Technology Evaluation of Robotics Technology in Power Industry

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Technology Evaluation of Robotics Technology in Power Industry

Byung Sung Yoon, Portland State University
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Terry Oliver, Bonneville Power Administration
Robert Grizzi, Electric Power Research Institute
John Lindberg T., Electric Power Research Institute

Abstract

The electric power utilities as important social infrastructures should be operated stably without any failure in supply of electricity. For stable operation, it is necessary to input huge amount of resource and investment throughout power generation, transmission and distribution facilities. Particularly, constant inspection and maintenance of the facilities requires highly skilled manpower and advanced technologies. In spite of endless efforts, the electric power industry is facing serious challenges from social, economic and environmental problems. In this regard, a number of robotic systems have been tested and applied for inspection and maintenance in nuclear power plants and high voltage power transmission lines. The Electric Power Research Institute (EPRI) which conducts research, development and demonstration (RD&D) relating to the generation, delivery and use of electricity for the benefit of the public has also required efficient technology management in providing a blue print of robotics technologies in electric power sector for the future. The organization wants to centralize the R&D capability of robotics technologies which are dispersed by each division in order to prevent duplicated investments and manage its R&D capability effectively. This research is a step towards assessing the current robotics technology being used in the power industry and identifying the technologies that would benefit the industry most by using the Technology Development Envelop (TDE) approach.
Project Overview

Project Background
- Electric Power Research Institute (EPRI) wants to centralize the R&D capability of robotics technologies which are dispersed by each division
- To prevent duplicated investments and manage its R&D capability effectively

Project Objective
- To evaluate the current robotics technologies and identify the future development strategy in power industry with the Technology Development Envelope (TDE) methodology

Introduction of TDE
- “...to link technology to organization strategy so that managers can understand where technologies fit into their organization strategy and where the technologies are going in the future.”

- Formed by connecting technologies that have the highest technology value in each period throughout the specified timeframe
Six Steps for Formation of TDE

**Step 1:** Develop a forecasting model using Delphi for identifying the trend of emerging technologies.

**Step 2:** Identify criteria and technological factors satisfying a company’s objective.

**Step 3:** Assess the technological characteristics of each emerging technology along the factors.

**Step 4:** Develop a hierarchical model and determine the relative desirability of measures of effectiveness on the company’s objective.

**Step 5:** Evaluate the value of emerging technologies on the company’s objective.

**Step 6:** Construct the TDE and technology development paths.

Project Timeline

- **10/31** Kickoff Meeting
- **01/01** Official Start
- **01/08** 1st Monthly Meeting
- **02/15** Model Development
- **04/15** Forming Expert Panels
- **07/30** Model Validation
- **09/30** Model Quantification
- **11/30** Model Verification
- **01/01** Official Start
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Expert Identification

Bibliographic Database

- Title
- Authors
- Affiliations
- Keywords
- Abstracts
- References

Data file

- CSV
- BibTex
- Refworks
- ISI

Pre-processing

- Co-Authorship
- Co-Occurrence
- Frequency

with Sci2 & MS Excel

Post-processing

- Social Network Analysis
  With Gephi

1st Analysis Report

- Main keywords in CARPI 2010-2014
  - Main usages of Robotic Tech. (RT)
  - Features and functions
  - Challenges
- Proactive People
- Main Reference Source
  - Journals
  - Other conferences
  - Books

Keyword Analysis – Social Network Analysis

- Similar results with frequency analysis
- Actively researched application of robotic technology in power industry
  -> Inspection & Maintenance for power transmission line
- Main features
  Sensor & Vision, Telerobotics (Remote handling, Teleroperation), Mobile robots

INSPEC Controlled Keywords

INSPEC Uncontrolled Keywords
Co-Authorship Analysis

- Most active player in CAPRI 2010-2012
  - Gilles Caprari (ETH Zürich, Switzerland)
- Most of top rankers belong to Switzerland & Canada
- Rare co-authorship between each country except EU countries

Robotic Maintenance - Out of US in Robotics Journals

- Italy: Univ. of PISA & Scuola Superiore Sant'Anna (SSSA)
- France: CEA List (Atomic Energy and Alternative Energies Commission) & AREVA
- Japan: AIST & Univ. of Tsukuba
- Canada: Univ. of Quebec & IREQ
- Japan: Osaka Univ. & Yokogawa Elect Corp.
Robotic Inspection-US in Robotics Journals

Chris Urmson
CMU - Navigation & autonomous system

Canada
Univ. of Quebec & IREQ

Dieter Fox

Gaurav S. Sukhatme
USC – Large scale & distributed robotic system

Example of Individual Expert Information

Dr. Vijay Kumar
(kumar@seas.upenn.edu)

- UPS Foundation Professor in Univ. of Penn
- Recent 4 papers
  - Cooperative Visibility Maintenance for Leader-Follower Formations in Obstacle Environments (2014)
  - Opportunities and challenges with autonomous micro aerial vehicles (2012)
  - Decentralized Feedback Controllers for Multiagent Teams in Environments With Obstacles (2010)

Affiliation, Brief Bio, Co-Authorship Network, Research Topic Network
Potential Hierarchical Decision Model (HDM)

Model Metrics
Assignment of Experts on Items of HDM

Result of Validation

Dropped a perspective and five criteria which are not reached on the acceptable criterion.
New Validated Model

Objective

Identifying the Robotics Technologies which Benefits the Power Sector Most

Perspectives

Functionality

- Multi-Functions
- Multi-Environments
- Multi-Applications

Design

- Heavy Duty
- Moving Flexibility
- Compact
- Contamination Proof
- Nondestructive

Technological

- Global Positioning
- High Precision
- Real-Time Assessment

User Experience

- Easy to Use
- Upgradable
- Maintainable
- Safe and Fast

Electronics

- Remotely/Radio-Wireless
- Visual Capability
- Dual Communications
- Data Processing
- Interface Proof-Rad.
- Interface Proof-EF

Criteria

Alternative Technologies

- Submersible Mini-Robot
- Concrete Crawler Robot
- Remote Inspection Robot
- Underground Transmission Vault Inspection Robot
- Snake Robot
- Transmission Line Robot

Model Quantification

Objective

Identifying the Robotics Technologies which Benefits the Power Sector Most

Perspectives

Functionality 0.3

- Multi-Functions 0.2
- Multi-Environments 0.33
- Multi-Applications 0.47

Design 0.2

- Heavy Duty 0.16
- Moving Flexibility 0.28
- Compact 0.2
- Contamination Proof 0.17
- Nondestructive 0.19

Technological 0.15

- Global Positioning 0.19
- High Precision 0.38
- Real-Time Assessment 0.43

User Experience 0.22

- Easy to Use 0.18
- Upgradable 0.13
- Maintainable 0.13
- Safe and Fast 0.18

Electronics 0.13

- Remotely/Radio-Wireless 0.22
- Visual Capability 0.15
- Dual Communications 0.25
- Data Processing 0.12
- Interface Proof-Rad. 0.06
- Interface Proof-EF 0.20

Criteria

Alternative Technologies

- Submersible Mini-Robot
- Concrete Crawler Robot
- Remote Inspection Robot
- Underground Transmission Vault Inspection Robot
- Snake Robot
- Transmission Line Robot
Model Quantification – Global Weights

<table>
<thead>
<tr>
<th>Perspectives</th>
<th>Criteria</th>
<th>Global Weights</th>
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<tbody>
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<td>(F1) Multi-Function 0.20</td>
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<td></td>
<td>(F2) Multi-Environment 0.33</td>
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<tr>
<td></td>
<td>(F3) Multi-Applications 0.47</td>
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<td>(P2) Design</td>
<td>(D1) Heavy-Duty 0.16</td>
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<tr>
<td></td>
<td>(D2) Moving Flexibility 0.28</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>(D3) Size 0.20</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>(D4) Contamination Proof 0.17</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>(D5) Nondestructive 0.19</td>
<td>0.04</td>
</tr>
<tr>
<td>(P3) Technological</td>
<td>(T1) Global Positioning 0.19</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>(T2) High Precision 0.38</td>
<td>0.06</td>
</tr>
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<td></td>
<td>(T3) Real-time Assessment 0.43</td>
<td>0.06</td>
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<tr>
<td>(P4) User Experience</td>
<td>(U1) Easy to Use 0.38</td>
<td>0.08</td>
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<td></td>
<td>(U2) Upgradable 0.13</td>
<td>0.03</td>
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<td></td>
<td>(U3) Maintainable 0.13</td>
<td>0.03</td>
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<tr>
<td></td>
<td>(U4) Safe and Fast 0.38</td>
<td>0.08</td>
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<tr>
<td>(P5) Electronics</td>
<td>(E1) Remotely/Wireless 0.22</td>
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<tr>
<td></td>
<td>(E2) Visual Capability 0.15</td>
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<td></td>
<td>(E3) Dual Communication 0.25</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>(E4) Data Processing 0.12</td>
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</tr>
<tr>
<td></td>
<td>(E5) Interference Proof - Radiation 0.06</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>(E6) Interference Proof – Electromagnetic Field 0.20</td>
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</tr>
</tbody>
</table>

To get Technology Value, each Global Weight will be multiplied by the Desirability Score of each Technology Alternative.

Description of Desirability Curve

- A desirability curve presents the preference on the technological metric of each factor. (Gerdsri, 2007)
- Development of a desirability curve*
  - Step 1: Identify the best and worst desirable limiting metrics that each factor can take on.
  - Step 2: Verify the measures of effectiveness whose desirability value is linearly proportional to their numerical value between the two limits.
  - Step 3: Develop a semi-absolute scale by assigning 0 point to the worst and 100 points to the best desirable limiting metrics under each factor.
  - Step 4: Calculate the relative desirability of the intermediate values between the two limits.
  - Step 5: The relative desirability values of metrics under each factor can be graphically presented as a desirability curve by arranging the range of metrics value on the horizontal axis (X-axis) and the desirability value on the vertical axis (Y-axis).

## Calculation of Technology Value

### Desirability Curves

![Desirability Curves Diagram]

### Calculation of Technology Value

<table>
<thead>
<tr>
<th>Perspectives</th>
<th>Criteria</th>
<th>Global Weight</th>
<th>Robotic Systems</th>
<th>Transmission Line Robot</th>
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<tbody>
<tr>
<td></td>
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<td></td>
<td>Submersible Mini-Robot</td>
<td>Transmission Line Robot</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tech Metrics</td>
<td>Desirability Values</td>
</tr>
<tr>
<td>Functionality</td>
<td>Multi-Functions</td>
<td>0.06</td>
<td>2 (Locomotive-ability, imaging)</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Multi-Environments</td>
<td>0.10</td>
<td>1 (Submerged)</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Multi-Applications</td>
<td>0.14</td>
<td>2 (Inspection, Monitoring)</td>
<td>80</td>
</tr>
<tr>
<td>Design</td>
<td>Heavy-Duty</td>
<td>0.06</td>
<td>2 (&lt; 0.001mm (1σ))</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Moving Flexibility</td>
<td>0.06</td>
<td>2 (4 DOF)</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Compact</td>
<td>0.04</td>
<td>1 (Small)</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Non-destructive</td>
<td>0.04</td>
<td>1 (No failure)</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>High Precision</td>
<td>0.04</td>
<td>2 (≥ 99%)</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Real-Time Assessment</td>
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<td>1 (Real-time)</td>
<td>100</td>
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<td>User Experience</td>
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<td>0.06</td>
<td>1 (one-time training)</td>
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<td>Upgradeable</td>
<td>0.06</td>
<td>1 (Improveable)</td>
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<td></td>
<td>Maintainable</td>
<td>0.06</td>
<td>1 ( ≤ 12 hrs)</td>
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</tr>
<tr>
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<td>Fast</td>
<td>0.08</td>
<td>2 (Uninhabitable)</td>
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<td>Electrics</td>
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<td>1 (&lt; 0.01 ft.)</td>
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<td>Visual Capability</td>
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<td>1 (VGA)</td>
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<td>Data Processing</td>
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<td>1 (&lt; 0.01 MBps)</td>
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<td>Interface Proof</td>
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<td>1 (&lt; 0.7 μCoh arc)</td>
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<td>Tech Level</td>
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<td></td>
<td>96.42</td>
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### Calculation of Technology Value

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<th>Perspectives</th>
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<th>Robotic Systems</th>
<th>Snake Robot</th>
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</table>

### Conclusions

- Functionality has been identified as the most important perspective.
- Transmission Line Robot was rated as the most valuable technology in this case.
- This presentation demonstrated how we can integrate the following concepts:
  - Hierarchical Decision Modeling
  - Technology Value
  - Bibliometric Analysis
  - Social Network Analysis
References


