협동로봇 충돌안전시험 소개 및 사례

신 헌 섭

주식회사 세이프틱스 & 경희대학교 로봇공학연구실

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Safetics Inc. Robotics Lab

Collaborative robot

기존 산업용 로봇

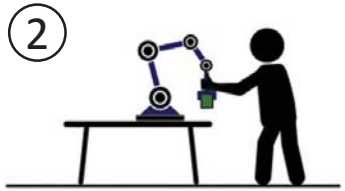
펜스로 작업자
안전보장

협동로봇

펜스의 부재로
충돌위험성 잠재

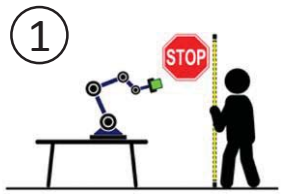
Collaborative robot

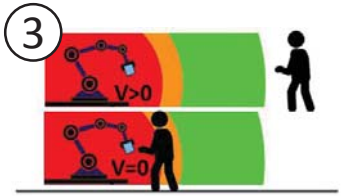
협동로봇의 협동모드 종류



[핸드가이딩(2번 Operation)]

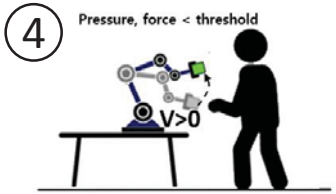
안전보장방법 : 로봇자체제공





[일정거리이내 접근 시 정지 (1번, 3번 Operation)]

안전보장방법 : 센서



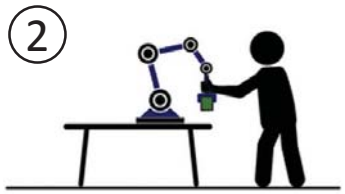
[거리 상관없이 운행 (4번 Operation)]

안전보장방법 : 충돌시험

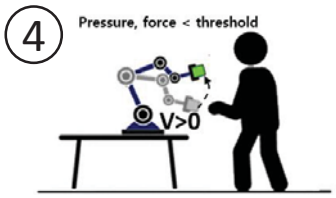
협동로봇의 사용 형태

이상적

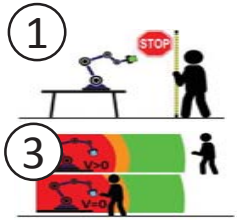
[교시]



[로봇 속도 : 느림]

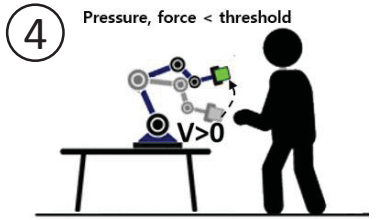


[로봇 속도 : 빠름]



Distance > min separation

+

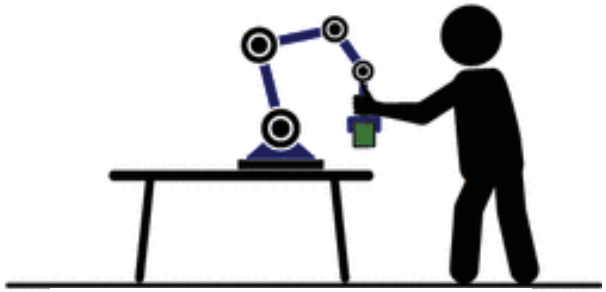


Distance < min separation

펜스가 없는 대신, 펜스에 준하는 정도의 안전 레벨을 지켜야 한다.

Types of Collaborative Operation ISO 10218-1:2011

ISO 10218-1,2 ISO/TS 15066

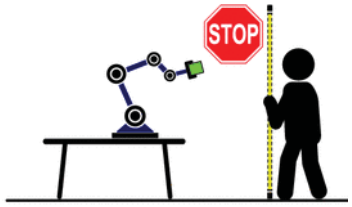


2. 핸드가이딩

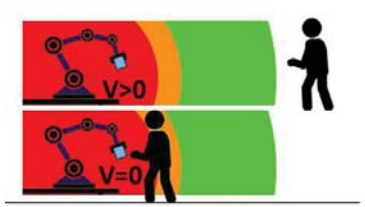
- 협동작업가 주된 프로세스인 경우
- 환경 : 교시모드가 지원되는 협동로봇

Types of Collaborative Operation ISO 10218-1:2011

ISO 10218-1,2 ISO/TS 15066

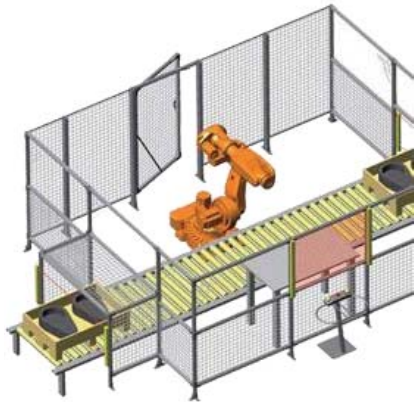


1. 안전정격 감시 정지

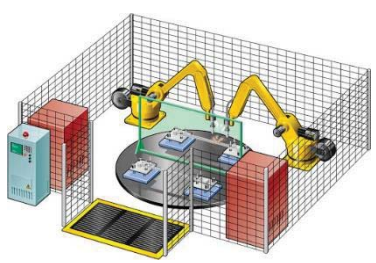


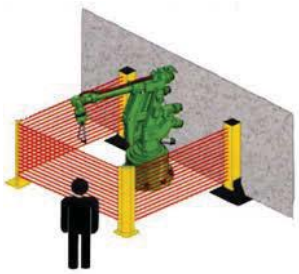
3. 속도 및 위치 감시

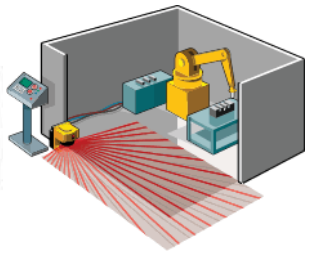
- 사람과 협동작업을 많이 하지 환경에서 주로 사용됨
- 환경 : 라이트 커튼, 안전매트, area 센서 등이 필요



[기존 산업용 로봇의 로봇 설치환경]



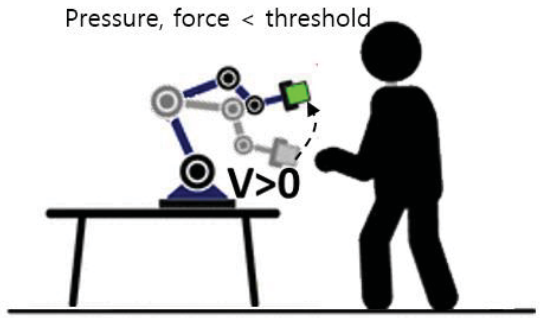




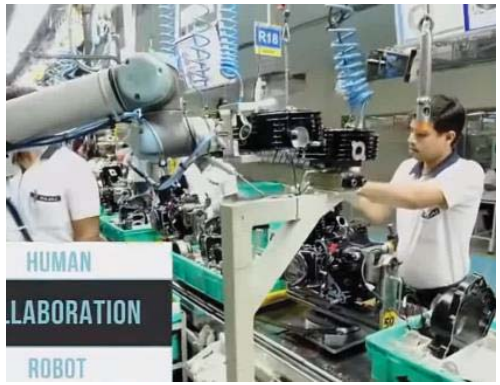
[1,3번 모드로 설치된 협동로봇]

Types of Collaborative Operation ISO 10218-1:2011

ISO 10218-1,2 ISO/TS 15066



4. 설계 또는 제어에 의한 파워 및 힘 제한



- 사람과 협동작업을 많이 하는 경우 사용
- 환경 : 충돌 위험성 테스트 결과

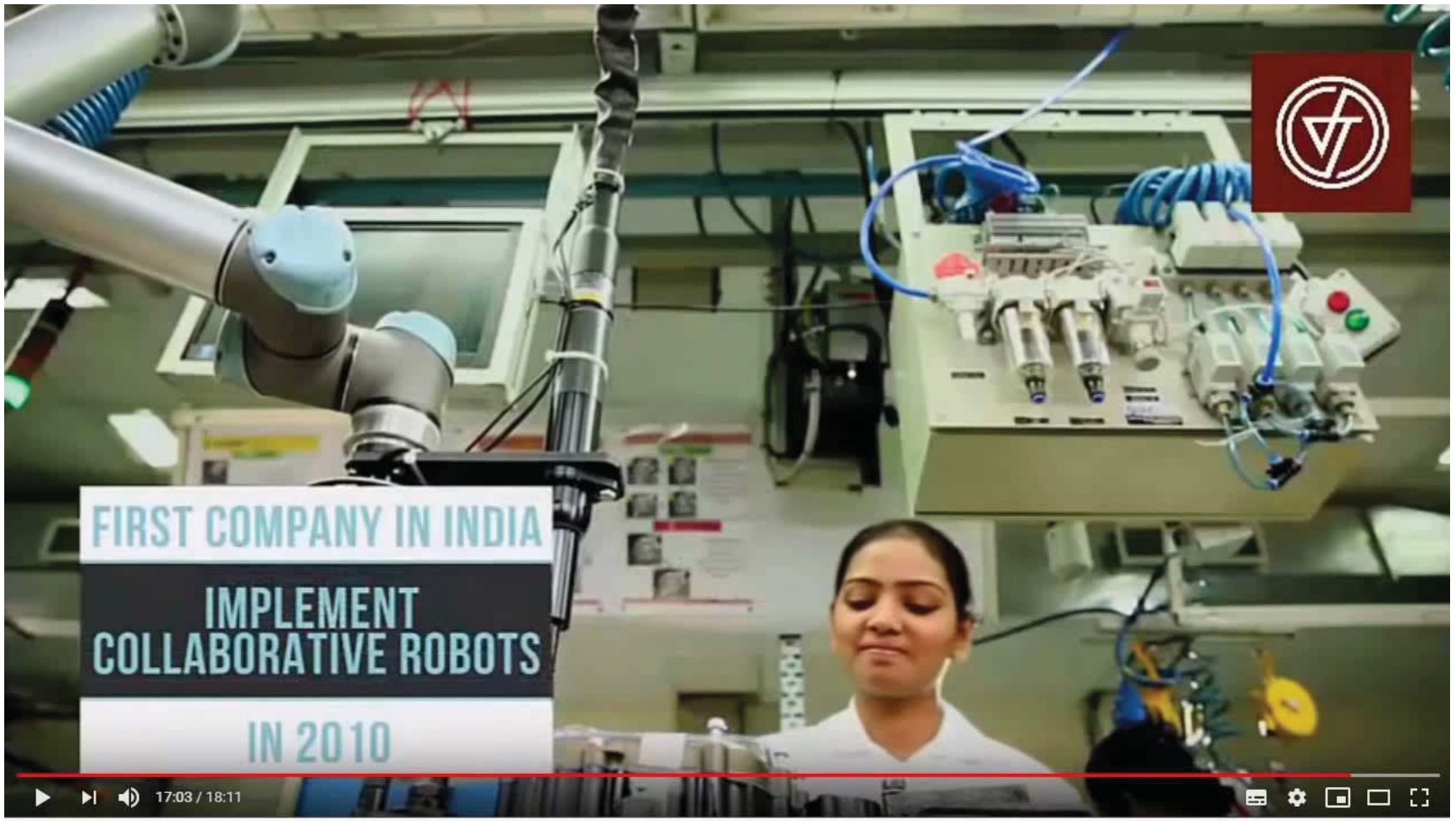
Types of Collaborative Operation ISO 10218-1:2011

ISO 10218-1,2 ISO/TS 15066

Cobots enables Xiamen Runner Industrial Corporation to achieve flexible manufacturing

Types of Collaborative Operation ISO 10218-1:2011

ISO 10218-1,2 ISO/TS 15066



#cobot #robotics #universalrobots
universal robot - cobot - applications - case studies

Types of Collaborative Operation ISO 10218-1:2011

ISO 10218-1,2 ISO/TS 15066

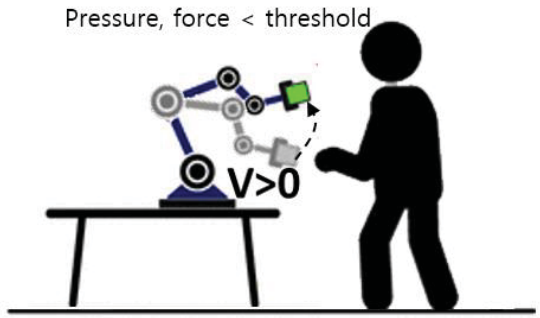
Innovative Human-Robot Collaboration for BMW/MINI Crash Can Assembly

Types of Collaborative Operation ISO 10218-1:2011

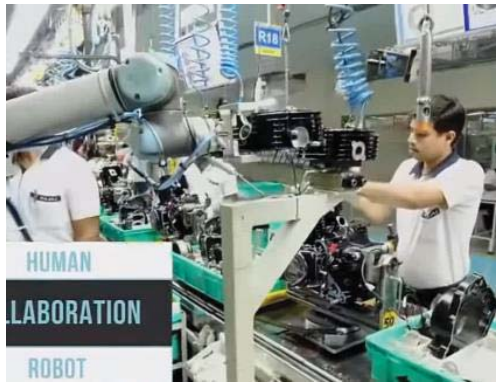
ISO 10218-1,2 ISO/TS 15066

Types of Collaborative Operation ISO 10218-1:2011

ISO 10218-1,2 ISO/TS 15066

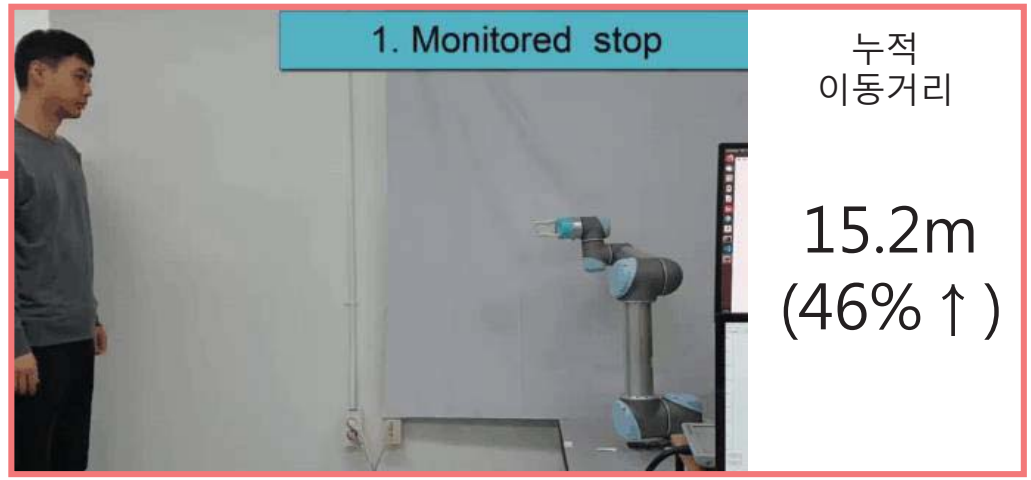


4. 설계 또는 제어에 의한 파워 및 힘 제한



- 사람과 협동작업을 많이 하는 경우 사용
- 환경 : 충돌 위험성 테스트 결과

Types of Collaborative Operation ISO 10218-1:2011



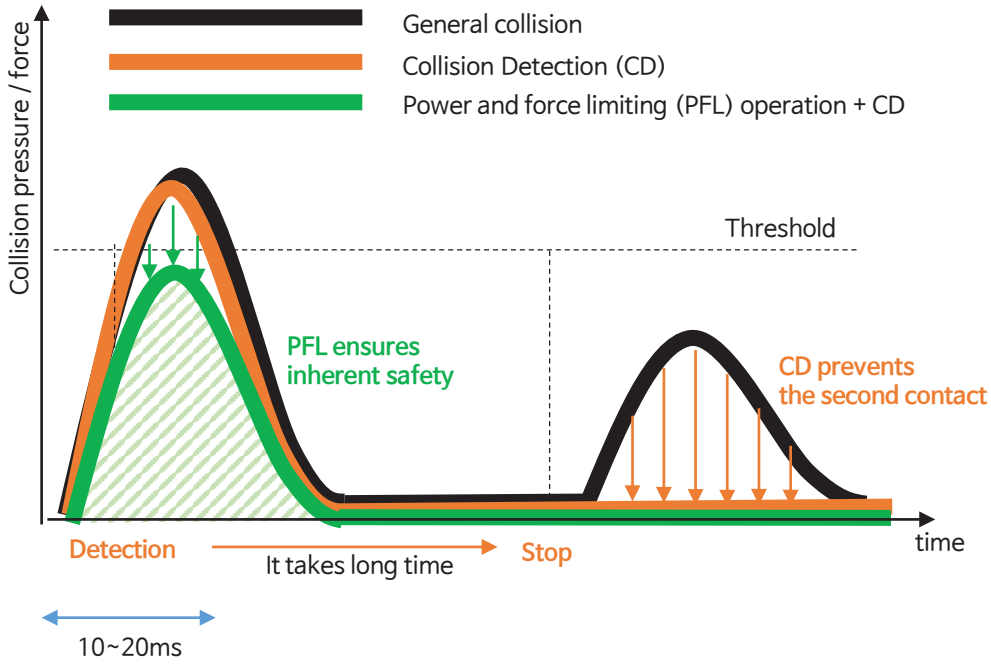
누적
이동거리

15.2m
(46% ↑)

누적
이동거리

10.4m

Collision Safety

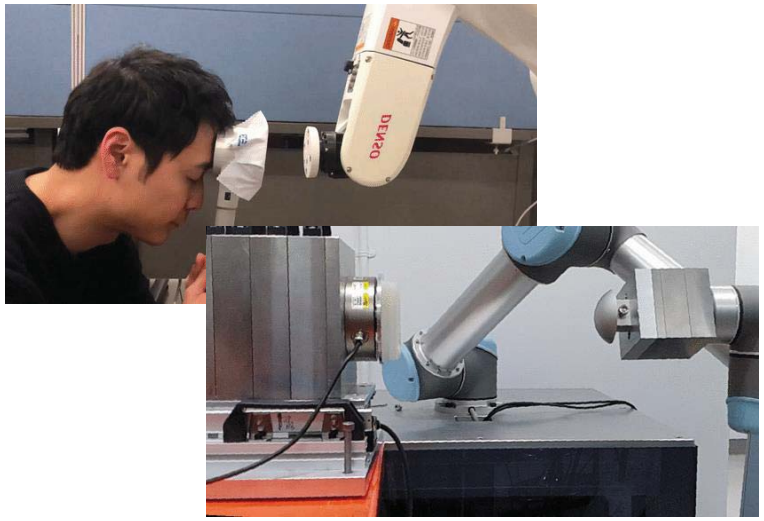


2차 사고만 방지

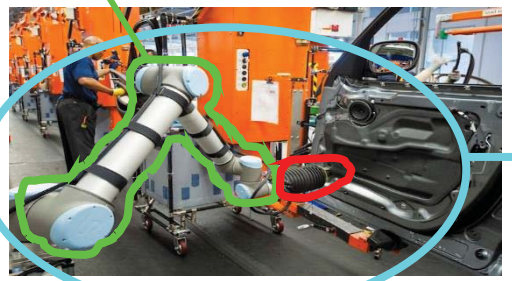
원천적 충돌 상해 방지

Collision Test for PFL

- **ISO 12353**
- Road vehicle
- **Vehicle 제조사 수행**



- **ISO 10218-1**
- Robot관련
- **Robot 제조사 수행**



- **ISO 10218-2**
- Robot System
- **Robot System 사용자or설치자 수행**

Collision Test for PFL

KS B ISO TS 15066:2016

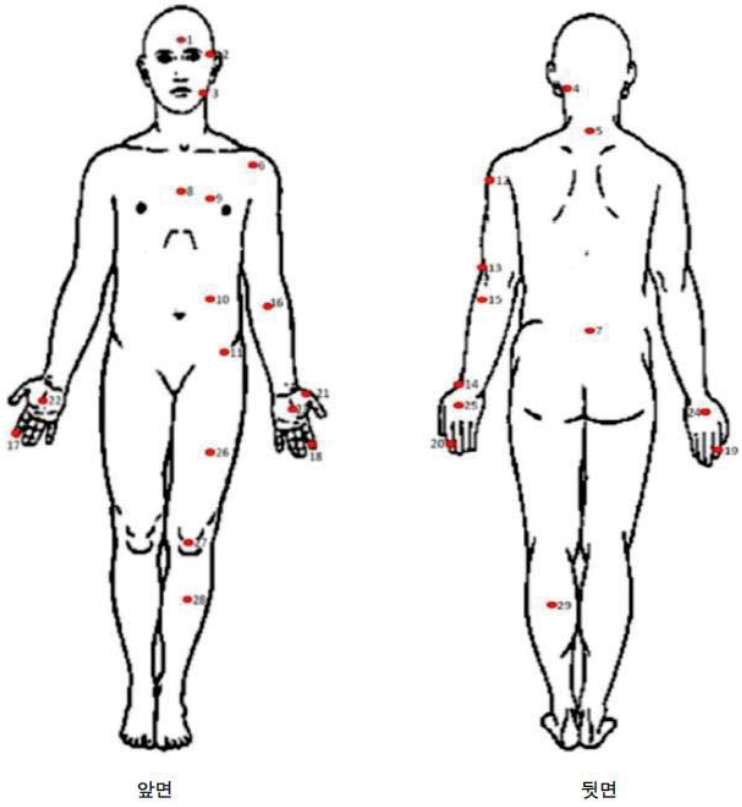


그림 A.1 — 신체 모델

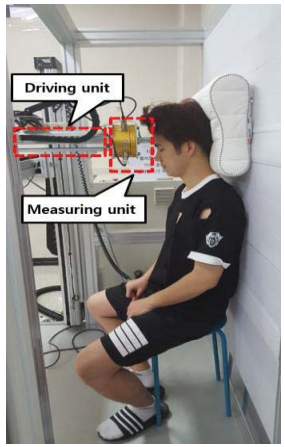
표 A.2 — 생체 역학적 한계

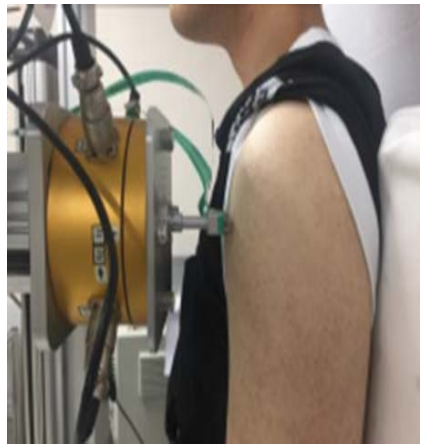
신체 부위	특정 신체 영역		준정적 접촉		동적 접촉	
			최대 허용 압력[a] p_s N/cm^2	최대 허용 힘[b] N	최대 허용 압력 배수[c] P_T	최대 허용 힘 배수[c] F_T
두개골과 이마[d]	1	*이마 중앙*	*130*	*130*	*해당 없음*	*해당 없음*
	2	*관자놀이*	*110*		*해당 없음*	
얼굴[d]	3	*저작근*	*110*	*65*	*해당 없음*	*해당 없음*
목	4	경근	140	150	2	2
	5	7번 경추	210		2	
등과 어깨	6	견관절	160	210	2	2
	7	5번 요추	210		2	
가슴	8	흉골	120	140	2	2
	9	흉근	170		2	
배	10	복근	140	110	2	2
골반	11	골반 뼈	210	180	2	2
상완과 주 관절	12	삼각근	190	150	2	2
	13	상완골	220		2	
전완과 손목 관절	14	요골	190	160	2	2
	15	전완근	180		2	
	16	팔 신경	180		2	

Collision Test for PFL

독일 : 마인츠, 프라운호퍼

KHU





[quasi-static collision 임상실험]

[dynamic collision 임상실험]

Collaborative Robot

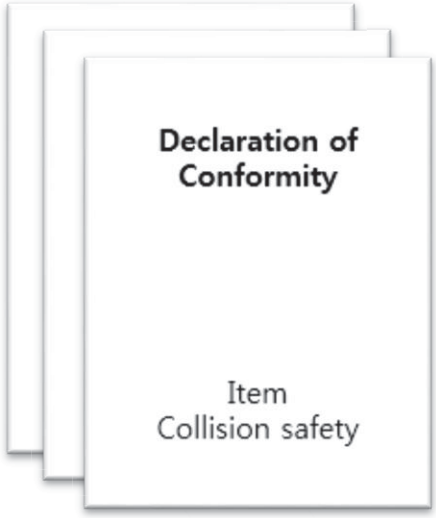
2020

ISO 10218-2 인증

[해외]

무한책임

자가인증후 바로 생산라인에 도입



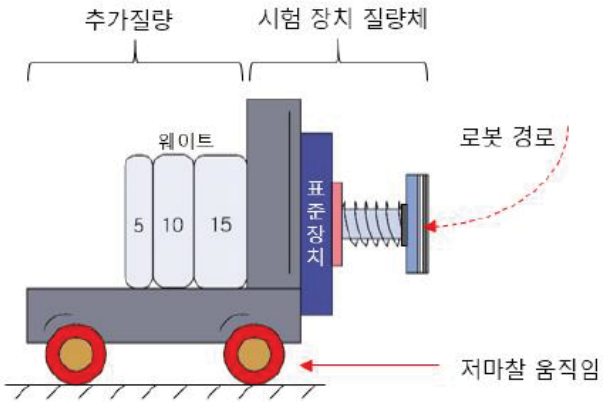
[국내]

국가 공인기관의 인증 필수

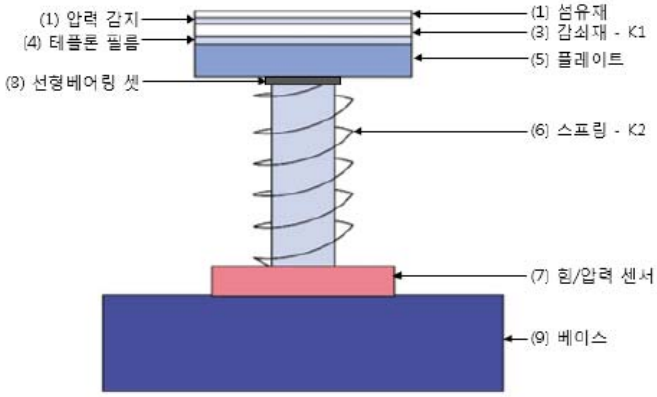
KIRIA
한국로봇산업진흥원
KOREA INSTITUTE FOR ROBOT INDUSTRY ADVANCEMENT

협동로봇 설치
안전인증제도(안)

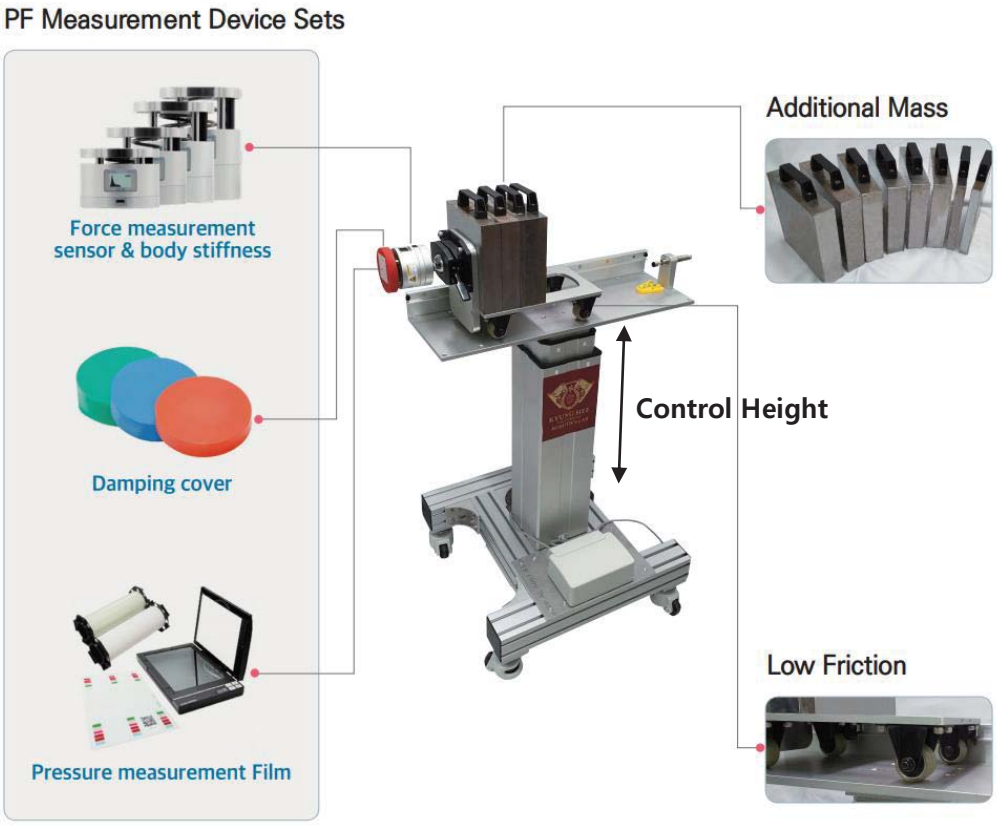
Method of Power and force limit evaluation



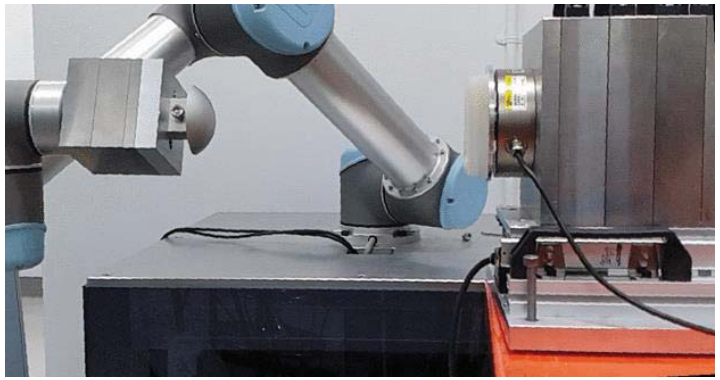
유효질량 (M_H)=시험 장치 질량 + 추가 질량



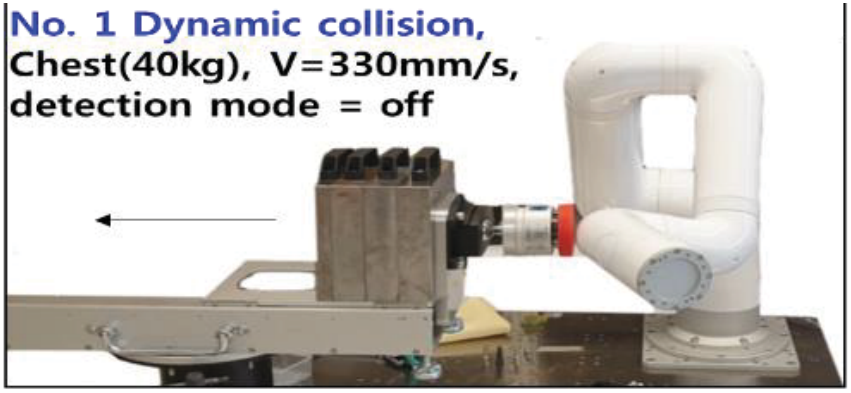
동적접촉 안전성평가를 위한 힘/압력 측정장치]



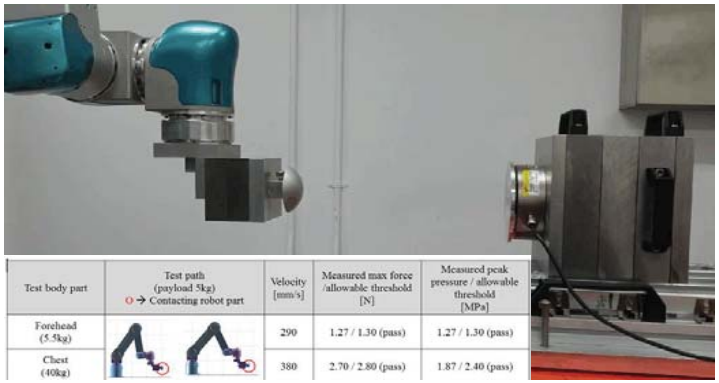
Method of Power and force limit evaluation



유니버셜 로봇



뉴로메카



Test body part	Test path (payload 5kg) O → Contacting robot part	Velocity [mm/s]	Measured max force /allowable threshold [N]	Measured peak pressure / allowable threshold [MPa]
Forehead (5.5kg)		290	1.27 / 1.30 (pass)	1.27 / 1.30 (pass)
Chest (40kg)		380	2.70 / 2.80 (pass)	1.87 / 2.40 (pass)

디에스티 로봇

한국기계연구원

Method of Power and force limit evaluation

실험적 접근의 한계 : 경로 중 가장 위험한 충돌을 찾아내기 어려움

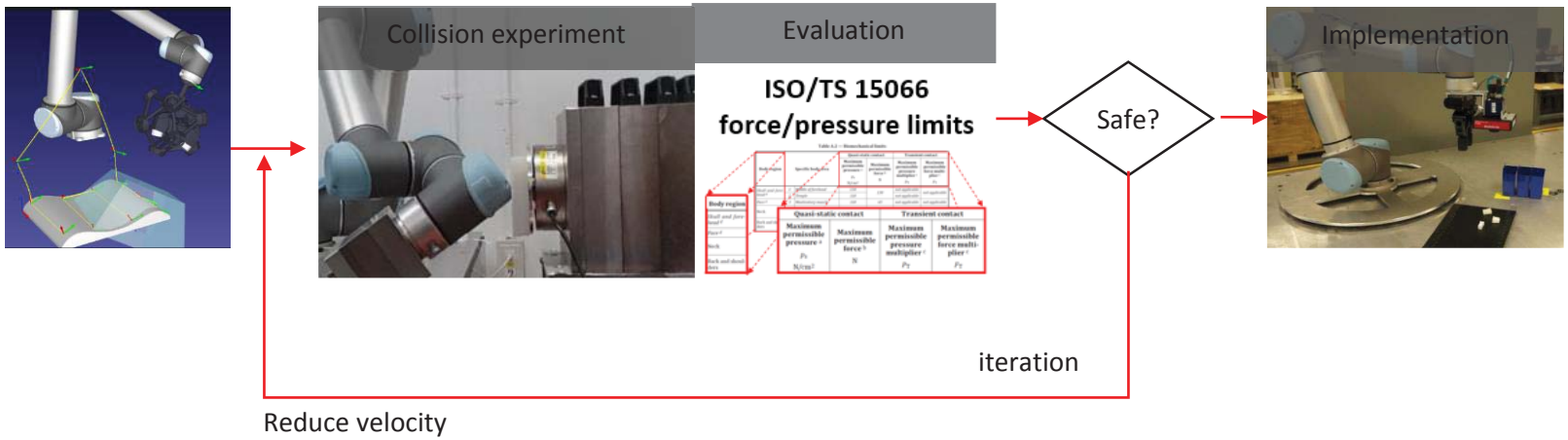
✓ 언제 가장 위험한가?

✓ 어디가 가장 위험한가?

실험에만 의존하는 경우

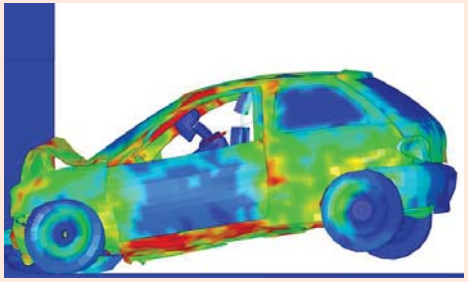
여러 번 실험을 통해 가장 위험한 순간, 위험한 방향을 반복적으로 찾아내야 함.

Method of Power and Force Limit Evaluation



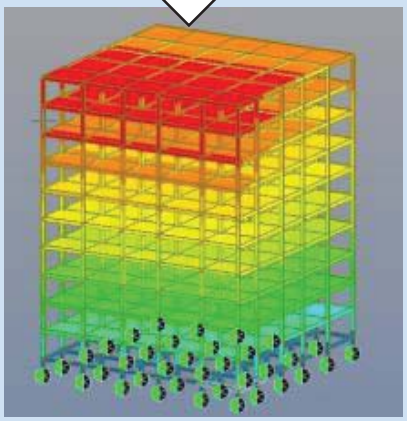
PFL test method

자동차



1~3 days

건축물



0.5 days

로봇안전

10 analysis / sec

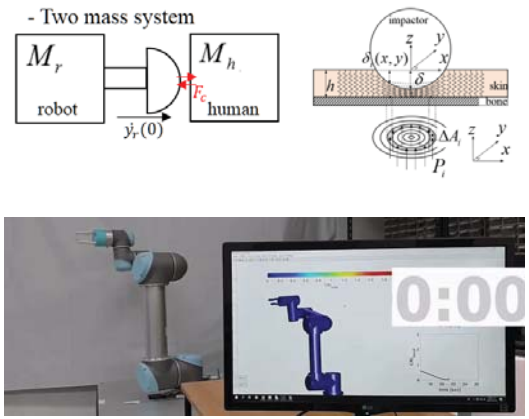
0.1 days

20초 모션

?

20 days

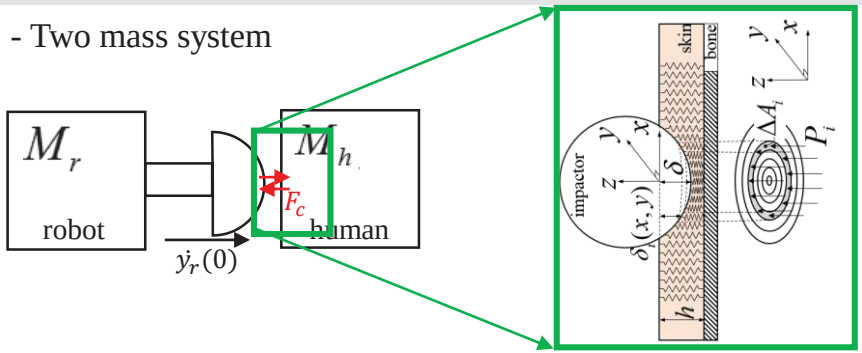
PFL test method

Evaluation method	Description		
정확한 압력측정이 가능한가	최고 위험 부위, 최고 위험 순간을 찾아낼 수 있는가	충돌면과 충돌방향이 수직인가	생산라인내에서 측정장치 설치가 가능한가
Mathematical Model			0.2sec / 1 collision case

PFL test method

경희대 사람-로봇 충돌모델 (형상, 피부물성치 등 비선형성 고려)

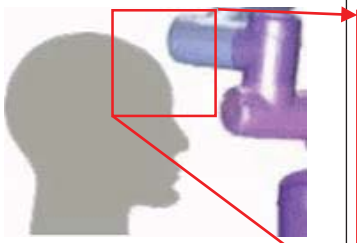
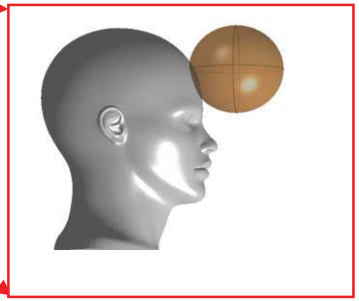
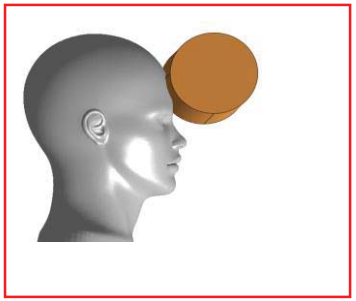
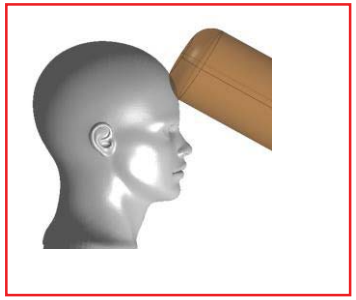
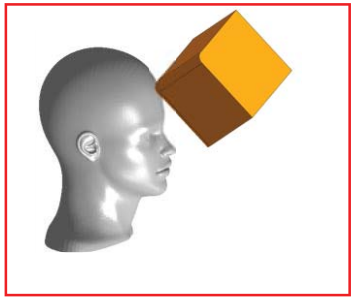
- Two mass system



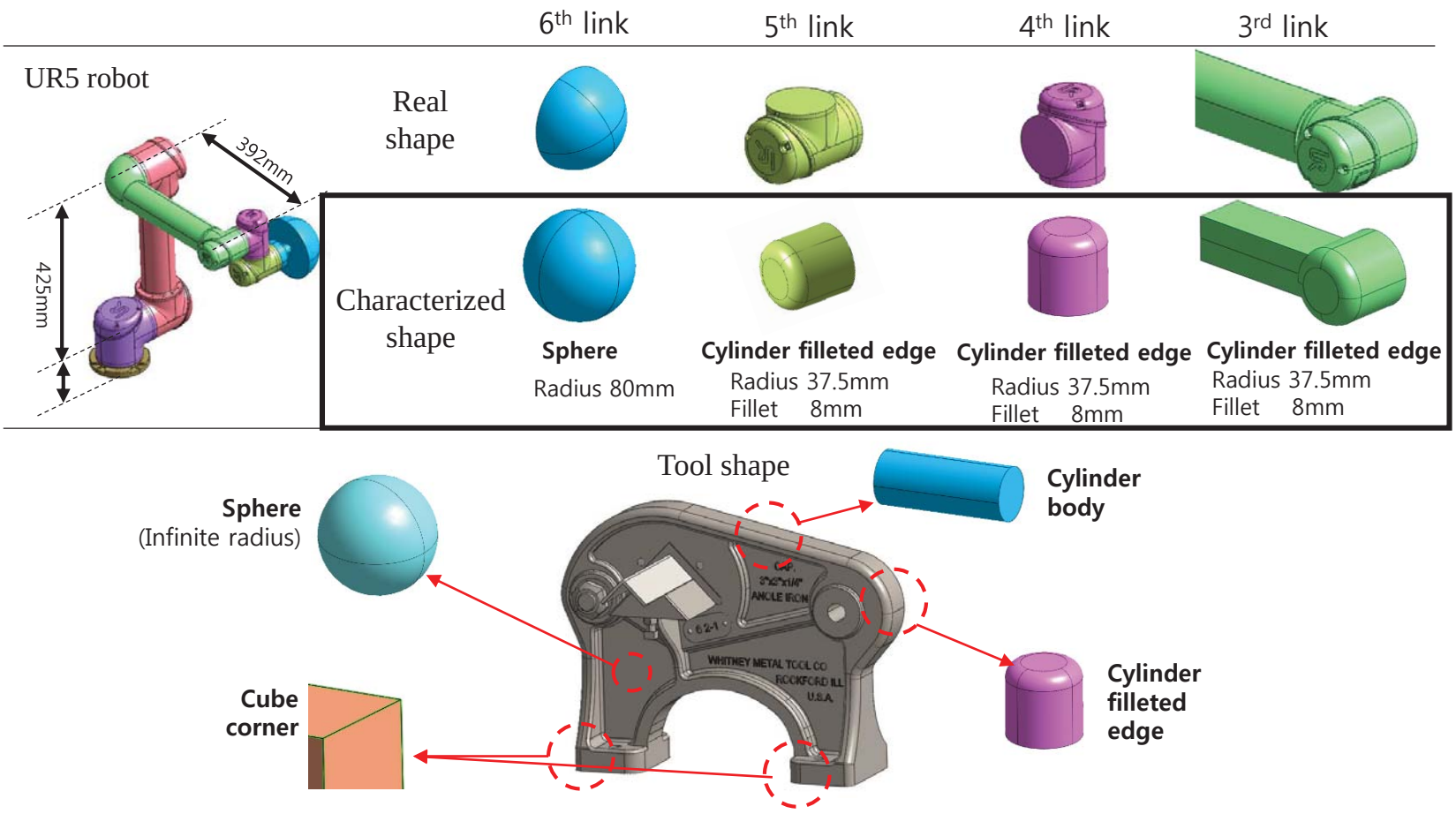
Eq. (1)
$$\begin{bmatrix} M_r & 0 \\ 0 & M_h \end{bmatrix} \begin{Bmatrix} \ddot{y}_r(t) \\ \ddot{y}_h(t) \end{Bmatrix} = \begin{Bmatrix} -F_c(t) \\ F_c(t) \end{Bmatrix}$$

Eq. (2)
$$F_c(t) = \sum_{i=0}^{n} \beta(S) P_i \left(\frac{\delta_i(x,y,t)}{h} \right) H(\alpha) \Delta A_i(t)$$

Peak pressure

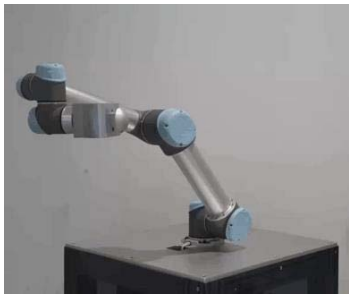
Shape	Sphere	Cylinder	Cylinder filleted edge	Cube filleted corner
				
Variable	radius	radius	radius, fillet radius	fillet radius
	collision direction			

PFL test method

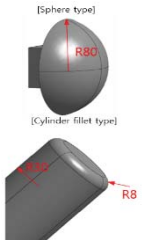


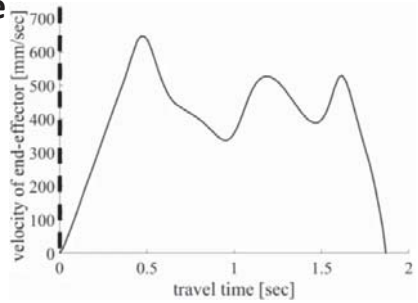
PFL test method

1. 1.9초동안 800mm를 가변속도 모션 지정
(UR5, Tool shape : 구 R40 & 실린더 필렛 R8)

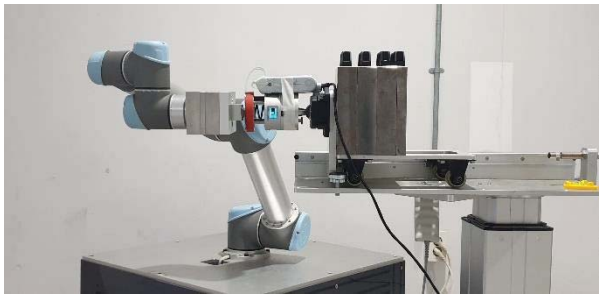


Tool shape



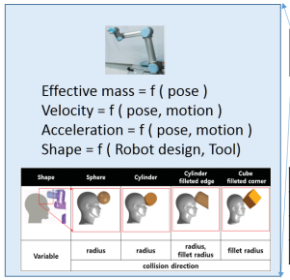


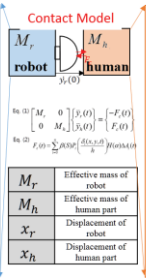
2. 경로 중 임의의 위치에서 충돌 및 힘/압력 측정
(경로 내 10개 지점, 충돌부위 가슴)



3. 소프트웨어를 통해 힘과 압력 예측
(경로 내 1000개 지점 해석수행, 충돌부위 가슴)

Collaborative Robot





M_r	Effective mass of robot
M_h	Effective mass of human part
x_r	Displacement of robot
x_h	Displacement of human part

Human

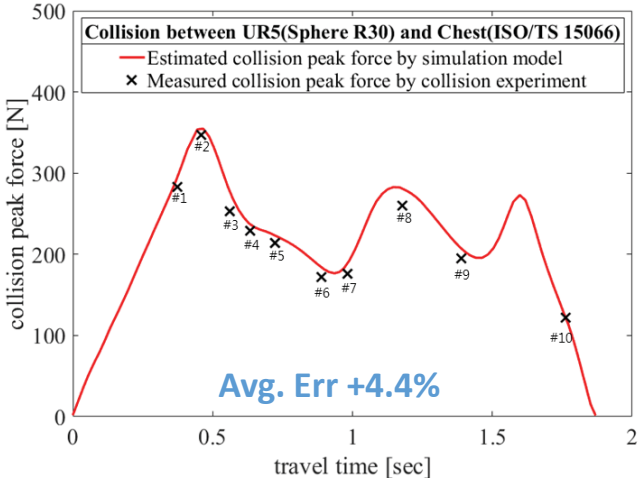
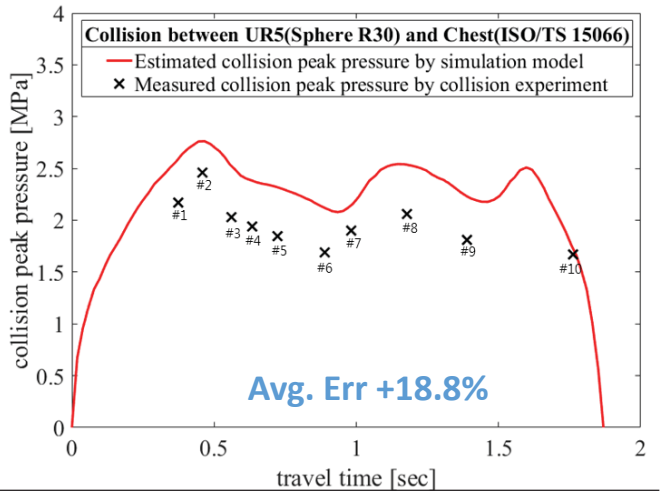
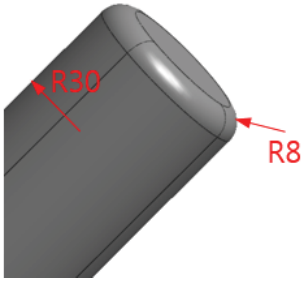
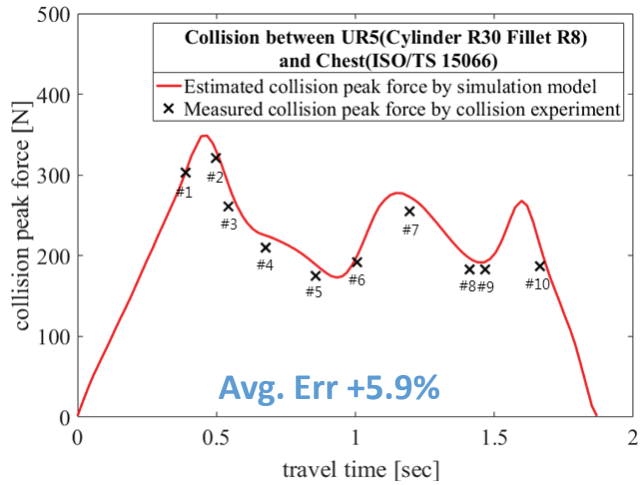
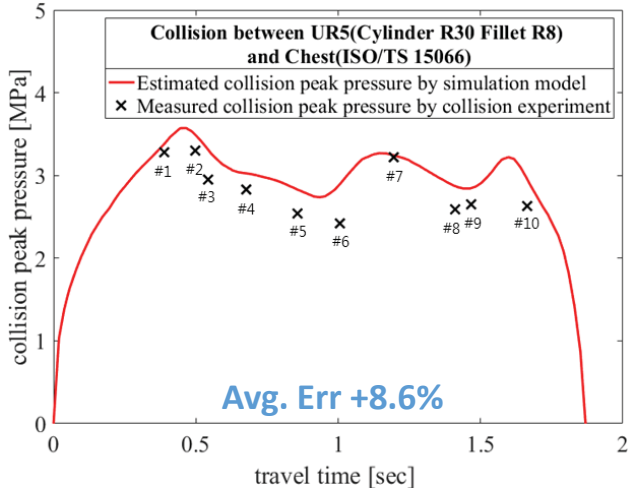
Body Region	Hardness (K1-Shore A)	Thickness (mm)	K2-Stiffness (N/mm)	M_H-Effective Mass (kg)
Skull and forehead*	70	7	180	4.4
Face*			75	4.4
Hand and finger			75	0.6
Neck			80	1.2
Lower arm and wrist			40	3.0
Chest			20	40.0
Pelvis			25	40.0
Lower leg			80	78.0
Thigh and knee	30	14	80	78.0
Back and shoulders			35	40.0
Upper arm and elbow			30	3.0
Abdomen	10	21	10	40.0

RIA TR R15.806
Testing Methods for Power & Force Limited
Collaborative Applications

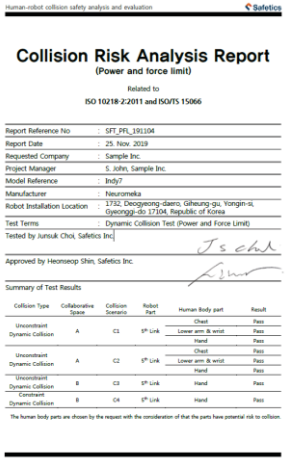
4. 소프트웨어와 실험치 비교

Sphere R40	Travel time (s)	Velocity (mm/s)	Estimated force (N)	Measured force (N)	Error (%)	Estimated pressure (MPa)	Measured pressure (MPa)	Error (%)
Case 1	0.374	521	293	283	3.5	2.59	2.17	19.4
Case 2	0.459	641	347	347	0.0	2.74	2.46	11.4
Case 3	0.561	551	275	253	8.7	2.51	2.03	23.9
Case 4	0.634	463	236	229	3.1	2.38	1.94	22.7
Case 5	0.723	425	221	214	3.3	2.31	1.84	25.1
Case 6	0.889	356	183	172	6.4	2.11	1.69	24.9
Case 7	0.982	345	189	176	7.4	2.14	1.90	12.6
Case 8	1.178	526	277	260	6.5	2.52	2.06	22.3
Case 9	1.389	417	205	195	5.1	2.22	1.81	22.7
Case 10	1.762	291	120	122	0.0	1.72	1.67	3.4
Average	–	–	–	–	4.4	–	–	18.8

PFL test method

	Force	Pressure
Shape of end-effector [Sphere type]  [Cylinder fillet type]	 	
[Cylinder fillet type]  	 	

Example of PFL test


Collision Risk Analysis Report
(Power and force limit)

Related to
ISO 10218-2:2011 and ISO/TS 15066

Report Reference No	:	SFT_PFL_191104
Report Date	:	25. Nov. 2019
Requested Company	:	Sample Inc.
Project Manager	:	S. John, Sample Inc.
Model Reference	:	Indy7
Manufacturer	:	Neuromeka
Robot Installation Location	:	1732, Deogyeong-daero, Giheung-gu, Yongin-si, Gyeonggi-do 17104, Republic of Korea
Test Terms	:	Dynamic Collision Test (Power and Force Limit)
Tested by Junsuk Choi, Safetics Inc.		
Approved by Heonseop Shin, Safetics Inc.		

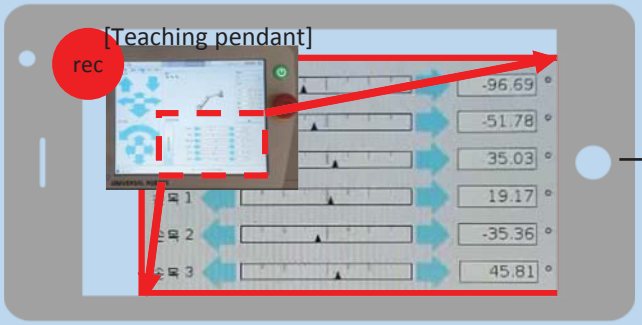
Summary of Test Results

Collision Type	Collaborative Space	Collision Scenario	Robot Part	Human Body part	Result
Unconstraint Dynamic Collision	A	C1	5th Link	Chest	Pass
				Lower arm & wrist	Pass
				Hand	Pass
Unconstraint Dynamic Collision	A	C2	5th Link	Chest	Pass
				Lower arm & wrist	Pass
				Hand	Pass
Unconstraint Dynamic Collision	B	C3	5th Link	Hand	Pass
Constraint Dynamic Collision	B	C4	5th Link	Hand	Pass

The human body parts are chosen by the request with the consideration of that the parts have potential risk to collision.

Safety Evaluation Software

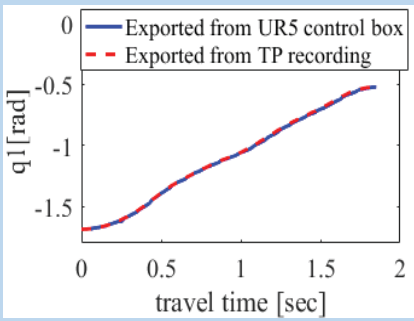
필요데이터	제공자	특징	취득 난이도	취득 방법
Joint angle/vel/acc	**User or SI**	**가변 (모션)**	**상** (로봇마다 취득방법/ 가능여부 다름)	**Teaching pendant 화면 레코딩**
Tool shape	User or SI	고정	하	User or SI 제공
DH parameter	Maker	고정	중	Maker 제공
Inertia	Maker	고정	중	Maker 제공

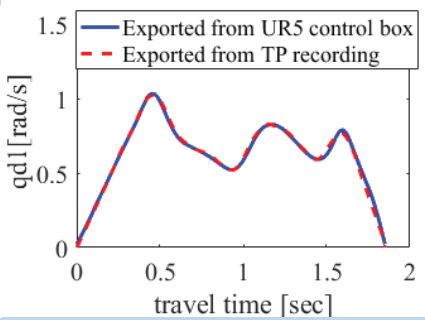


로봇 : 기존 대비 5~10%정도의 느린 속도로 이동

영상 인식

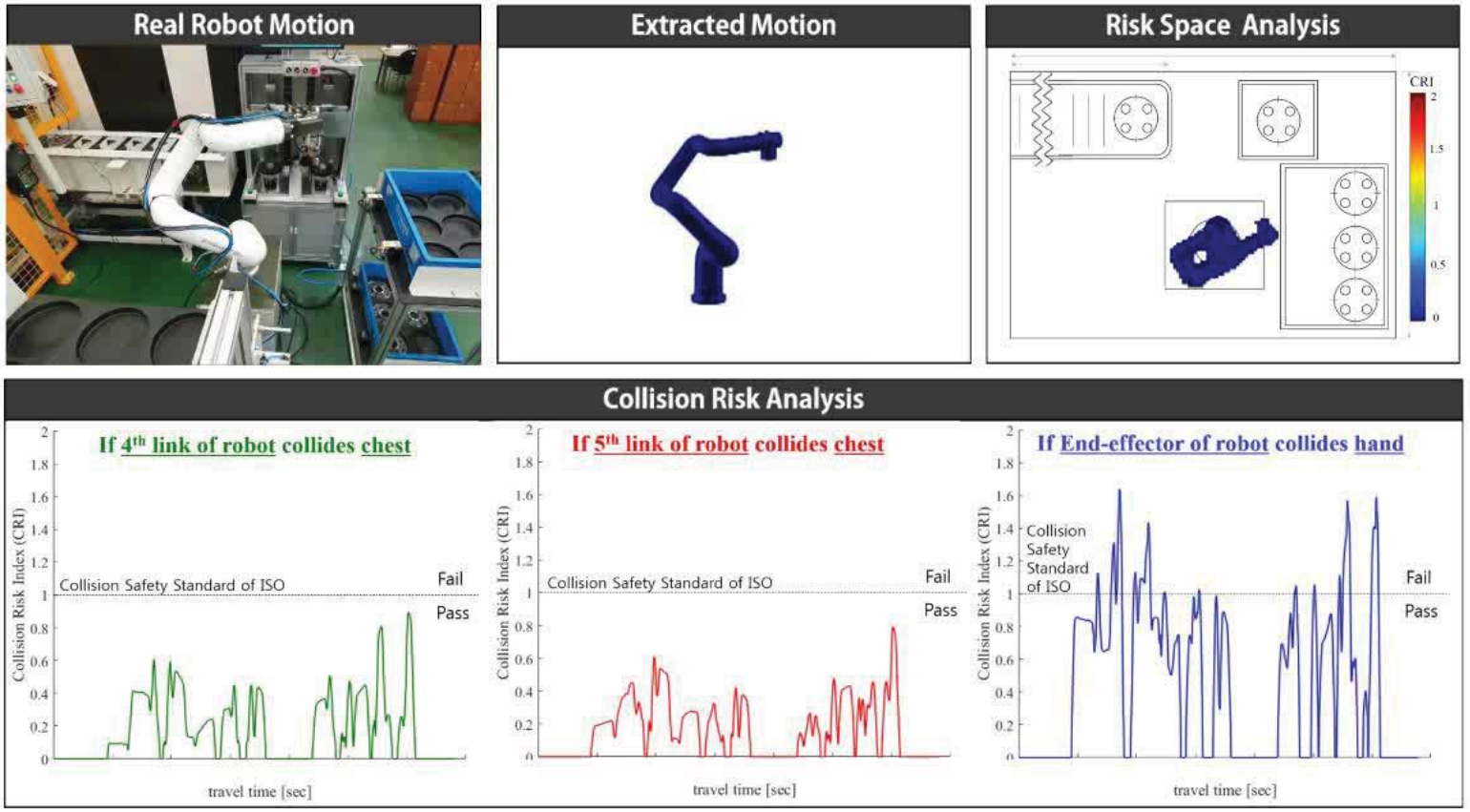
속도기준 2~4% 오차





Example of PFL test

$$CRI = \max\left(\frac{P_{est}}{P_{allowable}}, \frac{F_{est}}{F_{allowable}}\right)$$



Example of PFL test