영상기반 3D 프린터 적층 품질 보증을 위한 플랫폼 개발

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UNIST

3D Printer

- 3D 프린터의 다양한 활용 분야

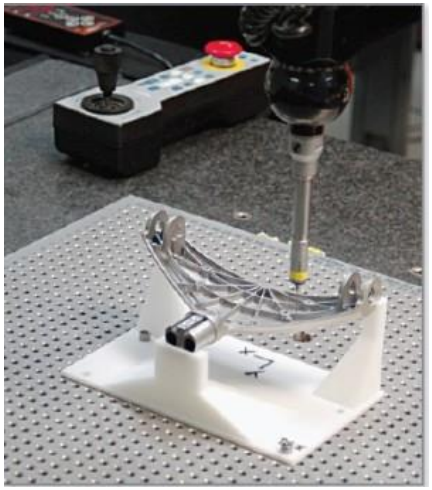
의료

시제품

예술

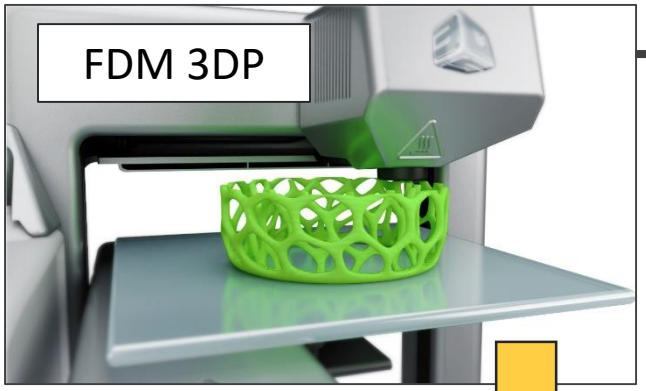
건축설계

- 디지털 직접 제조 (DDM: Direct Digital Manufacturing)
  - 3D 프린터의 제작물을 시제품 수준이 아닌 최종품으로 사용
    - 3D 프린터 시스템 성능 및 신뢰성 향상
    - 재료의 물리 화학적 특성 개선
    - 엔지니어의 인식 전환



Malfunctions of 3D Printer

- 다양한 FDM 3D 프린터 제작 오류
  - 3D 프린터의 신뢰성을 높이기 위해 적절한 모니터링이 필요



재료 수급 오류

- 노즐 막힘이나 필라멘트의 팽창에 의한 막힘
- 필라멘트의 부족

모터 및 히터 동작 오류

- 스텝 모터 드라이버 고장
- 스텝 모터 탈조
- 마이크로 컨트롤러 고장

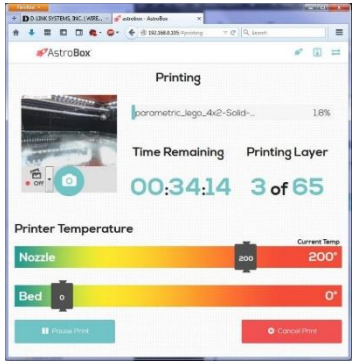
적층 오류

- 바닥 고정 불량
- 수축에 의한 들뜸

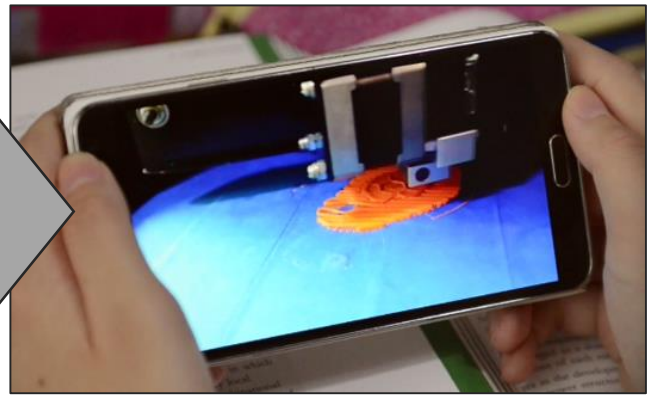
Malfunctions of 3D Printer

- 모니터링을 위해 개발된 플랫폼
  - 카메라를 이용한 영상 디스플레이 (제작 과정 확인)
  - 사용자가 카메라 화면을 확인하고 정지할지를 선택

Sindoh 3D printer



AstroBox & AstroPrinter



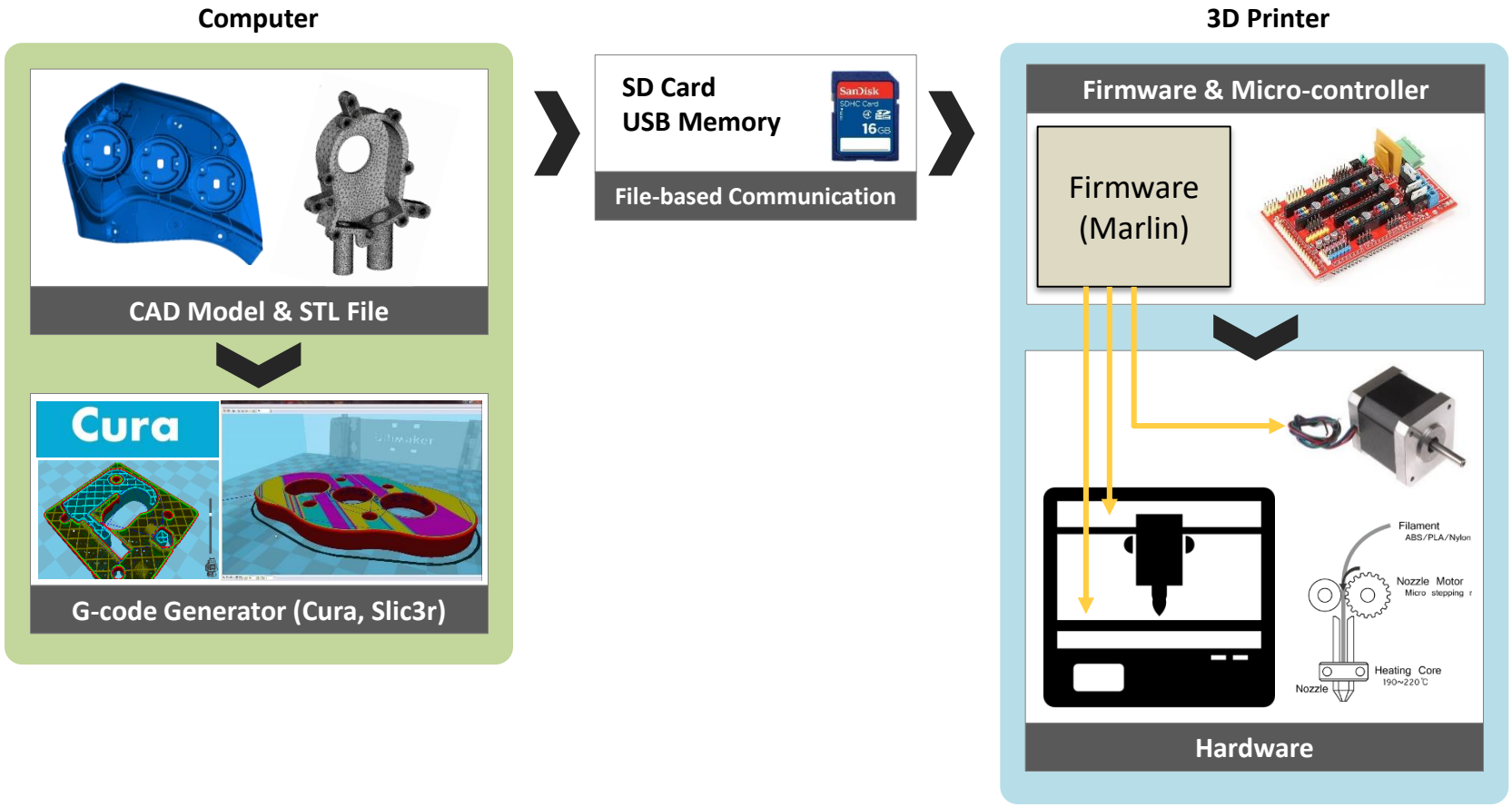
단순한 카메라 영상 송출 기능

품질 보증을 위한 실시간 진단 기술 필요

3D Printer: Open-loop

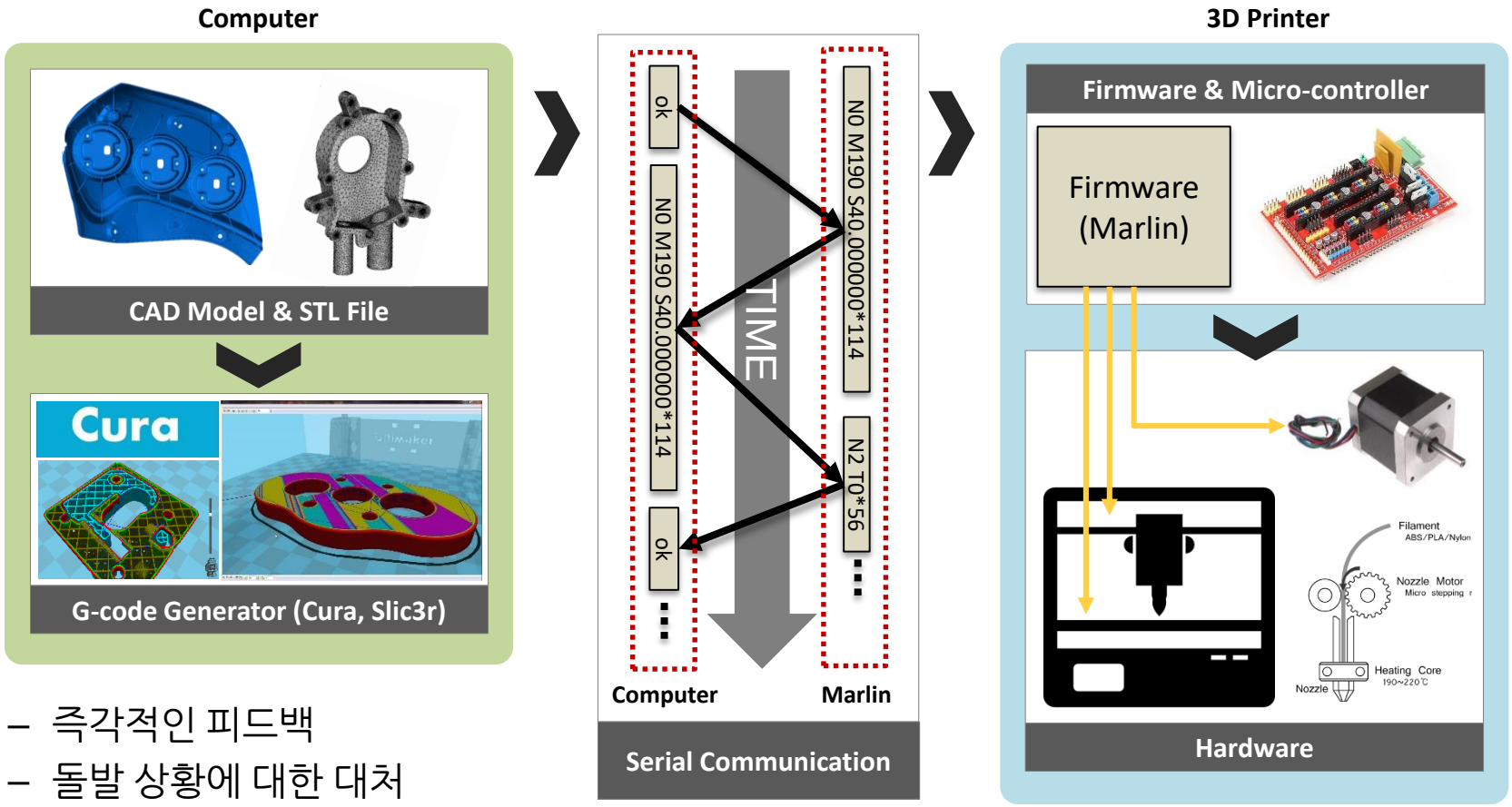
- 기존 3D 프린터의 한계
  - 저장 매체를 이용한 STL file 명령 전달
  - Open-loop 컨트롤 시스템

→ **센서 데이터와 3D 프린터의 동작 동기화 필요성**



Proposed 3D Printer: Closed-loop

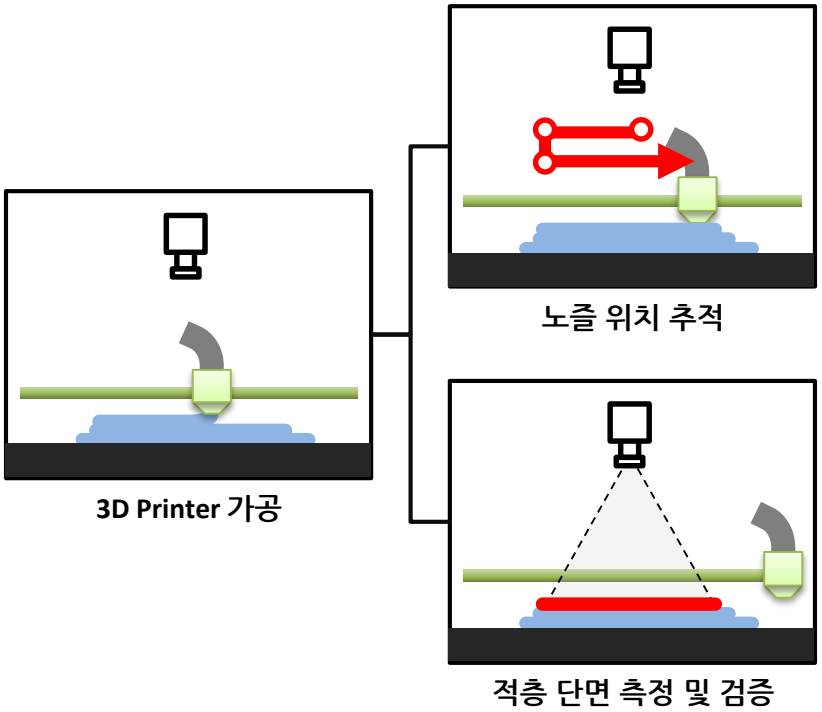
- 시리얼 통신을 이용한 3D 프린터
  - **센서 데이터와 3D 프린터의 동작 동기화**
  - Closed-loop 컨트롤 시스템

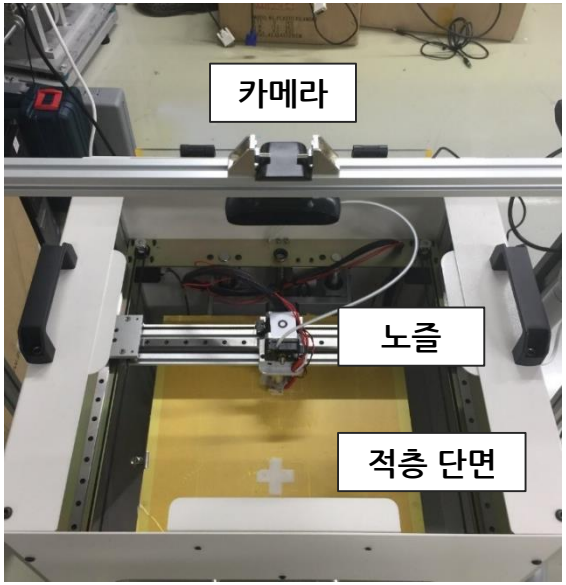


  - 즉각적인 피드백
  - 돌발 상황에 대한 대처

Proposed 3DP Monitoring Platform

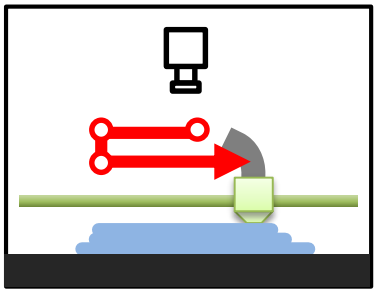
- 카메라 기반의 품질 모니터링 시스템 개발
  - G-code (Ground truth)와 비교
    - 노즐 위치 추적 → 모터의 동작 오류 모니터링
    - 적층 단면 별 확인 → 적층 오류 모니터링



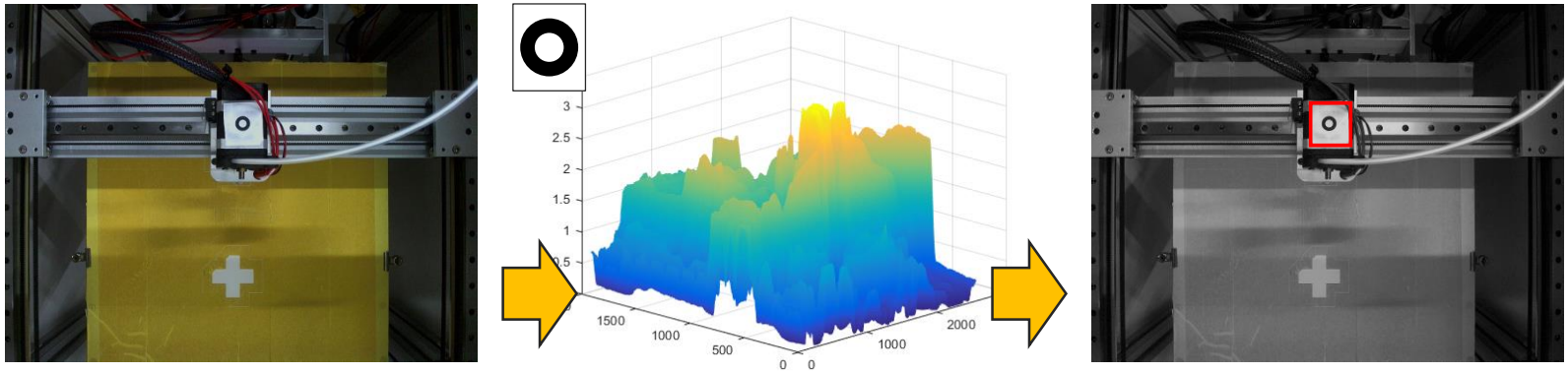


1) Nozzle Tracking

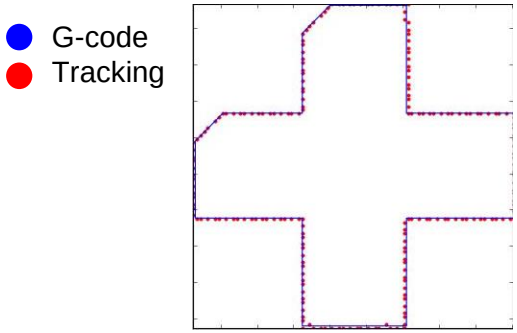
- Cross-correlation with template
  - 템플릿과 유사한 정도를 측정
  - 유사도맵을 이용하여 노즐 위치 추정



$$(f * g)[n] = \sum_{m=-\infty}^{\infty} f^T[m] g[m+n]$$



입력 이미지 Cross-correlation Map 노즐 위치 추정

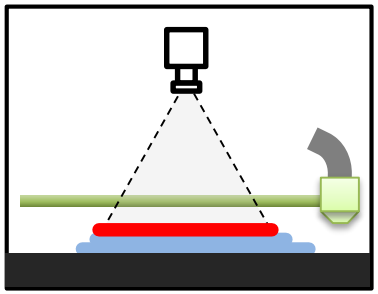


G-code vs. Nozzle Tracking

- 트래킹 오차가 거의 없음
- 단면의 넓이를 공정 정확도 건전성 인자로 선정

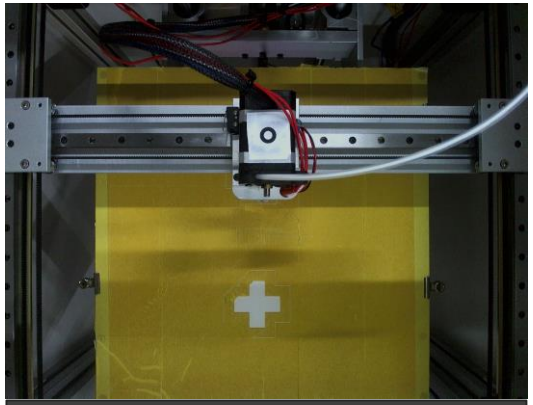
2) Layer Cross-section Estimation

- General Hough Transform (GHT)
  - 일반적인 형태의 도형을 인식 하기 위한 알고리즘
  - 적층 단면의 위치 추정

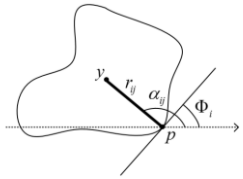


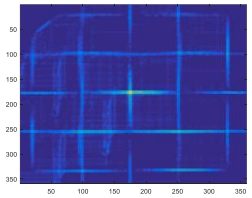
$\phi_1 = 0$	$(r,\beta)_{1_1}$	$(r,\beta)_{1_2}$	$\cdots$	$(r,\beta)_{1_{n_1}}$
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
ϕ_j	$(r,\beta)_{j_1}$	$(r,\beta)_{j_2}$	$\cdots$	$(r,\beta)_{j_{n_1}}$
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
$\phi_k = \pi$	$(r,\beta)_{k_1}$	$(r,\beta)_{k_2}$	$\cdots$	$(r,\beta)_{k_{n_1}}$

예상 단면 G-code table 작성

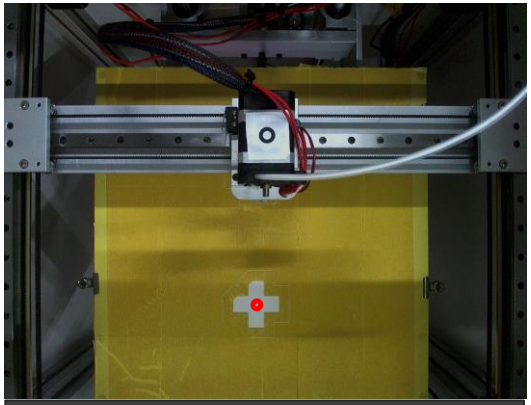


입력 이미지





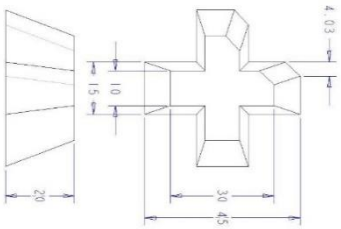
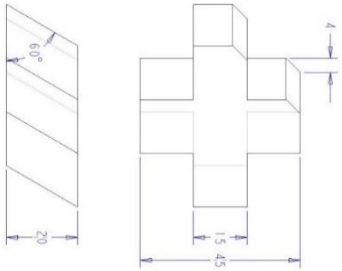
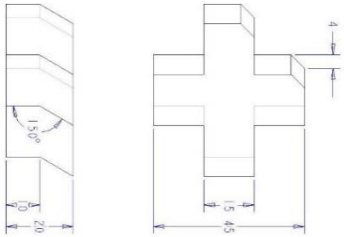
GHT



단면 중심 추정

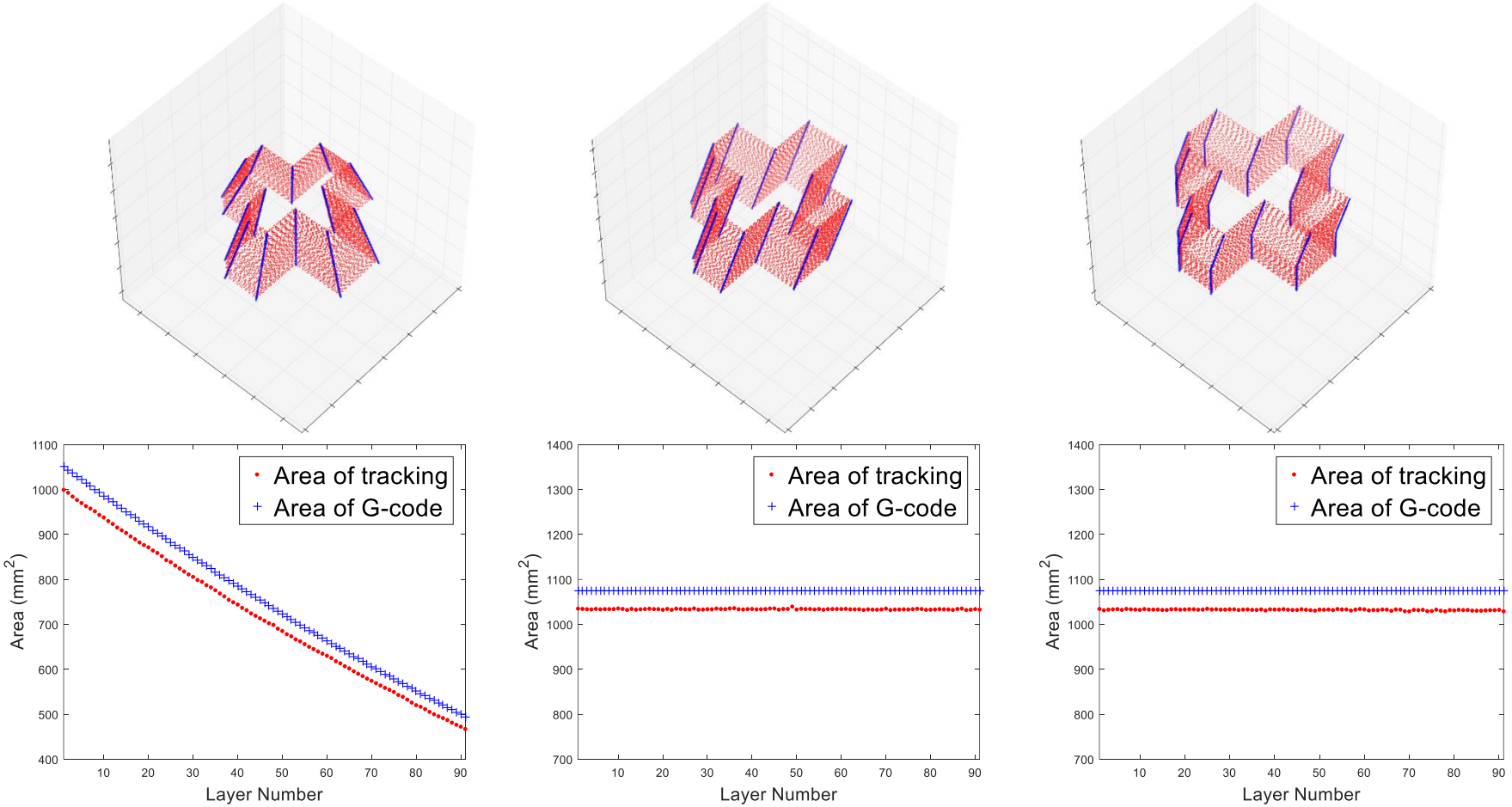
Samples for Testing

- 제안한 알고리즘 검증을 위한 테스트 샘플
  - 단면 넓이 변화 → Nozzle Tracking 알고리즘 검증
  - 단면 중심의 변화 → Cross-section Estimation 알고리즘 검증

	Sample 1	Sample 2	Sample 3
3D 이미지			
도면			

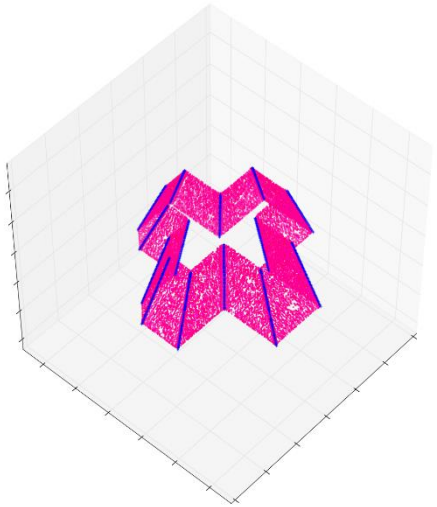
Experiment Result: Nozzle Tracking

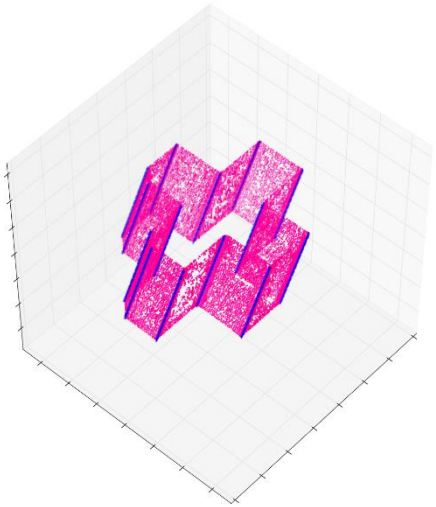
- G-code vs. Nozzle Tracking
  - 단면 넓이 비교

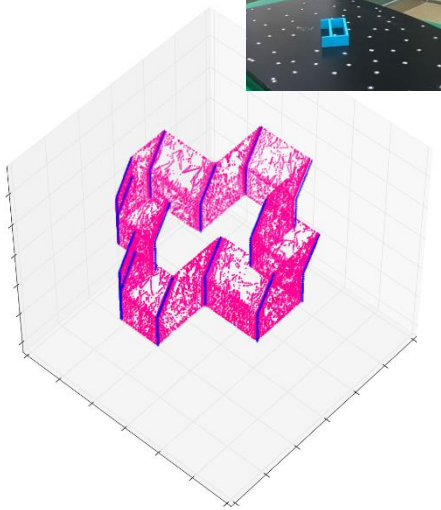


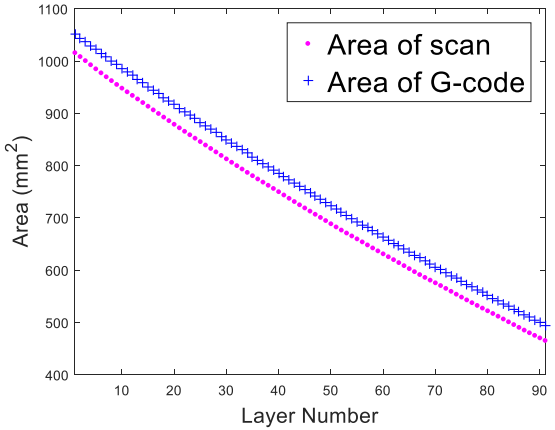
Validation: Nozzle Tracking

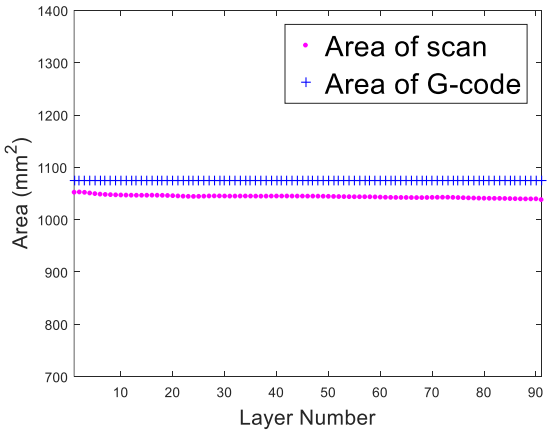
- **3D Scanner**
  - 제안된 알고리즘의 유효성 검증

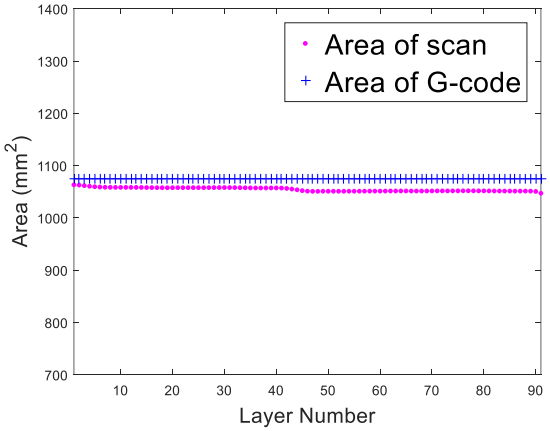






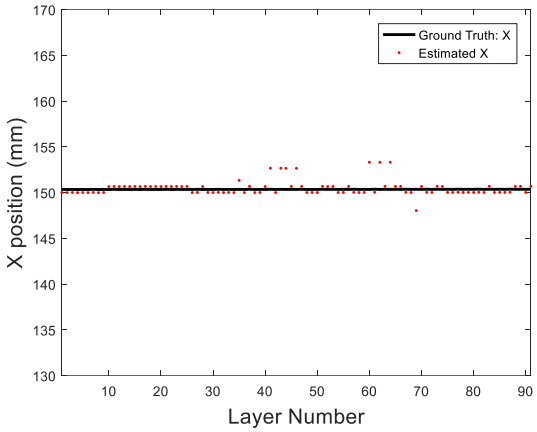


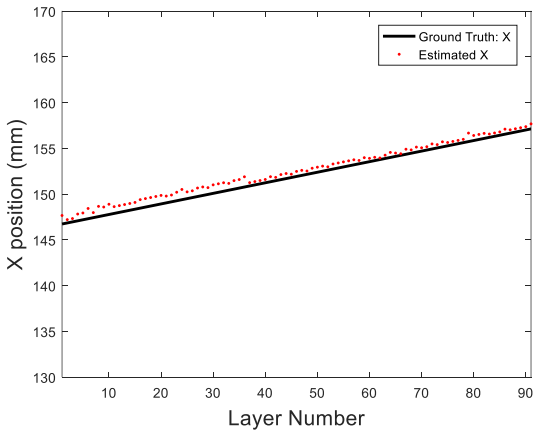


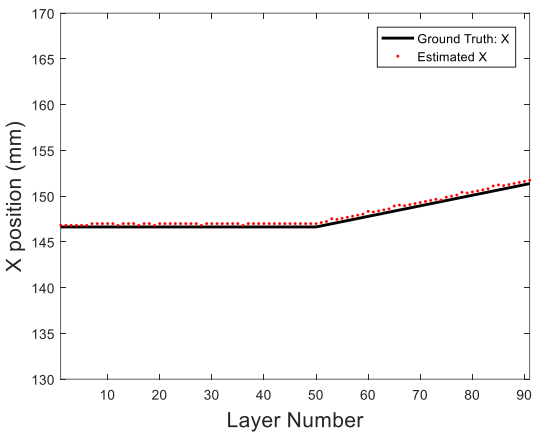


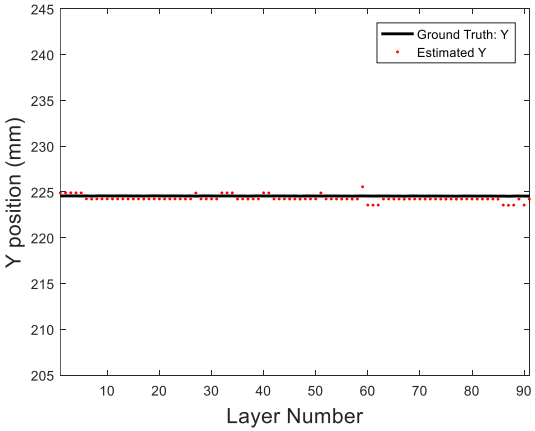
Experiment Result: Cross-section Estimation

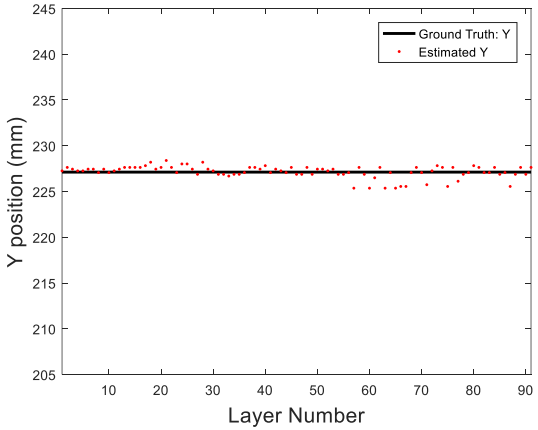
단면 중심

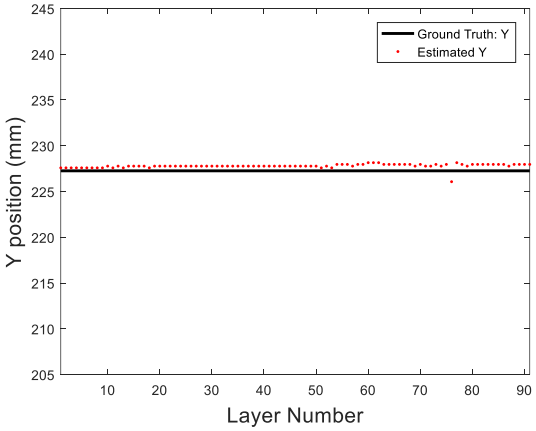






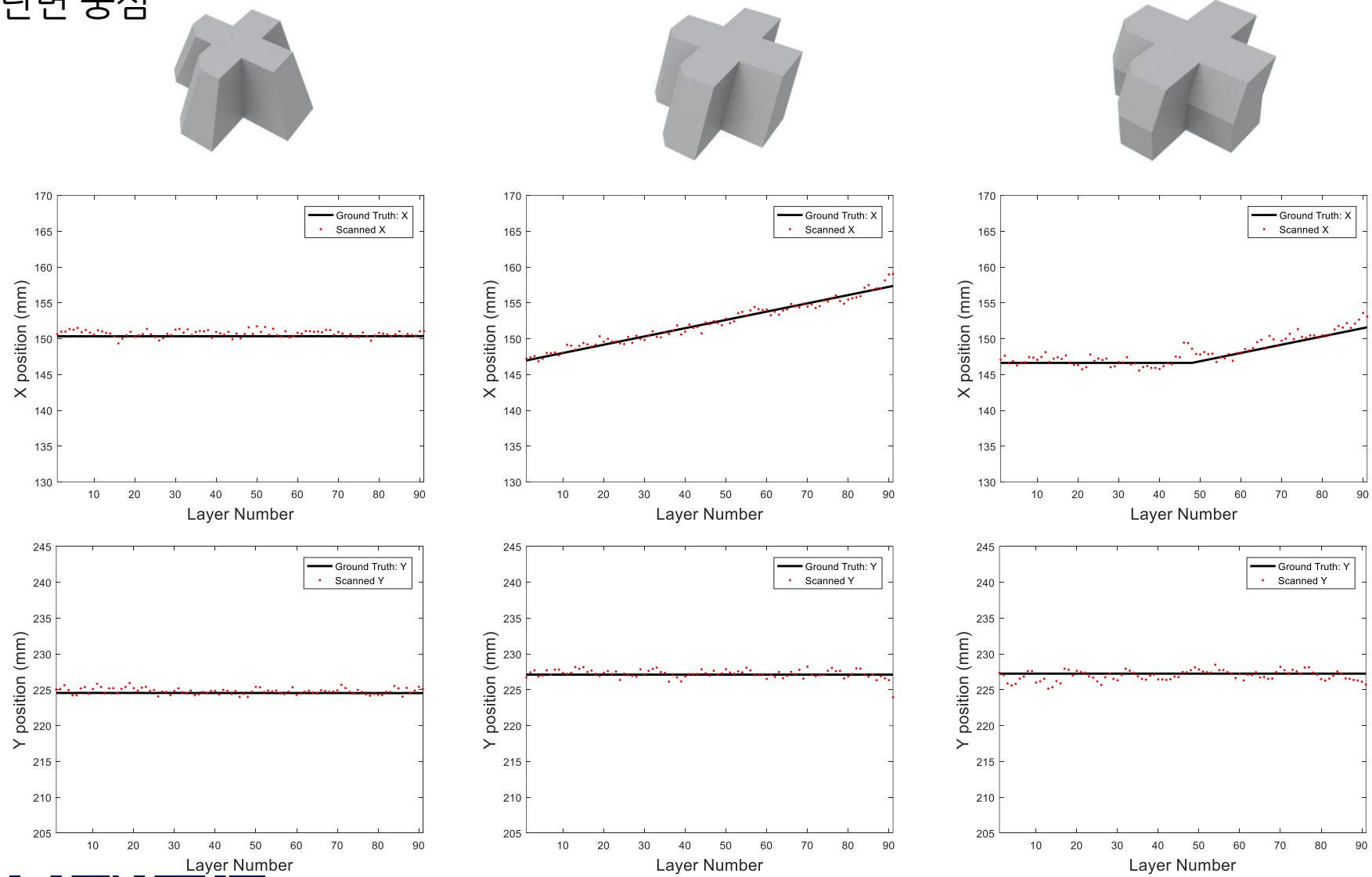






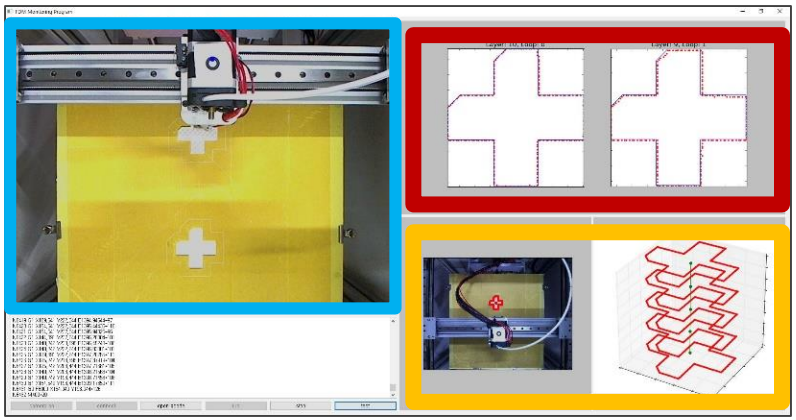
Validation: Cross-section Estimation

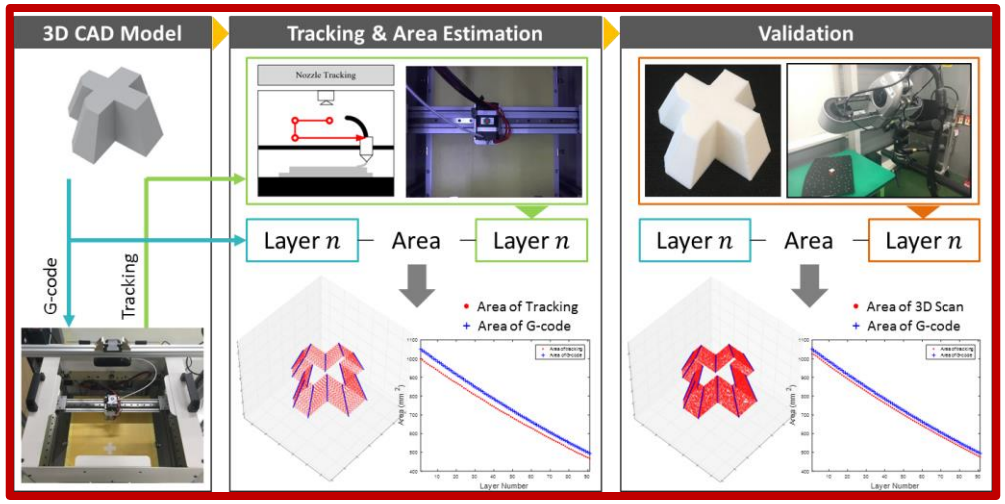
단면 중심

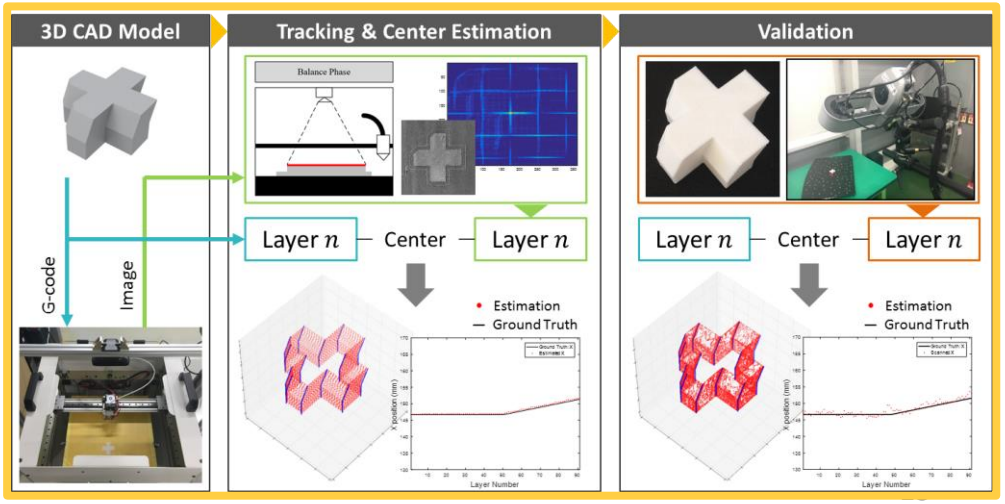


3DP Monitoring Platform

- Real-time Quality Assurance Platform for 3DP Additive Layers
  - Serial communication based 3DP
  - Real-time nozzle tracking
  - Layer quality estimation
    - 공정 정확도 추정
    - 레이어별 품질 퀄리티 추정







결론

- 카메라를 이용한 3D프린터 모니터링 시스템 개발
  - 시리얼 통신 기반 close-loop 3DP 제안
  - 노즐 트래킹 데이터와 G-code의 비교를 통해 동작 오류 진단
  - 단면 외곽 검출을 통한 적층 오류 진단

- Future work
  - 카메라 외에 추가 센서를 이용한 모니터링 (온도, 진동 등)
  - 3DP 제작품 품질 예측을 위한 건전성 인자 개발
  - Diagnostics Platform for SLA 3DP