A Practical and Low-cost Contact Force and Contact Position Detection Module for Robot Grippers

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1. Research Background

Research Background

Pickommerce Secures $3.4M Investment to Advance Innovative Robotic Piece-Picking Technology [15]

Visit http://www.pickommerce.com for further information

EXCLUSIVE

How Amazon used Oreos and dog toys to develop an army of robots to grab what you buy [16]

ABB expands robotic Item Picking Family with new AI-powered functional modules to transform fashion and logistics industries [17]

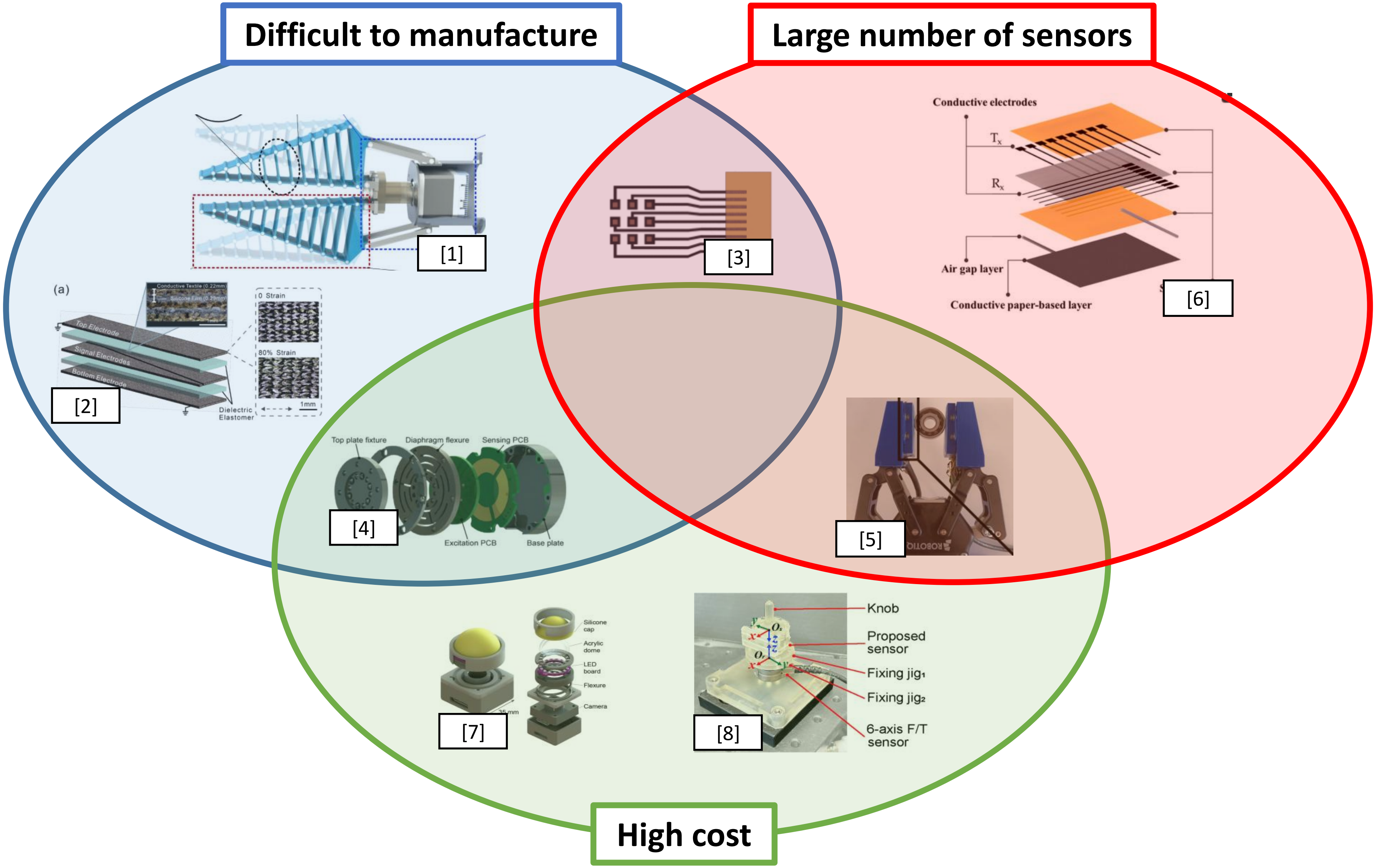
[로봇 피킹 시스템]
(ChatGPT 그린 그림)

많은 회사들이 공장에서 로봇 그리퍼를 사용한 **자동화 물류 시스템**에 투자하며 **제품 파손을 최소화**하고 **물류 운영 비용을 절감**하려고 시도함

이를 위해서는

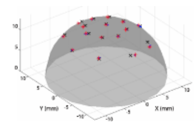
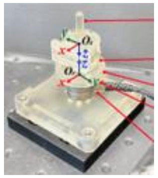
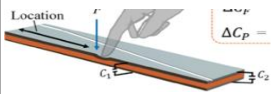
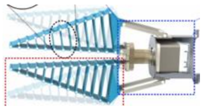
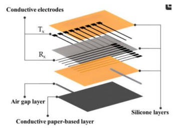
1. 다양한 크기, 강도, 형태의 물체를 안전하게 잡을 수 있어야 함.
2. **파지력**과 **파지점**을 **실시간으로 측정**하여, **적절한 힘과 자세로 제어**할 수 있어야 함.

Research Background



위 파지력과 파지점 센서들은 복잡하고 고가이며 부품이 많이 필요하고, 실시간 주문 변화 대응이 어려움.

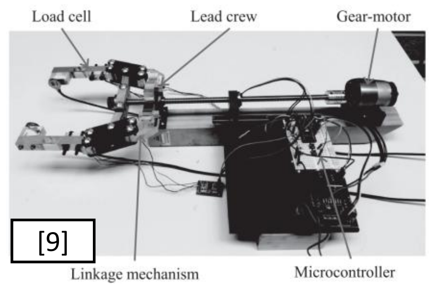
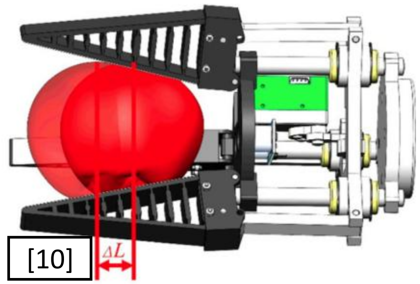
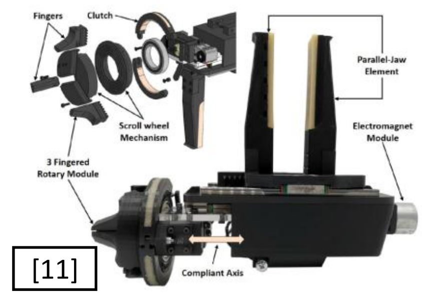
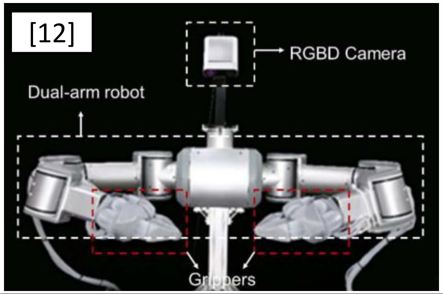
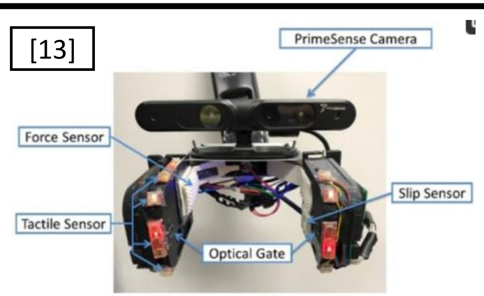
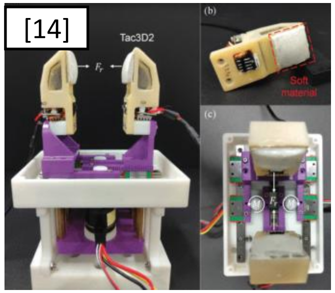
- **파지력 파지점 센서 스펙**

센서	파지력	파지력 오차	파지점	파지점 오차	Sampling Rate
	1~10N	0.3N	X:20 Y:20 Z:10 	최대 1mm	40Hz
	0~50N	0~25N: 2.5N 오차 25~50N: 3.75N 오차	18mm x 36mm (2차원)	1.1~1.4mm	20Hz
	**힘** Fz: 32N, Fx/Fy: 15N **토크** Tz: 250N-mm, Tx/Ty: 300N-mm	**힘** Fz: 1N, Fx/Fy: 0.5N **토크** Tz: 2.45 N-mm Tx/Ty: 8.64 N-mm			2000Hz
	0.0021N~25N	0.4 N	60mm (1차원)	최대 2.5mm	50Hz
			18mm x 18mm (2차원)	최대 0.35mm	1000 Hz
	0.5N~3N	중심 부분: 0.09 N 끝부분: 1.5 N	153mm (1차원)	최대 0.2mm	25Hz
	0~3.2N	0.025 N	100mm x 100mm (2차원)	최대 1.5mm	

현재 파지력과 파지점을 파악하는 센서들의 성능은 위와 같고, 특히 낮은 Sampling Rate는 제어 시스템의 응답 속도 저하, 노이즈 처리 어려움, 동적 시스템 모델링 부정확 등의 문제를 초래할 수 있음.

Research Background

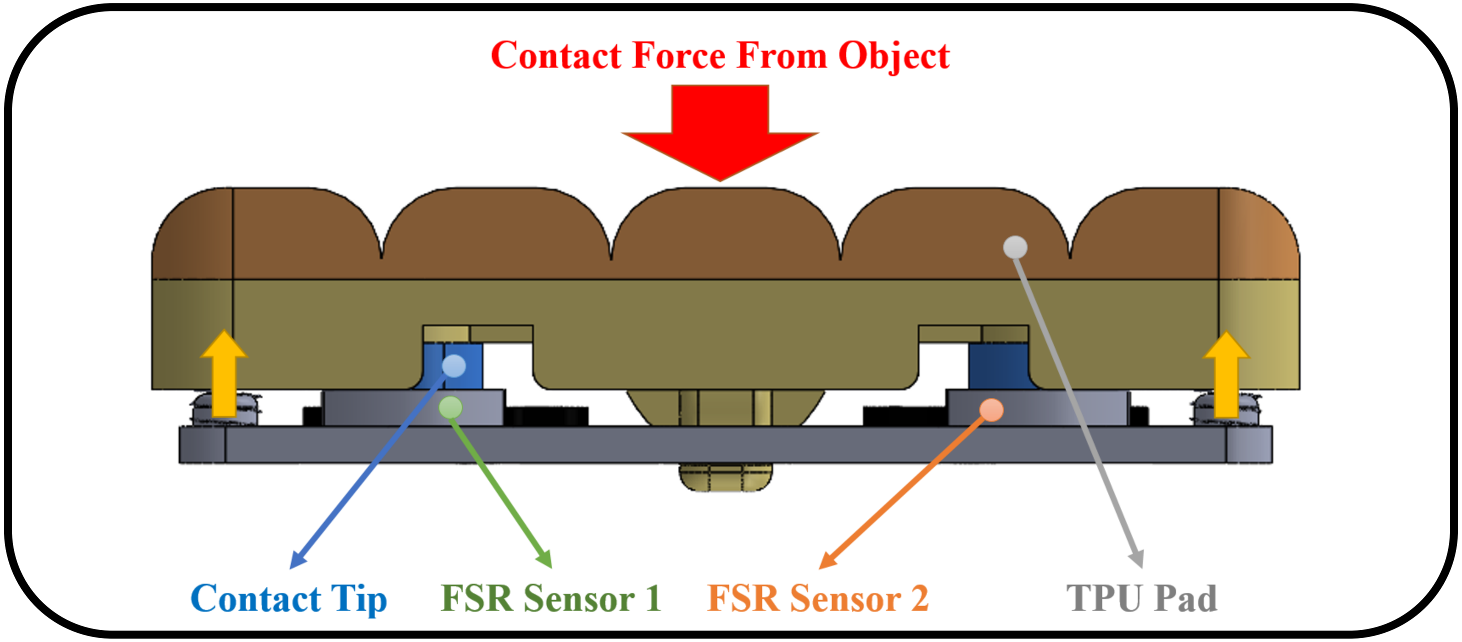
- **센서를 사용한 그리퍼 제어**

제어 종류	원리	선행 연구
Force Control	작용과 반작용 힘의 균형을 맞추는 제어	 
Compliance Control	접촉이 일어났을 때 포지션을 조절하여 외부 힘을 줄이는 제어	 
Adaptive Control	제어 대상의 수학적 모델을 만들기 어려울 때 제어기의 구조나 매개변수를 변경하는 제어	 

그리퍼로 물체를 잡을 때 진행하는 제어로는 힘 제어, 순응 제어, 적응 제어가 주로 사용되며 안정적인 그리핑 제어를 진행하기 위해선 실시간 성능과 파지력 및 파지점 파악이 필수적임.

Research Background

- 본 연구에서 제안하는 Lever mechanism contact sensor module(LMCSM)



[Design of the Lever mechanism contact sensor module]

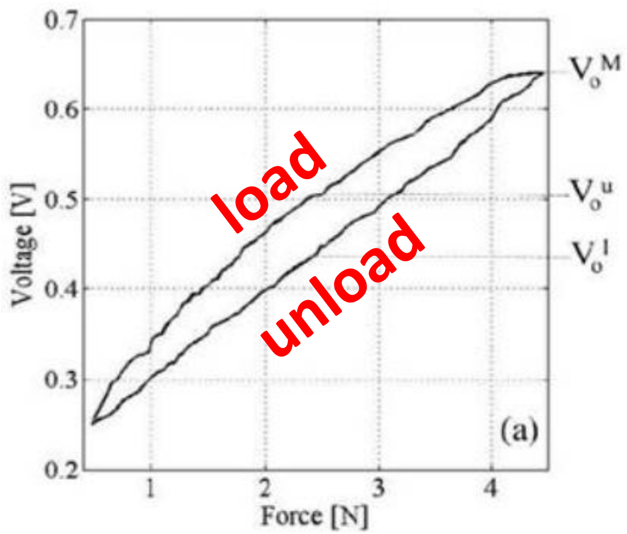
Reference sensors	Lever Mechanism Sensor Module
복잡한 구조와 어려운 제조 과정	간단한 설계와 쉬운 제조 과정
고가의 재료 및 장비로 인한 높은 가격	FSR센서를 사용한 낮은 가격
많은 수의 센서로 인한 낮은 실시간성	적은 수의 센서로 높은 실시간성을 통한 제어

2. FSR Sensor

FSR sensor

FSR sensor characteristics

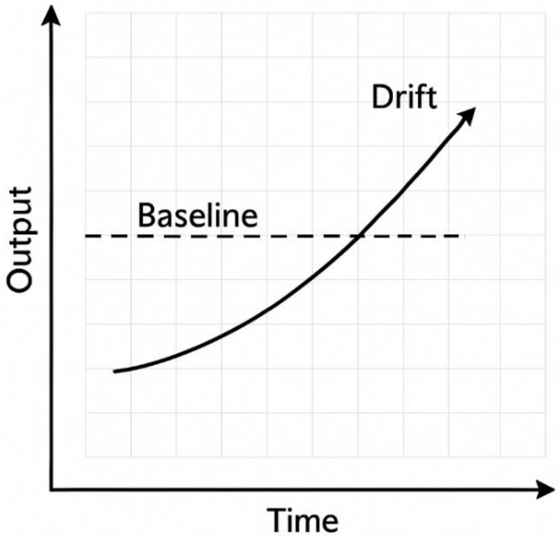
Hysteresis



[Force-Voltage Hysteresis Loop]

가압/감압 경로에 따라 출력이 달라지는 현상

Drift



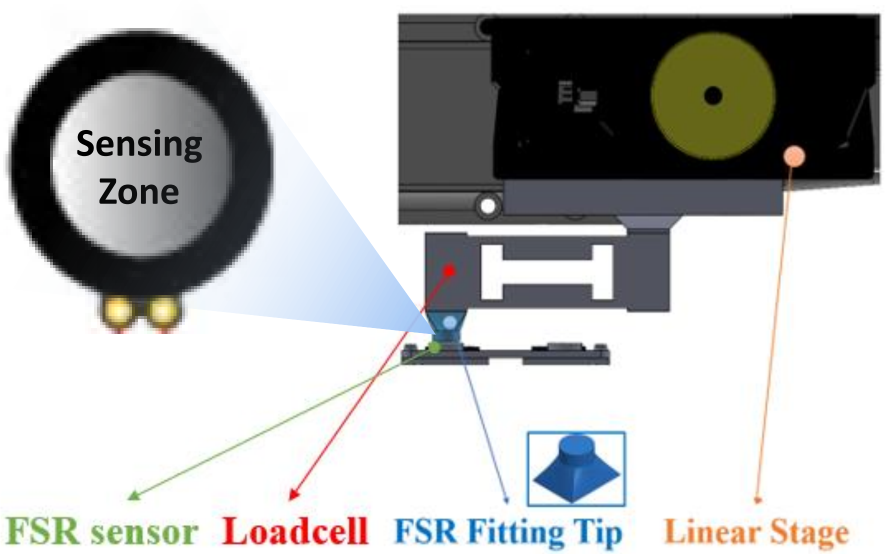
[Sensor Output Baseline Drift Over Time]

일정한 하중을 가해도 출력이 시간에 따라 변동

모델 기반 알고리즘 보정		데이터 기반 보정	
Modified Prandtl-Ishlinskii(MPI model)	[20]	TCN(Temporal Convolutional Network)	
Preisach hysteresis operator	[19]	LSTM(Long Short-Term Memory)	[21]
Closet Match Algorithm (CMA)	[21]	Neural ODE	

FSR sensor

FSR sensor experimental setup

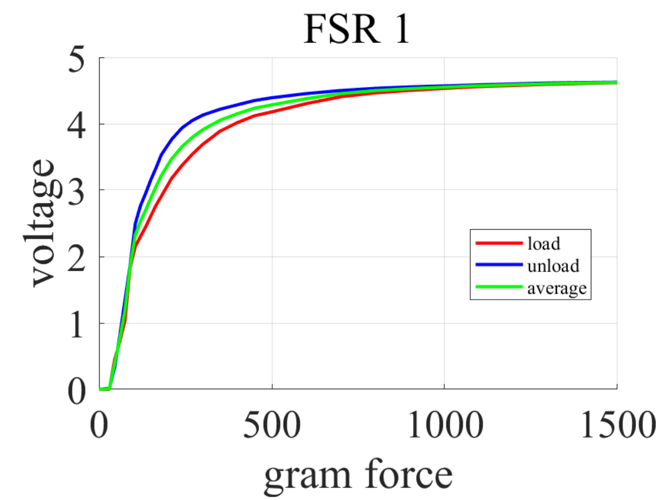


[Experimental setup: Loadcell on linear stage pressing FSR]

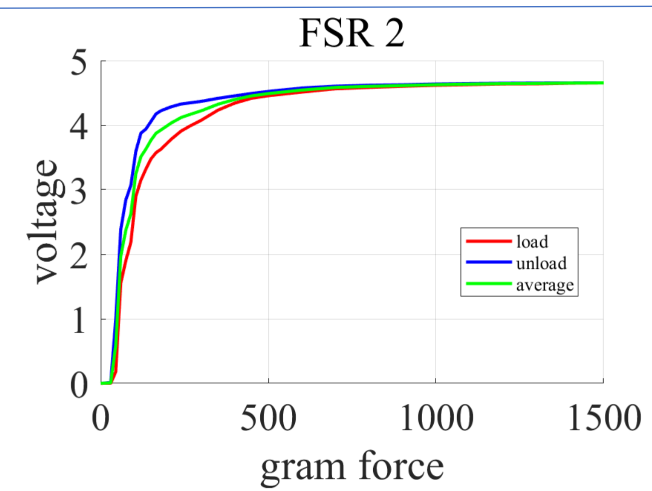
Test result

- 센서별로 측정되는 전압 차이가 다름
- 가하는 힘이 클수록 기울기가 낮아지는 비선형성 보임
- 로딩 및 언로딩 곡선을 평균화하여 피팅 곡선으로 활용함

FSR sensor calibration curve



[FSR Sensor 1 Calibration Curve]

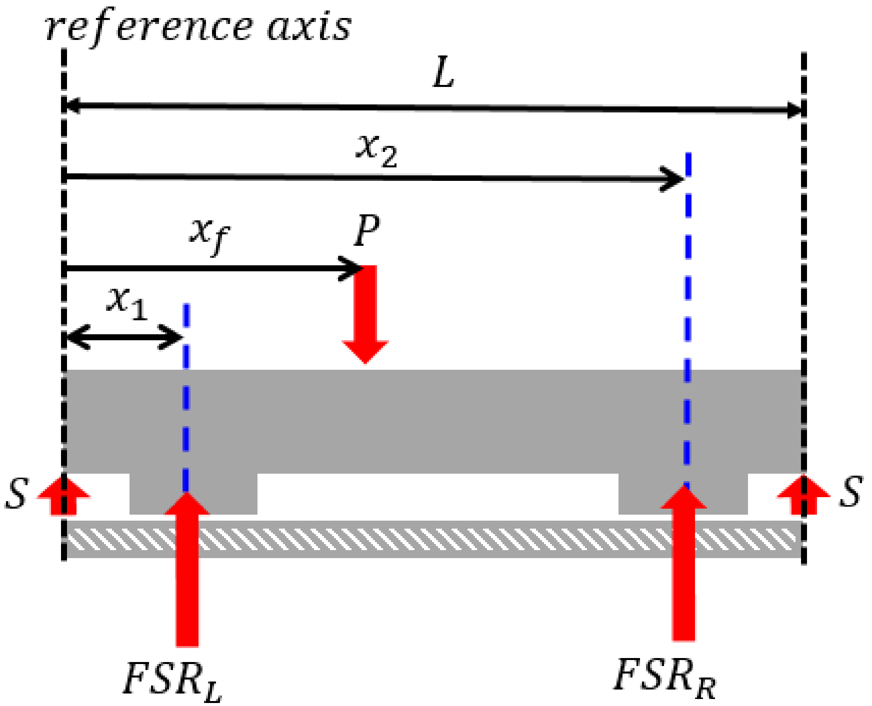


[FSR Sensor 2 Calibration Curve]

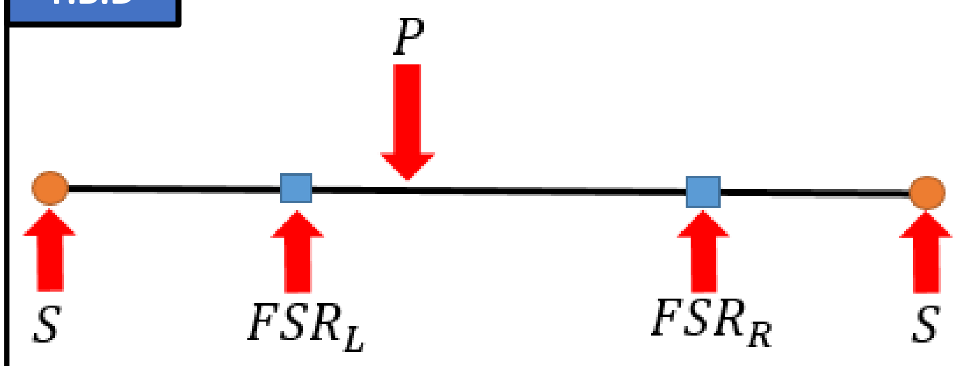
3. Lever mechanism contact sensor module

Lever mechanism contact sensor module

Model



F.B.D



x_f = 힘이 작용하는 위치까지 거리

x_1 = $reference\ axis$에서 FSR_L까지 거리=10.25

x_2 = $reference\ axis$에서 FSR_R까지 거리=46.75

$k = 0.559\ N/mm$ 스프링 상수

$\delta = 0.36mm$ 스프링 눌린 깊이

$S = k \times d \times 2$: 스프링 힘

평형 방정식

$$\sum F = 2 \times S + FSR_L + FSR_R - P = 0$$

$$\sum M = S \times L + FSR_L \times x_1 + FSR_R \times x_2 - P \times x_f = 0$$

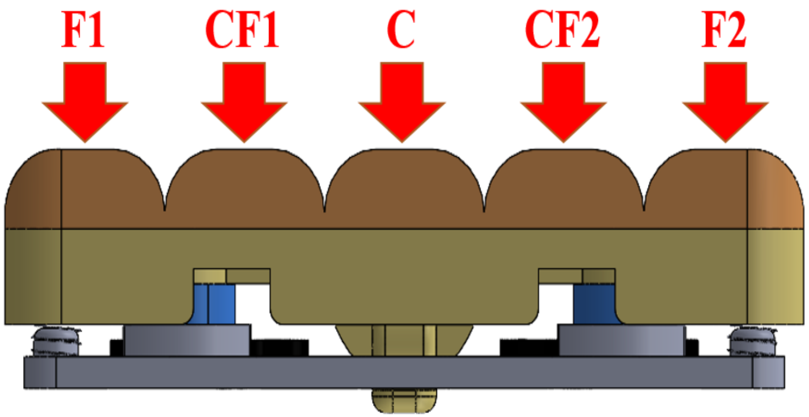
힘 위치 방정식

$$P = 2 \times S + FSR_L + FSR_R$$

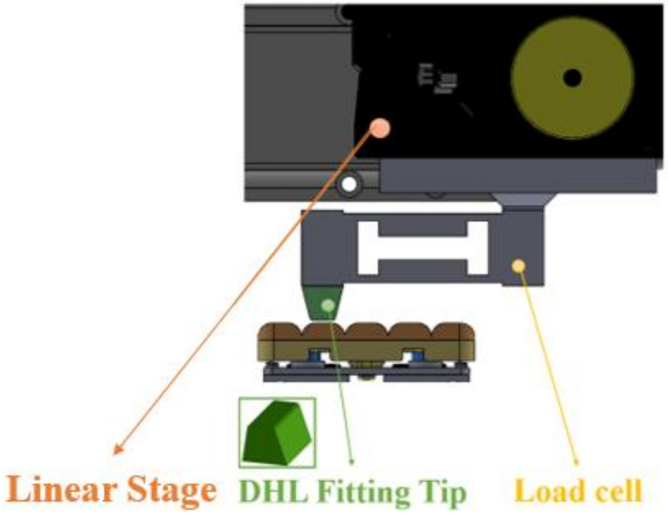
$$x_f = \frac{S \times L + FSR_L \times x_1 + FSR_R \times x_2}{P}$$

Lever mechanism contact sensor module

Pressing position & Experemental setup

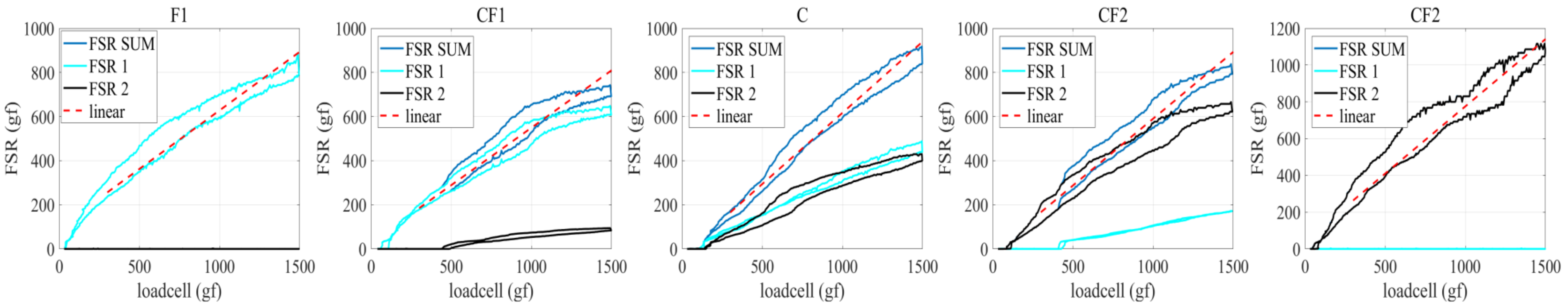


[Test points on the contact surface]



[Experimental setup:
Loadcell on linear stage pressing LMCSM]

Force distribution result by position

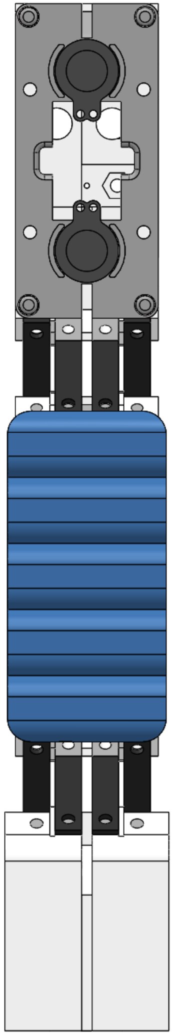


[Evaluation test result]

4. Grasp force control

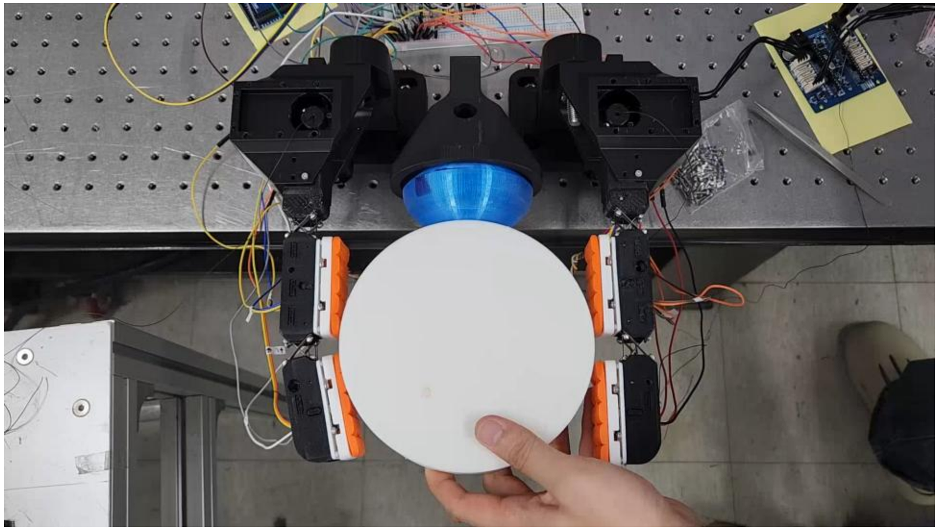
Grasp force control

Soft robotic Gripper



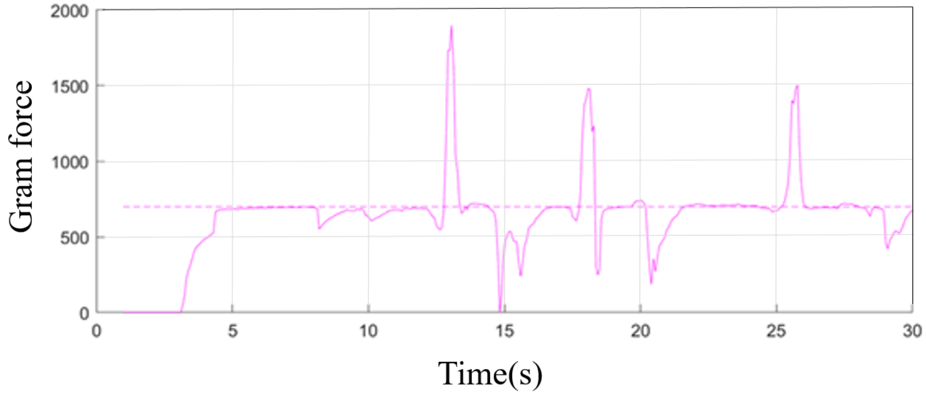
[Soft robotic gripper]

Cylindrical object picking demo



[Cylindrical object picking demo video]

Force Graph



[Force Graph Measured by LMCSM During Grasping of a Cylindrical Object]

5. Future Works

Future Works

- Neural Network를 사용하여 FSR센서의 히스테리시스 및 드리프트 현상 보정
- 히스테리시스 및 드리프트 현상을 표현할 수 있는 데이터 수집
- Lever mechanism contact sensor module을 사용한 그리퍼 제어 알고리즘 개발

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Thank you for your attention