WEBINAR

How 3D Printing is leveraged in Greece at the National Technical University of Athens

Presented by:
Dr. Stamatios Polydoras, PhD, Mechanical Engineer

Co-presenters:
Dr. Dimitrios Tzeranis, PhD, Mechanical Engineer

Mr. George Zogopoulos, Electrical Engineer, PhD Cand.

Mr. George Vasileiou, Mechanical Engineer, PhD Cand.

Webinar Layout

- Brief intro about NTUA, School of ME & RP&T Lab
- FDM Cases of the Rapid Prototyping & Tooling Laboratory
- FDM Cases of the Vehicles Laboratory
- FDM Cases of the CS Lab / Team of Prof.Papadopoulos
- FDM Cases of the CS Lab/ Team of Prof. Kyriakopoulos
- FDM Cases of the Systems Bioengineering Lab
- FDM Cases of the Machine Design Lab
- Discussion, conclusions & suggestions
- Q & A

NTUA & School of ME
Brief History

NTUA's Historic Building, Patission Str.

NTUA's Modern Campus, at Zografou

• NTUA was founded in 1837, originally under the name ***Polytechnic School***
• In 1887, faculties for Civil Engineers, ***Machinists*** and Foremen were introduced
• In 1914 the School was renamed to ***National Technical University of Athens***, including the faculty of Mechanical Engineering, within the Highest Department of Mechanical and Electrical Engineering
• In 1975, the Department of Mechanical and Electrical Engineering were separated into two independent departments

NTUA is Greece's **oldest** and **most prestigious** technically oriented academic institution, having constantly contributed to the country's reconstruction, industrial and economic development and growth for over 170 years.

Rapid Prototyping & Tooling Laboratory, School of ME

LOM 1015 (1996)

uPrint (2010)

FDM 360mc Small (2015)

• **RP&T Lab**, was established in 1996 and was officially declared a NTUA Laboratory within the School of ME in 2001.
• Has introduced the technology of Rapid Prototyping/ 3D Printing to NTUA's School of ME and has been operating Additive Manufacturing equipment of LOM and FDM technologies (it's own uPrint & the Department's Fortus 360mc)
• Also equipped with state of the art 3D CAD/CAE/RE & RP-supportive software and RE/ Industrial Metrology equipment
• Offers education, laboratory exercise and 3D Printing support of all types to the School's Students and has successfully conducted several RP-involving research projects in strictly mechanical, as well as other fields

Rapid Prototyping & Tooling Laboratory

Head: Professor C.Provatidis

Cases

Industrial Design – Modular Furniture
Product Concept – Parcel Delivery Station
Cultural Heritage – Archeological Artefacts
Paleontology – Skeletal Reconstructions

Cases presented by:
Dr. Stamatios N. Polydoras
PhD, Dipl. Mechanical Engineer
Laboratory Teaching Staff, School of ME
Rapid Prototyping & Tooling Laboratory

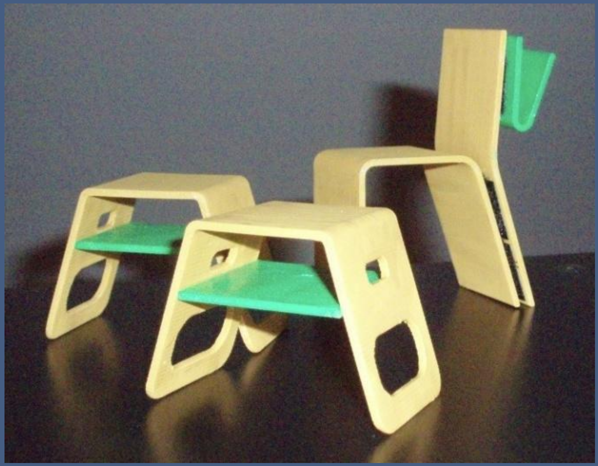
RP&T Lab, Case 1: Modular/versatile furniture

Application Type: Industrial Design Models, Proof of Concept prototypes, Communication/Presentation media

Made for : Student Diploma Thesis
Made with: Stratasys uPrint





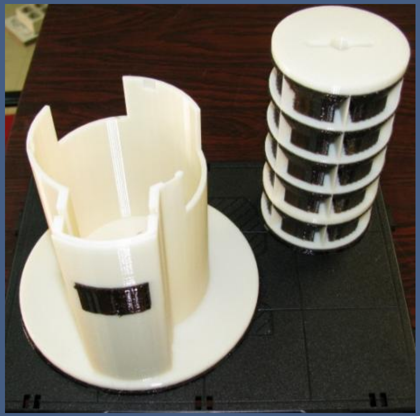
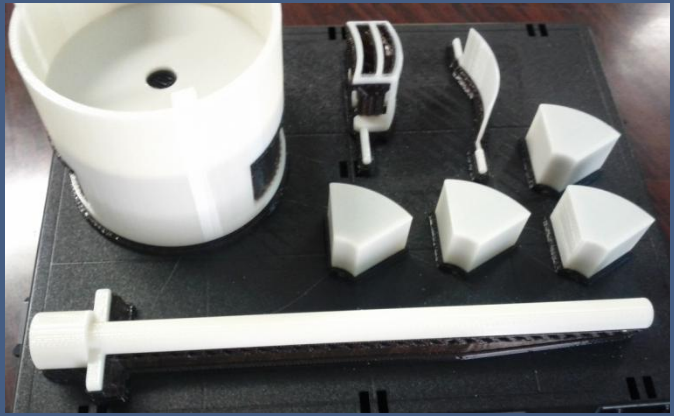
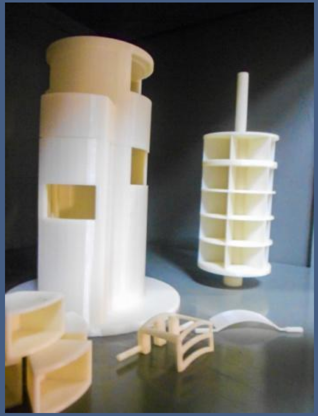
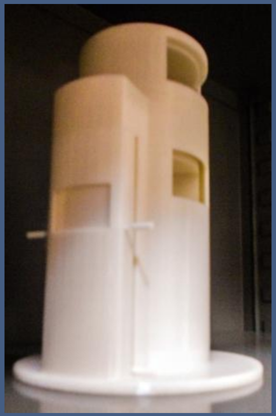



- ✓ Very fast & cost-effective prototyping of 1:10 scaled-down furniture modules
- ✓ Built in ABS P430 material
- ✓ Time 5h 50min, Model & Support Materials: 57.5ml, minimal post processing required
- ✓ Models durable enough and suitable for gluing and painting
- ✓ Excellent verification of intended modular design architecture
- ✓ Were used in conjunction with actual Barbie dolls for exhibition purposes
- ✓ Served perfectly for the presentation of the student’s diploma thesis to the examining committee

RP&T Lab, Case 2: Parcel Delivery Station

Application Type: Proof of Concept prototypes, communication/presentation media, kinematic assembly

Made for : Students' Project for the course of "Innovative Design"
Made with: Stratasys uPrint

- ✓ Many different parts, some out of the machine's maximum dimensions / CAD-level splitting required
- ✓ Parts were built in ABS P430 material in two builds. Appropriate clearances applied for later assembly and kinematic operation
- ✓ Total Time 27,5 hours (2 builds), Model & Support Materials: 406ml, post processing required
- ✓ Models accurate enough to be assembled and manually moved (rotated-slid-inserted) to demonstrate the proposed machine's operating principle
- ✓ Excellent understanding of the design intent with the prototype
- ✓ Served perfectly for the presentation of the students' work during the project

RP&T Lab, Case 3: Archaeological Artefacts

Application Type: Originals' Reproduction, Digital Documentation, Assistance for disabled people (esp. visually impaired)

Made for : Feasibility Testing/ Collaboration with Greek Archeological Museums & Institutions

Made with: Stratasys uPrint & Fortus 360mc

- ✓ Non-contact Reverse Engineering Method (Laser Scanning) has been applied to the originals at a prior stage, to produce raw data for digital model preparation
- ✓ RE exploiting re-modelling software was used to produce STL files for 3D Printing
- ✓ Despite the 0,254mm layer thickness (standard for uPrint and T16 tip-related for the Fortus), all artefacts were produced with acceptable quality
- ✓ The ABS material (P430 and M30) is compatible and well suited for many post processing operations (e.g. smoothing, sanding, painting, plating, aging) to improve the replicas' visual properties and aesthetics.
- ✓ All artefacts were reproduced with acceptable time and material consumption, especially the Egyptian one, where Insight SW offered more control for the interior.

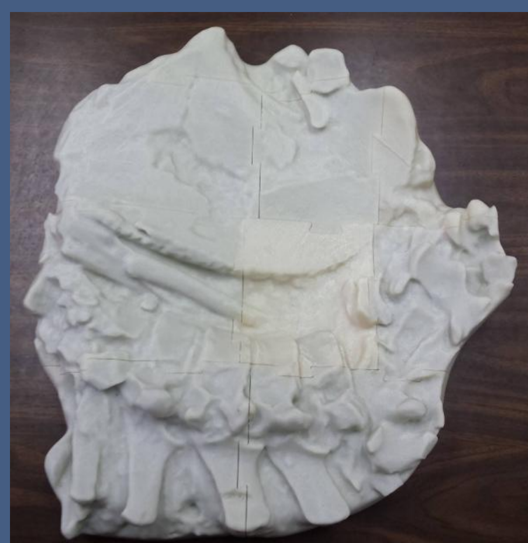
RP&T Lab, Case 4a: E. tiliensis skeletal elements

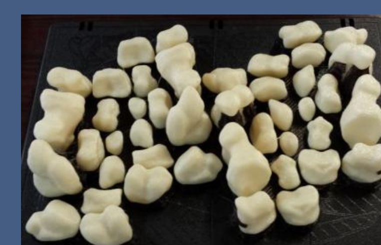
Application Type: Paleontology, Original Research, Reproduction/Reconstruction of extinct elephant’s skeleton

Made For : Thales - MIS380135 NSRF 2007-2013 EU-funded Research Project
Made with: Stratasys uPrint & Fortus 360mc







RP&T Lab, Case 4b: E. tiliensis skeletal elements

Application Type: Paleontology, Original research, Reproduction/Reconstruction of extinct elephant's skeleton

Made For : Thales - MIS380135 NSRF 2007-2013 EU-funded Research Project
Made with: Stratasys uPrint & Fortus 360mc

RP&T Lab, Case 4c: E. tiliensis skeletal elements

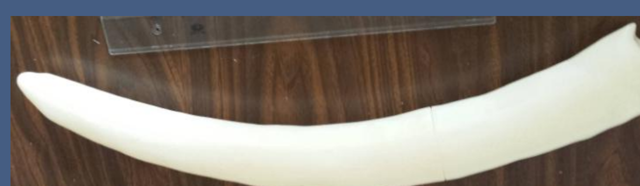
Application Type: Paleontology, Original research, Reproduction/Reconstruction of extinct elephant’s skeleton

Made For : Thales - MIS380135 NSRF 2007-2013 EU-funded Research Project
Made with: Stratasys uPrint & Fortus 360mc







RP&T Lab, Case 4d: E. tiliensis skeletal elements

Application Type: Paleontology, Original research, Reproduction/Reconstruction of extinct elephant's skeleton

Made For : Thales - MIS380135 NSRF 2007-2013 EU-funded Research Project

Made with: Stratasys uPrint & Fortus 360mc

- ✓ CT & Laser Scanning employed into original fossils for raw data collection
- ✓ Allometry & other statistical methods produced the dimensions of a typical elephant
- ✓ CAD models prepared with the above data, STL files prepared, split and packed for building in all of the Lab's available machines
- ✓ Proper clearance applied - when needed - for proper fitting and assembling
- ✓ <u>Maximum</u> economy pursued both for time and material consumption (Sparse fills)
- ✓ Total: 35 builds, 448 h, 5660ml @ uPrint / 35 builds, 575 h, 14200ml material @ Fortus
- ✓ Accurate fit, easy montage (sliding, gluing, drilling, screwing) of all different parts
- ✓ Excellent results, a true breakthrough for the paleontological community internationally

Vehicles Laboratory

A.Professor D. Koulocheris

Cases

Concept Realization – New Bicycle Frame

Functional Prototyping – Open Wheeler Race Car Air Intake

Cases presented by:
Dr. Stamatios N. Polydoras
PhD, Dipl. Mechanical Engineer
Laboratory Teaching Staff, School of ME

Vehicles Lab, Case 1: Bike Frame & Fork

Application Type: Geometrical Prototype for Design Verification, Communication/Presentation media

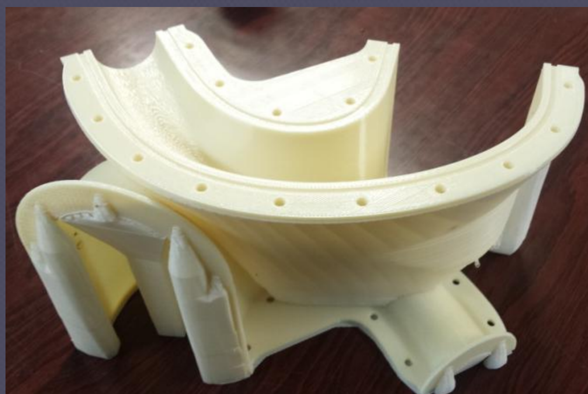
Made For : Student's Diploma Thesis presentation
Made with: Stratasys uPrint

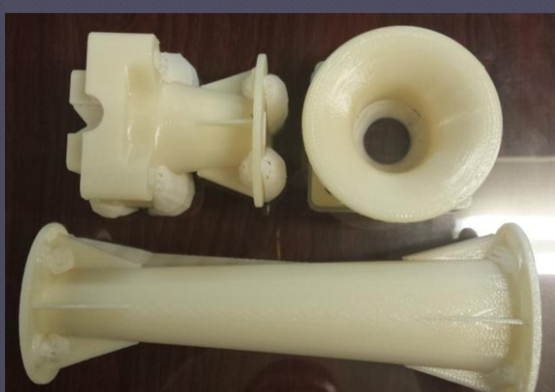
- ✓ Demand for high speed – minimum cost prototyping
- ✓ Scaled prototype – had to keep proper dimensional analogies => Thin parts
- ✓ Fork and main frame had to fit together => Appropriate clearance in CAD level
- ✓ All above goals achieved, Build time: 1 h, Tot.Mater.Volume: 14 ml
- ✓ Some deformations of the very small form features (<4mm) observed
- ✓ Very illustrative display of the new design of the bike frame

Vehicles Lab, Case 2a: Full Engine Intake Assembly

Application Type: Directly Functional Components, Analysis - Testing - Design Iteration Cycle

Made For : NTUA's PROM Racing Team, competing in Formula Student Contest
Made with: Stratasys Fortus 360mc

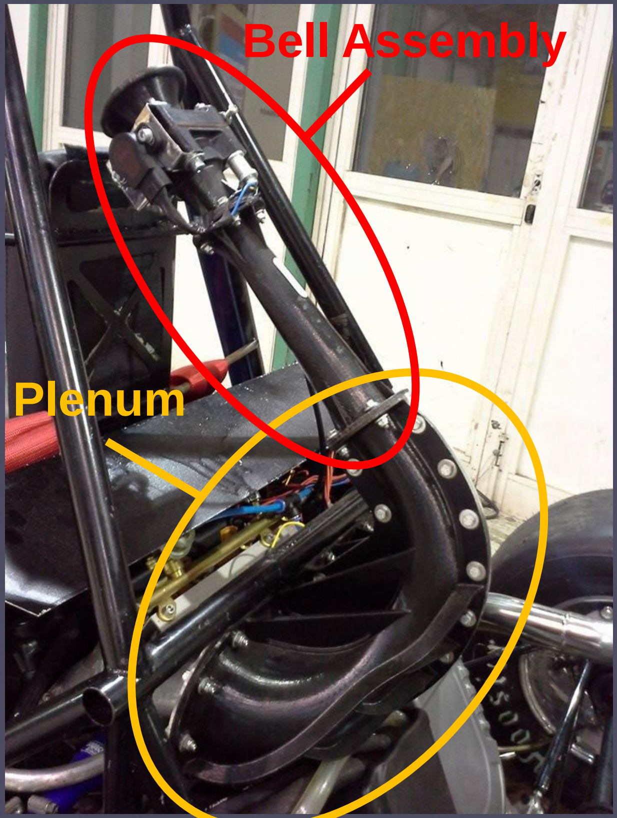




Vehicles Lab, Case 2b: Full Engine Intake Assembly

Application Type: Directly Functional Components, Analysis - Testing - Design Iteration Cycle

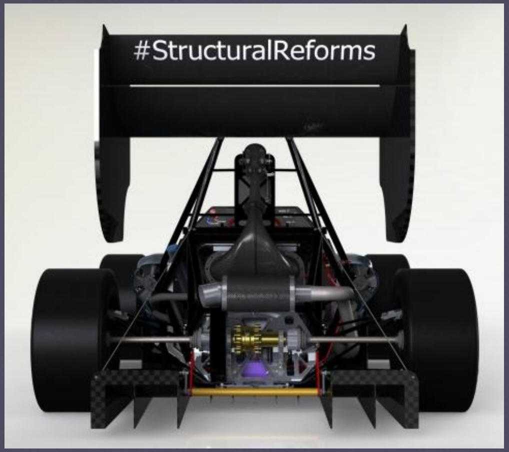
Made For : NTUA's PROM Racing Team, competing in Formula Student Contest
Made with: Stratasys Fortus 360mc



Vehicles Lab, Case 2c: Full Engine Intake Assembly

Application Type: Directly Functional Components, Analysis - Testing - Design Iteration Cycle

Made For : NTUA's PROM Racing Team, competing in Formula Student Contest
Made with: Stratasys Fortus 360mc



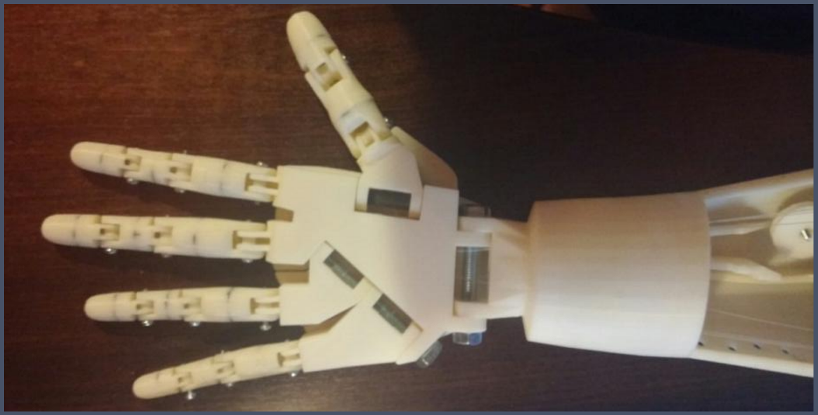
- ✓ Excellent ability for the team to test and validate the FEA-estimated air flow performance of the complete engine air intake system
- ✓ ABS M30 material proved strong enough and adequate to serve as final material for the air intake components, since the application was not thermally demanding
- ✓ Components had to be wet-sanded and spray-painted (acrylic paint) though, to improve the surface quality of their active flow surfaces
- ✓ The FDM-built components were well combined with flange materials and standard fasteners in the final assembly working on the car
- ✓ A design iteration cycle was needed and well performed for the plenum, since due to layered manufacturing it proved to deform more than estimated in FEA
- ✓ No of Builds: 3, Total Mater. Consumption: 1780 ml, Total. Build Time: 75 hours

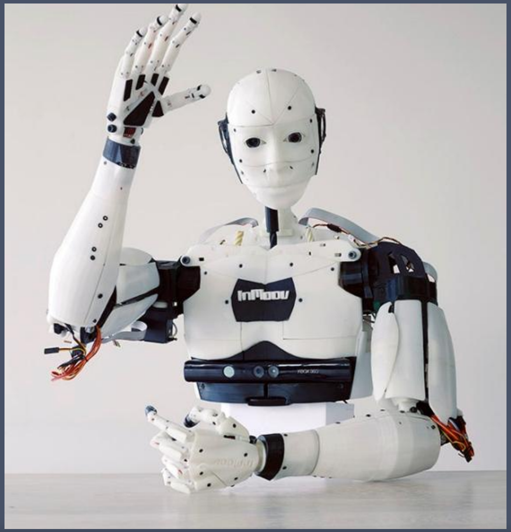
Control Systems Laboratory
Team of Professor E. Papadopoulos
Cases
Bionic Prosthetics – InMoov Bionic Hand
Space Robots – Zero-gravity maneuvering controls testing

Cases presented by:
Dr. Stamatios N. Polydoras
PhD, Dipl. Mechanical Engineer
Laboratory Teaching Staff, School of ME

CSL Lab, Team of Prof. E. Papadopoulos, Case 1a: InMoov's Hand (uPrint SE)

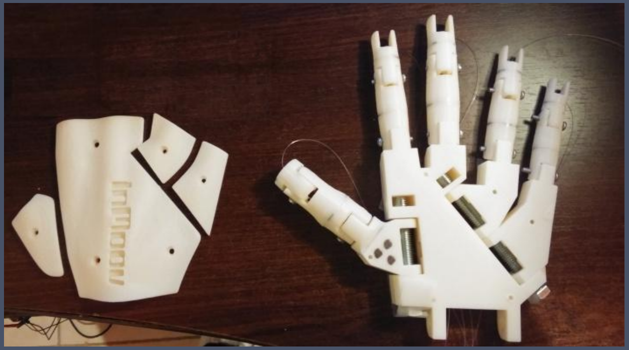
- Cost ~380 €
- Material Consumption
  - Model: 586,08 cm^3
  - Support: 197,12 cm^3

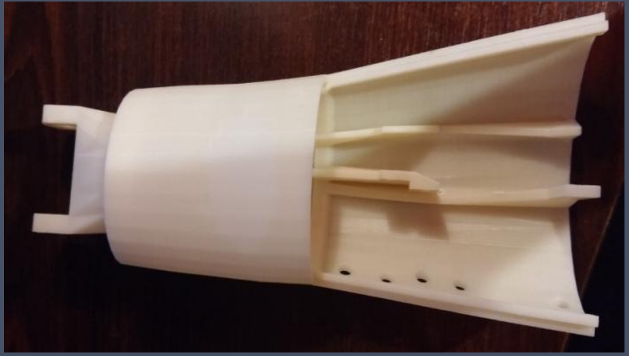




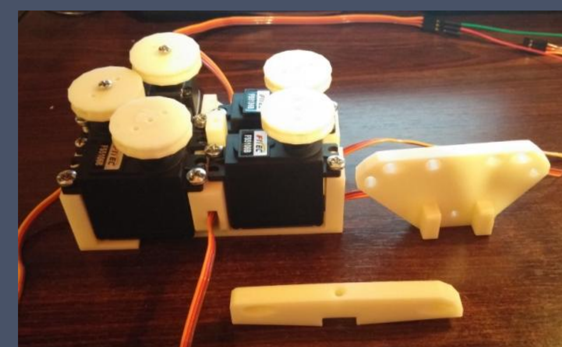
CSL Lab, Team of Prof. E. Papadopoulos, Case 1b: InMoov's Hand (uPrint SE)

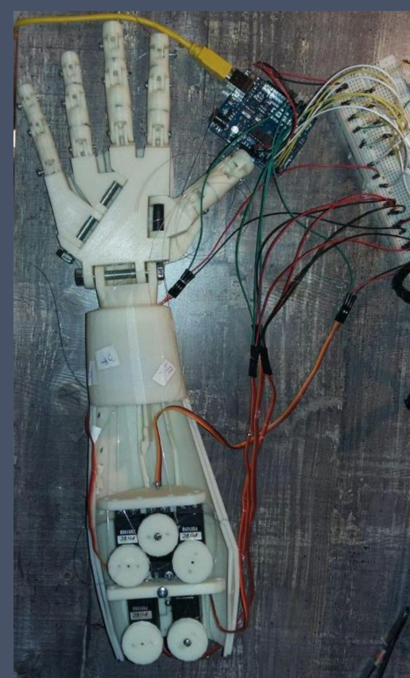
- Pros
  - High quality 3D printing
  - Recyclable (support can be used as glue for ABS, with the addition of pure acetone)
- Cons
  - High cost
  - Prolonged 3D printing





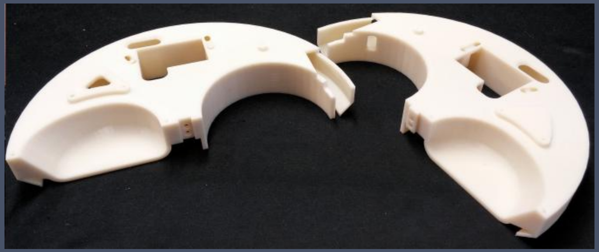
CSL Lab, Team of Prof. E. Papadopoulos, Case 1c: InMoov's Hand (Details)

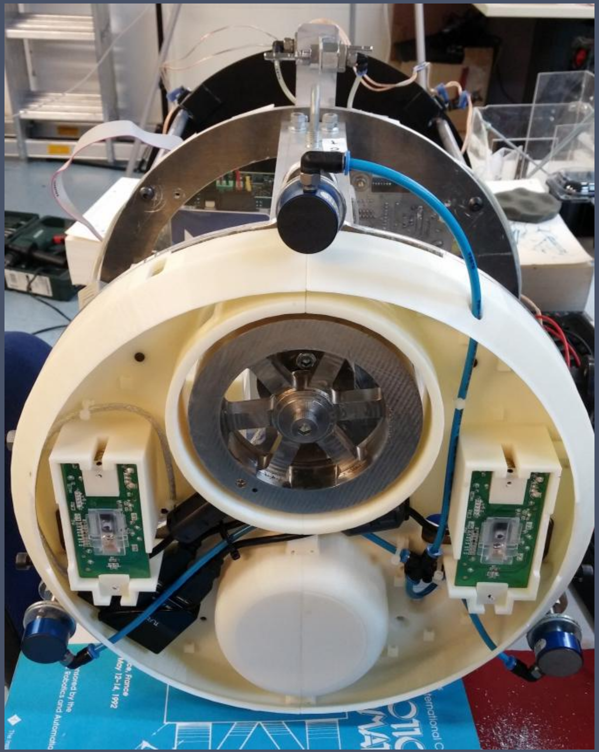




CSL Lab, Team of Prof. E. Papadopoulos, Case 2a: Space Robot Base (Fortus 360)

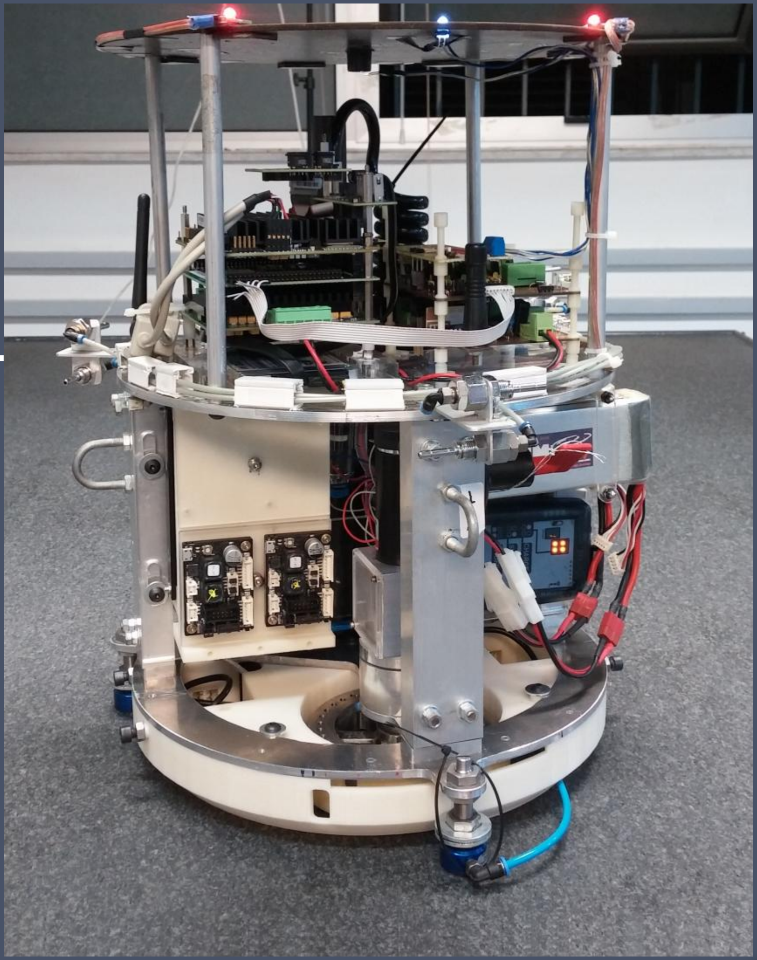
- Rigid robot base to host
  - optical sensors
  - reaction wheel
- Requirements
  - Low weight
  - Accuracy on sensor placement
  - Easy adjustment of sensor clearance from table





CSL Lab, Team of Prof. E. Papadopoulos, Case 2: Space Robot Base (Fortus 360)

- Pros
  - High quality 3D printing
  - Durable
  - Developed as one piece
  - Sensors position accuracy
- Cons
  - High cost
  - Prolonged 3D printing



Control Systems Laboratory
Team of Professor K. Kyriakopoulos
Cases

FDM 3D Printing for prototype components

FDM 3D Printing enabling student creativity – OpenBionics Project

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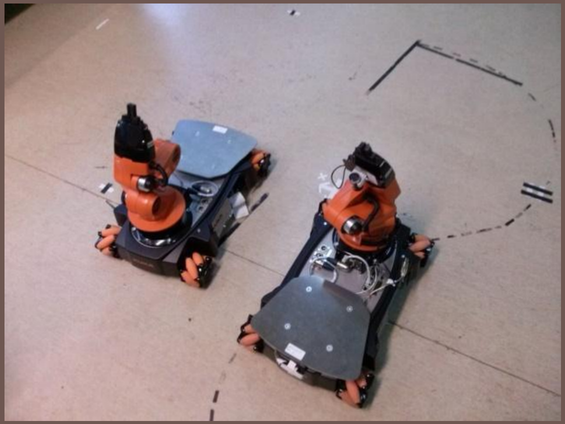
Cases presented by:
Mr. George Zogopoulos-Papaliakos
PhD Cand., Dipl. Electrical Engineer

Lab Intro – Activities in Robotics

Unmanned Underwater Vehicles

Neurorobotics

Mobile Robots



Unmanned Aerial Vehicles

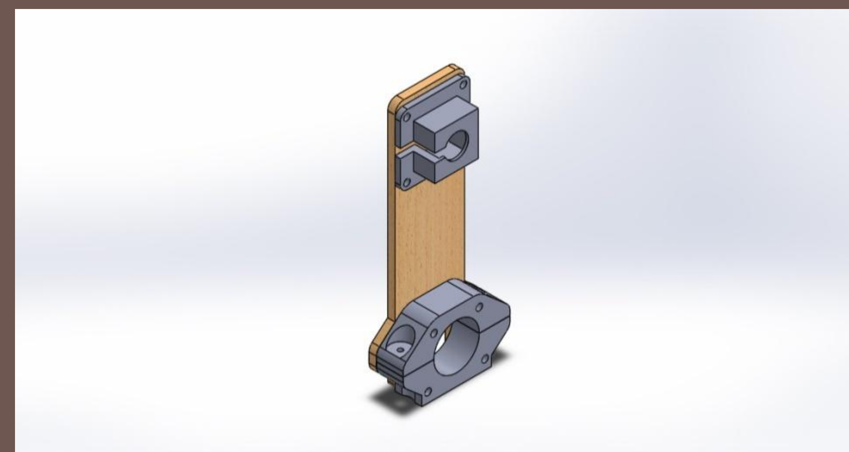
3D Printing as a Prototyping Tool

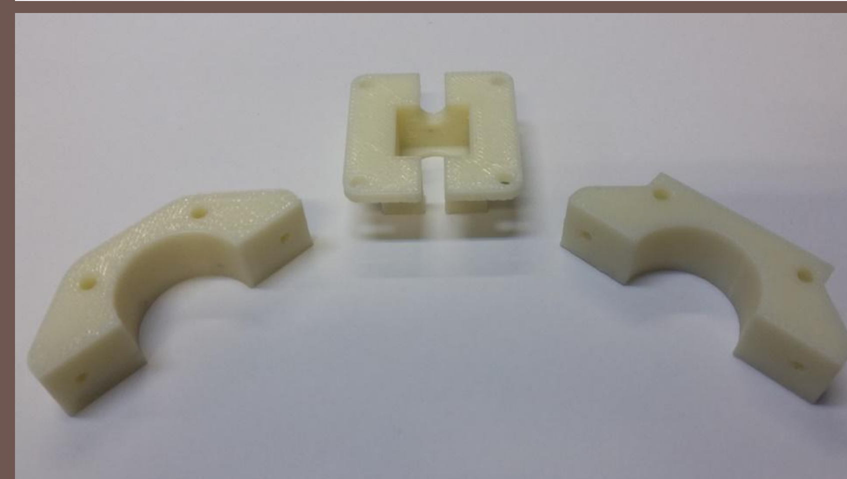
Compliant UGV gripper

Multi-purpose flange

3D Printing as a Prototyping Tool

Airdata Calibrator – Various structural parts



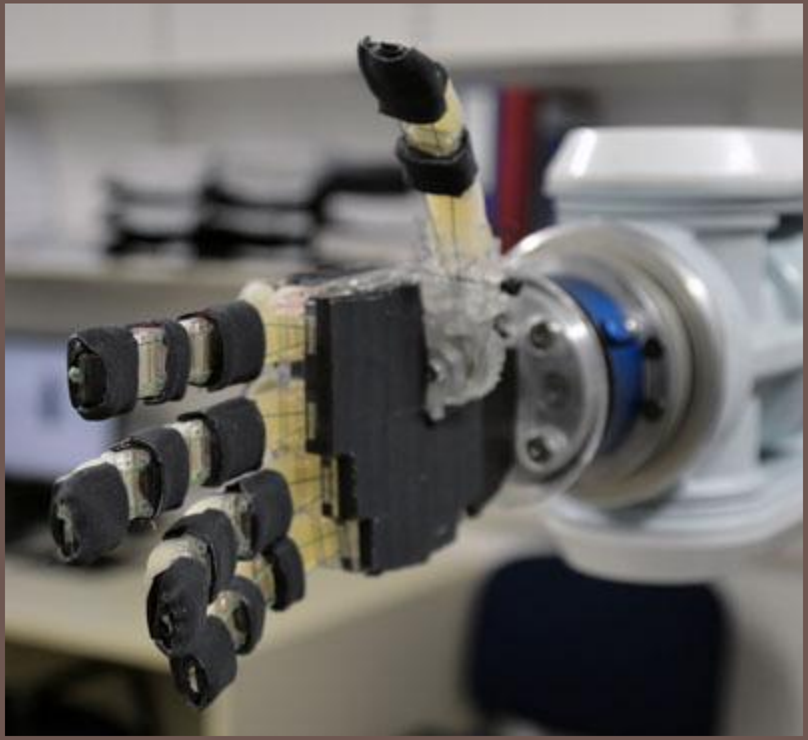


3D Printing as an Enabling Technology

The OpenBionics project

OpenBionics is a spinoff project from our lab, whose main focus is the design of **low cost prosthetic and robotic hands**

This was possible thanks to rapid prototyping technologies and inexpensive materials

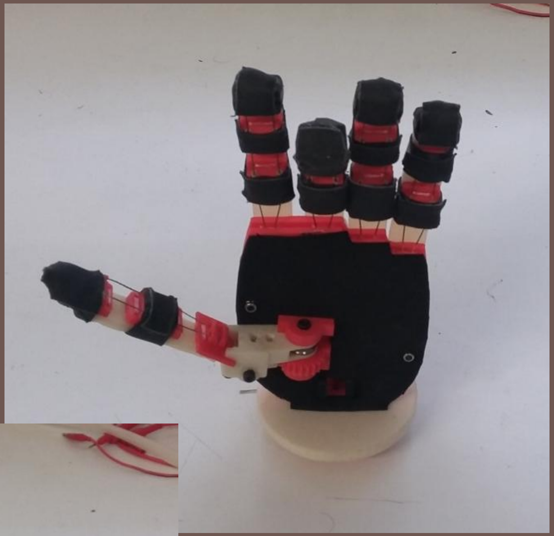


3D Printing as an Enabling Technology

The OpenBionics project

3D printing allows for

- Unlimited design iterations
- Per-case modifications



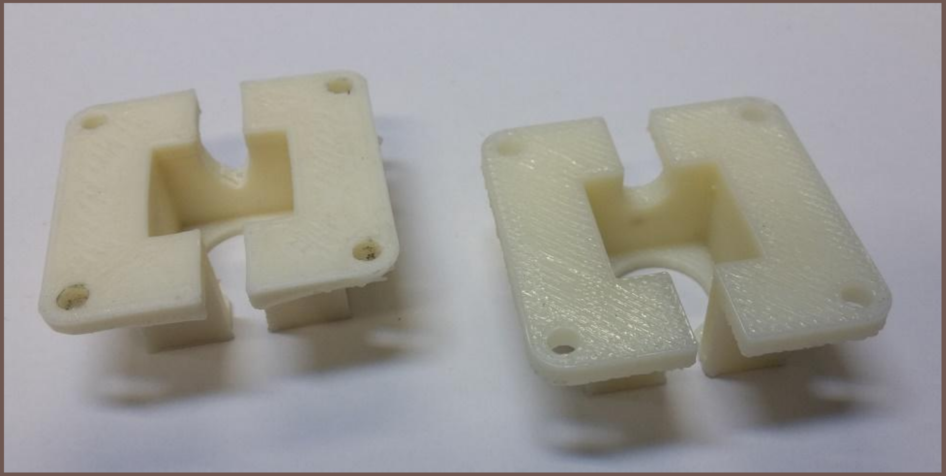

Different Requirements for Different Needs

Prototyping Grade

- Printer needs to be fast
- Material needs to be cheap
- Workflow iterations need to be short
- Printer must be robust in the presence of untrained hands

Production Grade

- Printer must produce model with low tolerances
- The result must be repeatable



Systems Bioengineering Laboratory

A.Professor Leonidas Alexopoulos

3D Printing Applications in Bioengineering

Dimitrios Tzeranis, Ph.D.
Theocharis Iordanidis

NTUA Systems Bioengineering Lab

- Multi-disciplinary Lab
  - Biology & proteomics
  - Device design
  - Computation & algorithms
- Applications
  - Drug discovery
  - Basic biology research
  - Tissue engineering & biomaterials
  - Point-of-care devices

Application 1: Portable Cell Microscope

- Design a small microscope for monitoring cell growth
  - Student class project
- 3D-printed microscope frame
  - House optics and camera
  - Holds biological sample
  - Can be place in a cell incubator
- 3D-printing implementation
  - 3 components built by 3D printing, assembled using flextures

Application 2: Closed-Circulation Air System

- Design a closed circulation air system, part of a custom incubator around a mechanical test device

- 3D-printed flanges & air circuit connectors
  - Reduce size and volume
  - Prevent air leakage
  - Ensure sterility

Application 3: Molds for Elastomer Casting

- Molds for casting custom PDMS housings for cell culture systems
- 3D-printed mold components that result in elaborate PDMS components
  - Enable complex shapes
  - Optimize material use
  - Enable to conduct complex experiments

Possible Future Applications of 3D Printing

- Complex-shaped mold components
  - Elastomer fabrication, biomaterials, tissue engineering
- Custom fluid handling components
  - Luers, flanges
- Components of cell-matrix culture systems
  - Housings
- Light-weight components for custom mechanical testing apparatus

Machine Design Laboratory

A.Professor V. Spitas

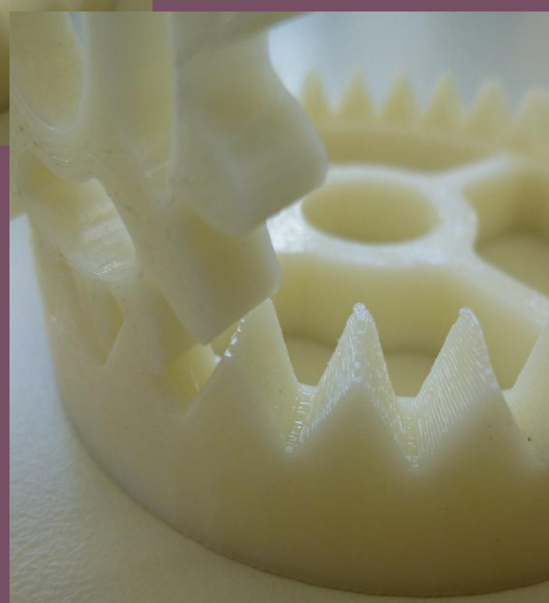
Cases

Geometrical Prototypes – Innovative Face Gears
Prototype Tooling – Fibre Reinforced Polymers Aparatus
Design Validation & Kinematic Testing – Ashtray
Concept ual & Kinematic Demonstration – Screw Slurry Pump

Cases presented by:
Mr. George Vasileiou
PhD Cand., Dipl. Mechanical Engineer

Machine Design Lab, Case 1: Face Gears

Application Type: Geometrical Prototypes (Fortus 360)



- Design of face gears to mesh with involute spur pinions
- Application of the Unified Theory of Gearing
- Produced prototype 1:1 scale
- Material: ABS Plastic
- Used as reference model for assessing the accuracy of Stratasys Fortus 360mc

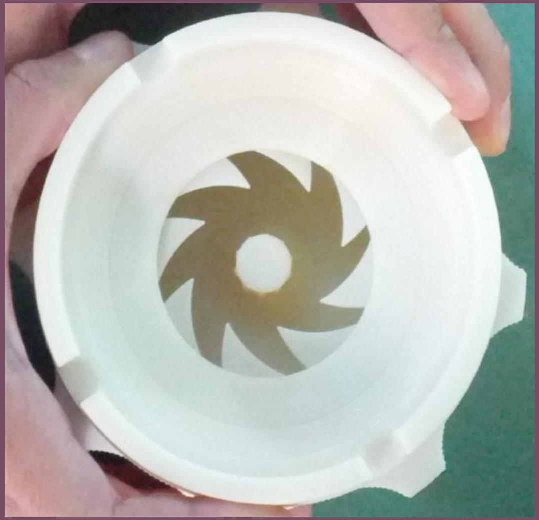
Machine Design Lab, Case 2: Co-rotating Tooth Rollers

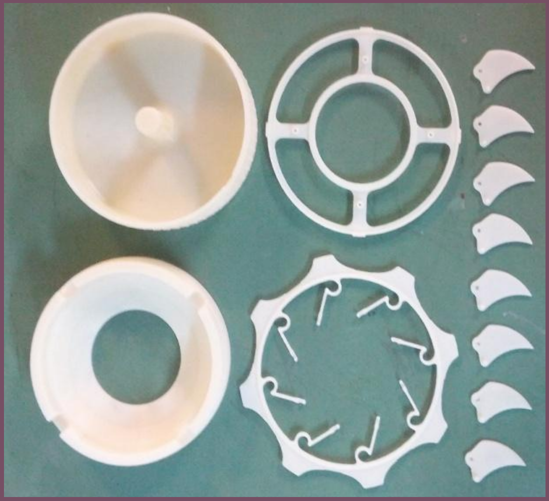
Application Type: Prototype Tooling (uPrint)

- Lab-scale apparatus for producing continuous Fibre-reinforced polymers (FRPs)
- Non-meshing tooth rollers using 3D Theory of Gearing
- Better resin penetration and overall performance of the FRP when compared to conventional rolling devices
- Material: ABS Plastic
- Small divergence from the nominal dimensions (verified using laser-scanning techniques)

Machine Design Lab, Case 3: Ashtray

Application Type: Design Validation & Kinematic Testing





- Design of an innovative ashtray to remove ash and unpleasant odours
- Material: ABS Plastic
- Fully functional prototype including all moving parts
- Made with Fortus 360

Machine Design Lab, Case 4: Flex.-stator Screw Slurry Pump

Application Type: Conceptual & Kinematic Demonstration

- Used for cement and water-based materials with maximum grain size of 10mm
- Innovative conical shape profile for easy declogging
- Prototype built for demonstration purposes
- Machine: uPrint
- Material: ABS Plastic

Discussion

FDM Pros and Benefits

- ✓ Very reliable equipment, both the ***uPrint*** series (small office/ laboratory machines) and the ***Fortus*** (professional series)
- ✓ Robust Design, quality engineered & manufactured
- ✓ Industrial Grade Materials
- ✓ Durable, long-lasting models
- ✓ High repeatability & dimensional stability / acceptable accuracy
- ✓ Separate & Soluble Support material a major plus
- ✓ Volumetric material consumption
- ✓ Enable directly functional prototyping
- ✓ Network operation & control
- ✓ Continuous and reliable technical support (4th Dim. Tech.)

FDM Cons and Difficulties

- ❖ High material cost per cc (estimated 0.44 - 0.51 € / cc)
- ❖ Fixed layer thickness per model-tip
- ❖ Humidity can affect raw materials in the long term if opened
- ❖ Machines need to stay on and hot = energy consumption
- ❖ Used bases, empty spools/ canisters and EPROMs become unexploited resources as they accumulate
- ❖ Control over the build parameters is quite limited in the uPrint models

Conclusions

- FDM-based Additive Manufacturing / 3D Printing equipment has been an invaluable tool for the ME School's Mechanical Design & Control Systems Department the last 6 years
- uPrint and Fortus offer our students and researchers design freedom, speed and potential, unimaginable a few decades ago
- Our students cultivate their creativity early on in their studies, can communicate their ideas better and easily test and share them
- All of the School's disciplines can effectively be combined and validated on actual physical parts and prototype products
- The ME School is thus assisted by FDM in keeping its teaching and research in state-of-art, high quality level, especially in difficult times of deep, unprecedented economic recession for our country
- We already transfer knowledge and benefits from AM and FDM beyond the field of ME, into other disciplines and sciences

Suggestions

We would very much welcome from Stratasys, its group of partnering companies and sales network:

- A new/ improved pricing policy, especially for raw materials
- Essential and affordable (or even free) Machine Spec and Software upgrades for all existing/ installed machines (uPrint & Fortus), to boost their capabilities against modern competition
- “Unlocked” build parameters for uPrints / Fully unlocked Fortus (Small → Large / 400) for academic users
- An environmentally-conscious, active “take back” and customer reward policy for used materials and consumables, empty canisters, EPROMs etc., that could significantly help reduce their prices
- Bilateral Work & Research Partnerships on FDM-AM, materials and applications (e.g. 4D Printing, composites, elastomers, innovative applications)
- Factory student trainings and/or practicums
- Sponsorships of all kind!

Thank you for your attention!

We'll be happy to answer your questions

Stamatios N. Polydoras, PhD

Dipl. Mechanical Eng.

RP & T Laboratory, School of ME, NTUA

polsntua@mail.ntua.gr

http://mkae.mech.ntua.gr

http://www.mech.ntua.gr