Miniature Flexible & Reconfigurable Manufacturing System for 3D Micro-products (Micro-3D)

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Outline

➢ Project brief
  - Project background and motivation
  - Project structure and team
  - Project concept and deliverables

➢ Progress to date

➢ Customers & market

➢ Impacts & plans

➢ Concluding remarks
Why micromachining

Micromachining: machining products whose functional features, or at least one dimension, are in the order of μm (10⁻⁶m)

- Miniaturisation
- Function integrations
- Functional features (freeform or structured surfaces) in micro scale do matter.

First & new generation of mobile phones
(laforeta.blogspot.com)

Smart phone
(iphonic.tv)
Freeform or microstructured surfaces

Emerging micro-products are characterized as:

• 3D complex geometries (asperics, freeform/structured surfaces)
• Made of multi-materials (including ceramics, hard steels)
Motivation of the project

Mass production → Agile manufacturing

High volume & low variety → High value & low volume

Precision

Automation

Energy efficiency

Flexible manufacturing cell

Reconfigurability
Project structure and team

Aim: highly flexible manufacturing capability for emerging 3D micro-products

Investigators:
University of Strathclyde: Xichun Luo¹, Yi Qin¹, William Ion¹,³
University of Huddersfield: Xiangqian Jane Jiang²
Heriot-Watt University: Xianwen Kong⁴ and Matthew Dunnigan⁴

Industry partners: Contour Fine Tooling⁵, Gyrus Medical Ltd⁶, UPM Ltd⁷, ST Microelectronics⁸ and Renishaw⁹

Task allocation:

¹Strathclyde & ⁵Contour
²Huddersfield & ³AFRC
⁴Heriot-Watt & ⁸ST & ⁶Gyrus
¹⁷Strathclyde & ⁷UPM & ⁹Renishaw
Bench marking micro machines

FANUC ROBONANO α-0iB
AZ250L (Sodick)
Micro Pyramid Nano
Cranfield μ4

Demand Time and Cost at unload and setup

High precision and ultra precision machining processes enable to achieve a very high accuracy from 10 nm to 100 nm and a material removal rate above $10^{-4}$ mm$^3$/s. But these highly accurate miniaturized 3D complex parts are made via a variety of separate high precision machining processes.
Concept of hybrid micromachining

More benefits than multifunctional machining process

• Improve machinability
• Improve surface integrity

• Improve machined surface roughness
• ….
Bench mark-machining capacity

Volume, parts/year

Low | medium | high
---|---|---
Low | Standalone NC machine | Current micro-factory
Medium | Multifunctional machine | Proposed hybrid
High | Manual method | Transfer line

Variety, part styles/year

Low | Medium | High
---|---|---
Manual method | Multifunctional machine | Proposed hybrid
Current micro-factory | Standalone NC machine | Transfer line
6-axis hybrid micro machine tool

Specifications:
- Stroke:
  - X:300 mm Y: 150mm Z: 150mm
- Resolution: 1nm
- Accuracy: < 0.2μm
- Spindle speed: 180,000 rpm
- Floor space: 0.85m by 0.75 m

Key features:
- Reconfigurable machine structure
- High stiffness air bearing systems
- 5-axis NURBS tool path control
- Advanced dynamic motional error compensation
- On-line surface metrology

(A Laboratory prototype will be commissioned in November 2015 at University of Strathclyde)
Software based CNC controller

Super-twisting sliding mode controller

Aerotech 3200 Software based CNC controller, PID control

Max reduction: 70%

Max reduction: 90%
On-line surface metrology

Dispersed Reference Interferometry
- Single point interferometric method
- Remote common-path fibre probes
- Highly miniature probes: <1 mm Ø
- High measurement rates
- Vertical resolution: <5 nm
- Vertical range: >600 μm

Below: Prototype interrogation interferometer rendering
Top right: Example fibre probe configuration
Bottom right: DRI schematic diagram
Material Handling System

Challenges:
• Manipulate large range of masses - up to 1.2 Kgs
• Adjust screws on the work piece holder

Pick and Place
• Manipulate large range of part sizes - few millimetres up to 51 mm

Gripper Selection
• Compliant Gripper
• Commercial Modular System
• Four Degree of Freedom Scara Robot
• Automated Screw Tightening System

Stepper Motor and Gearbox
0.175Nm to 5.7Nm
100mm Linear Stage

Differential torque controlled, zero-backlash gripper

Allows for large range of part sizes and masses to be manipulated
Hybrid micromachining processes

Laser assisted micromilling
- Mould
- Burrs on micro channel
- Laser deburring

Laser assisted microgrinding
- Hardware setup
- Comparison of sub-surface quality by Microgrinding and Laser assisted grinding

Bio-chip
- Micro pins
Multiscale modelling
Micro-Assembly System

To design a reconfigurable hybrid manipulator (Coarse/Fine positioning system) for assembly parts of different materials from 1mm to 10mm in size, with a 5μm positioning accuracy within a workspace of 150mm x 150mm.

Mobile phone camera
http://www.electronics-eetimes.com/

Frequency response test of a compliant XY stage

Novel 2-axis module realizing the human-eye rotation
(Courtesy of Patrick J. Lynch, Yale University School of Medicine)

2-DOF micro-motion stage driven by Voice-Coil actuators

Concept of a hybrid manipulator
Customers & market

• **Smart phone market** (> $270 billion in 2015): A company will sponsored one PhD student in this area

• **Medical device market** (predicted to reach $115.8 billion in 2020): DePuy (Ireland) sponsored two PhD studentships (Oct 2015 - Oct 2018)

• **Automotive market** (low cost diffractive optics, freeform optics)
Our role
Designer &
developer

Licensing
Machine tool builder

Product manufacturer

Consumers

Spin-out

Business model

Commercialisation routes
• We will seek further funding support to develop commercial prototypes after the ESRC project
• Licensing to a machine tool builder
• To establish a spin-out company as an ultra precision machine tool designer & machining process developer, provide services and consultancy contracts to other users in the value chain

Impact & plan
• Training 6 postdoctoral researchers and 5 PhDs
• 20+ journal papers published in the past 2 years

EPSRC
Engineering and Physical Sciences Research Council
Concluding remarks

- We will deliver a flexible & reconfigurable hybrid machines tools, which targets:
  - High positioning accuracy
  - Fast machining efficiency
  - Small floor space
  - Cheap building cost

- We target emerging high value-added products in the smart phone, medical device and automotive markets

- Laboratory prototype machines will be produced in November 2015, we will do machine and system integration and process development and industrial validations in the following two years

- We will seek further funding to develop commercial prototype after the EPSRC project