Laser Driven Robot-on-a-chip (LDRoC)
-Part 1: Bilateral control system of integrated optical tweezers-

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多点操作と高速操作の両立：新しいレーザ操作系の仕組みとは？

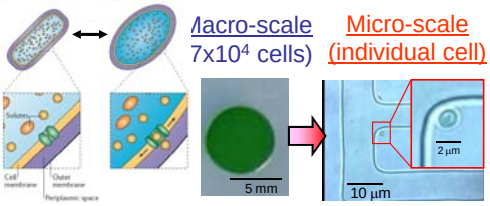
Abstract:

Multi-beam Optical Tweezers (MOT) such as Time-Shared Scanning method (TSS) and Generalized Phase Contrast method (GPC) is suitable for dexterous cell manipulation using multiple microtools. We developed Integrated Optical Tweezers (IOT) which was integrated with TSS for high speed manipulation and GPC for a lot of trapping. We applied unilateral master slave control (UMSC) to TSS for dexterous manipulation. We applied bilateral master slave control (BMSC) to TSS. We confirmed the effectiveness of constructed BMSC system from experimental results.

Background:

Importance of single cell analysis

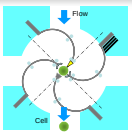
Macro-scale 7x10⁴ cells) Micro-scale (individual cell)



Function and mechanism of membrane translocator
Ex: MscL (Mechanosensitive channel)

Conventional manipulation system

Manipulation using micromanipulater ICRA2000



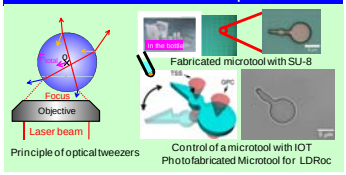
μ-TAS2008

1. High speed
2. High accuracy
3. Local environmental control
4. Small disturbance
5. Disposable
6. Compatible with μ-TAS

Robot-on-a-chip(ロボットオンアチップ)

単一細胞レベルでの各種計測・分析・クローニング・解剖操作を目的とし，細胞ソーティングなどの微細作業を行うためのマイクロ・ナノロボットを搭載したマイクロ流体チップをロボチップと呼ぶ．

レーザ駆動Robot-on-a-chip（LDRoc）

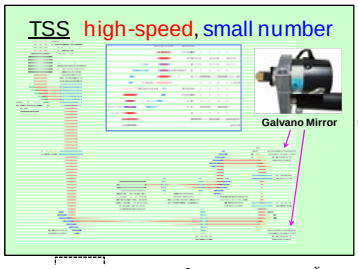


Concept:

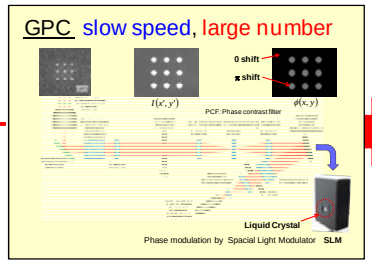
Integrated Optical tweezers (IOT)

IOT=TSS (Time shared scanning) と GPC (Generalized phase contrast)

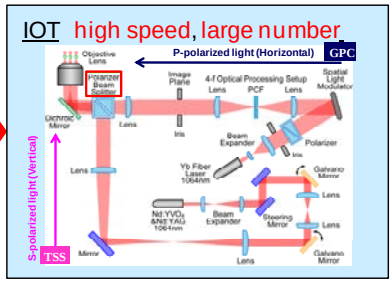
TSS high-speed, small number

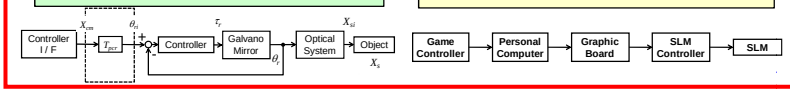


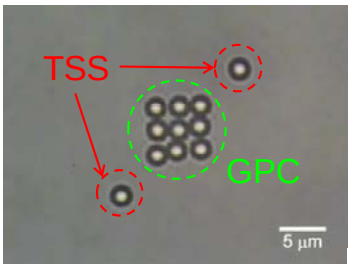
GPC slow speed, large number



IOT high speed, large number



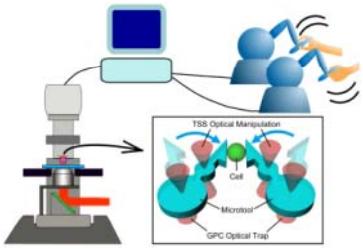




Particles manipulation using IOT

Experiments:

BMSC using TSS

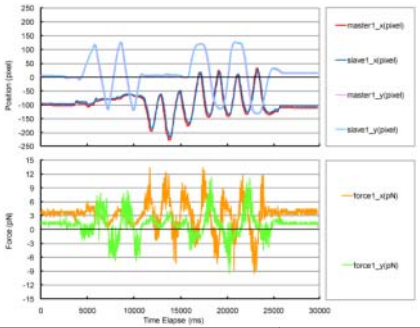


Experimental condition of BMSC

TSS Laser Power	38 mW
Optical Trap Stiffness	10.49 pN/μm (In two trapping)
Temperature	20±1℃
Camera Type	High Speed Camera 60 FPS
Observation System	Objective Lens : 100x Wide-angle Lens : 1x C Mount : 1x
Force Transfer Ratio s_f	10^{11}
Control Cycle	20 ms
Force Measurement Cycle	17 ms

Teleportation with TSS using BMSC

Multiple beads manipulation using TSS using BMSC

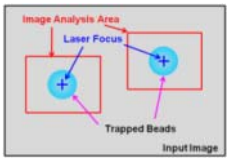


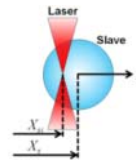
Comparison of TSS and GPC and CGH

		Time-shared Scanning (TSS) Fast but Small num.	Generalized Phase Contrast (GPC) Large num. but Slow	Computer Generated Hologram (CGH)
2D Trajectory control	Small num.	Fast*	Slow**	Slow**
	Large num.	Slow*	Slow**	Slow**
3D Trajectory control	Small num.	Very Slow*	Slow**	Slow**
	Large num.	Not recommended*	Slow**	Slow**
Response speed	Small num.	Fast*	Slow**	Slow**
	Large num.	Slow*	Slow**	Slow**
Computation	Small num.	Simple	Simple	Complex
	Large num.	Complex	Simple	Complex
Stability	Small num.	Stable	Stable	Stable
	Large num.	Unstable	Stable	Stable
Laser Power (Trap force)		Large	Weak**	Weak**
Hardware		Simple	Complex	Complex

* Depends on the scanner ** Depends on Spatial Light Modulator (SLM)

Force measurement by Image processing





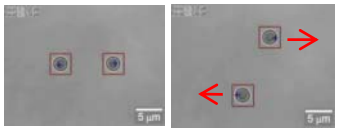
$$F_s = K(X_s - X_{si})$$

Fs：スレーブに働く力 [N]
K ：バネ定数 [N/m]
Xsi: レーザ位置 [m]
（既知）
Xs：スレーブ中心位置 [m]
（観察画像より取得）

スレーブ中心の追跡

$$R_{NCC}(a,b) = \frac{\sum_{j=0}^{H-1}\sum_{i=0}^{W-1}|I(a+i,b+j)T(i,j)|}{\sqrt{\sum_{j=0}^{H-1}\sum_{i=0}^{W-1}I(a+i,b+j)^2 \times \sum_{j=0}^{H-1}\sum_{i=0}^{W-1}T(i,j)^2}}$$

I：入力画像，T：テンプレート画像，a：X座標，b：Y座標，，W：テンプレート画像幅，H：テンプレート画像高さ



Position sensing of laser and beads

Conclusions:

- 統合型光ピンセットの光学系及び制御系の構築を行った．
- TSS部の制御系にバイラテラル制御システム（制御周期：20 ms）を適　用し操作性を向上した．
- 高速度カメラを用いた画像力計測手法（計測周期：17 ms）を提案した．
- 画像力計測法とバイラテラル制御系を用いたTSSによる操作システムの有効性を確認した．

References：

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