ca’lcula’ted like this equation. And this wm was obtained by a cluster vibration test and FFT analysis.

Based on relation between wp and wm, natural frequency was Estimated.

And The natural frequency was used in the modified input shaping

Comparison between mean and estimated natural frequencies



(A) Normal Input Shaping

- Used mean value of ω_m.

(B) Proposed method (Modified input shaping)

-Used ω_e regression line of individual ω_m based on cluster parameter d, m, and l.

Here is a relation between wp and wm. The difference between the proposed method and normal input shaping is difference of natural frequency.

Normal input shaping used mean of wm

Proposed method used individual wm based on d, m, and l.

This blue color line is mean value of these wm. *You can see maximum error of normal input shaping (that is the difference between mean value line and individual omegam) was 32%.

while that of proposed method that (is the difference between this regression line and individual omegam) was 18%.

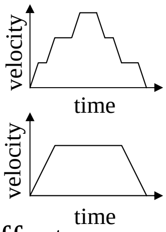
Numerical simulation

(A) Normal input shaping

(B) Proposed method

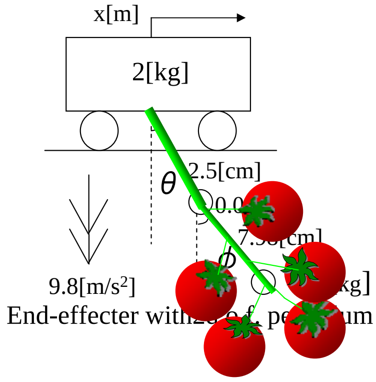
(C) Unshaped method

– Velocity of the end-effector was controlled to be trapezoid shaped



Compare first mode vibration

Numerical model



Simulation parameter

	(A)	(B)	(C)
Transportation distance (m)	0.5	0.5	0.5
Maximum Acceleration (m/s^2)	4.8	4.8	2.45
Maximum Velocity (m/s)	0.5	0.5	0.25

In order to verify superiority of the proposed method, following three types of control methods were compared. (daikei)

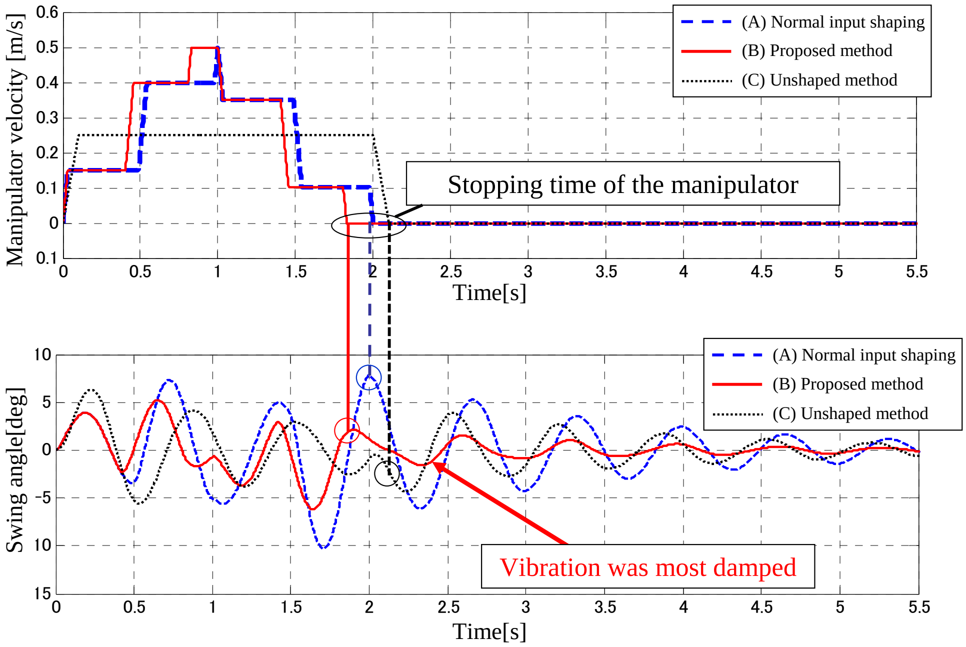
As I mentioned, 32% error was included in the natural frequency for this method (A), and 18% error for Method (B).

While method (C), was not input shaping, that was a method that velocity of the end-effector was controlled to be trapezoid shaped like this.

Numerical model is shown here. Flexible vibration of the tomato cluster was modeled as 2 d.o.f. pendulum motion.

Simulation parameters is shown here Under this conditions, we compared the first mode vibration.

Simulation results
（Velocity and swing angle）



Here is simulation results. this is manipulator velocity(vilas(lazy)aty) and this is swing angle of tomato cluster.

Blue dot line is represented normal input shaping, red line is proposed (prapouse) method, black dot line is unshaped method.

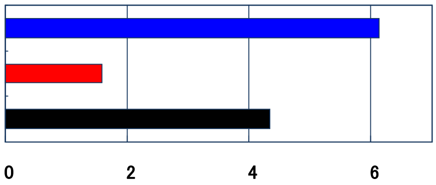
You can see input shaping methods showed velocity steps like this. Proposed method stopped earliest and its vibration was the most damped.

That’s red line

Considerations of numerical simulation

Amplitude of vibration right after the transportation

(A) Normal input shaping
(B) Proposed method
(C) Unshaped method



6.13[deg]
1.58[deg]
4.34[deg]

The proposed method was the most effective.

Amplitude of vibration right after the transportation is like this. The proposed method vibration amplitude this red one was about 1/4 of normal input shaping. About 1/3 of unshaped method.

Experimental devices and methods

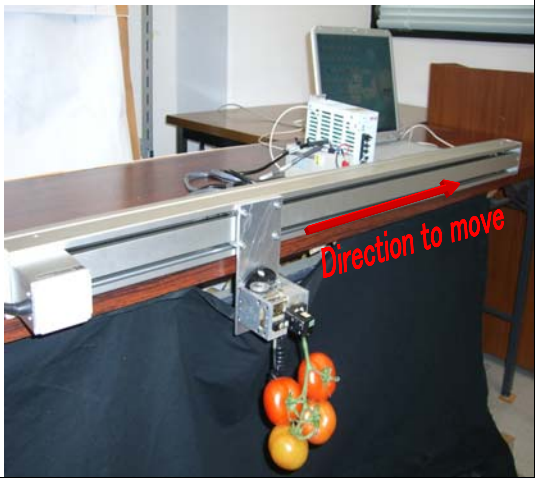
(B) Proposed method

- Modified input shaping method

(C) Unshaped method

- Velocity is controlled to be trapezoid shaped.

- Transportation by 1 DOF manipulator
- The motion of tomato cluster was recorded by video camera
- Compared experiment with simulation results

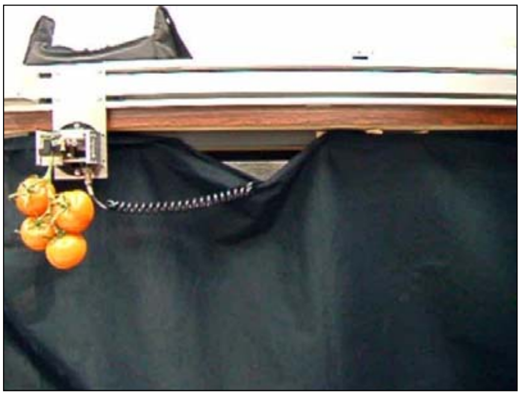


We conduct an experiment to compare the methods as well as the simulation. Here, these two methods were actually compared by use of this 1 DOF manipulator.

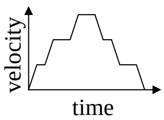
The motion of tomato cluster was recorded by a video camera and cluster swing angle was measured on image. Then compared(k(lazy)a) experiment with simulation results.

Experimental result

Videos showing the whole manipulator

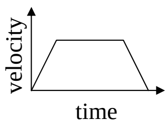


(B) Proposed method



Transportation duration, 1.8 s

(C) Unshaped method



Transportation duration, 2.2 s

Let me show you experimental results by these videos

Here are the videos showing the whole manipulator

Left hand side video is proposed method. Its transportation duration was 1.8(s)

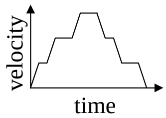
Right hand side video is unshaped method. Its transportation duration was 2.1(s) as well as the simulation.

You can see proposed method transportation time was short and small swing angle compared with unshaped method.

Experimental result

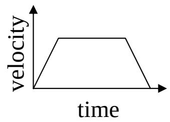
Zoom in videos at the stopping positions of the end-effector

(B) Proposed method



Transportation duration, 1.8 s

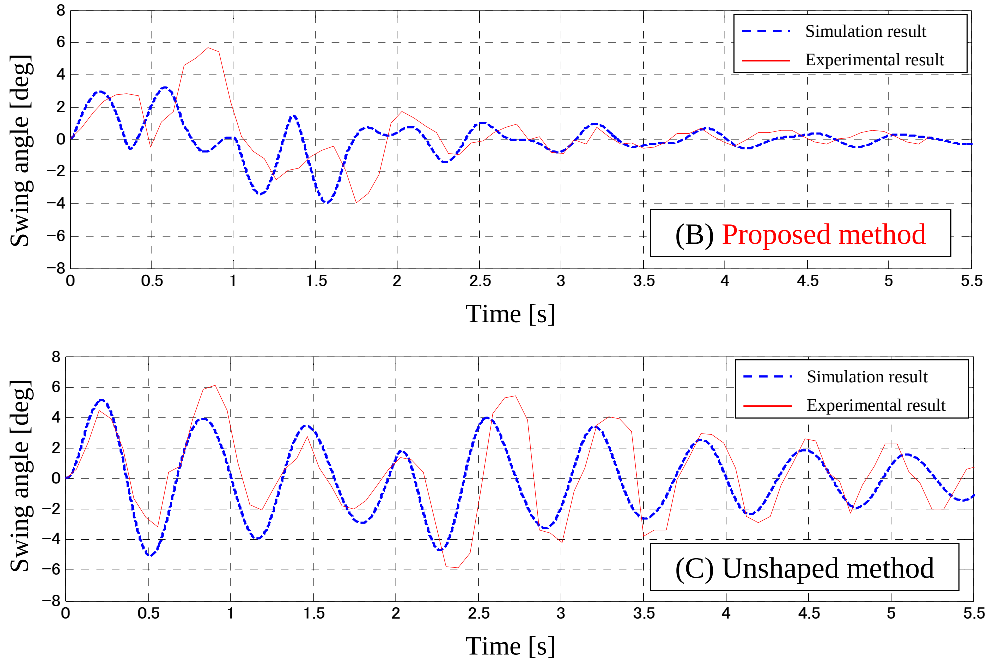
(C) Unshaped method



Transportation duration, 2.2 s

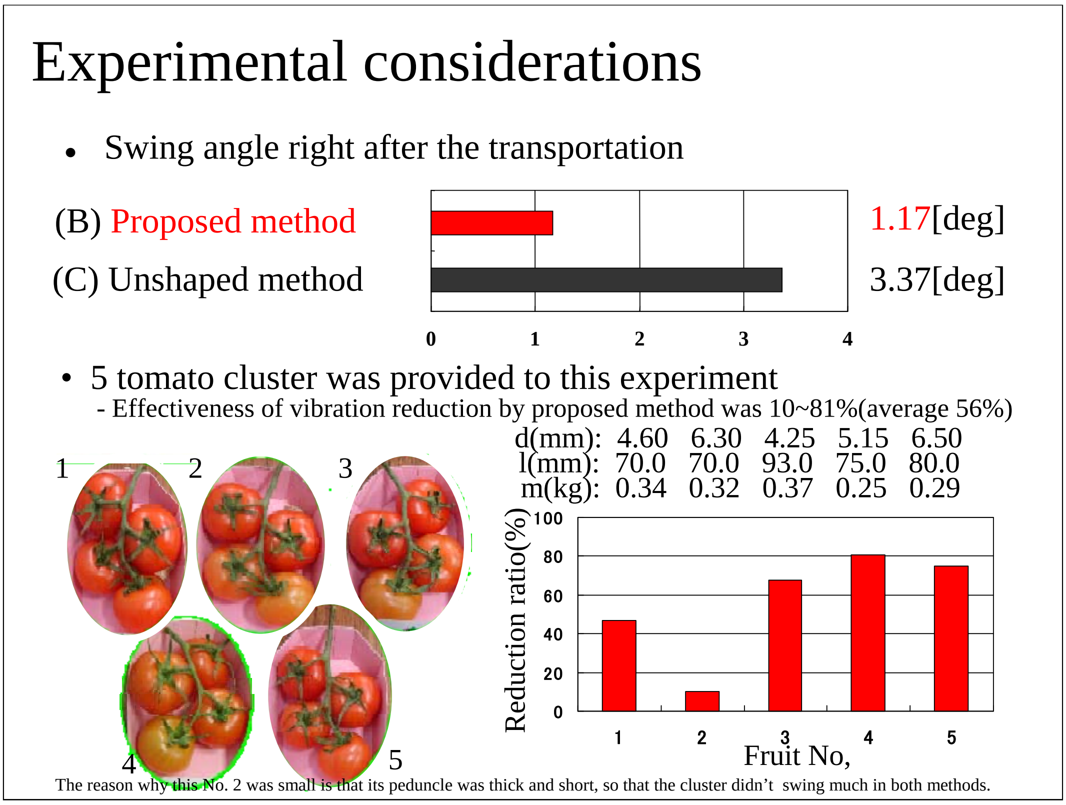
This is zoom-in video at the stopping position of end-effector
Left video is proposed method, and right video is unshaped method.
It is easier to see the both vibration when the manipulator stopped.

Experimental results



Here is experimental results with simulation results. Red line is experimental result and blue dot line is simulation result. Both results are very similar after end-effector stopped.

You can see the proposed method was effective to reduce the vibration compared with the unshaped method.



Amplitude of vibration right after the transportation is shown like this. Swing angle of proposed method was about 1/3 of unshaped method.

5 tomato clusters were provided to this experiment. From the results, it was observed that effectiveness of vibration reduction was 10-81% and its average was 56%.

The reason why this no2 is small is large and firm peduncle and the cluster was didn't swing much even in this unshaped method.

Conclusion

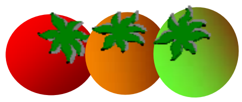
• Modified input shaping (proposed method) was effective to reduce fruit cluster vibration, because natural frequency of individual fruit cluster was used as a parameter.

• Possibility to remove the pushing device of the end-effector was found, if the proposed method was used.

• As a future subject, a harvesting robot system consisting of a manipulator, an end-effector, a machine vision, and traveling device should be investigated to confirm this proposed method effectiveness.

Read velocity(vilas(lazy)aty) compared(k(lazy)anper proposed (pr(lazy)apouse

Thank you for your kind attention

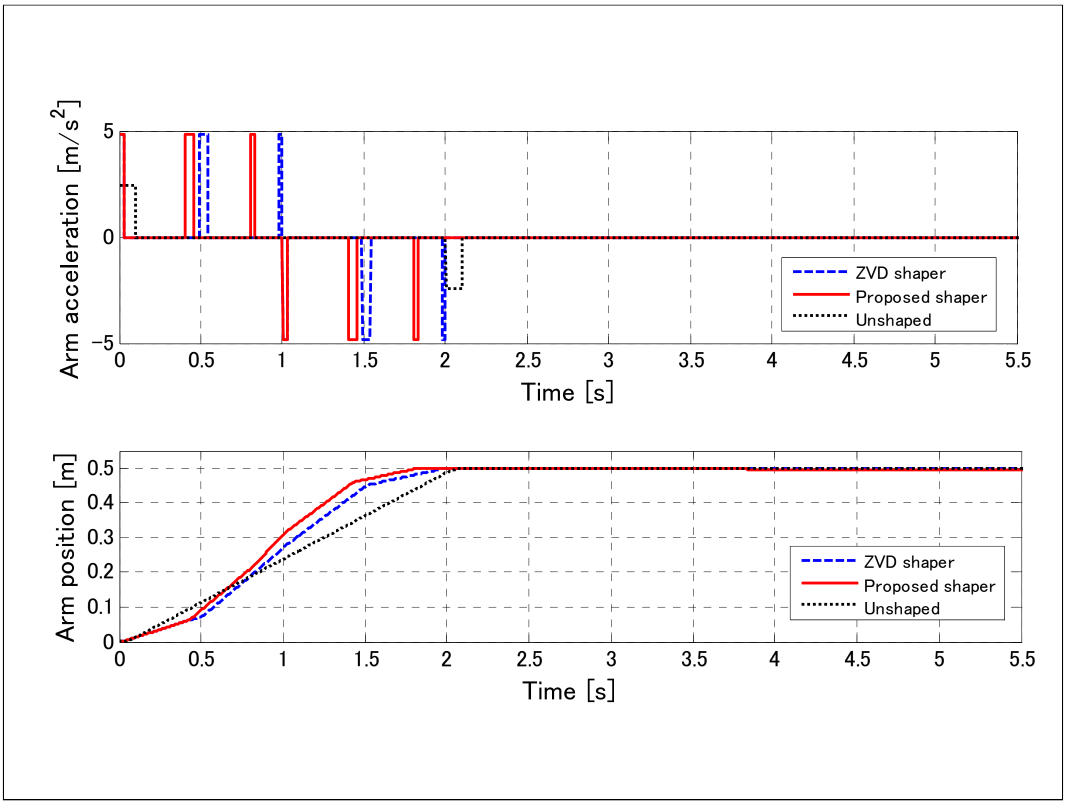


In this study, object for the harvesting robot is round tomato like this picture

This tomato plants are hung down from top and fruits are for cluster harvesting.

However, the fruit clusters look to come out in various directions like this.

The end-effector needs to have a function to grasp and cut peduncle which exists in any direction.



Arm acceleration [m/s^2]
5
0
−5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
Time [s]
ZVD shaper
Proposed shaper
Unshaped
Arm position [m]
0.5
0.4
0.3
0.2
0.1
0
Time [s]
ZVD shaper
Proposed shaper
Unshaped

Simulation results (Acceleration　displacement)

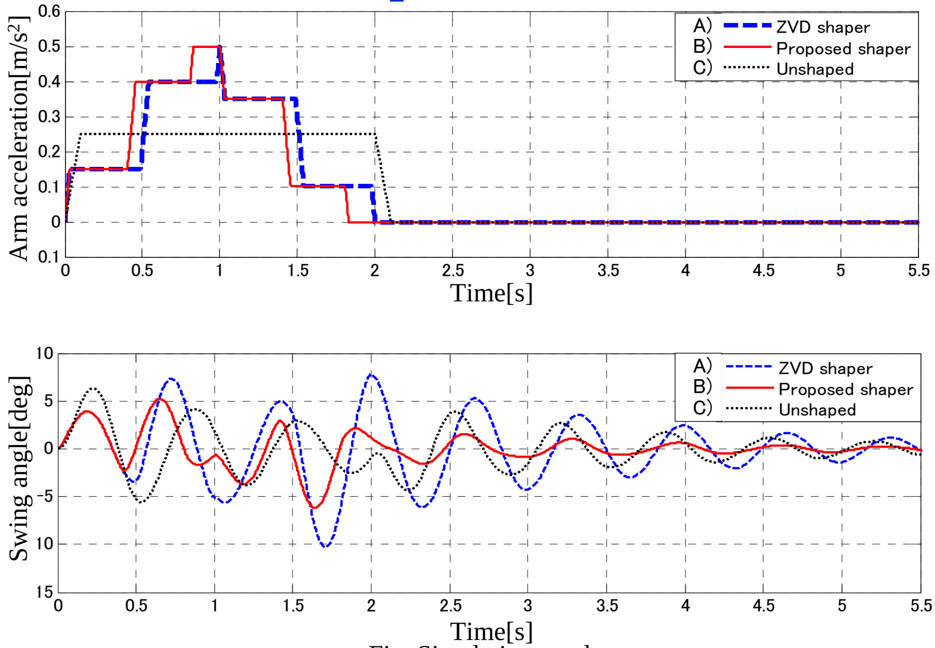


Fig. Simulation result

シミュレーション方法は手法えーとして固有周波数平均値を使用した通常のZVD

手法びーとして果房のパラメータを使用した提案手法

手法しーとして一般的に搬送に用いられる台形の速度軌道を加え、

各手法の1時モードの振動を比較します、シミュレーションモデルは2自由ど振り子とし右図のようになります

実際のトマトに当てはめるとこのようになります

またそれぞれの速度波形はこのような形で表されます

下の表はシミュレーションのパラメータです

一番下の時間が短く、振動の値が少ないほど今回の目的を満たしている方法といえます

シミュレーション結果です

上のグラフが加速度波形、下のグラフが振れ角度のあたいです

このように加速度のインパルスを与えます

上のグラフが速度波形、下のグラフが振れ角度のあたいです

Bの提案手法が赤色

Aの手法が青色

Cの手法が黒色で表されています

Magnitude of the remaining oscillation for *nth* inputs is formulated as follows like this

それぞれの台車停止位置は図のようになり、

It is obvious that natural frequencies and damping ratios of the objects must be known to apply the input shaping. In general, the number of waves is more than two, and sum of them is constrained to be zero amplitude.

台車移動後の振動は赤色の提案手法がもっとも小さくなっています

考察です

At first, let us denote angular frequency of the oscillation as , damping ratio as , initial amplitude corresponding to the input as , time after th input as . T

台車移動後の最大振幅の値は

このようになります

When the input shaping is applied, and are solved from given and . There are a few methods to solve this constraints. A zero vibration derivative shaper (ZVD shaper) is one of them, where following constrain equations are satisfied.

台形型の方法と比較を行うと

Aの手法では141%

提案手法では36%となりました

これより提案手法のシミュレーション上での有効性が示されました

さらにパラメータ誤差、モデル化誤差の検証実験を行いました

実験では手法として提案手法と手法Cを用いました

まずハンドに果柄を把持させ搬送させ動画を解析

シミュレーションと結果を比較します

実験結果です、

まずマニピュレータ全体の移動をお見せします

それではご覧ください、

左の台形はによる方法のトマトが大きく揺れ　右の提案手法の揺れが小さいことがわかります

さらに同じ動画のマニピュレータ停止位置の拡大動画をご覧ください

マニピュレータ停止後の振動の違いがよく分かると思います

この結果をグラフであらわすと

」このようになります

上が提案手法

下が台形はの方法で

青い線がシミュレーション結果、赤い線が実験結果となります

下の手法Cは実験とシミュレーションが良好に対応していますが

提案手法は、このようにインパルスのずれが生じています、このグラフの場合目標の値とは0.15s、約30％のずれがあり、実験とシミュレーションの結果がうまく対応できていません

We used this methods and. is supposed to be 3. Solution is obtained as follows.

しかし、残留振動の値は抑えられていることが分かります

I want to あとまわし

マニピュレータ停止後の最大振幅はこのようになり

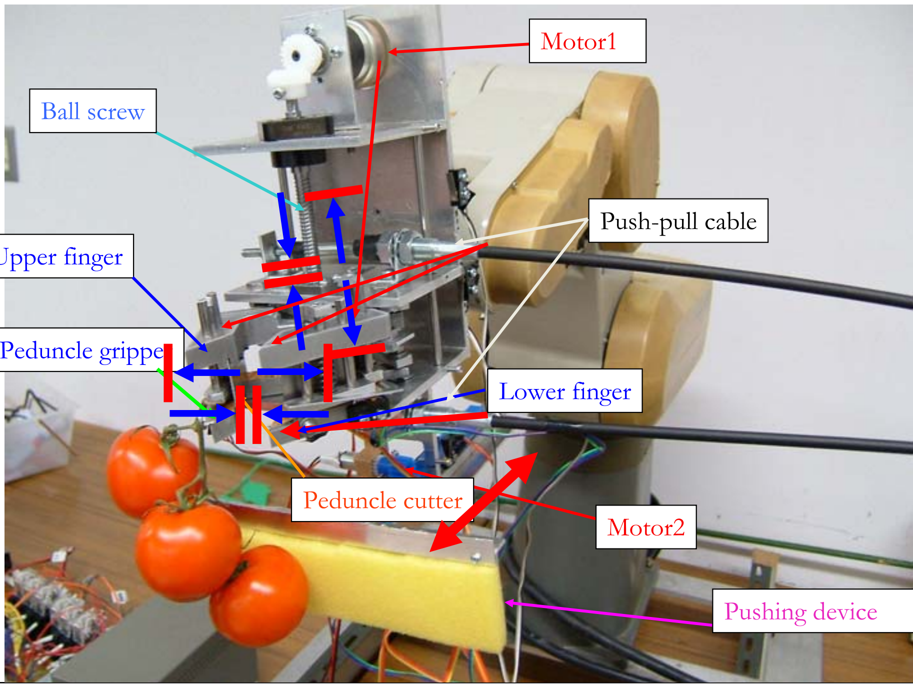
台形派の方法と比べると提案手法は29．5%の値に抑えられている

また台形はではシミュレーションと実験結果が良好に対応していました

今回は提案手法にインパルスのずれが生じていましたが、マニピュレータの動きをシミュレーションに近づけることで

さらに振動抑制できるとかんがえられます

さらに時間短縮と高速化をおこなうと提案手法の効果はさらに大きくなります



This is the end-efector we made.

The main parts of the end-effector consist of upper fingers , lower-fingers and a pushing device .

The Upper fingers have peduncle grippers and cutters.

Motor-1 makes the upper fingers to move up and down through the ball screw .

The peduncle cutters slide down together with the downward movement of the upper fingers.

The sliding parts have springs to grip up the peduncle by its elastic force.

Both upper and lower fingers open and close by push pull cables, which move by solenoid because of end-effector mass reduction.

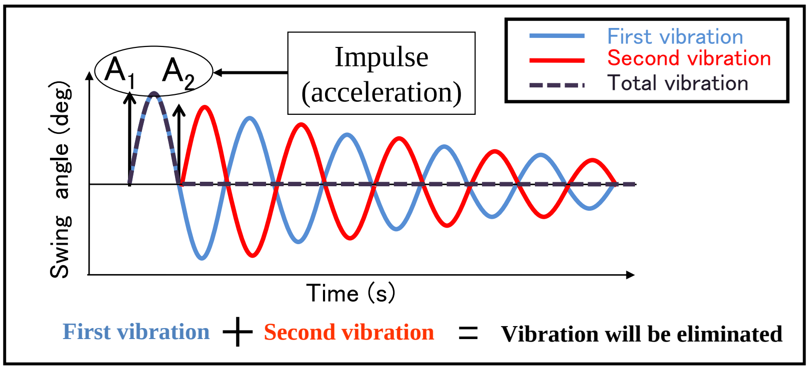
A pushing device with a soft bed for reducing cluster vibration is moved by motor-2 .

This vibration reduction is incorporated to prevent harm of the tomatoes causing from the vibration of cluster while it’s quick transportation to a container.

動画必要

Process of Input Shaping

Vibration elimination process:



- We have to consider tomato cluster natural frequency
  - Velocity and acceleration to cancel the vibration depends on the natural frequency.
- ZVD shaper
  - Kinds of input shaping, three impulses by accelerations are added

Static test

Searching relationship between peduncle diameter and bending displacement

• Four elemental (Burgers) model is used to represent the tomato peduncle

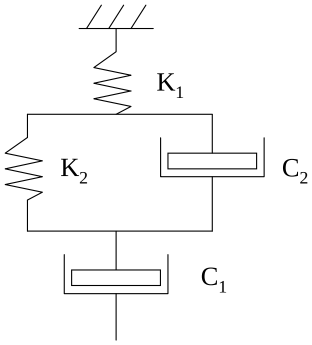


Fig. Four elemental model

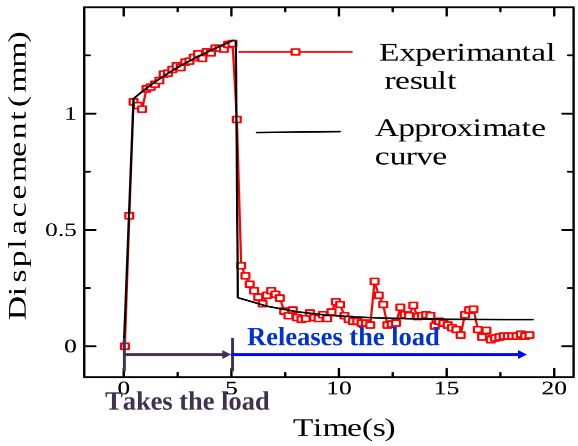


Fig. A result of peduncle static test

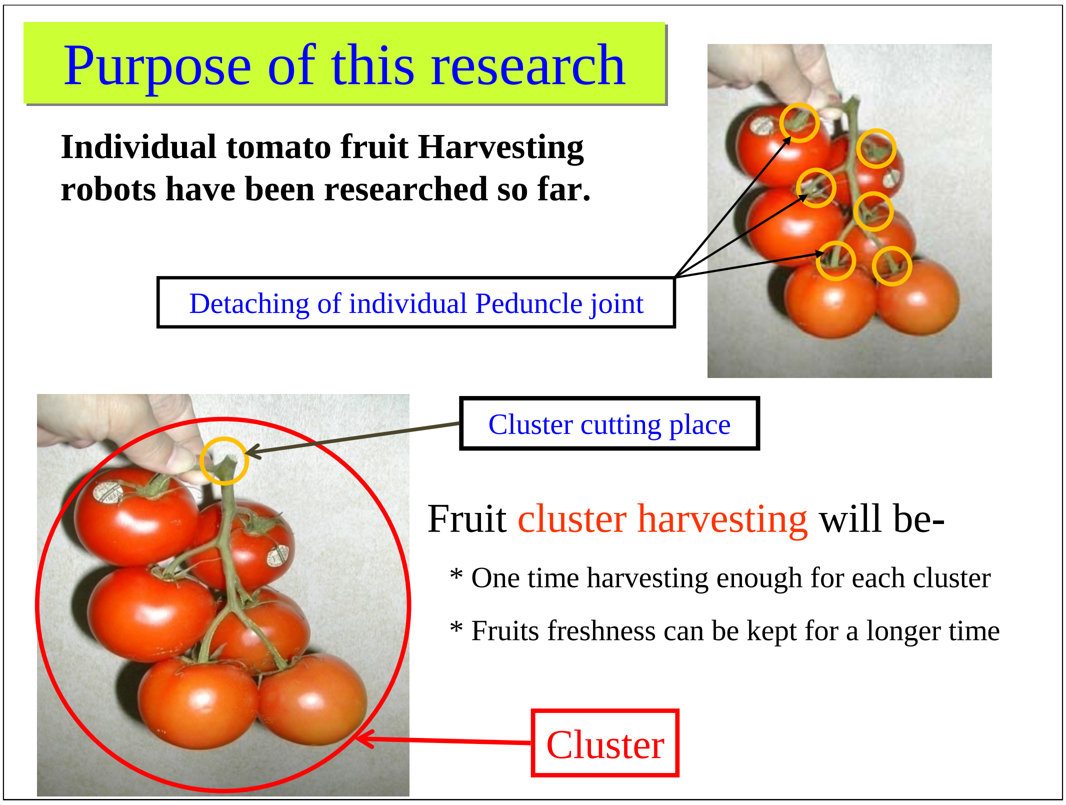
We did static test to obtain that relation between bending angle and reaction torque of the tomato peduncle

Tomato peduncle is modeled with a four element model as shown in here.

In the static test we observe peduncle displacement when taken the load to peduncle at five second right after release the load.

This figure is history of displacements when load is applied.

And we obtain parameters of peduncle by approximate curve.



Therefore, harvesting robot is desirable in Japan.(Our tomato harvesting operation is done for individual fruit and some tomato harvesting robots have been researched so far). Some individual tomato harvesting robots have been researched so far.個別のトマト収穫ロボットはすでにリサーチされている.

But, they did not overcome human workers, because their speed was NOT faster than human. In the Netherlands, or some places, US, cluster harvesting is popular.

The advantages are one time harvesting enough for each cluster, and it is said that fruits freshness can be kept for a longer time than individual fruit harvesting . In Japan also, cluster harvesting is now being started in large scale greenhouses.

From these reasons, we are now researching a tomato cluster harvesting robot.