Point-to-Point Iterative Learning Control with Optimal Tracking Time Allocation

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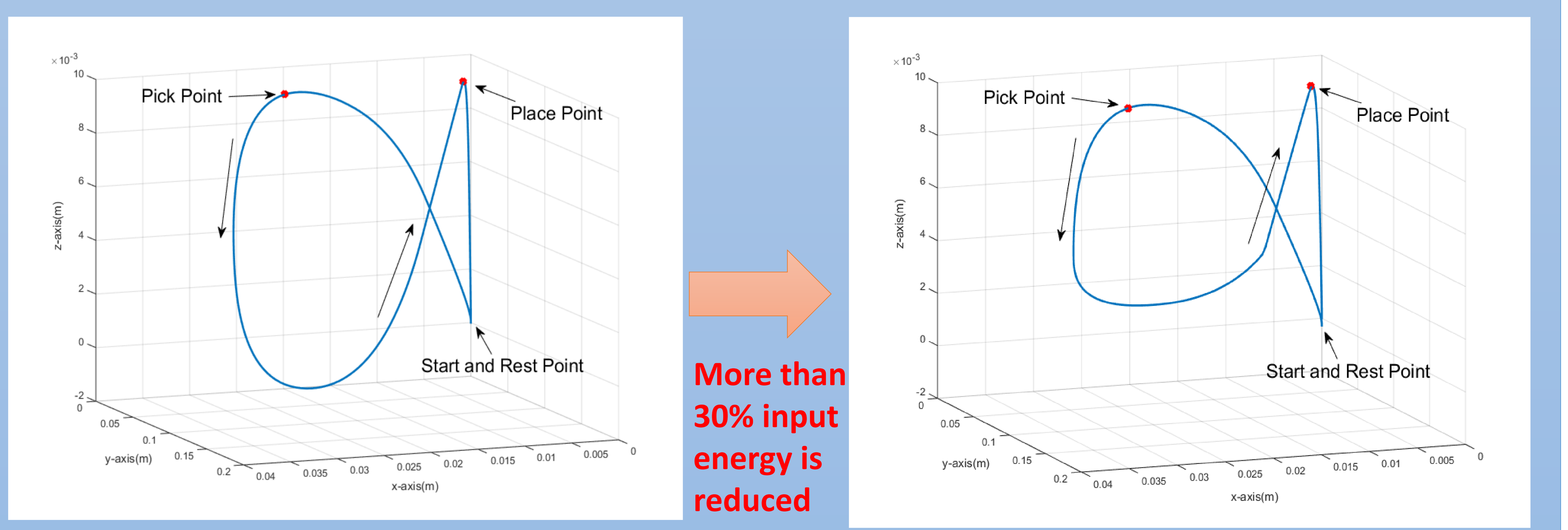
Introduction to ILC

- Iterative learning control (ILC) is a **high performance** control technique applied to system performing **repeated** tasks.
- ILC has a **wide range** of applications: robotics, chemical process, stroke rehabilitation, etc.
- The design objective is to update the input u such that the output y^p at **a subset of time instants** $\boldsymbol{\Lambda} = [t_1, t_2, \ldots, t_M]^T$ follows a given reference r_p and perfect tracking is achieved.

Motivation

- In current point-to-point ILC, $\boldsymbol{\Lambda}$ is known ***a priori***.
- The **input energy** $\|u\|^2$ depends on $\boldsymbol{\Lambda}$. Taking a robotic arm's 'pick' and 'place' task as an example, much control effort is saved after changing $\boldsymbol{\Lambda}$.



(a) Original Allocation [0.5,1.5] **(b) New Allocation** [0.65,1.35]

Fig.1 Reference Trajectory Before and after Changing Tracking Time Allocation

Question: Can we design a control law to choose $\boldsymbol{\Lambda}$ **automatically** to optimise $\|u\|^2$ subject to the tracking requirement $r_p = G^p(\boldsymbol{\Lambda})u$?

A Two Stage Design Framework

Stage One : Assume $\boldsymbol{\Lambda}$ is **fixed** and solve:

$$\min_{u}\{f(u) = \|u\|^2\}, \text{ subject to } r_p = G^p(\boldsymbol{\Lambda})u$$

whose solution $u_\infty(\boldsymbol{\Lambda})$ can be obtained by applying norm optimal point-to-point ILC update.

Stage Two : Substitute $u_\infty(\boldsymbol{\Lambda})$ into the original problem:

$$\min_{\boldsymbol{\Lambda}}\{\tilde{f}(\boldsymbol{\Lambda}) = f(u_\infty(\boldsymbol{\Lambda}))\}$$

which cannot be solved **directly** and an iterative algorithm is used.

A Gradient Based Algorithm:

Begin with $\boldsymbol{\Lambda}_0$ and $j = 1$

Stage One Solution: $u_{k+1} = u_k + (G^p(\boldsymbol{\Lambda}_{j-1}))^* e_{k+1}^p$ with stop criteria $\|e_k^p\| < \varepsilon\|r_p\|$. Obtain $\tilde{f}(\boldsymbol{\Lambda}_{j-1})$.

Stage Two Update: $\boldsymbol{\Lambda}_j = \boldsymbol{\Lambda}_{j-1} - \gamma \cdot \frac{\partial \tilde{f}(\boldsymbol{\Lambda}_{j-1})}{\partial \boldsymbol{\Lambda}_{j-1}}$.

If $|\tilde{f}(\boldsymbol{\Lambda}_j) - \tilde{f}(\boldsymbol{\Lambda}_{j-1})| < \delta|\tilde{f}(\boldsymbol{\Lambda}_{j-1})|$ is satisfied.

No → Go to Next loop: $j \rightarrow j+1$

Yes → Stop

A Gantry Robot Test Platform

Fig.2 A Gantry Robot Test Platform

- We use a multi-axis **gantry robot** as a test platform.
- The gantry robot has a **wide range** of applications in industry.
- The design objective is to follow the reference in Fig. 1 to pick the payload from the dispenser and place it on the conveyor.

Experimental Verification

a) Significant Reduction in Input Energy:

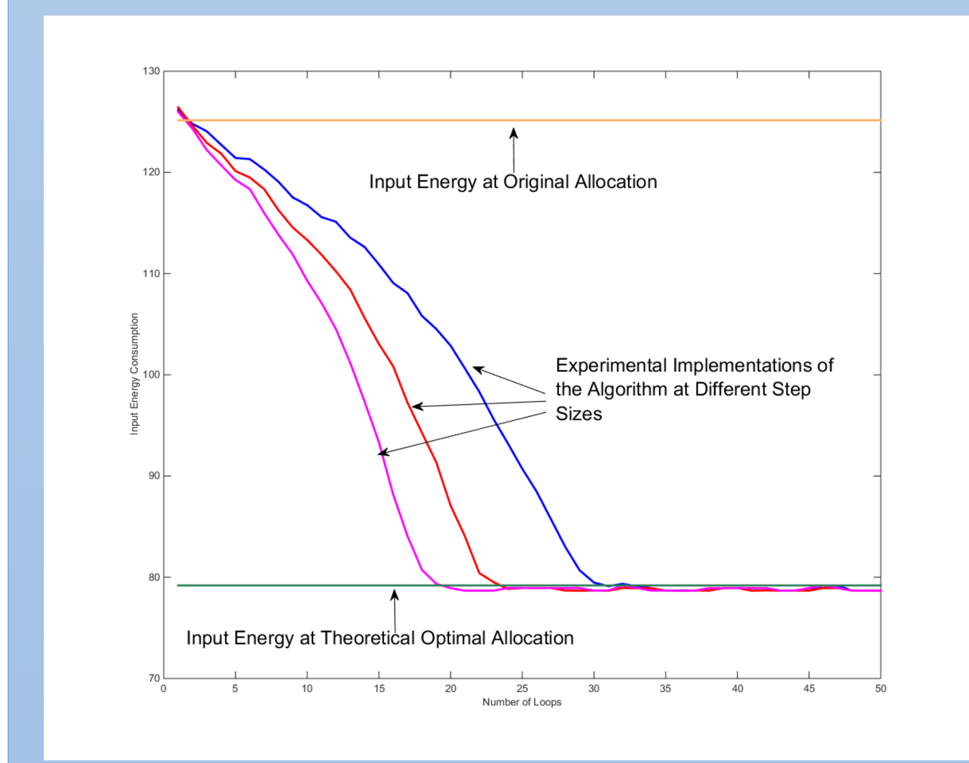


Fig.3 Experimental Results at Z-axis Using Accurate Model

- The proposed algorithm achieves **perfect tracking**.
- All time points converge to the **same time positions**.
- Around **35%** input energy is saved compared to the input energy at original allocation.

b) Robustness against Model Uncertainties:

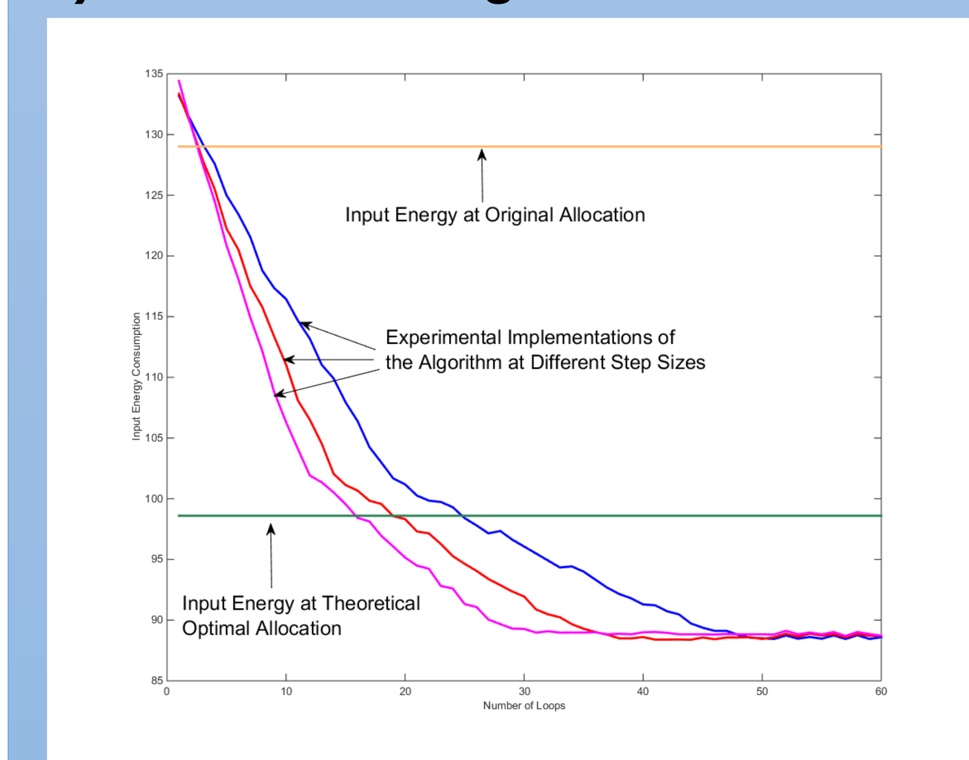


Fig.4 Experimental Results at Z-axis Using Approximate Model

- Not easy to obtain an accurate model **in practice**.
- The proposed algorithm achieves **perfect tracking**.
- All time points converge to the **same time positions**.
- The algorithm can **still** reduce about **28%** of input energy and has a certain degree of **robustness** against model uncertainties

Conclusion

- A **two stage** design framework is proposed to optimise the performance index and achieve perfect tracking at the same time.
- The proposed framework is verified at an experimental test platform to demonstrate its **effectiveness** in practice and **robustness** against model uncertainties.

Reference

[1] Y. Chen, B. Chu and C. T. Freeman, "Point-to-point Iterative Learning Control with Optimal Tracking Time Allocation," 54th IEEE Conference on Decision and Control, Osaka Japan, December 15-18, 2015.

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