THE INTERNET OF SKILLS: 
ONLINE VIRTUAL SIMULATORS FOR SKILLED TRADES

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Future of Manufacturing: More

Global GDP Growth: Next two decades 2x the past 20 years

- More demand → more manufactured products
- More complexity per product
- Manufacturers are under-invested in automation

Manufacturing Contribution to GDP

Top 12 U.S. Economic Sectors
Manufacturing Employment: More Demand for Skills

• Skilled trades shortage #1 issue past 7 years
• 88% manufacturers report trouble finding skilled workers
• 500k vocational jobs unfilled 2016 & will get worse
  • Silver Tsunami: employees in skilled trades older than average
• Workforce training #1 impediment to automation (2016 MAPI survey)
Future of Training: Virtual Skills Simulator

Can’t close skills gap with incentives, K-12 voc-tech, etc. ➔ Breakthrough needed

Skills Training Revolution 1.0
• 1927, Edwin Link, first Flight Simulator
• Enormous progress underlying electromechanical, display, computing systems

Skills Training Revolution 2.0
• 2027 (?) name TBD, first Virtual Skills Simulator achieves True Virtual Reality
• Revolutionary for healthcare, gaming ... everything ... Interactive Internet

1927 Edwin Link Flight Simulator

2027 Virtual Skills Simulator

Interactive Internet
Virtual Skills Simulator: Enabling Technologies

Sensors
• Sight, sound, touch (smell, taste)

Networks
• Cyber-physical & Haptic latency ~ 1-10ms → 100-1000km

Software
• Exascale at the center & HPC at the edge

Neuropsychology & neurophysiology
• Active MRI + exascale → Perception of reality

Actuators
• Immersive reality emulation → conformal human-friendly
Virtual Skills Simulator: The Hard Problems

Sensors & Actuators for cyber-physical systems

**Sensors:** Detect & transmit reality
- Force, location, roughness, softness/hardness, warm/cold, friction
- Accuracy, resolution, speed and no power
- Solutions: Moore’s Law + new conformal bio-compatible materials

**Actuators & Haptics:** Transition from cyber to physical world
- Creating force – physical realism – move atoms not bytes
- *No Moore’s Law*
Actuators: Gatekeeper Tech for Cyber-Physical Systems

Requirements
• Sensitivity, speed, linearity, repeatability, stability, strength, compliance, etc. etc.
• Force, displacement, scaling, efficiency

Options
• Mechanical (ultrasonic, MEMS), thermal, chemical, optical, shape memory alloy (SMA), electro phenomena (piezo, motors), electro reactive polymers
Actuators: Tyranny of Power in Cyber-Physical Systems

Challenges at small & human scales
- Deliver enough power, efficiently
  - (Most data ignores energy source & power electronics overhead)
- Conformal & impedance matched

@ Ant-size
- Actuator $\sim 100$ mW vs insect $< 100$ $\mu$W $\rightarrow$ 1,000 x less efficient
- Engine (10 mm) $< 1\mu$W $\rightarrow$ 100,000 x less efficient
Muscles: Magic of Biological Actuators

Muscles conquer the blend of key metrics:
• Strain, stress, deformation, displacement, power
• Conformal, coupling efficiency
• Power efficiency (>50% v ~5%)

Material revolution needed to mimic nature

Promising progress but miles from Nirvana
• Beijing Institute of Physics carbon nanotube bimorph EAP (200 W/kg)
• UCLA elastomer sandwich
• Harvard self-healing stretchy electopolymer
• LBNL vanadium dioxide torsional muscle/motor (40 kW/kg)
• UT fishing-line coil w 50% displacement (5 kW/kg)
• LSU bio-inspired shape-memory polymer

300 W/kg (10x cockroach)
Enabling Virtual Simulators – Biomimetic Muscle Actuator

Time to follow Feynman’s “Room at the Bottom” ➔ but for atoms, not bytes

Need actuation tech equivalent to the vacuum-tube-to-transistor for information

New science & transformational tools unlock that possibility:
- Computational materials & materials genome (Exascale coming)
- Molecular machines -- 2016 Nobel Prize in chemistry
- Analytical instruments see molecular processes in real-time
  - Cryo-electron microscopy & super-resolved fluorescence microscopy
  - 3D printing biomaterials @ microscale

KEY GOAL EQUIVALENT TO LSI: Biomimetic Muscle Actuator (BMA)
- Enormous potential beyond Internet of Skills
- Age of Responsive Media, Interactive Internet, Tactile Internet
When BMAs Scale Like LSI

Cyber-physical equivalent of mainframe → PC?
• Conformal bio-compatible force-sense force-delivering glove

Cyber-physical equivalent of mainframe → smartphone?
• Multi-layer molecular-dimensioned smart-powered exoskin
• @ bio-efficiency delivering kW-class power w kg of fuel
Time for a Grand Challenge: Jaynes Prize for Biomimetic Muscle Actuator


• “We are speculating about the possibility of advancing the technology of energy convertors by taking hints from how Nature has managed it in biology.”

• “Having seen this [muscle] biological system...It is easy to believe that ... macromolecules could be ‘designed’ to do similar things, perhaps more easily.”

• “In time the design of useful anti-Carnot molecular engines (artificial muscles) might become as systematic and well understood as the design of dyes, drugs, and antibiotics is now.”