

Table of Contents

1. Introduction	1
1.1. Objectives	1
1.2. Scope of Research	2
1.3. Problems of Construction	4
1.4. Potential of Robotics in Construction	8
1.5. Problems of Robotization in Construction	10
1.6. Relevant Prototypes	13
1.6.1. Introduction	13
1.6.2. Shotcrete Robot	14
1.6.3. Slab Finishing Robot	16
1.6.4. Fireproofing Spray Robot	17
1.6.5. Wall Climbing Robot	21
1.6.6. Examples of Preliminary Design of Robotic Sandblasting	23
1.6.7. Conclusion	25
1.7. Summary	25
2. Analysis Framework and Methodology	26
2.1. Introduction	26
2.2. Classical Methods	26
2.3. Implementation Environment	28
2.4. Multi-Dimensional Analysis and Evaluation	29
2.4.1. Extent of Robotics Impact on Construction Activities	30
2.4.2. Extent of Robotics Impact on Process Levels	34
2.4.3. Extent of Robotics Impact on Proximate vs. Off-Site Work	35
2.4.4. Time Dimension	36
2.5. Prospects for a Modular Design of Construction Robots	37
2.6. Presenting the Case Study Applications	40
2.7. The Estimation of Costs and Benefits	43
2.7.1. Costs	43
2.7.2. Benefits	47
2.8. Simplified Cost-Benefit Analysis	50
2.9. Conclusion	51
3. Robotic Sandblasting Process	52
3.1. Introduction	52
3.2. Traditional Work Methods	53
3.3. Justification for Introducing Robots	54
3.3.1. Reduction in Health Hazards	55

3.3.2. Expected Increase in Work Productivity

3.3.3. Labor Cost Savings

3.4. Robot Design Specifications

3.4.1. Description of Robot Work Task

3.4.2. Robot Components and their Availability

3.4.3. Robot System Setup

3.5. Cost Estimation

3.5.1. Cost of System Components

3.5.1.1. Automatically Guided Vehicle

3.5.1.2. Robot Manipulator

3.5.1.3. Material, Power and Utility Supply

3.5.2. Robot Operating Cost

3.5.3. Cost of System Engineering

3.6. Benefit Estimation

3.7. Net Present Value Estimation

4. Robotic Concrete Formwork Cleaning

4.1. Introduction

4.2. Traditional Work Methods

4.3. Justification of Choosing a Robot

4.4. Proposed Robot Design Specifications

4.4.1. Analysis of the Present Cleaning Process from a Robotic Performance Perspective

4.4.2. Robot Simplified Work System

4.4.3. Robot Components

4.4.4. Robot Control System

4.5. Cost Estimation

4.5.1. Cost Analysis of the Manual Work Process

4.5.1.1. Estimation Procedure

4.5.2. Robot Cost Estimation

4.5.2.1. Cost of Adopting Existing Industrial Robotic Components

4.5.2.2. Cost of Initial Investment in the Form Cleaning Robot

4.5.2.3. Annual Robot Operating Cost

4.6. Benefit Estimation

4.7. Net Present Value Estimation

4.7.1. Sensitivity Analysis

4.7.2. 'Break-Even' Initial Robot Investment Cost

4.8. Conclusions

5. Summary and Conclusions

5.1. Accomplishments of the Multi-Dimensional Analysis Method

5.2. Constraints on Preliminary Robot System Design

5.3. Results from Robot System Cost Estimation

5.4. Results from Robot Benefit Estimation

5.5. Relevance of the Obtained Results

5.6. Future Extensions of this Research

Appendix A. Miscellaneous Relevant Robots	118
A.1. Examples of Robots for Tunneling	118
A.1.1. Five-Boom Drilling Robot	118
A.1.2. Shield Driving	120
A.2. Examples of Robots for Excavation	121
A.2.1. "REX"	121
A.2.2. Ultradeep Diaphragm Wall Excavator	123
A.2.3. Automatic Grading Control	124
A.3. Examples of Robots for Assembly	124
A.4. Examples of Robots for Inspection	125
A.4.1. Robotized Coreboring [19]	125
A.4.2. Tile Inspection Robot	126
A.5. Robotized Cutting of Rock and Concrete Structures	127
A.6. Conclusion	128
Appendix B. Characteristics of the Traditional Sandblasting Process	130
B.1. Air Compressors and Aggregates for Sandblasting	130
B.2. Air Supply	135
B.3. Abrasive Media	139
B.4. Moisture Problem	141
B.5. Nozzle Angle	145
B.6. Work Methods and Operator Habits	145
B.7. Pressure Maintenance	150
B.8. Efficiency of Sandblasting	153
B.9. Dust and Abrasive Removal	154
B.10. Using the Hose	157
B.11. Vacu-Blast System	159
B.11.1. Vacu-Blast System - Open Circuit	166
B.11.2. Operating Techniques	167
B.12. Special Equipment	169
B.12.1. Closed Circuit - Application to Pre-Welding Purposes	169
B.12.2. The Limpet Blaster	170
B.12.3. Ancillary Equipment	170
B.12.3.1. The Crawler Unit	170
B.12.3.2. Portable Spotting Blast Gun	171
B.13. Ship Hull Cleaning Plant	172
Appendix C. References Describing the Danger of Silicosis	177
C.1. U.S. Silicosis Statistics	177
C.2. Relevant Clinical Studies	178
Appendix D. A Review of Autonomous Mobile Platforms	186
Appendix E. Some Available Motion Control Devices	192
Appendix F. Motors and Actuators	212
Appendix G. Testing Techniques for Roughness and Cleanliness	220
G.1. Reflectance Meter	221
G.2. Roughness Gauge	223

G.3. Surface Finish Meter

G.4. *Talysurf* Measuring Instrument

G.5. The Profilometer

G.6. The Brush Surface Analyzer

G.7. Laser Beam Method of Measuring Surface Roughness