Demonstration Projects

Call for Ideas to Boost the Competitiveness of the Estonian Manufacturing Industry

Final Report

Please fill in the Final Report in English
The content of the Final Report is published also in AIRE GitHub
To be filled by the Lead of the Development Team

Demonstration Project Title

AI-based Quality Assurance and Control System for Enhancing a Coordinate Measuring Machine with Machine Vision.

Company

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Development Team

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Objectives of the Demonstration Project

The primary objective of this demonstration project was to test and validate an AI-based quality control system that enables optimal utilization of industrial coordinate measuring machines (CMM), including empowering manufacturing companies with a fully autonomous (robotized) specimen loading system. The project aimed to validate a system capable of measuring 100% of products with minimal human intervention and system reconfiguration requirements.

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Activities and results of the Demonstration Project

Challenge addressed (i.e. whether and how the initial challenge was changed during the project, for which investment the demonstration project was provided)

The demonstration project addressed a key challenge in high-mix, low-volume manufacturing environments, where small and medium-sized enterprises (SMEs) produce diverse products in small batches. The primary challenge was the inefficient quality control process that relied either on manual inspection or coordinate measuring machines (CMM). When using CMM, each unique part required custom fixtures and machine reconfiguration, making the quality control process disproportionately time-consuming and costly for small batch productions.

The market lacked an automated solution where a CMM could identify parts, detect their position, and initiate appropriate measurement programs without manual setup. This technological gap drove the development of our AI-based solution, with the core challenge remaining consistent throughout the project's duration.

Activities implemented and results achieved

During the project, we evaluated two distinct technical approaches for AI-based object detection and pose estimation:

1. Image Processing Approach
    - Implemented the Find Object ROS package for initial position estimation
    - Benefits included rapid setup and deployment
    - Limitations identified: high sensitivity to camera positioning and lighting conditions
2. Deep Learning Approach
    - Deployed Deep Object Pose Estimation (DOPE) with pre-trained models
    - Demonstrated superior reliability in object detection and pose estimation
    - Key challenge: significant time investment required for model training

Both approaches were successfully implemented and tested, with the DOPE-based solution ultimately showing more promise for robust industrial deployment despite its longer initial setup time. The project demonstrated the technical feasibility of automating the CMM measurement process through AI-based part recognition and positioning.

Data sources (which data was used for technological solution)

The project relied on two types of data sources:

1. Real-world Data
    - Custom dataset collected specifically during the project implementation
    - Captured images of actual parts under various measurement conditions
2. Synthetic Training Data
    - Generated using DOPE repository scripts
    - Approximately 20,000 synthetic images per training set
    - Generation process typically required 12+ hours of computation time
    - Synthetic data proved sufficient for initial model training and validation

Description and justification of used AI technology

The project implemented two AI-based approaches for part detection and positioning:

1. Computer Vision-based Solution (Find Object ROS)
    - Traditional image processing algorithms for object detection
    - Suitable for controlled environments with consistent lighting
    - Requires minimal training but needs careful calibration
2. Deep Learning Solution (DOPE)
    - Advanced neural network architecture for precise pose estimation
    - More robust against environmental variations
    - Requires substantial training data but offers better generalization

The AI technology was specifically chosen to eliminate the need for mechanical fixtures and extensive operator training. By integrating AI-based part detection and positioning with the coordinate measuring machine, the system automatically provides necessary instructions and initial conditions for measurements and report generation. This technological choice was justified by its ability to:

- Automate part recognition and positioning
- Reduce setup time between different product types
- Minimize human intervention in the measurement process
- Enable flexible quality control for diverse product lines

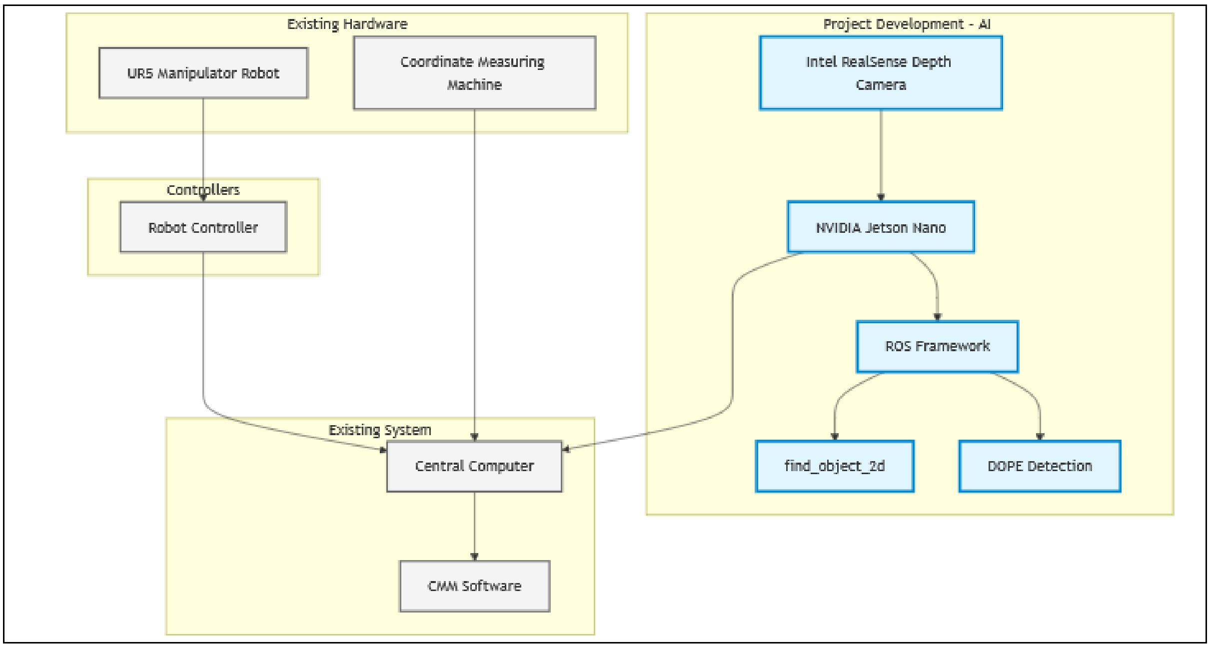
Results of testing and validating of the technological solution

The two implemented approaches were extensively tested, revealing distinct advantages and limitations:

1. Find Object Approach
    - Quick implementation with minimal setup time for new objects
    - Performance varied significantly between different object types:
        - Simple objects (e.g., Gear): Reliable detection with single reference image
        - Complex objects (e.g., Fork): Required multiple reference images
    - Key limitations identified:
        - High sensitivity to light reflections on metallic surfaces
        - Poor performance with objects lacking distinct surface features
        - Detection reliability heavily dependent on consistent lighting conditions
2. DOPE (Deep Object Pose Estimation) Approach
    - Demonstrated more robust detection capabilities
    - Implementation challenges:
        - Extensive preparation time required
        - Resource-intensive model training process
        - Data generation requirements disproportionate to final tool quality
    - Cost-benefit analysis indicated that the current implementation may be impractical for rapid deployment in high-mix manufacturing environments

The testing phase concluded that while both approaches are technically viable, further optimization would be needed for industrial-scale implementation, particularly in environments requiring frequent introduction of new parts.

Technical architecture of the technological solution (presented graphically, where can also be seen how the technical solution integrates with the existing system)



Potential areas of use of technical solution

While initially developed for CMM-based quality control, the AI-based object detection and pose estimation system demonstrates potential for broader industrial applications:

1. Manufacturing Operations
    - Automated pick-and-place operations in flexible production lines
    - Quality control integration in various manufacturing processes
    - Assembly line automation with mixed product variants
    - Part sorting and classification in production environments
2. Warehouse and Logistics
    - Automated inventory management of unstructured stock
    - Intelligent bin picking systems for order fulfillment
    - Mixed-item package handling and sorting
    - Automated loading/unloading operations
3. Robotics Applications
    - General-purpose robotic grasping systems
    - Collaborative robot implementations
    - Flexible automation cells
    - Multi-purpose robotic workstations
4. Quality Control Integration
    - Integration with other measurement and inspection systems
    - Automated defect detection systems
    - In-line quality verification processes
    - Material handling in testing facilities

The solution's ability to handle varied objects makes it particularly valuable in environments requiring flexible automation and precise object manipulation.

Description of User Interface (i.e. How does the client 'see' the technical result, whether a separate user interface was developed, command line script was developed, was it validated as an experiment, can the results be seen in ERP or are they integrated into work process)

During this demonstration project, the focus remained on validating the core technological solution rather than developing a dedicated user interface. The interaction with the system was facilitated through:

1. Existing Tool Interfaces
   - Native GUI of the coordinate measuring machine
   - ROS-based visualization tools for pose estimation validation
   - Command-line interface for system configuration and control
2. Development Environment
   - Direct command-line access for testing and debugging
   - Visualization tools for real-time pose estimation results
   - Standard output for system status and measurements

While a production-ready interface was not part of this project's scope, the successful validation of core functionalities provides a solid foundation for future user interface development that could include:

- Integration with existing ERP systems
- Custom GUI for operator interaction
- Automated reporting dashboard
- Real-time monitoring interface

Follow-up activities and plans for future (e.g. developments, potential for scalability, creation of spin-offs aso)

Based on the demonstration project's results, several promising directions for future development have been identified:

1. Technical Enhancements
   - Optimization of training data requirements for faster deployment
   - Development of hybrid detection approach combining benefits of both tested methods
   - Integration of advanced lighting control systems to improve detection reliability
   - Implementation of automated calibration procedures
2. System Integration
   - Development of dedicated user interface for production environments
   - Integration with enterprise resource planning (ERP) systems
   - Creation of standardized APIs for broader system compatibility
   - Implementation of cloud-based training and model management
3. Market Expansion
   - Adaptation of the solution for different industry sectors
   - Development of industry-specific packages for common use cases
   - Creation of scalable deployment methodology
   - Exploration of potential software-as-a-service (SaaS) model
4. Research and Development
   - Investigation of alternative AI architectures for improved performance

- Development of transfer learning approaches to reduce training requirements
- Research into automated data generation techniques
- Exploration of edge computing implementation

The demonstrated technology shows significant potential for commercialization, particularly in the SME manufacturing sector where flexible automation solutions are increasingly in demand.

Lessons learned

i.e. assessment whether the technological solution actually solved the initial challenge

The demonstration project successfully validated the technical feasibility of AI-based quality control automation, while also revealing important insights for future implementations:

Key Successes:

- Confirmed the viability of AI-powered part detection and positioning for CMM applications
- Successfully demonstrated automated measurement program selection
- Proved the concept of fixture-free quality control for diverse parts

Critical Challenges:

- Object library expansion requires significant effort and technical expertise
- Current workflow for introducing new parts is not optimized for production environments
- Time investment for training varies significantly between different part types

Areas for Improvement:

- Need for streamlined tools and processes for adding new parts to the system
- Requirement for more user-friendly interfaces for quality control personnel
- Opportunity to optimize the balance between setup time and detection reliability

While the core technology demonstrates strong potential for solving the initial challenge of flexible quality control automation, the project highlighted the importance of developing supporting tools and workflows for practical industrial deployment.

Projekti lühikirjeldus (AIRE kodulehele, eesti keeles)

Projekti pealkiri, millist väljakutset lahendati, projekti eesmärk, millist tehisintellekti tehnoloogiat valideeriti, projekti tegevused ja tulemused, kuni 10 lauset

Projekt lahendas väikeste ja keskmise suurusega tootmisettevõtete kriitilist väljakutset kõrge tootemiksi ja madala tootmismahu keskkonnas, kus traditsioonilised kvaliteedikontrolli meetodid nõuavad aeganõudvat mehaaniliste rakiste seadistamist iga unikaalse detaili jaoks. Eesmärk oli valideerida tehisintellektil põhinev süsteem, mis võimaldab koordinaatmõõtemasinal (CMM) automaatselt tuvastada detaile ja nende asendit, elimineerides vajaduse käsitsi rakiste seadistamiseks ning vähendades kvaliteedikontrolli kitsaskohti. Valideeriti kaks tehisintellekti lähenemist: masinnägemisel põhinev lahendus kasutades Find Object ROS kimpu ning süvaõppel põhinev lahendus kasutades Deep Object Pose Estimation (DOPE) tehnoloogiat. Projekt demonstreeris edukalt, et mõlemad lähenemised suudavad automatiseerida detailide tuvastamist ja mõõtmisprogrammi valikut, kusjuures masinnägemisel põhinev lahendus võimaldas kiiremat seadistust, kuid oli tundlik keskkonnatingimuste suhtes, samas kui süvaõppe lähenemine pakkus töökindlamat tuvastust, kuid vajas pikemat treenimisaega. Loodud süsteem näitab märkimisväärset potentsiaali kvaliteedikontrolli protsesside võimestamiseks paindlikes tootmiskeskkondades, kuigi süsteemi edasine optimeerimine on vajalik uute detailide lisamise lihtsustamiseks.

Project description (to be published on AIRE webpage, in English)

Project title, what challenge was addressed, aim of the project, what AI technology was validated, project activities and results achieved, max 10 sentences

This project addressed a critical challenge faced by small and medium-sized manufacturers operating in high-mix, low-volume environments, where traditional quality control methods require time-consuming setup of custom fixtures for each unique part. The aim was to validate an AI-powered system that enables coordinate measuring machines (CMM) to automatically identify parts and their positions, eliminating the need for manual fixture setup and reducing quality control bottlenecks. Two AI approaches were validated: a computer vision-based solution using the Find Object ROS package, and a deep learning solution utilizing Deep Object Pose Estimation (DOPE). The project successfully demonstrated that both approaches could automate part recognition and measurement program selection, with the vision-based solution offering quick setup but environmental sensitivity, while the deep learning approach provided more robust detection but required longer training times. The resulting system shows significant potential for revolutionizing quality control processes in flexible manufacturing environments, though further optimization is needed for streamlining the introduction of new parts to the system.