TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
DEPARTMENT OF ELECTRICAL POWER ENGINEERING AND MECHATRONICS

MACHINE-VISION-BASED MANIPULATOR POSITIONING SYSTEM FOR SORTING

MASINNÄGEMISEL PÕHINEV MANIPULAATORI POSITSIONEERIMISSÜSTEEM SORTEERIMISEKS

MASTER THESIS

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Tallinn 2022

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Mechatronics
Thesis Task

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Thesis topic:

(In English) Machine-vision-based manipulator positioning system for sorting.

(In Estonian) *Masinnägemisel põhinev manipulaatori positsioneerimissüsteem sorteerimiseks.*

Thesis main objectives:

1. Overview of recognizable objects and required recognition patterns
2. Camera and lighting system
3. Manipulator integration and safety IO functions according to standards
4. Experimental set-up

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PREFACE

The topic of thesis was proposed by senior lecturers Madis Lehtla and Valery Vodovozov from Tallinn University of Technology. The author has genuinely accepted the challenge of perusing it as a master thesis for a double degree master's program in collaboration between ITMO University, Saint Petersburg, Russia, and Tallinn University of Technology, Tallinn, Estonia. The research conducted in this thesis has been done in Tallinn, Estonia, by using the hardware and software available at the computer laboratory in the Department of Electrical Power Engineering and Mechatronics of Tallinn University of Technology.

One of the promising application of robots is the material classification and sorting process. Sorting by size is simple to implement via mechanical measures but sorting by shape and other properties requires more information and skills. Modern machine-vision systems allow training of different object shapes to the smart camera-based systems. There are still many uncertainties that have to cover to smart control system and its software. This thesis focuses on the Industrial robot programming and positioning.

Primarily, I would like to praise and thank GOD, the Almighty, who has granted countless blessings, knowledge, and opportunity to the writer, so that I have been finally able to conduct the thesis. The author would like to express his deepest gratitude to senior Lecturers Madis Lehtla and Valery Vodovozov from Tallinn University of Technology and Professor Sergey Kolyubin from ITMO University, for their unlimited support and guidance throughout this project, and to the staff of the Mechatronics Department from TalTech University and Faculty of Control System and Robotics from ITMO University.

Special gratitude goes to my family for their help to remain outside somewhere far off from home, and to my companions for all the ethical help given to me to satisfy my fantasies in the most ideal way conceivable.

LIST OF ABBREVIATIONS AND SYMBOLS

CCD	Charge-Coupled Device
Cobots	Collaborative Robots
CPU	Central Processing Unit
DC	Direct Current
DH	Denavit-Hartenberg
HRI	Human-Robot Interaction
IRB	Industrial Robots
LED	Light Emitted Diode
OEPs	Original Equipment Manufacturers
PatMax®	Pattern-Matching
RGB	Red, Green Blue
SIFT	Scale Invariant Feature Transform
TCP	Tool Centre Point
TPU	Teach Pendant Unit
VC	Virtual Controller
VGR	Vision Guided Robotics
PC	Personal Computer
FOV	Field of View
PMAG	Primary Magnification

1 INTRODUCTION

The autonomous extraction of significant information from digital pictures is known as machine vision. Machine vision systems are a collection of interconnected components meant to autonomously direct manufacturing and production tasks such as sorting, positioning, testing, and quality control procedures using information retrieved from digital pictures. Machine vision is mostly used in industrial activities such as inspection, measuring, counting, localization, and decoding. Lighting systems, optical systems (including lenses), sensors, vision processing systems, and communications systems are all examples of machine vision systems. Robot manipulators have been quickly used in numerous applications, such as fabrication, finishing, transfer, and assembly of parts in the industrial industry. Robots are employed for selecting, sorting, packing, and palletizing items in material handling sectors where completed products are readied for delivery.

Robot vision refers to a robot's ability to visually detect its surroundings and utilize this knowledge to carry out various activities. Robot vision extends computer vision algorithms to perform tasks assigned to robots and robotic systems. The purpose of robot vision is to use visual sense to watch, perceive, and react to the environment. Robot vision is a mix of machine vision and robot manipulation in which valuable information is extracted using a machine vision system and the coordinates of the item are sent to the robot controller for manipulation processes such as picking, sorting, packing, and palletizing products.

The robot integrated vision system such as "ABB Integrated vision" enables a smart and effective detection of the robot workpieces for performing its tasks. Collaborative robots are an evolution of industrial robotics manipulators to enhance the safety of human operators to work side-by-side carrying out complex tasks which were not possible before. The dual-armed collaborative robot (cobots) ABB IRB14000 also known as "YuMi" can be used as development and experimentation platform for Vision Guided Robotics (VGR) applications. The cobots YuMi was launched by ABB in 2015 to aid workers in lightweight assembly tasks.

Lightweight arms with soft padding to eliminate pinch spots and excellent motion control with collision detection are among the safety and ergonomic features of cobots. Cobots are meant to be deployed beside people in workstations to boost flexibility by allowing humans and robots to collaborate on jobs that would previously have needed safety barriers or cages.

A tool is a vital component of any robot's system. This ABB YuMi robot features a servo gripper, a servo gripper with a camera, a servo gripper with a vacuum, a servo gripper with a camera and a vacuum gripper, and a servo gripper with two vacuum grippers.

The experimentation of the thesis is carried out in ABB RobotStudio software with a robot controller and smart camera integrated vision system.

The aim of this research is to develop a machine-vision based manipulator positioning and sorting system for recognizable objects using collaborative robot.
This paper aims to: -

I. Reviewing on the machine vision methods and technologies available.

II. Develop a sorting system based on Yumi robot Image Processing System.

III. Overview of recognizable objects and required recognition patterns.

IV. Camera set up and developing lighting system.

V. Manipulator integration and safety IO functions according to standards.

VI. Experimental set-up, integrating and implement the system.

VII. Test and verify that the goal is met.

Chapters of the thesis:

1. Introduction: This chapter discusses the introduction of a machine vision system and its application in robot manipulation systems.

2. Literature review: This chapter explicates the research papers that have been done before in machine vision-based sorting and positioning using the industrial manipulator. Robot modelling and an overview of machine vision system will be discussed.

3. Modelling of a Robot system: In this chapter, there will be two main things that will be addressed, firstly, the modelling of manipulator using simulation package. Secondly, the main objective of the thesis which is to develop a vision-guided sorting system based on the ABB robot integrated Image Processing System. In addition to this object recognition and required recognition patterns in the integrated vision system and the camera and lighting system of the process will be addressed. Integration and

experimentation this topic deals with the integration of the developed system in Robot Studio software and using its integrated vision system. This includes object shape training for recognition using Cognex InSight or ABB RobotStudio Integrated Vision system.

4. Conclusion and discussion: This chapter discusses the output result and gives the general conclusion of the experiment and recommendations for further future works

2 LITERATURE REVIEW

2.1 Machine-Vision Guided Robot Applications

Several approaches to object recognition exist for robot-based sorting systems. Machine vision-based object identification for sorting can be implemented using a line scan camera [1]. Sorting of objects using machine vision was performed using an algorithm of pattern matching template that was stored in the computer memory. A machine vision solution of ABB Yumi Robot uses a single HD external camera has been implemented the based on Colour Pattern Matching algorithm for non-flat objects [2]. An adaptive industrial robot using machine vision that enabled self-learning in industrial robot has been developed based on the colour and shape of the test object [3]. This paper explores the developments in machine vision for flexible feeding systems of assembly parts for human-robot assembly cells using both 2D and 3D cameras [4].

Fr example, the robot sorting system based on the parallel manipulator robot and Cognex In-Sight 7000 type intelligent camera is developed and described in literature sources [5]. Automatic sorting of 3D vision target positioning using manipulator and a point cloud information collected from Microsoft Kinect camera can be found in literature. The point-cloud data from the camera images is pre-processed, and the template is preliminarily matched with the target object by using the signature of a histogram of orientation [6].

An industrial robot control teaching system based on machine vision is also described in some literature sources [7]. Such teaching system is a combination of machine vision, robot manipulator, and human-machine interface that has been developed for control by using human gesture images from the camera. Some sources also describe a vision-based control strategy to perform high-speed pick-and-place tasks on automation product line using control software with a delta robot and CCD camera [8]. A low-cost open-source software libraries can also be used in vision-guided closed-loop robotic controls. Such system is developed to identify construction materials in the workspace and calculate their position in space and determine their place in the facade panel assembly using RGB camera [9].

A vision guided robotic arm system for picking and placing of objects can also be implemented using Scale Invariant Feature Transform (SIFT) key point extraction for object recognition and localization purpose [10]. In this work a leaf sampling system that includes a monocular camera is used for control of 6-DOF robot arm to detect, track, and pick leaves [11]. A vision-guided robot is developed for pick and place of different gears according to the decision of the image processing system [12]. The model-based 3D pose estimation is also used in some pick-and-place applications. Such vision-guided robot system for picking of singulated 3D objects is describe in literature [13]. Besides, of pick-and-place applications the 3D vision guidance can also be useful in other applications such as automatic robot-based charging stations. For example such system for plugging and unplugging the charger is developed using an Universal Robots UR10 manipulator [14].

The vision systems are also required in augmented environments for a real-time active collision avoidance , where virtual 3D models of robots and real camera images of operators are used for monitoring and collision detection[15]. Vision aided pick and place Cartesian robot as a combination of machine vision system and robotic system in described in literature [16]. A Cartesian robot based vision guided system is developed for flexible gluing process in the footwear industry [17]. Some papers study a 3D robotic vision for bin picking and obstacle avoidance to able to analyse the imagery of cluttered objects, classify those objects and estimate their pose for grasping [18].

Robot arm equipped with a 3D camera is presented in some literature sources [19] for vision-guided pick-and-place tasks .A vision guided parallel robot FANUC M-1iA can be used for object identification and filtering the data about its position and orientation for automated assembly process[20]. A vision-based grab control system is developed for precise positioning, recognition and capture of targets in some applications [21].

2.2 Robot Modelling for Robot Selection and Configuration

The most essential part of mechanical model of articulated arm robots is kinematic models. Robot kinematics applies geometry to the study of the movement of multi-degree of freedom kinematic chains that form the structure of robotic systems. The emphasis on geometry means that the links of the robot are modelled as rigid bodies and its joints are assumed to provide pure rotation or translation.

The vision-guided robot needs the geometric coordinate conversions for its coordinate conversion from different camera coordinate frames (that are also called as scenes) to the robot positioning Cartesian systems. This can be incredibly challenging and complicated task when the camera view angles differ in different scenes. There are also many optical effects that affect the detected coordinates such as shadows.

2.2.1 The essential parameters for the selection of robots

Selecting robots or cobots for some production needs to consider the following parameters.

1. **Payload:** is the weight that the robot can convey. All robots have a given payload, which is figured out without the heaviness of the end effector or robot apparatus. This implies that the real payload that can be conveyed by the robot is the nominal payload minus the weight of the robot's end effector.
2. **Repeatability:** is characterized as the capacity of a robot to get back to a similar customized position over and over. It also describes the precision of the robots. Modern robot repeatability changes from one model to another, yet most fall inside a scope of +/ - 0.02 mm to +/ - 0.4 mm.
3. **Reachability:** is the estimation of the distance that can be reached by the robot's wrist. This estimation is taken from the robot's base.
4. **Robot Weight:** is the heaviness of the robot proves whether you can move the robot effectively, or on the other hand assuming that you will require a forklift to do as such.
5. **Cost:** is the price of the robot has its own factor in the selection process, It's affordability and production cost.

In addition, to these parameters, the ease of programming, estimation of operation hours, and safety are considered. Here are different collaborative robot products that are currently available on the market.

2.2.2 Advantages and disadvantages of collaborative robots

Collaborative robots are robots that can share the same workspace with humans without any protective devices. A cobots can act as an assistant to a human operator and is typically used in applications working alongside human operators. Cobots are designed to work around and collaborate with humans. Cobots are safe and easy to use. Different sensors and cameras that are integrated on the cobots ensure that the robot never injuries its human colleagues. They do not require advanced knowledge to operate, and this type of robot can boost efficiency, manufacturing speed, and quality by working along with humans. One of the main purposes of cobots is to make the workplace safer, cobots are suitable for automating repetitive work such as packaging and palletizing, assembly, material processing, and screw and nut driving. Cobots are partnerships and collaboration with humans, easy to use, train and program, increase versatility and functionality, and higher softy.

Table 2.1 Difference between Robots and Cobots

	Robot	Cobots
1	Work as an alternative to humans and eliminates their job	Works along with humans and eliminates difficulties to them
2	Programming and re-programming are complex tasks as it has to be changed in the backend program.	Programming and re-programming are extremely easy as they are capable of learning and can be reprogrammed just by moving in a particular path.
3	It requires Safety blockades or a Separate workspace.	Does not require any safety blockades and can share the workspace with humans.
4	Requires huge investment and the rate of investment return is slower	Less investment in comparison to robots and the rate of investment return is faster.
5	Easily manage heavier and larger materials. They are not flexible.	Not much efficient to oversee heavy materials like robots. They are flexible. some cobots are mobile and flexible
6	Repeats the same tasks all the time.	Can be changed for multiple tasks.
7	Robots are better for high volume jobs	cobots are better for complex tasks

Human-Robot Interaction, or HRI, manages how to show and assess automated frameworks that are utilized by or with people and how the communication among people and robots occurs. Communication is influenced by the proximity between robots and humans. Considering the proximity, three categories of interaction can be defined:

I. Remote HRI: humans and robots are physically in remote places. This type of operation, called teleoperation, could involve dangerous scenarios that are not accessible to humans.

II. Co-located HRI: human and robot are in a shared space, and they interact without physical contact.

III. Physical HRI: humans and robots are in a shared space, and they interact through physical contact.

The types of human robot interaction most used is the co-located HRI. In fact, it can be used in a wide range of operations. For example, robots can perceive the presence of humans, map the movement of a human, recognize speech through sensors. In this case, based on whether the workspace is shared or not and, on the timing, i.e. the presence at the same time of the human which works and a robot which moves As Table 2.2 shows, four types of operation might be distinguished:

1. No interaction: the operator and the robot do not work in the same workspace at the same time.
2. Coexistence: the operator and the robot work simultaneously, but they do not share the workspace.
3. Cooperation: the operator and the robot work sharing the same workspace, but not at the same time.
4. Collaboration: the operator and the robot work sharing the same workspace at the same time.

Table 2.2 Different types of HRI based time and space parameters

Application	**Different workspace**	**Shared workspace**
Sequential Processing	No interaction	Cooperation
Simultaneous Processing	Coexistence	Collaboration

The HRI is utilized in many fields of use: in a modern setting, for example, an assembling plant, joint effort among people and robots can utilize the capacities of both to advance the creation chain, for instance taking advantage of the accuracy and the capacity to move weighty objects of robots. HRI can give benefits in medical services, for example in the recovery area or under the watchful eye of patients and in independent direction and space investigation.

2.2.3 Comparison of cobots products

There are several Cobot manufacturers on the market today. Even though ABB YuMi is used for illustration of the suggested mechanism, here are other examples from the market to compare and choose the suitable product for the machine vision process. There are several cobot manufacturing businesses, including ABB, Fanuc, Universal Robots, Kuka, Yaskawa, and others. In 2014, Kuka created the world's first cobot, LBR Iiwa [22]. Universal Robots is one of the world's major collaborative robot manufacturers [23]. Similarly, Fanuc has a separate collaborative robot and is the first major Cobot manufacturing firm [24]. ABB, like ABB YuMi, GOFA, and SWIFTI, is another cobots robot manufacturer [25].

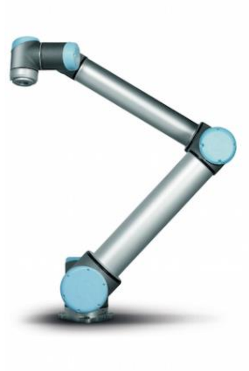
a)

b)

c)

d)

e)



f)

Figure 2.1 Different Cobots products. a) KUKA robot LBR Iiwa,b) ABB GOFA, c) ABB SWIFTI, d) single arm Yumi, e) Fanuc CR 4iA, CR 7iA, CR 7iA/L, and CRX 10iA, f) Universal robot UR3,UR5, and UR10. [26]

Table 2.3 Essential parameters of some cobots products [22] [23] [24] [25]

Manufacturer /Name	**DOF**	**Payload (Kg)**	**Weight (Kg)**	**Repeatability (mm)**	**Reach (mm)**	**Price (USD)**	**Integrated Camera**
KUKA / LBR IIWA 7	7	7	22	+/-0,1	800	70000	Gripper/ External
KUKA / LBR IIWA 14	7	14	30	+/-0,15	820	70000	Gripper/ External
ABB / Single arm YuMi	7	0,5	9,6	+/-0,02	560	20000	Smart Gripper
ABB / Dual arm YuMi	14	0,5	38	+/-0,02	559	44000	Smart Gripper
ABB / GOFA	6	5	27	+/-0,05	950	25000	Gripper/ External
ABB / SWIFTI	6	4	21	+/-0,01	580	35000	Gripper/ External
Fanuc / CR 4iA	6	4	48	+/-0,02	550	45700	Gripper/ External
Fanuc / CR 7iA	6	7	53	+/-0,02	717	48000	Gripper/ External
Fanuc / CR 7iA/L	6	7	55	+/-0,03	911	48000	Gripper/ External
Fanuc / CRX 10iA	6	10	39	+/-0,05	1249	60000	Gripper/ External
UR / UR3	6	3	11	+/-0,1	500	28000	Gripper/ External
UR / UR5	6	5	18	+/-0,1	850	35000	Gripper/ External
UR / UR10	6	10	29	+/-0,1	1300	45000	Gripper/ External

Even though the experimentation of this proposed system is done using ABB YuMi but according to the specification of the different cobots referred to in Table 2.3 By considering the payload, repeatability, reachability, price, safety, and other parameters of cobots universal robot, ABB and Fanuc are the recommended cobots for the industrial-based vision guidance system.

2.2.4 The ABB YuMi collaborative robot as a development platform

The robot used in this thesis is the collaborative. A dual-arm industrial robot IRB 14000 YuMi was introduced by ABB in 2015 [27]. This is the first-generation dual arms articulated arm robot with 7-rotational axis revolute joint on each arm. Manufacturing industries use such industrial cobots for robot-based flexible automation. This cobots has integrated controller, each arm has seven axes, which gives an extra degree of freedom compared to traditional 6-axis articulated arm robots and thus give the robot kinematic redundancy for operation. The robot has an open structure that is especially adapted for flexible use and can communicate extensively with external systems. Cobots arms are therefore lightweight and padded, and the controller can stop the motors upon detected collision. This allows it to maintain a larger workspace and reach more diverse poses than a traditional 6-axis industrial robot.

ABB YuMi is swift and precise. When measured at the Tool Center Point (TCP) with no permanent loads, it may attain Cartesian velocities of 1.5 m/s and Cartesian acceleration of $11\frac{m}{s^2}$ while preserving positional repeatability of 0.02 mm when measured at the Tool centre Point (TCP) with no everlasting loads. It has a low payload of 0.5 kg and is suited for consumer electronics assembly. The arms have overlapping workspaces, which means that there is enough space in the workspace for both arms to reach the proper stance, providing YuMi additional freedom in dual-arm manipulation tasks.

The ABB YuMi integrated controller is based on the IRC5 controller and includes all the capabilities required to move and control the robot. RobotWare, the robot control software, manages every aspect of the robot system, including motion control, application program development and execution, and communication.

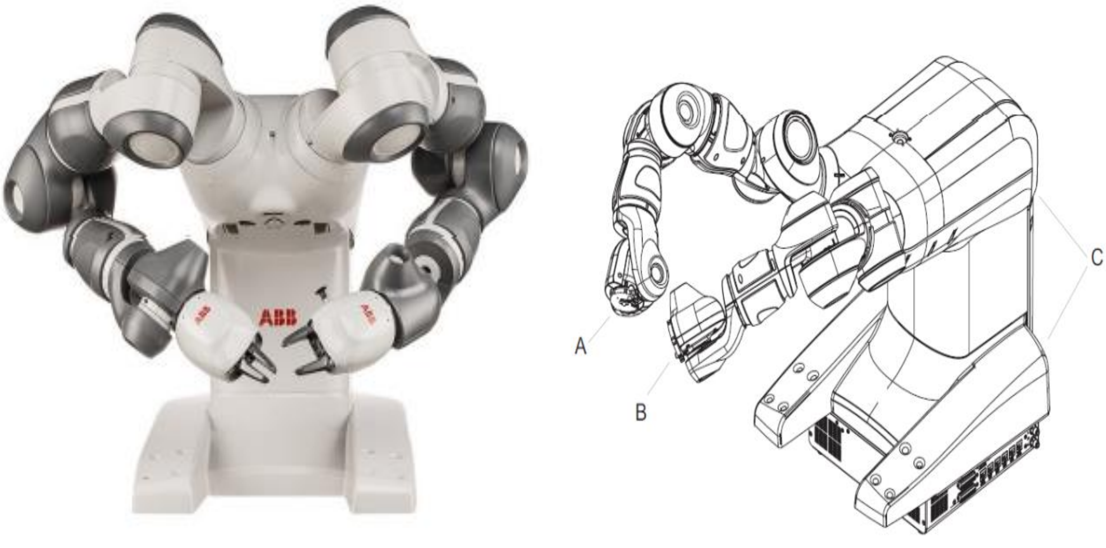


Figure 2.2 Yumi IRB 14000 robot [27]

Axes and Coordinate Systems: The axes of the robot can be jogged manually using the joystick. Figure 2.3 shows the location and movement patterns for each axis. The base coordinate system has its zero point in the base of the robot which is shown in Figure 2.4.

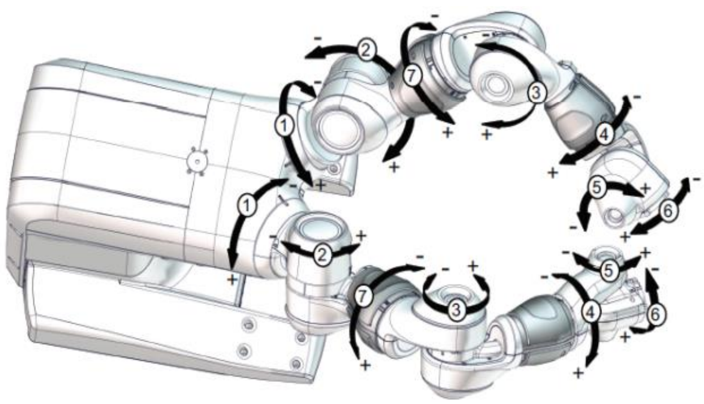


Figure 2.3 Robot joint axes [27]

When standing in front of the robot and jogging in the base coordinate system, drawing the joystick towards you moves the robot along the X-axis, while pulling the joystick to the sides moves the robot along the Y-axis. The robot may be moved along the Z-axis by twisting the joystick.

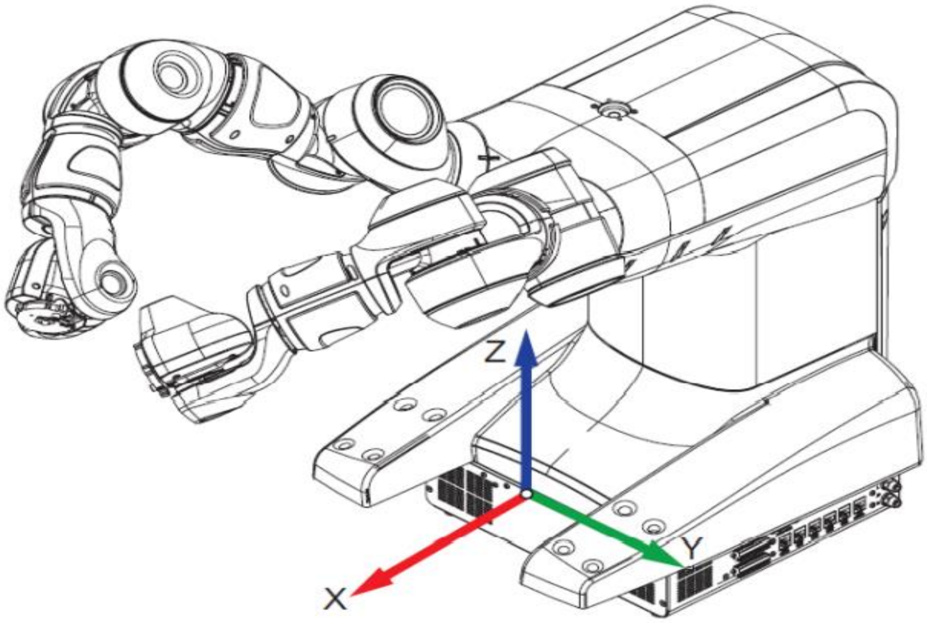


Figure 2.4 Robot Base Coordinate System

The Denavit-Hartenberg convention

Denavit-Hartenberg convention (DH convention) is a method for determining the four parameters of a robotic manipulator's links by attaching a frame to the links. The DH notation provides a consistent technique for obtaining a robot manipulator's kinematic equations[28, 29].

Table 2.4 DH parameters of ABB Yumi robot manipulator

Link no	Link Length(m)	Link angle (rad)	Link Twist (m)	Link angle (rad)	Offset
1	0,03	$-\frac{\pi}{2}$	0,166	θ_1	0
2	0,03	$-\frac{\pi}{2}$	0	θ_2	π
3	0,0405	$\frac{\pi}{2}$	0,2515	θ_3	0
4	0,0405	$\frac{\pi}{2}$	0	θ_4	π
5	0,265	$\frac{\pi}{2}$	0,265	θ_5	π
6	0,027	$\frac{\pi}{2}$	0	θ_6	π
7	0,027	0	0,12	θ_7	0

Table 2.5 The exact position of the ABB robot in degree

Axis	Right Manipulator	Left Manipulator
1	0	0
2	-130	-130
3	30	30
4	0	0
5	40	40
6	0	0
7	-135	135

Table 2.5 shows the exact position of the YuMi robot when the robot is calibrated. The robot can be calibrated if the following situation occurs first if the resolver values are changed, second if the revolution counter memory is lost and finally if the robot is rebuilt.

Table 2.6 ABB YuMi robot working range and types of motion of links

Axis	Type of motion	Degree of motion in Deg	Max Velocity in Deg/s
Axis1	Arm- Rotation Motion	-168.5 to +168.5	180
Axis2	Arm- bending Motion	-143.5 to +43.5	180
Axis7	Arm- rotating Motion	-168.5 to +168.5	180
Axis3	Arm- Bending Motion	-123.5 to +80.0	180
Axis4	Wrist- rotating Motion	-290.0 to +290.0	400
Axis5	Wrist-Bending Motion	-88.0 to +138.0	400
Axis6	Flange-bending wrist	-229.0 to +229.0	400

2.2.5 The kinematic redundancy of the robot

A kinematically redundant manipulator possesses more joints than those strictly required to execute its task. This provides the robot with an increased level of dexterity that may be used to avoid singularities, joint limits, and workspace obstacles, but also to minimize joint torque, energy or, in general, to optimize suitable performance indexes [30]. To determine the position and the orientation of the end-effector in the space six variables are required: three for the position and three for the orientation. In case of ABB YuMi 7 DOF dual arm robot that has 7 joints in each makes the solution of the inverse kinematic not unique. It means there are different configurations of the arm to reach the desired position and orientation. There are two main reasons making the redundancy is important:

- To get the robot away from the kinematic singularities.
- To change the robot's configuration without moving the end-effector.

The first is critical in maintaining the required velocity of the robot as well as the velocity of each individual motor to avoid overstressing them. The second reason is significant because it is possible to prepare the robot for the next movement by changing its joint configuration while the end-effector remains in the current pose.

The manipulator with more joints, such as YuMi's 7 joints, is very flexible for manoeuvring in its workspace, but it also adds complexity to its pose configuration.

Smart Gripper: The IRB 14000 gripper is a versatile, smart part handling and assembly tool. One basic servo module and two optional functional modules, vacuum, and vision are included in the gripper. The three components can be mixed and matched to create five unique combinations for users in various applications. For demonstration and testing purposes, a pair of getting-started fingers are included with the gripper. The system integrator should replace these fingers with fingers that are specifically suited for the purpose. If the vacuum module option is chosen, the gripper comes with the first set of suction cups and filters [27].

An Ethernet IP Access to productive resources connects the IRB 14000 gripper to the IRB 14000 controller. The gripper is controlled and programmed using the Smart Gripper RobotWare add-in. RAPID driver, FlexPendant interface, and configuration files are all included with the add-in. The three function modules (servo gripper, vacuum, gripper, and camera) can be combined into five different possibilities as listed in the following table.

Table 2.7 Different ABB smart-gripper combination for ABB YuMi [27]

	Combination includes	Picture	Advantages and disadvantages for pick and place applications
1	A servo-gripper with two fingers.		Simple, Servo finger angle positioning may be complicated for some objects.
2	A servo-gripper with two fingers and a vacuum suction gripper.		Vacuum suction gripper may disturb using servo fingers and vice-versa.
3	A servo-gripper with two fingers and two vacuum suction grippers.		Vacuum suction gripper may disturb using servo fingers and vice-versa
4	A servo-gripper with two fingers and a vision.		Additional camera is usable for close-up inspection tasks.
5	A servo-gripper with two fingers, a vision, and a vacuum suction gripper.		Additional camera is usable for close-up inspection tasks. Vacuum suction gripper may disturb using servo fingers and vice-versa.

I. The gripper's basic component is the servo module. It can grasp items. Fingers are attached to the servo module's base, and their movement and force can be regulated and monitored.

II. The vacuum generator, vacuum pressure sensor, and blow-off actuator are all housed in the vacuum module. When the suction tools are mounted, the gripper can use the suction function to pick up objects and the blow-off function to position them.

III. The vision module includes a Cognex AE3 InSight camera that supports all ABB Int egrated Vision capabilities.

2.3 Overview of Machine-vision systems

A vision-guided robotics (machine vision) system's basic premise is simple: a camera takes a picture of an item and analyses the image to give exact coordinates to a robotic arm, allowing it to move to the desired location. There are two key components in this system: an industrial robotic arm and an industrial vision system [31].

Industrial robotic arms employ programmed motion to place a part in the correct location. The arms' capabilities are extensive and easily adjustable. Robotic arms are available in a range of shapes, sizes, and capabilities, ranging from simple linear motions to complex seven-axis motions. Robotic arms can be programmed to move in a specified direction and/or at a specific pace. Robotic software may be designed based on programmed logic to enable various robotic motions. In this study, for example, the robot utilized for experiments is an ABB YuMi 7 DOF dual arm cobots. It is on hand in the laboratory. As mentioned in section, there are several factors for picking the right industrial robot for a certain vision guiding operation 2.2.1.

Industrial vision systems are made up of a camera that may be combined with machine vision and image processing software. Both the camera and the software may be configured to distinguish parts quickly and simply by taking a photo and analysing the image. Along with the camera, the industrial vision system may vary from 2-D to 3-D, and even the developing 3-D bin picking technology, which is meant to detect and choose items that are randomly displayed in a bin swiftly and efficiently. These vision systems may be designed to do the following, depending on your application [31]:

I. Calibrate the entire picture into real-world (X, Y) coordinates.

II. Look for a certain feature in an image.

III. Convert pixels to actual dimensions to measure picture characteristics.

2.3.1 1D vision systems

1D vision frameworks are different from other layered sees in dissecting an advanced sign each line in turn as opposed to breaking down an entire picture. These frameworks search for the fluctuation between the past and following gained lines. One of the most widely recognized applications for 1D machine vision is to distinguish and order surrenders on materials made in a consistent cycle like paper, metals, plastics, and nonwovens. In the material assembling industry, this strategy is utilized in distinguishing the deformities in a persistent interaction [32].

2.3.2 2D vision systems

2D Vision System In 2D vision frameworks utilizes a solitary 2D picture camera, the picture got from the camera is managed in two aspects in a plane. The acquired directions are in X and Y interpretations with a turnaround Z. 2D vision frameworks give region checks that function admirably for discrete parts. These frameworks are viable with most programming bundles and are the default innovation utilized for most machine vision applications. 2D frameworks are accessible in a ceaselessly growing scope of goals. Standard, broadly useful applications as a rule include goals with the furthest restriction of around 5 MPixels. Camera sensors in 10, 20, or 30 MPixels or more are turning out to be important for standard 2D item arrangements, nevertheless. Speed, cost, and related optics separate the accessible goals. Where a 2D region cluster framework takes a two-layered depiction of an article, 2D line filter frameworks assemble pictures line-by-line. A decent similarity to comprehend the contrast between region sweep and line check frameworks is to think about the distinction between printers, and fax machines or scanners [33].

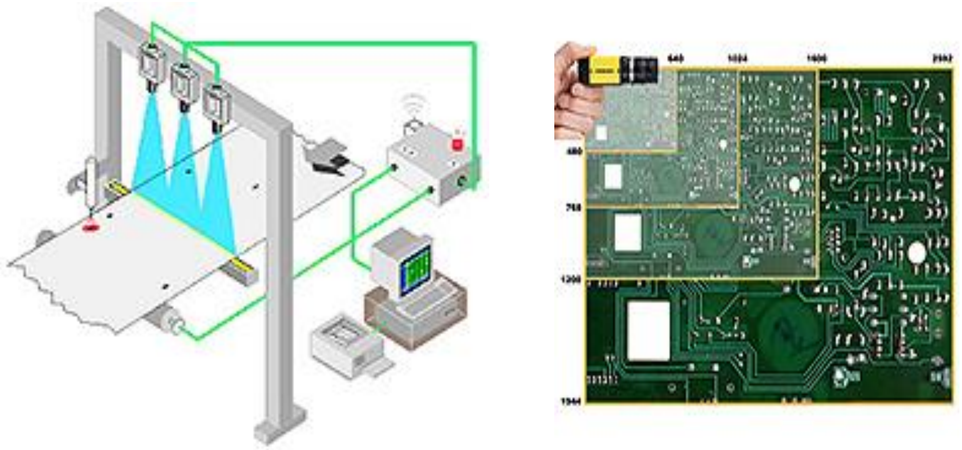


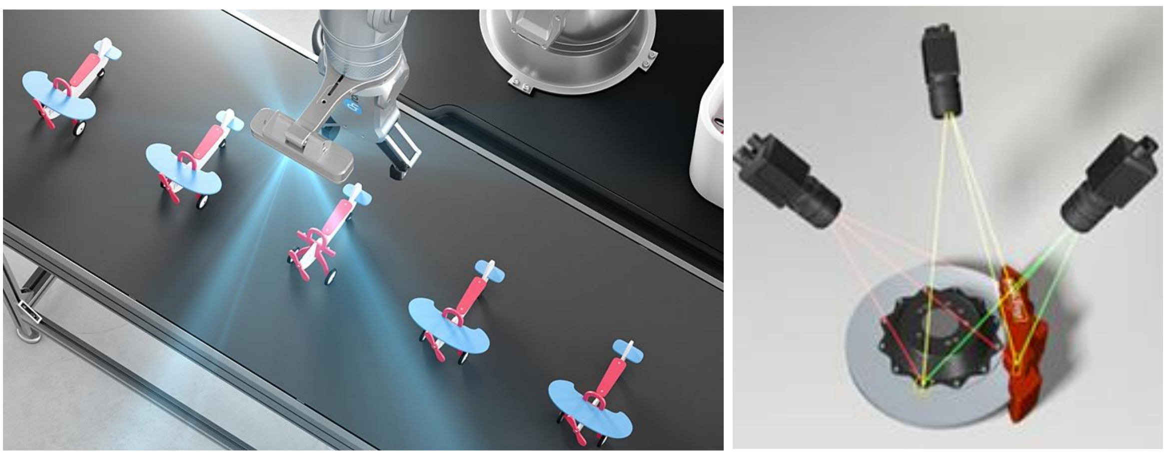
Figure 2.5 1D and 2D vision system respectively [33].

2.3.3 2.5D vision systems

A standard 2D machine vision picture is level and adjusted to permit the estimation of length and width, however it gives no level data. The subsequent stage, 2.5D, remembers the Z-axis height or level data for expansion to the X and Y. It additionally gives data that permits the machine vision framework to appraise the object turn (pitch and yaw) around two of the three aspects. 2.5D is quickly arising as the ideal innovation for vision-guided applications. 2.5D cameras lie on the spot somewhere in the range of 2D and 3D cameras, both concerning cost and abilities. Fit for deciding the level of articles, 2.5D cameras are great for situations in which items contrast in level and when things should be stacked. Impressively more affordable than their 3D partners and significantly more competent than 2D cameras, 2.5D cameras are many times an optimal fit for a wide scope of utilization, particularly in applications where 3D cameras would be costly needless excess. A few 2.5D frameworks are more straightforward to set up and adjust than others, some should be appended straightforwardly to your cobots, which limits their capacities.

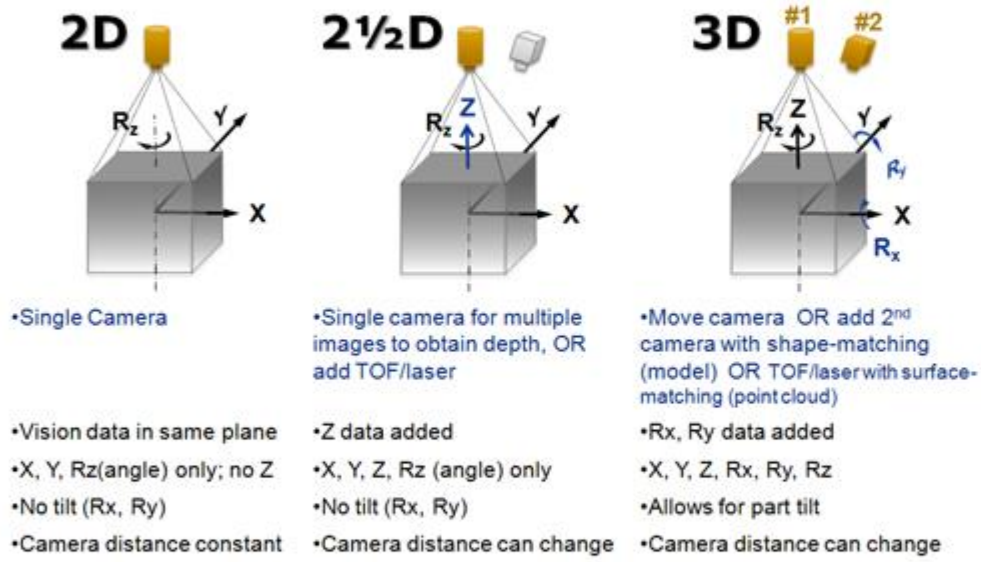
2.3.4 3D vision systems

3D vision system frameworks ordinarily utilize either numerous cameras or different laser sensors to recognize the size, shape, and profundity of the article. 3D vision permits a robot to more actually distinguish the direction of a section that necessities taking care of, in any event, when the area and position of the parts change. Previously, 2D frameworks required more reliable conveyance of parts for productive pick and spot, yet 3D vision frameworks are conveying added adaptability.



A B

Figure 2.6 2.5D vision system (A) and 3D vision system using multicamera (B)[34] [35]



Comparing 2D, 2.5D and 3D VGR (Courtesy of Universal Robotics)

Figure 2.7 Comparison of 2D,2.5D ,and 3D vision system [36]

3 DEVELOPMENT OF THE VISION-GUIDED POSITIONING SYSTEM

3.1 System Overview

Both sensing system and mechanical actuators are needed for object relocation and sorting according to their visual properties. Industrial manipulators may be good and feasible choice when the mechanical system may need frequent adjustments and reconfiguration. There are many different industrial manipulator products on the market, some are better suited for cooperation with humans, some are better suited for heavier loads. Machine vision is the use of optical noncontact sensing devices to automatically receive and analyse images of real-world scenes to collect information. Such information can be used to control machines or processes. Image analysis is the basic goal of machine vision. A machine vision system extracts usable information from two-dimensional representations of a scene [37].

A typical machine vision system executes the following processes in the specified order:

1. Image capture and enhancement
2. Segmentation and feature extraction
3. Matching features to models
4. Exploitation of constraints and image cues to recover information lost during image processing, and
5. Application of domain knowledge to recognize objects in the scene and their attributes.

This process can be repeated several times with different exposure times and lighting properties to reliably extract all necessary information. According to available components and their properties, the VGR positioning system was proposed. The data flow diagram of the proposed system as shown in figure 3.1.

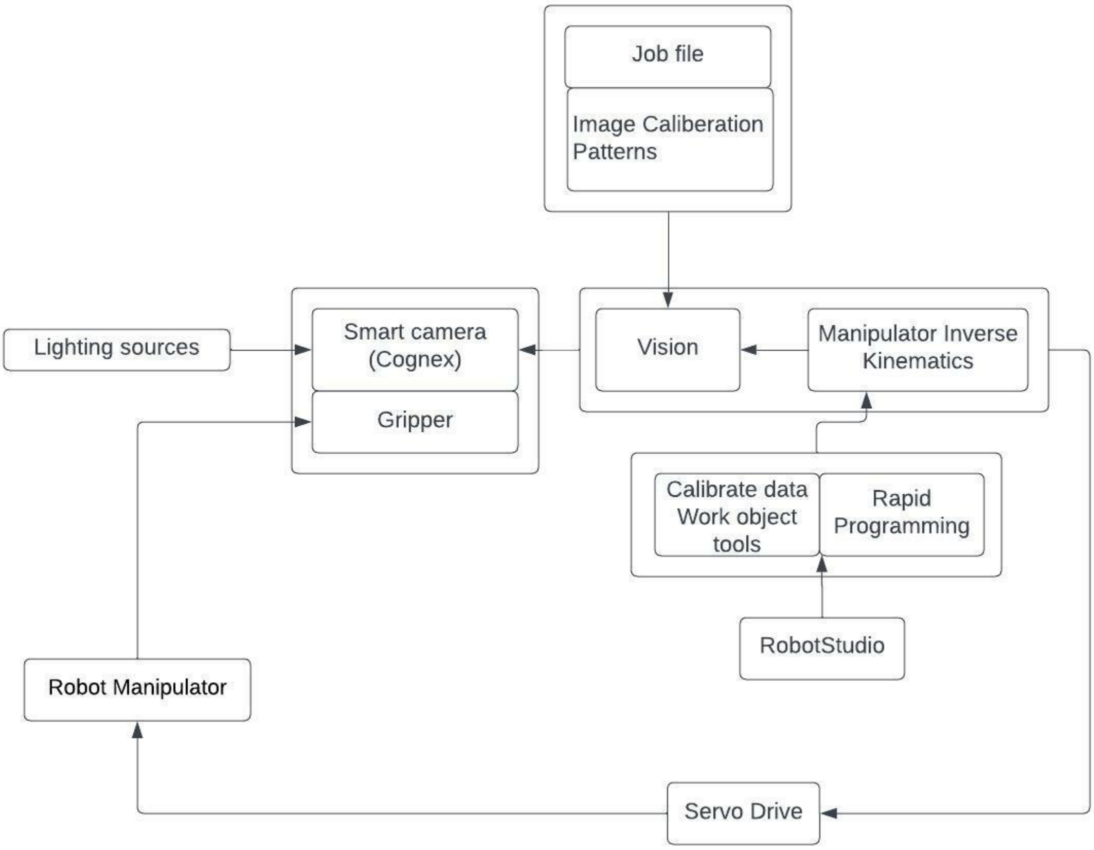


Figure 3.1 Flowchart of the proposed VGR positioning and sorting system

The proposed system shown in figure 3.1 consists of robot manipulator with flexible control system, a smart camera with internal image processing, system-integrated lighting system. The systems need input data that is acquired using image calibration procedure, object image pattern training procedures, robot work frame calibration procedures and programming of actions needed for different objects. The robot must "behave" differently with object of different shape. In the case of ABB manipulators, this is done using rapid language.

The 2D coordinates of the identified and categorized items will be obtained by the vision system. The robot controller will compute inverse kinematics from the provided X, Y, and Z coordinates and orientation to the joint angle of each joint, and then send a command to the servo drive based on the calculated joint value of the individual joints. The servo drive of the joints moves in tandem with the calculated inverse kinematics joint angles. As described in section 2.2.5, the ABB YuMi features 7 degrees of freedom (DOF) for each arm, which offers advantages in solving inverse kinematics and dealing with singularity, as well as having various configuration options. Furthermore, the sorting position must be inside the robot's workspace so that the robot may access the pre-set sorting space. and the right arm must be positioned such that it does not interfere with the visual system. The field of view (FOV) of the vision system have been within the workspace the cobots unless the robot cannot cover the field of view outside the workspace of the robot.

3.2 Smart Camera Parameters and Selection Criteria

One of the most flexible and also complex information collection systems for robots are camere-based machine-vision systems. A smart camera is made up of image detection sensors, that convert lens projections into a voltage sequence, a digital circuit that maps a set of points onto an image and converts them into pixels to generate a digital representation, and a display [31]. Central Processing Unit (CPU) executes algorithmic programs for interpreting a digital image code. The information is stored in storage hardware (usually FLASH memory), which is alse used to run CPU programs or to record and store images for future use. Stored images are analyzed and requested information is extracted according the algoritms and programs running in CPU. The external CPU such as robot controller uses those results and delivers commands to reactive equipment. The essential part of any optical sensing system is a lighting device for quality image captures. Highly varing ambient light sources may have a negative effects to the quality of image capture.

The ABB Integrated Vision system interfaces smart cameras with the robot control system, allowing them to be operated using the robot programming language (ABB RAPID). Cognex EasyBuilder is the vision programming software that works in tandem with ABB RobotStudio to construct the application for Integrated Vision System of the ABB IRC5 controller.

The company Cognex provides a comprehensive range of vision products, ranging from independent vision frameworks to 2D and 3D representation programming, to provide your robot with the "ability to see". It is a leading industry 2D and 3D perception programming for precision, speed, trustworthy execution, and independence. Insight arrangement sensors provide a reasonable, easy-to-implement solution for dealing with vision-directed automated (VGR) and stage applications. The graphical User Interface is only significantly altered to provide the optimum display for Vision Guided Robotics [38]. ABB, Denso, Staubli, FANUC, Kuka, Mitsubishi, and Motoman robots are supported by the Cognex Vision system. Besides the products of Cognex, the products from Zivid and Fanuc are also good possibilities.

Choosing the right camera is critical in developing a high-performing machine vision system. When choosing a camera, there are three factors to consider, and each is heavily dependent on the application. There are several aspects for camera type selection that have to be considered:

1. The first decision is whether to not only use a monochrome or color acquisition camera but laso to use 2D, 2.5D, and 3D cameras.
2. The second consideration in camera selection is whether or not the object of interest is moving.
3. The third consideration is resolution. A higher-resolution camera captures more information in the image. A lower resolution camera may also be effective depending on the application.
4. Technical parameters
    - **Field of View (FOV)** is the relationship between the camera's sensor and the chosen lens can be used to calculate the field of view (FOV). The angular field of view in degrees is defined by the focal length of a lens. The greater the magnification, the narrower the angular field of view. The larger the angular field of view and the lower the magnification, the shorter the focal length.
    - **Working distance** is the distance between the lens's front and the object. The distance between the front of the lens and the part to be inspected, detected, and localized varies depending on the application.
    - **Resolution** is the ability of an imaging technology to recreate the fine details of an object or feature. Image sensors are divided into pixels in both the horizontal and vertical axes, with each pixel having a specific micrometre size.
    - **Depth of field** is the maximum object depth can be always kept in focus.
    - **Sensor Size** is the active area of a camera sensor, often given in horizontal dimensions. Image sensors are available in a variety of sizes ranging from 1 inch to 1/4 inch.
    - **Primary Magnification (PMAG)** is the proportion of sensor size to FOV.

5. Software. The software dictates how inspection programs are executed and how rapidly they may function, and it acts as the backbone of the detection and inspection aspects of a machine vision system. Different programs provide a number of programming choices. Some programs have a graphical user interface and is typically easy to use, whereas code-based software packages are more sophisticated but may be better for application-specific features. Some software packages offer both an interface and code-based programming possibilities.

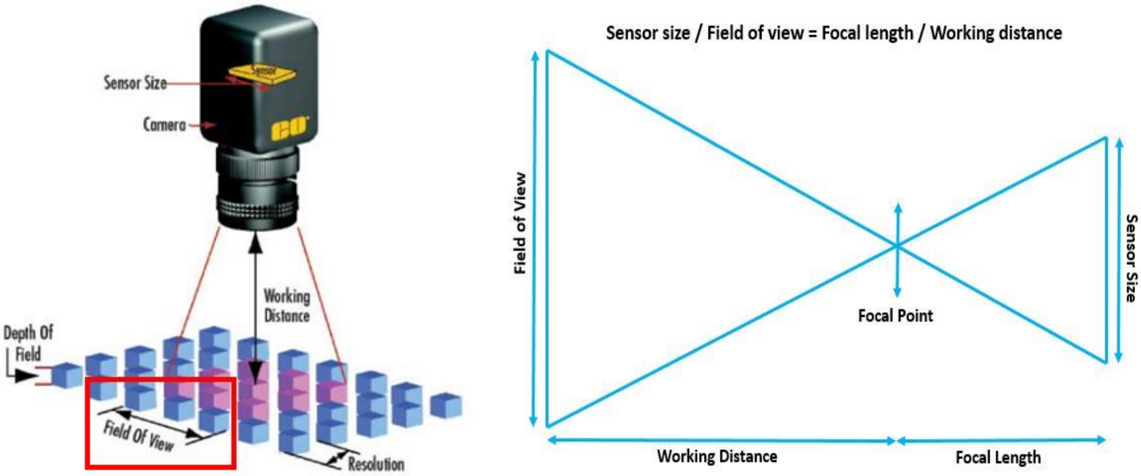


Figure 3.2 Parameters of Camera in a machine vision system[39].

Thus, in addition to selection of hardware components, it is also vital to spend time determining the software. Smart cameras have the essential part of the image processing built into firmware which compatibility with different external software tools should be analysed in each case.

3.3 Robot Controller Integrated Vision Systems

The goal of ABB's Integrated Vision system is to deliver a reliable and user-friendly vision system for general-purpose Vision Guided Robotics (VGR) applications. The system is comprised of a complete software and hardware solution that is fully integrated with the robot controller and the RobotStudio programming environment. The vision system is based on the Cognex In-Sight smart camera family, which includes inbuilt image processing and an Ethernet communication interface. RobotStudio includes a vision programming environment that exposes the entire palette of Cognex EasyBuilder features, as well as powerful tools for part placement, inspection, and identification. The RAPID programming language has been enhanced with camera operation and vision guidance instructions and error tracing.

The camera system is based on the Cognex InSight 7000 series, but most Cognex InSight cameras can also be utilized. The controller provides 24V DC and Ethernet to the camera. The cameras are linked to the Ethernet switch provided. In YuMi's example, there are two cameras for the two arms, but in general, up to three cameras can be connected.

Figure 3.3 Devices used in the proposed vision guidance system.

As in the Figure 3.3 describes the experiment is composed of the following apparatus and equipment’s.

1. Complete ABB YuMi cobots with internal IRC5 controller, and a FlexPendant.
2. The interface for Integrated Vision. This comprises a robot controller interface for vision, an Ethernet switch, an Ethernet cable to link the camera to the switch, a switch to the main computer's management port, a switch to the controller's management port, and a 24V DC power supply for the Ethernet switch and the camera.
3. Personal computer (PC) / Desktop.
4. Ethernet cable for connecting the PC to the controller.
5. Smart camera (Cognex In-Sight).
6. Lighting device.

In addition to the above hardware, the software component, which includes RobotStudio software and a licensed RobotWare that enables the integrated vision system in the RobotStudio, is required. The experimental set-up described on previous picture contains a YuMi robot with camera containing smart grippers on both hands. This is a bit different of YuMi original configuration where the camera is installed only on right hand and left-hand provides a vacuum gripper. The computer has an ABB RobotStudio software installed on it, which includes vision system set-up and debugging interface from Cognex.

3.4 Vision Integrated Development with ABB RobotStudio

ABB's RobotStudio software is primarily used for offline programming of ABB robots. It is a PC application for robot cell modeling, offline programming, and simulation. RobotStudio supports off-line controllers, which are virtual IRC5 controllers that run locally on your PC. The offline controller is also known as the virtual controller (VC). RobotStudio also lets you work with the real physical IRC5 controller, also known as the real controller. The online mode is used when RobotStudio is used with real controllers. RobotStudio is in offline mode when it is not linked to the real controller or when it is attached to a virtual controller. This has a number of advantages, including risk reduction, faster start-up, shorter change-over, and increased productivity.

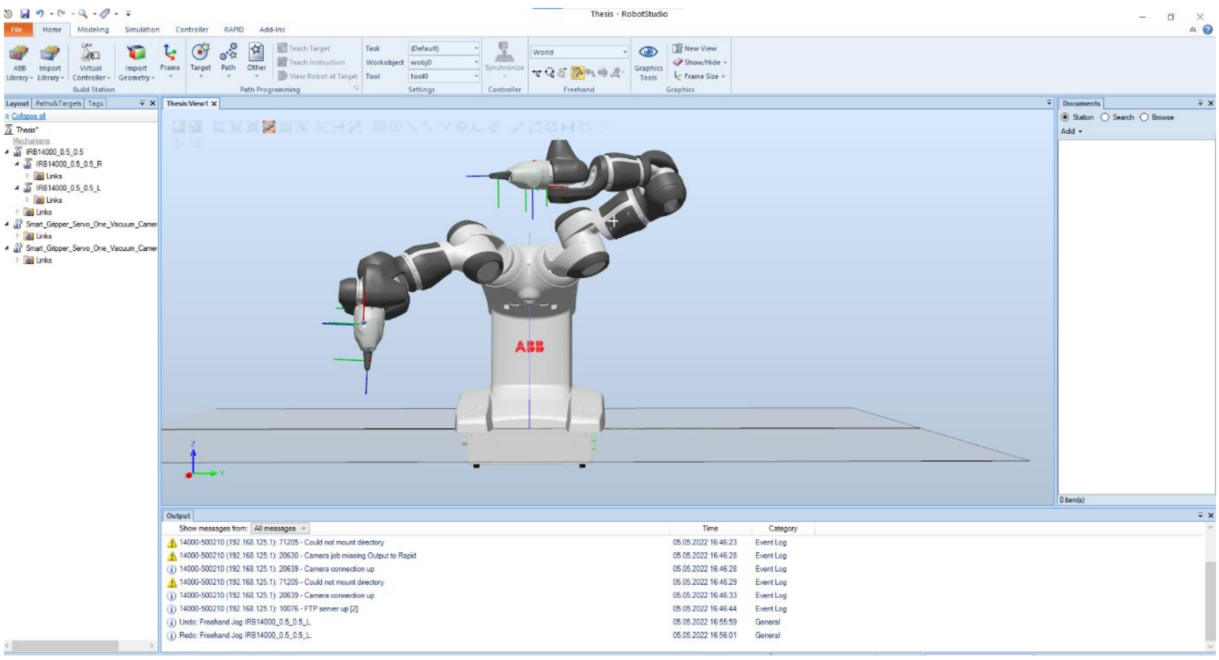


Figure 3.4 ABB RobotStudio software

Figure 3.4 shows the workstation of ABB YuMi cobots in the robot studio that is like the experimentation. As it is demonstrated in the picture the right arm is used as fixed camera position for capturing the images for classification and detection of the objects. The left arm is used as a manipulator for positioning and sorting of the detected objects according to the predefined place.

FlexPendant: The FlexPendant (teach pendant unit, TPU) is a hand-held operator unit used to execute a variety of tasks associated with operating a robot system, including executing programs, jogging the manipulator, and updating robot programs. The

FlexPendant is a complete computer that comprises of both hardware and software. It is a component of IRC5 and is linked to the controller via an integrated cable and connection. The FlexPendant may also power the integrated vision.

Figure 3.5 Vision system interface in ABB FlexPendant

The Figure 3.5 shows that the integrated vison system in the ABB FlexPendant. The vision system displays the output parameters of the detected object.

3.5 Development of Smart-Camera Based Robot Control systems

The Cognex vision system product range includes vision sensors, 2D vision systems, and 3D laser profiles that are utilized for a variety of industrial activities. Cognex InSight 2D vision systems excel at tasks such as examining, recognizing, and guiding parts. These industrial-grade vision systems can combine innovative vision tools with fast image collection and processing. Cognex Camera series models in 2D vision systems include the InSight 8000 series, InSight 7000 series, and InSight 5705 series. This vision system's tiny product design allows it to fit into tight production lines. An integrated vision camera is included in the ABB Yumi cobots. Integrated vision, vision is the part of the robot in which the camera is directly connected to the robot controller [41].

Figure 3.6 Cognex InSight camera series [42]

3.5.1 Application of the vision system

The Cognex vision framework is used in another current mechanization framework. It is used as part of a broad inquiry to look for gathering errors, surface deformities, injured portions, and missing elements, as well as to read 1D standardized tags and 2D grid codes. Distinguish particle and element direction, shape, and position. In estimating, consider the fundamental aspects as well as measure parts for arranging and grouping operations. It can also be used to command robotization equipment and automated devices to adjust parts for high precision assembly operations, which is what this project is all about. Furthermore, it is used in reading and validating alphanumeric characters stamped directly on parts and imprinted on marks.

PatMax design is a precise, extremely repeatable device that discovers prepared designs regardless of the size, turn, or area of the target part. Ideal for ventures and applications requiring large fields of view, great precision, massive point and scale resilience, and various targets. Design Compatibility In most vision applications, the first step is to precisely locate a segment. Cognex's industry-leading example matching innovations, such as PatMax RedLine, provide unrivalled precision and strength, even with pivot, scale, and illumination variations [43].

The vision system can be mounted in three separate ways. The first is vision-based PC; the camera is connected to a PC, and the PC communicates with the robot. The smart cameras gather photos and analyse them before communicating the vision results to the robot. The second mounting option is a camera mounted on a robot arm, which allows the robot to position the camera in any location and orientation. It has the advantage of flexibility and changing field of view in the case of the ABB YuMi robot because the camera is installed on the robot end effector that has an integrated Cognex vision system. The fourth one is a fixed mounted camera, which is permanently mounted. It has a fast cycle time but a limited field of view.

3.5.2 Cognex AE2 smart cameras

ABB's Integrated Vision is a software and hardware vision system that enables users to easily design Vision Guided Robotics (VGR) applications. Integrated Vision is divided into three components in terms of software. RobotStudio, the IRC5 controller with the RAPID programming language, and the FlexPendant are the three. Visual systems for needed vision tasks such as inspection and identification have been fitted to robots to make them more versatile in specific settings. The ABB YuMi robot's vision module includes a Cognex AE2 camera integrated in one of the servo vision and servo vison vacuum gripper combinations, giving the outstanding cobots a powerful and dependable vision for image processing. ABB's Integrated Vision system makes use of the Cognex camera.

Figure 3.7 Integrated Cognex smart camera in ABB YuMi gripper

The AE2 Advantage vision engine combines the capability of Cognex vision and ID tools in a device that is not only small (14.5mm x 29.1mm x 20.5mm), but also adaptable and cost effective. Unlike typical scan engines, the AE2 Advantage vision engine provides best-in-class 1D and 2D code reading, as well as a full suite of industry-proven vision tools for locating, analysing, and inspecting embedded vision parts or features. The AE2 Advantage vision engine is intended for extensive integration into OEM devices. Cognex's established and simple-to-use application software is also included with the AE2. The Advantage engines have two communication options for connecting, communicating, and transferring images: USB and RS-232. The Advantage engines are compatible with the conventional Cognex engines [44]. The camera in the ABB YuMi is an add-on camera, the specification shows in the Table 3.1.

Table 3.1 Cognex AE2 camera specification [27] [45]

Description	Data
Resolution	1,3 Megapixels
Lens	6,2 mm f/5
Illumination	Integrated LED with Programmable intensity
Software engine	Powered by Cognex in sight
Application Programming software	ABB integrated vision or Cognex In-Sight explorer

There are various Cognex cameras used for machine vision and visual guidance applications. Aside from their border fluctuation, they are also supported in multiple firmware versions. It is recommended that the camera have the accompanying firmware form when running Integrated Vision. Vision cameras and RobotStudio communicate via the main PC's administrator port. In Table 3.2 the essential characteristics of Cognex's pack cameras are listed below. When selecting a camera for machine vision or vision guided robot operation, evaluate the specifications that fulfil the system's requirements[45].

Table 3.2 Cognex cameras specifications [46]

Specification parameter	Camera DSQC1020	Camera DSQC1021	Camera DSQC1063	Camera DSQC1064	A3 Camera
Cognex version	In-Sight 7200	In-Sight 7402	In-Sight 7600	In-Sight 7601	In-Sight Micro 1402
Resolution	800x600	1280x1024	800x600	1280x1024	1280x1024
Program memory	512MB		7.2GB non-volatile flash memory		128MB non-volatile flash memory
Image processing memory	256MB SDRAM		512MB SDRAM		256 MB
Sensor Type	1/1.8-inch CMOS		1/1.8-inch CMOS, global shutter		1/1.8-inch CMOS
Shutter speed	16 µs to 950 ms		14 µs to 550 ms	17 µs to 750 ms	16 µs to 1,000 ms
Lens type	C-mount				CS-mount and C-mount
Firmware	4.10.05	4.10.05	5.07.03	5.07.03	4.09.04/4.10.02

3.6 Camera Set-Up and Usable Lighting Systems

3.6.1 Camera model

The pinhole camera model describes the mathematical link between a point's coordinates in three-dimensional space and its projection onto the picture plane of an ideal pinhole camera, where the camera aperture is specified as a point and no lenses are employed to focus light. Geometric distortions or blurring of unfocused objects induced by lenses and finite-sized apertures, for example, are not included in the model. It also ignores the fact that most practical cameras only have discrete picture coordinates. This means that the pinhole camera model can only be used to approximate the mapping from a 3D scene to a 2D image at first order. Its validity is affected by the camera's quality and, in general, diminishes from the centre of the image to the edges as lens distortion effects grow.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} f & 0 & p_x & 0 \\ 0 & f & p_y & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \tag{3.1}$$

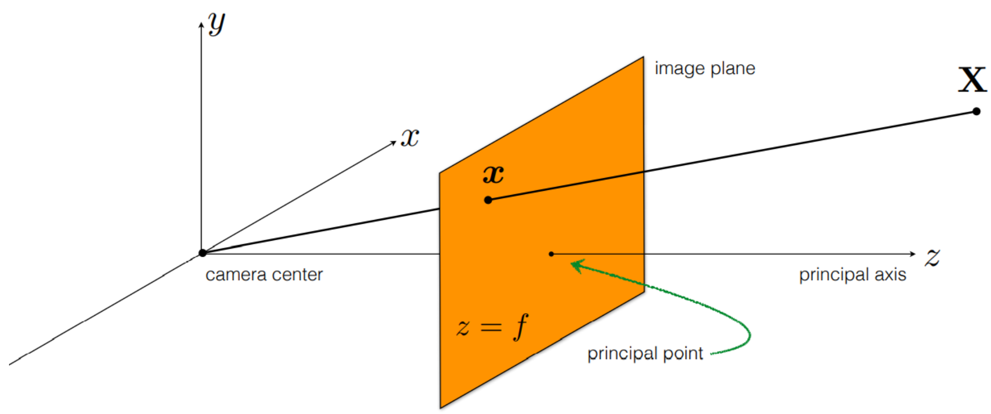


Figure 3.8 Pinhole camera model [47]

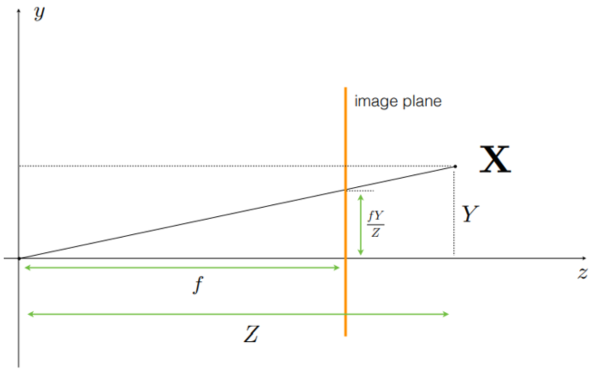


Figure 3.9 Conversion of 3D to 2D [47]

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \xrightarrow{yields} [f\frac{X}{Z} \quad f\frac{Y}{Z}] \qquad 3.2$$

3.6.2 Illumination

Machine vision frameworks create images by breaking down reflected light from an item rather than studying the actual thing. The primary goal of illumination for machine vision applications is to improve separation (grayscale distinction) between points of interest and the surrounding environment. Brightening is one of the most fundamental components of a machine vision architecture. The selection of the appropriate lighting component for a specific application is critical to ensuring that a machine vision framework performs its tasks reliably and stably.

The primary argument is that insufficient light results in data loss, which, in general, cannot be recovered through programming. As a result, determining the value of lighting parts is critical: there is no product calculation suited for it is not precisely enlightened to uncover highlights that. To make the best decision, one should consider several factors, including:

- Lighting geometry
- Light source type
- Wavelength
- Surface property of the material to be inspected (e.g., colour, reflectivity)
- Item shape, Item speed (inline or offline application)

- Mechanical constraints, Environment considerations and Cost

Because multiple constraints must be considered, the selection might be difficult, and often the best advice is to do feasibility tests with various light types to discover the features of interest. However, there are a few simple guidelines and best practices that can help with selecting appropriate lighting and improving image quality. The following are the primary goals for each application:

I. Maximizing the contrast of the features that must be inspected or measured

II. Minimizing the contrast of the features of no interest

III. Disposing of undesirable varieties brought about by the encompassing light and contrasts between things that are non-pertinent to the review task.

Lighting Sources: High-frequency fluorescent tubes, halogen lamps, xenon light bulbs, laser diodes, and light emitting diodes are the most often utilized light sources in machine vision systems (LED)[48].

High-frequency fluorescent: Because they generate a homogenous, uniform, and exceptionally dazzling brightness, high-frequency fluorescent light sources are commonly used in machine vision applications. Because they shine constantly with the power supply frequency, standard fluorescent light bulbs are not suitable for vision applications. Fluorescent lights come in a variety of sizes, shapes, and configurations. Aside from the standard light cylinder, there are fluorescent ring lights and square shape region lights [49].

Light Emitting Diodes (LEDs): LEDs are semiconductor devices that emit incoherent, monochromatic light with a wavelength that varies based on the chemical composition of the semiconductor. LEDs have advantages over other types of light sources. Because of their modest size, they can be utilized for a wide range of lighting techniques. Ring lights, dome lights, area or line lights, spotlights, dark-field lights, and backlights are examples. Controlling a single LED in a cluster is possible. As a result, by enabling and disabling specific LEDs, they may generate various lighting conditions such as varying lighting angles or intensities with a single setup. LEDs can also be used in strobe light mode. Other benefits of LEDs include their energy efficiency, long longevity, and cheap maintenance expenses. LEDs function at [49]. LED illumination sources are used in the integrated vision system of the ABB YuMi.

Halogen lights: are light bulb extensions that are loaded with halogen gas (e.g., bromine or iodine). Halogen lamps are frequently used with fibre optic light guides [49]. The light emitted by a light source is transferred through these fibre-optic light guides, increasing the flexibility of lighting configurations and techniques. This includes, as with LEDs, ring lights, dome lights, area or line lights, spotlights, dark-field lights, and backlights. One disadvantage of halogen lamps is that they generate a lot of heat. As a result, active cooling is necessary. If the light source is DC-regulated, halogen lamps, like LEDs, do not generate flickering effects. As a result, halogen lamps are suitable for high precision inspection operations. Xenon lights, which are sometimes used for strobe lighting, are quite like halogen bulbs. These lights produce short, intense light pulses that are used to lessen the impact of motion blur. LED lighting and fibre optics are extremely adaptable. They are adaptable to a wide range of machine vision tasks of varying size and geometry [49].

LED, Halogen lamps, and high-frequency fluorescent lighting are the most used lighting sources in machine vision systems, for small to medium scale inspection stations, while metal halide and xenon are used in large scope applications, or in areas needing an exceedingly brilliant source. The four pillars of visual illumination are as follows:

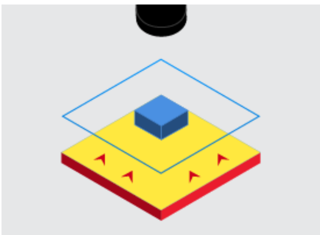
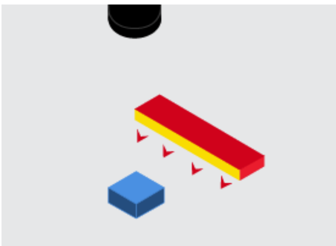
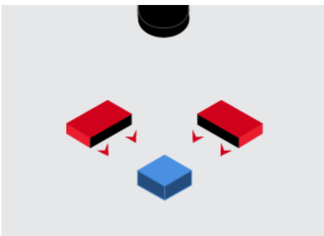
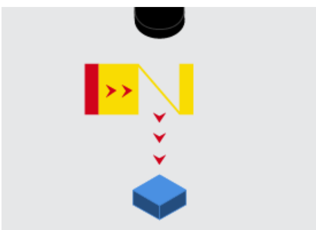
1. Geometry: The 3D spatial relationship among sample, light, and camera.
2. Structure or Pattern: The shape of the light projected onto the sample.
3. Wavelength or Colour: How the light is differentially reflected or absorbed by the sample and its immediate background.
4. Filters Differentially blocking and passing wavelengths and/or light directions.

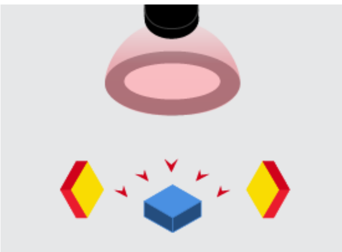
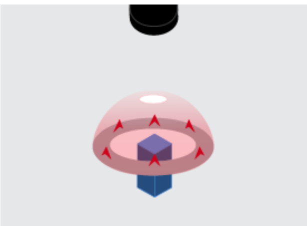
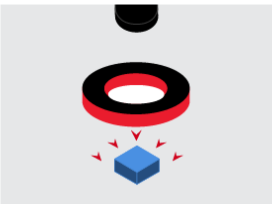
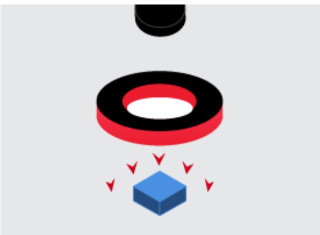
3.6.3 Machine vision lighting techniques

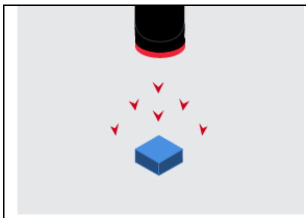
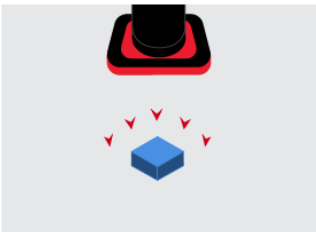
Lighting is one of the most fundamental aspects of machine vision applications. Inability to properly illuminate a goal might result in a lack of data and efficiency. A lighting approach consists of a light source and its placement in relation to the part and the camera. Cognex vision frameworks provide various combinations of outside and coordinated illumination options based on the climate and application.[50]. To supply the necessary lighting for the operation of the visual guiding, various forms of machine vision technics are available.

Table 3.3 Different lighting technics for machine vision [31][51][52]

Technics	Description, of the technics	Pros and Cons and decision on their applicability

Back Lighting 	Backlighting illumination casts light from behind the item, highlighting the shape of the object. It detects the existence or absence of opening holes, measures or confirms the item framework form, and improves cracks and scratches on visible objective portions.	Pros: Considering a certain surface, distance, certain dimensions may be limited. Cons: Creating shadows depending on the subject Decision: not usable with rubber conveyor belt.
Bar Lighting 	For consistent brightening in a narrow zone, bar lighting supplies a segment of light on the objective or at the perimeter of the goal. Depending on the angle of the light and the camera, bar lighting can improve or reduce specular reflection.	Pros: Best for estimating the radius of contours, edge elements. Cons: It strongly depends on the angle of incidence of the light. Decision: usable as additional lighting method.
Dark field Lighting 	The dark field lighting approach directs light to the target from a shallow point. Any surface features such as scratches, edges, engraves, or indents reflect light back to the camera, producing surface highlights to seem dazzling while the rest of the surface appears dull.	Pros: Scattered light (bright light on a dark background) enters the camera due to the relief of the subject. Cons: It strongly depends on angle of incidence of the light Decision: usable as alternate switchable additional lighting method
Diffuse On-Axis Lighting 	This technic distributes illumination orthogonal to the object and sends light rays at a 90-degree angle to the target through a mirror. It is used to identify faults in glossy, flat surfaces, as well as for measurements and inspection of shiny goods.	Pros: Best for inspecting shiny/glossy/lustre objects Cons: Only in fixed, directed light direction, only to be used on flat, even surfaces Decision: usable as additional lighting method for detection specific objects

Diffuse Dome (Ring Lighting) 	Diffuse lighting spreads light to lessen glare on shiny surfaces. This approach is used in all directed lighting to supply a more equal distribution of light across the target.	Pros: reduces the reflection of reflective parts. More even light. Cons: Very dependent on the dimensions of the object, not configurable for different dimensions Decision: usable for inspection of an object in close distance.
Dome Lighting 	Dome lighting provides consistent light from varied angles, resulting in no glare, even on reflected objects. Dome lighting is commonly used to evaluate glossy, curvy, or rough surfaces.	Pros: additional and consistent lighting. Cons: not configurable for different dimensions. Decision: usable for inspection of an object in close distance.
Low Angle Dark Field Lighting 	The low angle dark field illumination technique directs light to the object at an extremely slight angle (10-15 degrees).	Pros: For measuring reflecting surfaces from a low angle. Cons: Used for objects of certain dimensions. Decision: Implementation is complex.
Ring Lighting 	Ring or ring of bright, strong lighting that provides shadow-free illumination and high visual contrast is referred to as ring lighting. Because of its adaptability, ring lighting is a typical lighting style that covers a wide variety of applications.	Pros: Contrasting image. Incredibly good for detecting larger cuts. Cons: Seeing exceedingly small particles (dust can affect the result). It can be usable as an additional switchable lighting method
High-Powered Integrated Light	High-powered integrated light (HPIL) emits polarized or non-polarized light directly onto the target. This approach recognizes objects with	Pros: Polarized light Cons: Limited object dimensions. Decision: In use YuMi smart gripper cameras.

	constrained dimensions. Yumi Cobots from ABB includes an integrated lighting system.	
In-Sight Integrated Light 	The In-Sight integrated light is a diffuse circular light that provides brilliant continuous lighting on the object for machine vision applications. This integrated light avoids shadows and provides consistent lighting on matte items.	Pros: Good for evaluating contrast. Cons: Limited object dimensions. Decision: In use YuMi smart gripper cameras.

The majority of Cognex's lighting methods are high-powered integrated light and high-powered integrated light. However, lighting technologies have their own set of advantages and downsides, as previously described Table 3.3. The choice of the appropriate illumination source and lighting techniques is critical to the operation of the machine vision system. The lighting source in this project's experiments is a high-powered integrated light that is integrated with the ABB YuMi camera and extra room illumination. It is possible to choose the proper illumination source and approach for maximum performance and efficiency by evaluating the type of objects for which the machine vision system is required.

3.7 Pattern Matching for Object Location

The technique of finding one or more things in a picture and drawing a large box around their extent is known as object localization. Object detection combines these two goals by identifying and categorizing one or more objects in a picture. There are several patterns for recognizing the item. To distinguish things, several components such as circles, edges, and blobs can be employed. Cognex PatMax is the industry's best object location tool and the first geometric pattern-based object localization solution for machine vision. PatMax trains an object's geometry using a series of non-pixel-grid bounding curves and then looks for similar shapes in the picture without relying on precise gray levels. PatMax detects learnt patterns in run-time images independent of the amount of alterations performed to the pattern. As a result, there has been a significant advancement in the capacity to correctly find objects despite variations in angle, size, rotation, position, and coloring [53] [54]. Despite the fact that they are based on the same concept, there are several PatMax variants in ABB RobotStudio software's integrated vision system. A pattern is a tool that is used to locate only one object of the same type, yet it may identify several objects. Pattern(1-10): This tool can simultaneously count and find the coordinates of up to ten items of the same kind. Pattern(1-50), This tool may simultaneously count and locate the coordinates of up to 50 items of the same kind.

- High speed location of objects whose appearance is rotated, scaled, and/or stretched
- Location technology based on object shape, not on greyscale values
- Remarkably high accuracy and robustness

Patterns, PatMax Patterns, and Patterns identify trained Pattern Models, and they provide the highest accuracy among locating and inspection tools. PatMax RedLine Patterns and PatMax Patterns are more powerful than Patterns, accounting for more variations in lighting and pattern position. They also provide greater identification of changes in pattern scale and rotation, occlusion of pattern elements, and changes in pattern appearance owing to illumination fluctuations.

Although Patterns is faster than PatMax, certain scenarios necessitate the accuracy and dependability of the PatMax version:

1. When variations in lighting and reflections are difficult to control.
2. When the pattern being examined is similar in shape or shade to anything in the backdrop, or when the pattern is overlapped or partially covered by other things in the image.
3. When you need to distinguish one type of design from other, similar patterns.
4. When the deployment environment's conditions are too demanding for the Patterns Tool to execute consistently and dependably.

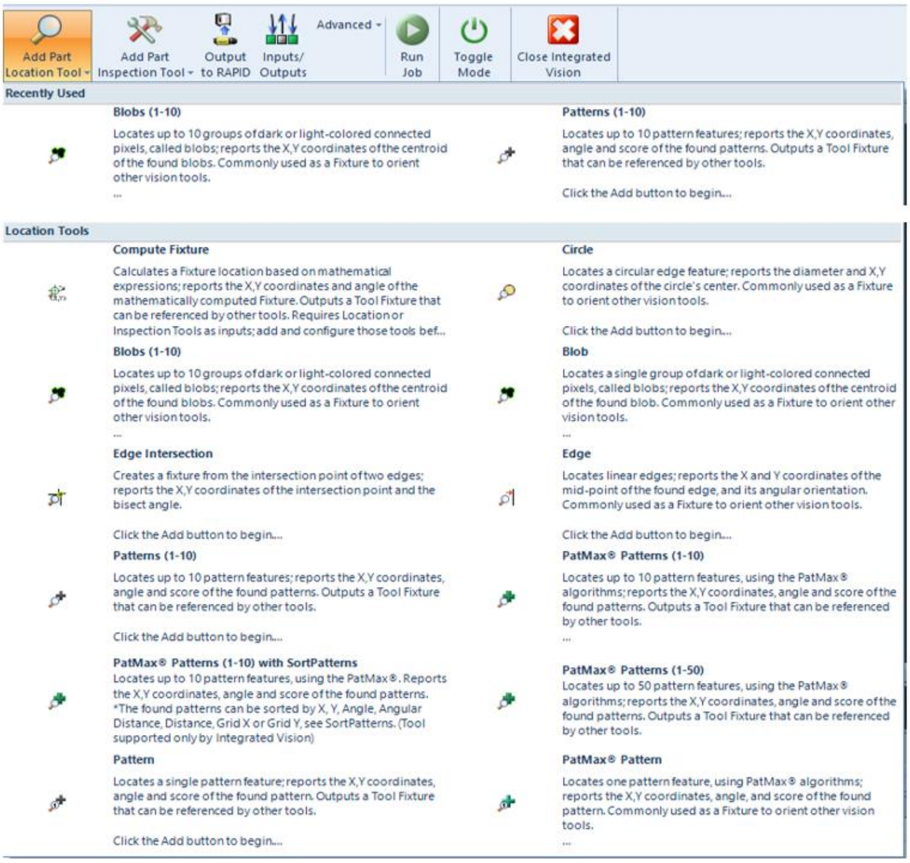


Figure 3.10 ABB RobotStudio integrated vision object identification tools

The PatMax® Patterns (1-10) uses the Cognex PatMax® algorithms to identify a single pattern or up to ten patterns and returns the x- and y-coordinates, angle, and score of the identified patterns.

3.8 Overview of Recognizable Objects and Required Recognition Patterns

Objects used for the demonstration of the proposed system in this paper are shown in the figure below, that are available in the laboratory. The first object is a red circular ring have an inner diameter of 38 mm and an outer diameter of 50 mm. the second object is a red cross. The shape, size, and colour of the objects have their own effect on the recognition of patterns. For instance, the shape of the ring makes the grasping process difficult because of lighting and angle of view the camera could not get the exact location and angle of the object. As the result, sometimes the servo gripper shifts some position and collides with the solid part of the circular ring, and the cross crash the manipulation process. The second factor is the size of the object. The size of both objects is the same size with the maximum opening and closing of the servo gripper. Consequently, it affects the accuracy and precision of the grasping operation. Therefore, this shows that selecting the gripper type and selecting a suitable recognizable object has an effect on the vision guidance robot operation. For example, in this case, it recommended others to use higher opening and closing or change the shape and size of solid materials and use another gripper like a pneumatic gripper.

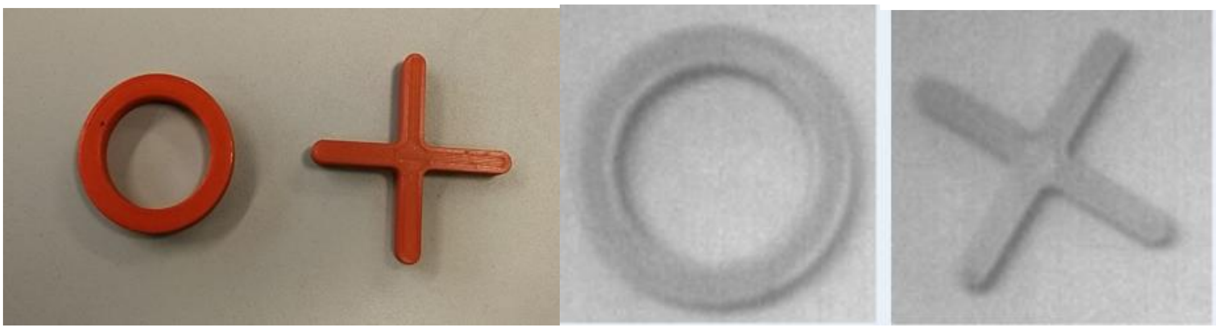


Figure 3.11 Objects used for the demonstration of the vision guidance system.

3.9 Configuring Integrated Vision

3.9.1 Preparation and initialization

The topic discribes the working procedure how the vision application is created. After the hardware and software is ready, the vision application is created according to the following procedures.The first step is preparing the intilization and load a rapid program. Creating the tool data for all needed tools and define TCPs, creating the work object data for all needed fixtures and define them.

After the preparation the next step is to set up the camera. Configring the camera network and connecting to a camera is mandatory. After the cameras are physically connected each camera needs to be configured with an IP address and name. in this case as it is shown in the figure below the camera IP adres is and name is "YumiCam_Left" for the left arm and "YumiCam" for the right arm. In RobotStudio the robot controller browser has a node named vision system, that used to configure and connecting the camera. To connect the Cameras first the integrated vision taskbar must be activated, the it will automatically allow to connect the working camera in this case YumiCam_Left. Figure 3.12 below shows the process how to activate and connect the camera.

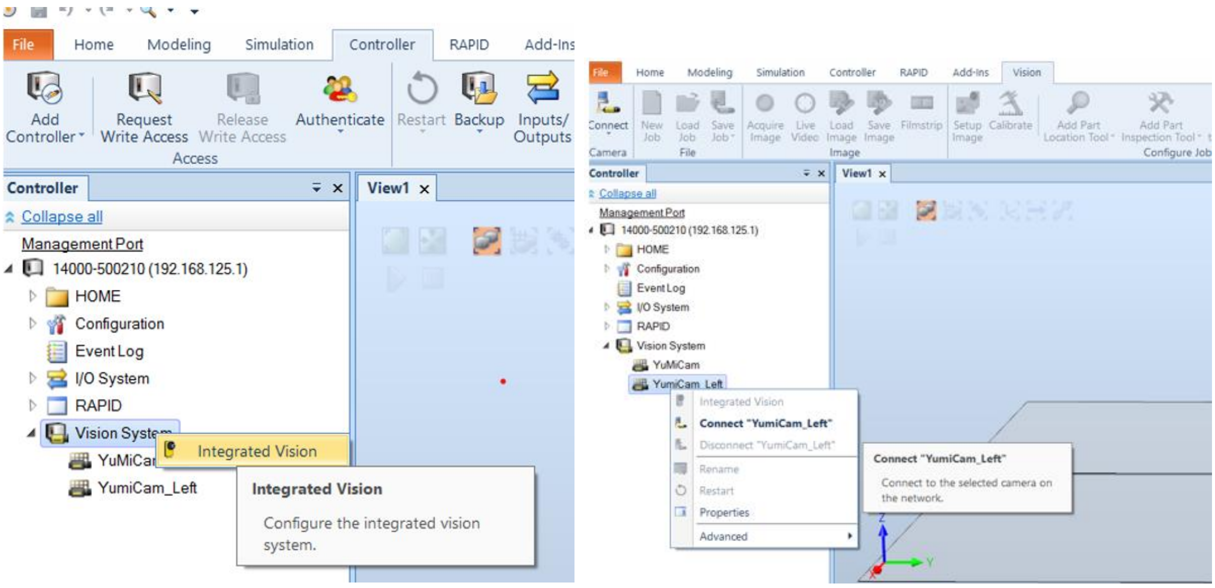


Figure 3.12 Configuring Integrated vision

In Figure 3.13 the camera is connected and as it sees the circular objects in the table. But at this moment there is no job file created and it is not possible to locate the objectes position and orientation. When the camera is connected the taskbars also activated and it is possible to creat job file.

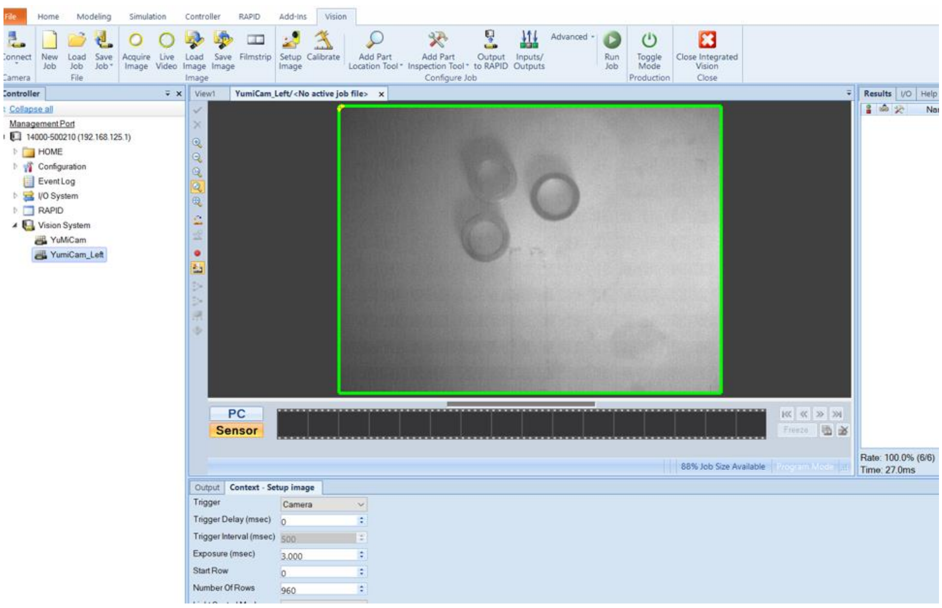


Figure 3.13 Connected Yumi integrated camera

3.9.2 Setting up a vision job file

After the camera has been setup and linked to the robot controller, a task file that is used for pattern matching, which implies locating the item, may be created and saved. The active job is saved in the camera's working memory. This job is used in fast programming to match the pattern to the trained model. It is advisable to make a backup in case the camera is destroyed. As shown in the picture below, a work file is produced, and the reference coordinate is on the top left corner of the green rectangle on the yellow coordinate axis, which requires camera calibration.

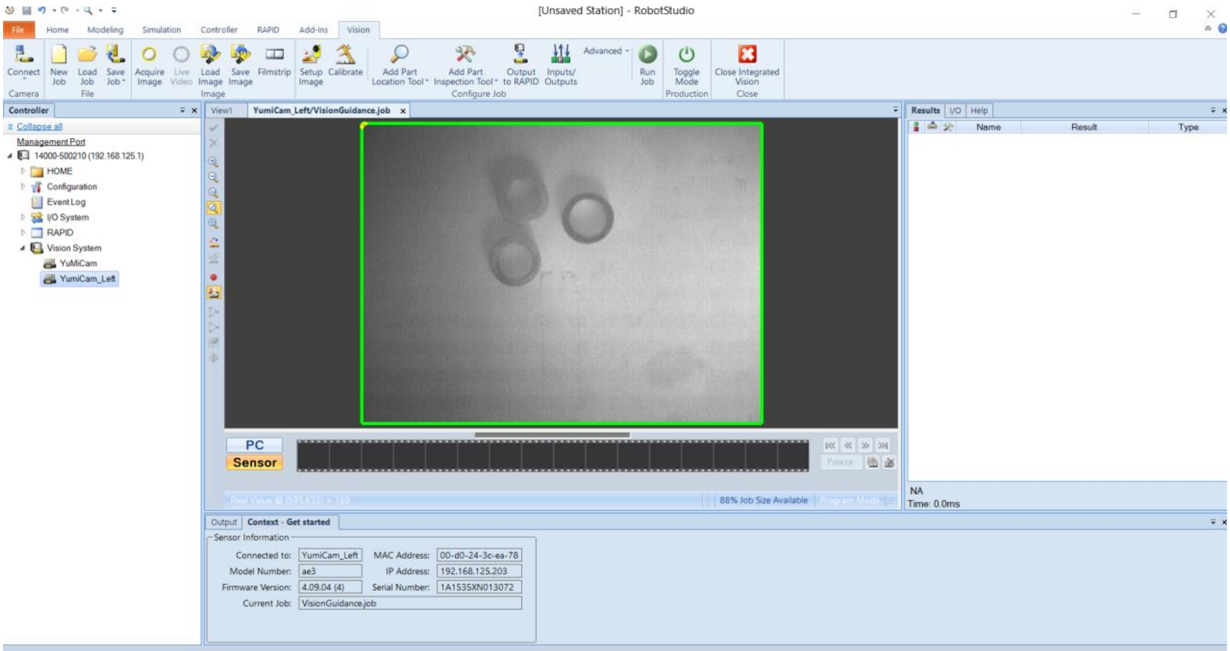


Figure 3.14 Creating the Job file for a smart camera.

3.9.3 Setting up the image

The exposure time is the most widely utilized parameter while shooting a photograph. The longer the period, the more light enters the camera, making the image brighter. Adjusting the parameters of a vision work may be an iterative process, and the exposure duration is frequently updated many times before the project is complete. It is preferable to acquire a clean image for calibration, which is used to determine the best setting for detecting the product. The exposure period is iterated till the item is detected in this study to make the picture capture process more resilient and optimum. When the camera obtains the coordinate, the rapid advances to the next phase for manipulation.

3.9.4 Calibration of the camera scene coordinates

The camera calibration procedure is needed to determine the internal camera quantities that impact the imaging process, such as image center, focal length, and lens distortion characteristics. Because a picture is made up of pixels, the camera image must be calibrated for each different scene to obtain the results in millimeters. The Calibrate feature is used to calibrate the picture to real-world units. Calibration consists of three key phases. First, the camera position should selected to achieve the suitable scene. Then the camera scene calibration should be carried out to get transforms of picture pixels to millimeters. Finally, it is nessesary to associate the image coordinates to the working coordinates of the robot. The last can be done using work object coordinates defined as robot work object coordinate frame or separate values in software. The preferred scene coordinate calibration method for integrated vision is a checkerboard with a fiducial.

By establishing a work object with the same coordinate origin as the calibration plate, the camera is calibrated to the robot. The origin of coordinates on a checkerboard calibration plate with a fiducial is placed at the junction of the extended X and Y arrows, as seen in the image below. The calibrated file should be exported as a cxd file format to the camera.

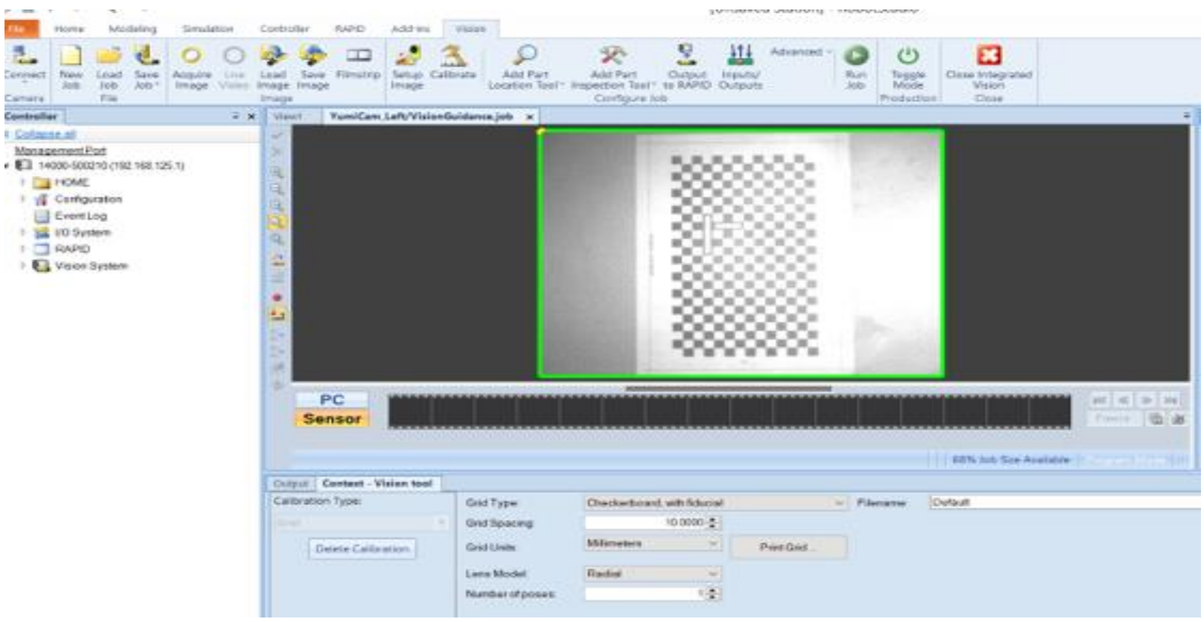


Figure 3.15 The calibration of camera scene coordinates

The camera calibration procedure is the first and most important stage in the vision system, since it provides the accurate coordinates of the identified item if done correctly. The first element that may interfere with the camera's calibration is illumination. They should have a suitable illumination source to detect the grid. The second factor is where the grid is placed. It is advised that it be a parallel axis with the robot's base coordinate axis. Aside from that, the calibration must be recorded to the internal memory of the smart camera. The coordinates of the robot will be measured from the calibrated axis to the base axis.

3.9.5 Image processing and pattern detection tools

Different object location tools can be used to define an image feature that contains positional data. These location tools generate a reference point that may be used to rapidly and consistently find a part in an image, even if the item being inspected rotates or appears in several positions in the picture. The object inspection tools can be used to inspect the pieces of an object that the locating tool has already detected and located. Depending on the needs of the specific application, several tools can be used simultaneously for verifying presence or absence, measurement, counting, geometry, and so on. In this phase, the developer can add vision tools based on the desired image processing operation. With Cognex smart-camera based system PatMat Pattern (1-10), PatMat Pattern (1-10) with sortPatterns, and PatMat Pattern (1-10) (1-50). These tools can find up to ten and fifty pattern features, respectively, and provide the X, Y coordinates, angle, and score of the discovered patterns. In this work, for example, the PatMat Pattern (1-10) with sortPatterns was used to sort the items after the location.

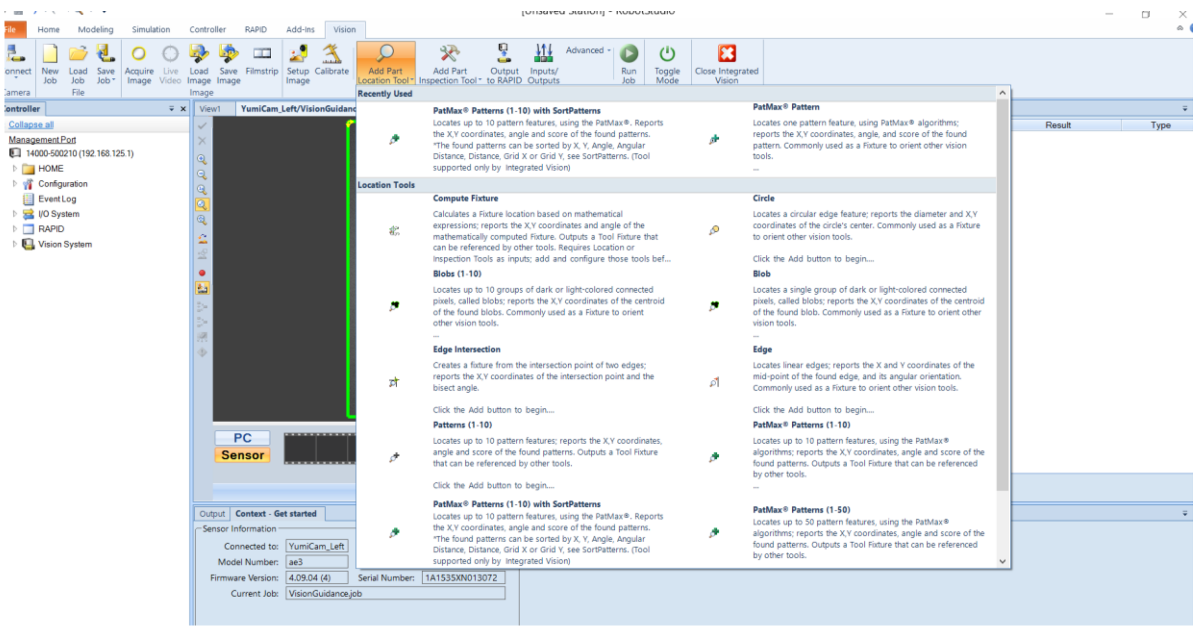


Figure 3.16 Different vision tools in ABB integrated vision environment

There are several parameters that can be updated while adding the vision tool:

1. **Number To Find.** This parameter specifies the number of instances to look for. When detecting numerous instances, the default number is frequently 1 and must be raised.
2. **Rotation Tolerance.** This parameter specifies how much the discovered pattern may be rotated from the training pattern while still being recognized as a valid pattern. The default setting of +/-10° to 15° is frequently insufficient and should be raised.

The PatMax® Vision tool has two steps: PatQuick and PatMax. The rotation tolerance option only pertains to the PatQuick stage. As a result, the ultimate rotational result of the component may be somewhat greater than planned.

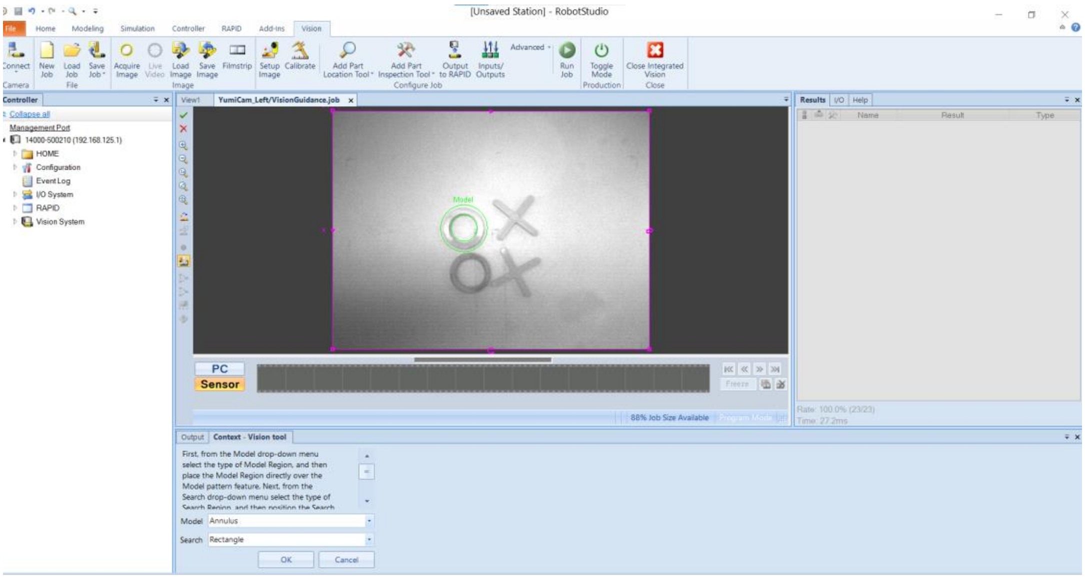


Figure 3.17 Adding Pattern Matching method in ABB Integrated Vision environment

3.9.6 Output of the camera result to the robot control program

Execution of the camera job file in smart camera produces several parameters with each image that is acquired. The output of the configured vision tools is most crucial, but extra data such as the utilized exposure duration, etc. are also vital. The mapping dialog in output to rapid allows the user to decide which data to convert to ABB Rapid programming language variables in a straightforward yet flexible manner. The goal is to allow the user to test with and change the vision task without having to change the quick software that uses the vision data.

The dialog allows the user to click and select which vision output parameter to be mapped to a specific property of the RAPID camera target record. It also allows the creation of categories of camera targets by defining the name property of the camera targets that are produced by the vision job. As it is demonstrated in Figure 3.18 the output result of the detected objects is displayed on the output taskbar. The output results are the X, and Y coordinates, the angle of rotation, and the score. The score is the percentage of to what extent the detected object is similar to the image used in training the image processing.

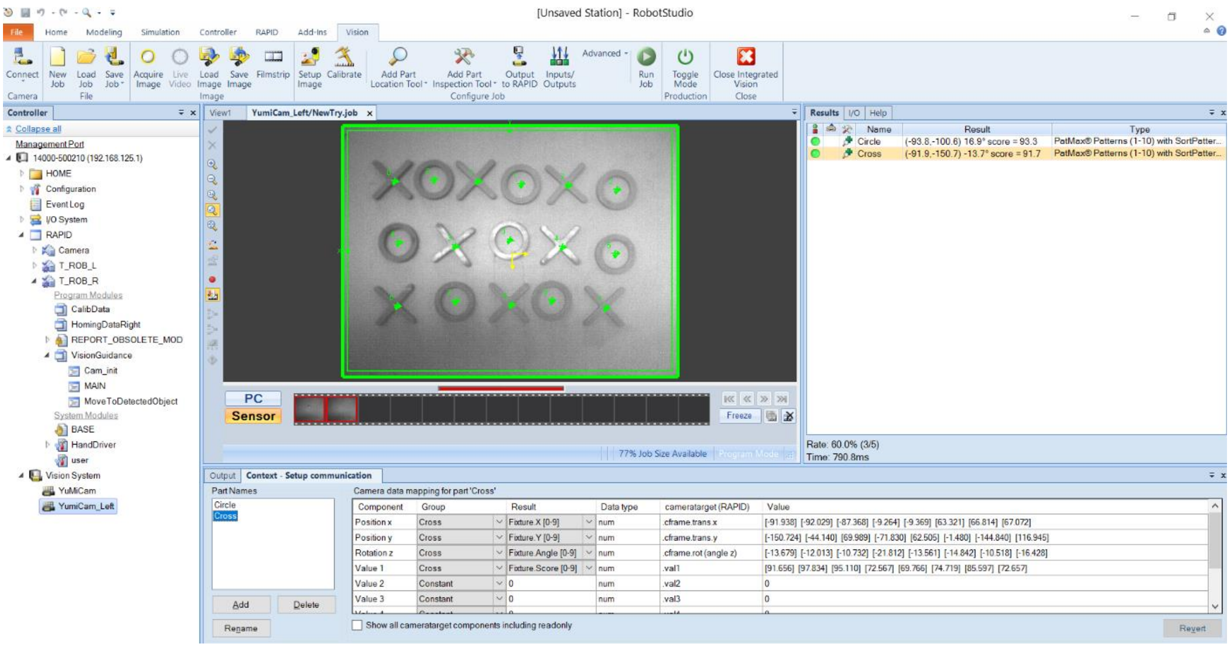


Figure 3.18 Output to RAPID Programming

Previous picture shows how arrays same type objects can be detected and ordered into coordinate arrays.

3.9.7 Robot control program development

The robot control program is in ABB RAPID language and is designed in such a way that the visual guiding system can identify, locate, and count items and provide their 2D coordinates.

The penultimate stage before manufacturing is rapid program preparation. Snippets are pieces of prepackaged rapid code that may be placed into the rapid program to direct the

robot to the identified item for manipulation. The X, Y coordinates and angle of the object received from the camera output as referenced in Figure 3.18.
Figure 3.19 illustrates that the flowchart of the proposed vision guidance system.

The developed rapid programming is divided into two parts: one for the left arm, which serves as a fixed camera position, and one for the right arm, which is used as an industrial robot arm for the task of positioning and sorting the detected objects in the predefined location, as shown in the appendices. The task of the left arm's rapid programming code is to move the robot from any arbitrary position to the camera position, where the vision system takes pictures for the image process and later detection, localization, and counting of the working objects as they are developed in the pattern recognition process.

The rapid programming code of the right arm, on the other hand, is to do the manipulation, which is choosing the detected items and arranging them in the predetermined location of the relevant objects. The initial step in this quick code is to load the task file from camera memory. The job file contains the trained model of the objects for pattern recognition and detection, as well as calibrated data and the objects' output parameters. While loading the job file the right arm moves to the initial position in such a manner that the right arm does not disturb the object detection process.

The "MoveToDetectedObject" routine, which controls the visual identification and detection process, is the core portion of the programming. After adjusting the exposure duration and flushing the camera, the integrated smart camera snaps a photo. If at least one item is discovered, it will distinguish between object one and object two. If not, the exposure time will increase and the camera will request an image. It will continue to increase until just one thing is identified and detected. Following the detection of the item, image processing follows and classifies the discovered objects according on the pattern specified in the job file.The identified items will be tallied and the 2D coordinates of the detected objects will be supplied progressively in array form. The software does different activities based on the identified item; for example, if the object is part one, it will take the ring and place it before aligning for the sorting process. If it is part two, the right arm selects the part and sort it in the predetermined location.

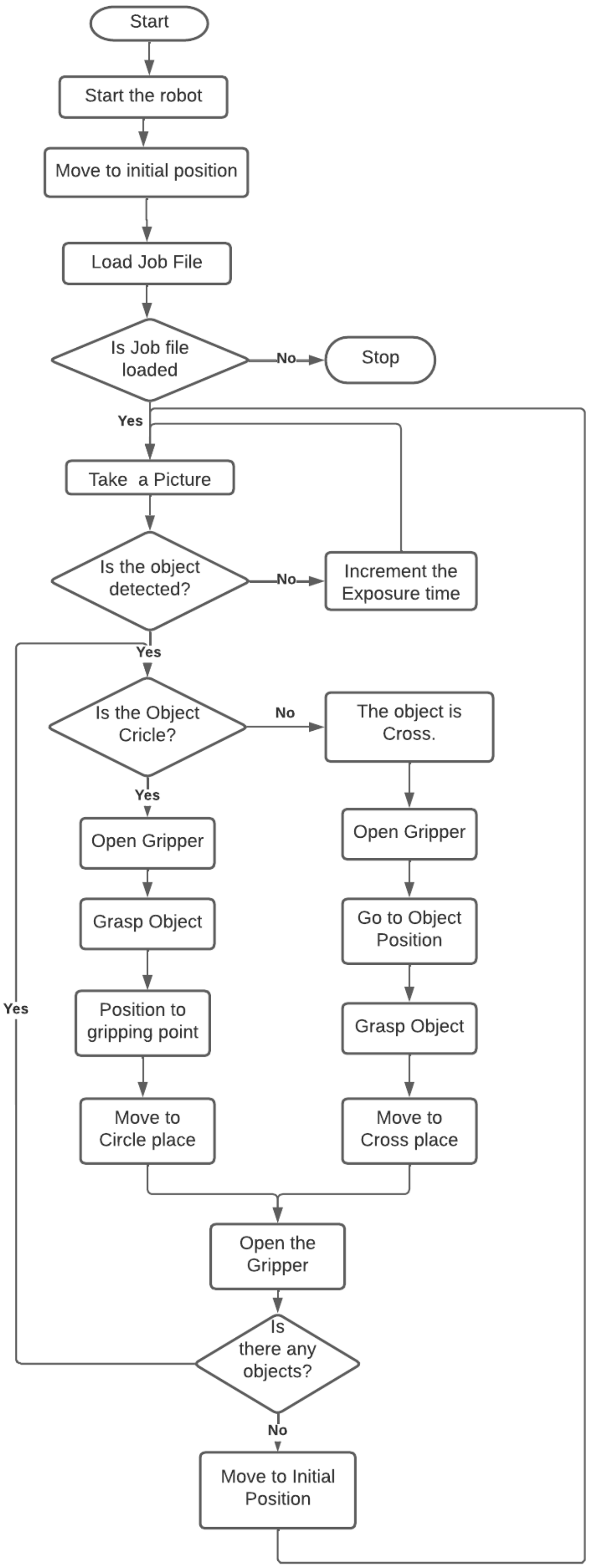


Figure 3.19 Flowchart of the output robot control program

3.10 Result and Discussion

The results under various situations are detailed in this portion of the report. Furthermore, the rationale for some failures in the gripping process is examined.

To see the effect of the lighting, the exposure time is looped, and it supplies the vision guidance system to detect the working objects in different lighting effects. The program starts from an exposure time that is set before running, and it increments by one until at least one object is detected. Figure 3.11 displays that at exposure time, the system could not detect the object. This is because of too much lighting effect from the room and smart camera also as a result the exposure time is too much. As a result, the result on the right and the box becomes red, this means that the operation could not detect any items in the workspace. If the system does not detect the manipulation is not going to happen, so consider under different conditions the exposure time increment in the range of exposure times 0msec and 10msec included.

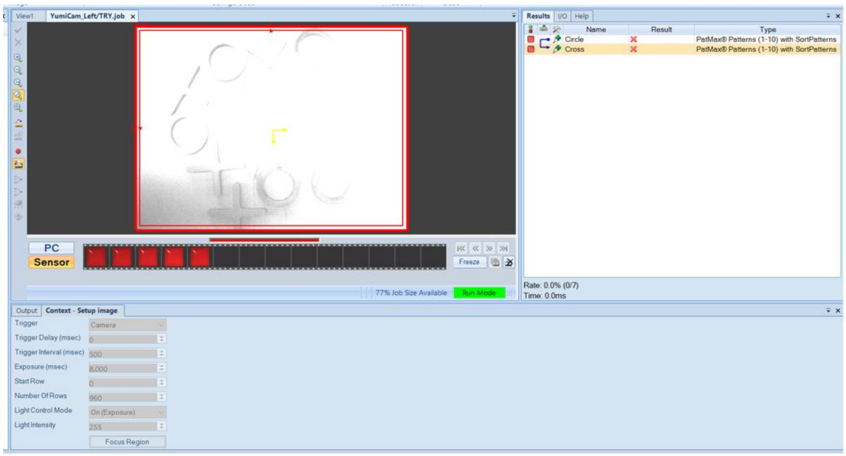
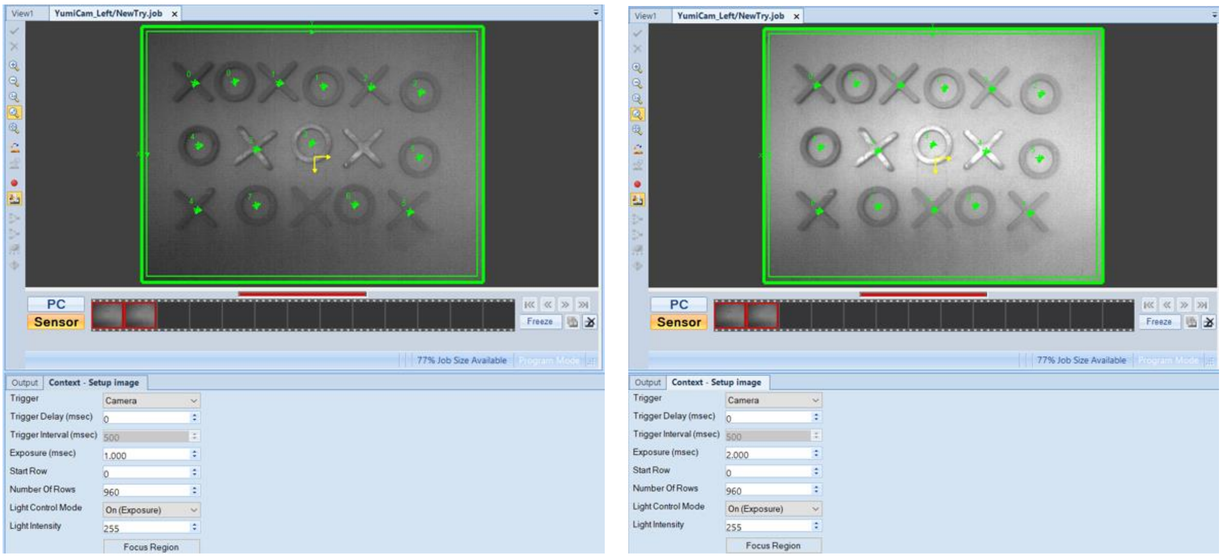


Figure 3.20 The result of the vision system at exposure time 8msec

The next result shows when the proposed system detects the object at different exposure times. For instance, in Figure 2.22 when the exposure time is 1msec (A) all objects are detected but in the case of the exposure time is 2msec (B) it is better than the earlier one. This is done while the room light is turned on, it has a huge effect on the detection and localization process. If there is no external lighting source in addition to the integrated light source in the Cognex integrated vision camera, the exposure time will increase to detect the objects. This shows that the light source and exposure time inverse relationship when there is good light the exposure time is less and if there is no good lighting source the exposure time is higher.



A B

Figure 3.21 The result of the vision system at different exposure time

Figure 3.22 The experimentation at the beginning of the manipulation

The manipulator and objects of the proposed system are depicted in Figure 3.22. The objects utilized in this visual guiding system are placed in a table with a known depth from the robot's base, and the depth of the objects is fixed because the system lacks a depth sensor or 3D camera capable of measuring the height of the objects. The left arm, which serves as a fixed camera, is suspended at a set height to identify objects with varying exposure durations. After the 2D coordinates of the identified items are communicated to the controller, the manipulation arm may accept orders from the robot controller.

Figure 3.23 The working station after manipulation

Figure 3.23 shows the result of the positioning and sorting process of the proposed system. According to the proposed method, the first step is to distinguish the objects in the workspace and after that, the robot moves to that specific object sequentially and picks the object, and sorts in the place where it should have to be. In this case, the 'Cross' is collected in one particular space and the 'Circle' in the other place. Even though it sorts and collected in a particular space, the manipulation of the objects has its own limitation because of different factors.

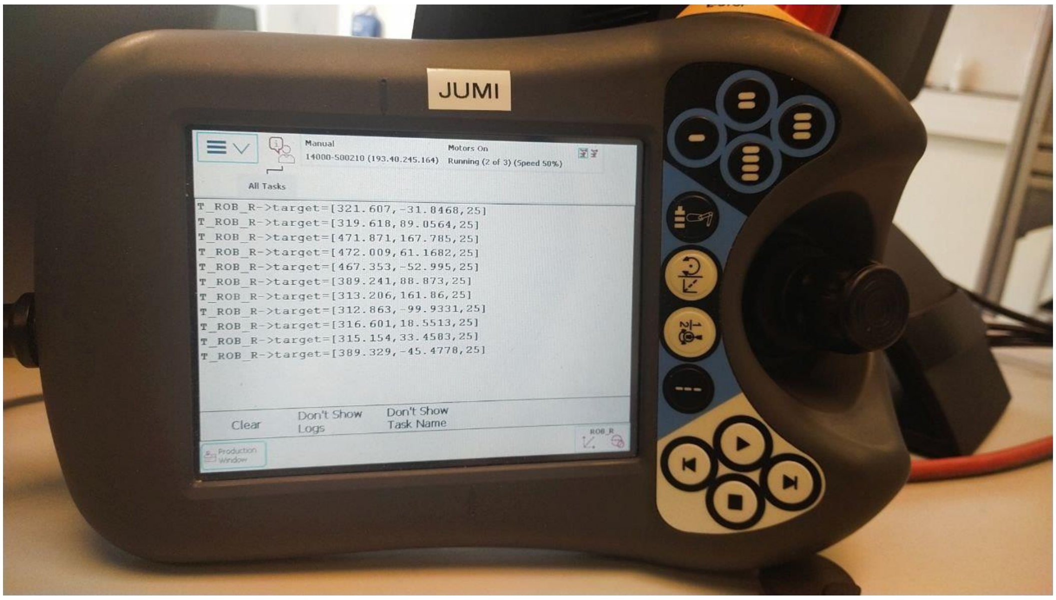


Figure 3.24 The coordination of the detected objects

Figure 3.24 shows the X, and Y coordinates, the angle of rotation, and the score of the detected objects. These coordinates are sent to the right arm of the robot, as a result, the robot moves that object sequentially as it is shown in Figure 3.18.

4 CONCLUSION AND FUTURE WORKS

The conclusion of the proposed machine vision system, limits, and recommendations for further study are discussed in this portion of the paper.

4.1 Conclusion

In this thesis, a machine vision-based manipulator positioning system for sorting purposes is developed. The vision guidance system is developed using the ABB YuMi dual-arm robot (Cobot) that is available in the laboratory. The investigated vision guidance system has shown that the accuracy and precision of the sorting and positioning operation mostly depended on the lighting source and lighting technics. An excessive amount of light on the workspace additionally affects the guidance system. As a result, appropriate lighting sources and technics have a lion's share in the detection and localization of the objects. During the selection process of the lighting sources and methods, the effect of lighting on the objects has to be under consideration.

The accuracy and pricison of the result of the vision system is depend on the parameters of the camera. The exposure time is the main factor in the vision system, which is related with the illumination of the lighting sources. Therefore the exposure time have to put in considertion during designing vision guidance robot system.

In developing the vision guidance system at the industrial level, the selection process of different hardware and software has to be under consideration. In the hardware part the selection of robotics arm, cameras, grippers, and so on have to be considered in accordance with different selection criteria and specifications of the hardware. In addition, the selection process also considers the software that is available with the hardware selection process.

Generally, the vision guidance robot system heavily depends on the illumination sources, lighting technics, and camera specifications. The pass and fail of the detection and localization process is the output result of the vision process.

4.2 Recommendation and Future Works

The developed machine vision system has the following limitation that is encountered during the implementation of the project.

1. The accuracy and precision of the vision system are significant depending on the illumination of light in the working space. The detection process is a crucial factor to get the precision coordinate of the object and as a result for the sorting and position process. Therefore, it is advisable to select the appropriate lighting system and technics according to the criteria of the required task.

2. ABB YuMi integrated Cognex camera is a 2D camera that can detect the 2D (X, Y) coordinate and angle of rotation. However, for the sorting and positioning the depth (the distance of the object from the camera) is necessary. In this paper, the depth of the object is fixed. But in practice, the depth must be determined automatically. It is recommended to use either sensor that can measure distance or use other cameras that can give information about the depth, like the 2.5D camera of OnRobot.

3. As a result of the different geometry, shape, and size of the objects the grasping processing has some limitations, this is because the objects used in the experimentation have dimensions almost equal to the maximum opening of the gripper. This shows that selecting the gripper type has to consider the specification of grippers for a particular robotization operation. For the "Circle" it is recommended to use a higher travel length than the current gripper, and for the "Cross" it is recommended to use a pneumatic gripper. Generally, pneumatic grippers are better than other gripper types for vision guidance robots.

4. As a future work it is also possible to guide vision to grasp a moving objects in the conveyors.Besises, it is also recommended to use other operating system like Robot operating system (ROS),CoppeliaSim, WeBot, and OROCOS (Open Robot Control Software project).

Generally, as a future work it is possible to use other collaborative robots as it is recommended in by considering different factors.

SUMMARY

The aim of the master's thesis was to develop a positioning system based on machine vision for the visual classification and sorting objects.

The control system is being developed and tested in the laboratory of industrial robotics of the Institute of Electrical Power Engineering and Mechatronics of Tallinn University of Technology. As a first step, the existing visual management system on the ABB collaborative robot YuMi was analysed. In the past, similar projects have been carried out for different applications and purposes, using different industrial robots and integrated vision systems. The vision control system described in the solution is based on the ABB YuMi and Cognex machine vision system, a double arm articulated collaboration robot with integrated machine vision in it's smart gripper.

The system was developed using the ABB RobotStudio software package, which also includes an integrated vision add-on. The integrated vision system uses Cognex's vision tool PatMax® to teach the vision control system to show and locate objects. The effect of ambient light shall be considered when teaching the complete calibration pattern model to the machine vision system. Light source and lighting technology have an important effect on object detection, localization accuracy and repeatability. The detected object cartesian coordinates X and Y, rotation, and shape similarity scores are only available after the camera and robot have been properly calibrated.

When the coordinates are given to the robot controller to position the robot arm, the robot hand moves to the detected object and performs an action at the specified location using the program. Based on the similarity score of the detected shapes, the necessary gripping alignment operations for different objects are distinguished. The sorting process is also based on the score. Exposure time is a principal factor in detecting subjects. To detect the subject in different lighting conditions, the program changes the shutter speed of the camera. The vision control system is equipped with two patterns that have been taught to recognize two different objects or up to ten related objects. Circular rings and cylinder-shaped cylinders were used as simple symmetrical objects. Cross-shaped objects were used as more complex objects, the lifting of which requires changing the angle of the gripping fingers according to the position of the object.

The experiments were performed using an ABB YuMi collaborative robot with an integrated vision system and a smart gripper, which is a very suitable platform for testing the control principles of the machine vision manipulator positioning system.

KOKKUVÕTE

Magistritöö eesmärk oli välja töötada masinnägemisel põhinev positsioneerimissüsteem objektide visuaalseks klassifitseerimiseks ja sorteerimiseks.

Juhtimissüsteemi arendatakse ja katsetatakse Tallinna Tehnikaülikooli Elektroenergeetika ja Mehhatroonika Instituudi tööstusrobootika laboris. Esimese sammuna analüüsiti ABB koostööroboti YuM olemasolevat visuaalset juhtimissüsteemi. Varem on sarnaseid projekte läbi viidud erinevatel rakendustel ja eesmärkidel, kasutades erinevaid tööstusroboteid ja integreeritud nägemissüsteeme. Lahenduses kirjeldatud nägemise juhtimissüsteem põhineb ABB YuM ja Cognexi masinnägemissüsteemil, kahe käega liigendrobotil, millel on integreeritud masinnägemisel intelligentne käepide.

Süsteem töötati välja ABB RobotStudio tarkvarapaketi abil, mis sisaldab ka integreeritud nägemise lisandmoodulit. Integreeritud nägemissüsteem kasutab Cognexi PatMax®-i nägemistööriista, et õpetada teile, kuidas teie nägemisjuhtimissüsteemis objekte tuvastada ja nende asukohta leida. Masinnägemissüsteemi täieliku kalibreerimismustri õpetamisel tuleb arvestada ümbritseva valguse mõjuga. Valgusallikal ja valgustustehnoloogial on oluline mõju objektide tuvastamisele, lokaliseerimise täpsusele ja korratavusele. Tuvastatud objekti X- ja Y-koordinaadid, pöörlemise ja kuju sarnasuse skoorid on saadaval alles pärast seda, kui kaamera ja robot on korralikult kalibreeritud.

Kui robotikontrolörile on antud koordinaadid robotkäe positsioneerimiseks, liigub robotkäsi tuvastatud objektini ja sooritab programmi abil toimingu määratud kohas. Tuvastatud kujundite sarnasusskoori alusel eristatakse erinevate objektide jaoks vajalikke haardejoondusoperatsioone. Skoori alusel toimub ka sorteerimisprotsess. Säriaeg on objektide tuvastamisel oluline tegur. Objekti tuvastamiseks erinevates valgustingimustes muudab programm kaamera säriaega. Nägemisjuhtimissüsteem on varustatud kahe mustriga, mida on õpetatud ära tundma kahte erinevat objekti või kuni kümmet omavahel seotud objekti. Lihtsate sümmeetriliste esemetena kasutati ringikujulisi rõngaid ja silindrilisi silindreid. Keerulisemate esemetena kasutati ristikujulisi esemeid, mille tõstmine eeldab haardesõrmede nurga muutmist vastavalt eseme asukohale.

Katsete läbiviimisel kasutati integreeritud nägemissüsteemi ja nutika haaratsiga ABB YuMi koostöörobotit, mis on väga sobiv platvorm masinnägemismanipulaatori positsioneerimissüsteemi juhtimispõhimõtete testimiseks.

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APPENDICES

RobotStudio RAPID programming

Right Arm

```
MODULE VisionGuidance

        ! Variable and constant parameter assignement.

    PERS bool picture_done;
    PERS bool camera_ready;
    VAR robtarget Pposition:=[[0,0,0],[0,0.707106781,0.707106781,0],[1,-1,2,4],[-178.063,9E+09,9E+09,9E+09,9E+09,9E+09]];
    VAR robtarget Uposition:=[[0,0,0],[0,0.707106781,0.707106781,0],[1,-1,2,4],[-178.063,9E+09,9E+09,9E+09,9E+09,9E+09]];
    VAR robtarget Start_position:=[[508.231,14.9673,250],[0,0.707107,0.707107,0],[1,-1,2,4],[-178.063,9E+09,9E+09,9E+09,9E+09,9E+09]];
    CONST robtarget Side_position:=[[508.58,-489.85,249.76],[0.000380127,-0.707031,-0.707182,-0.000108053],[1,-1,1,4],[-178.055,9E+09,9E+09,9E+09,9E+09,9E+09]];
    VAR robtarget adjustment_pos:=[[600,0,25],[0,0.707106781,0.707106781,0],[1,-2,2,4],[-131.078,9E+09,9E+09,9E+09,9E+09,9E+09]];
    VAR robtarget targetpos1:=[[613,0,100],[0,0.707106781,0.707106781,0],[1,-2,2,4],[-131.078,9E+09,9E+09,9E+09,9E+09,9E+09]];
    VAR robtarget targetpos2:=[[613,100,100],[0,0.707106781,0.707106781,0],[1,-2,2,4],[-131.076,9E+09,9E+09,9E+09,9E+09,9E+09]];
    VAR robtarget targetpos3:=[[613,-100,100],[0,0.707106781,0.707106781,0],[1,-2,2,4],[-131.076,9E+09,9E+09,9E+09,9E+09,9E+09]];

    VAR cameratarget mycamtarget;
    CONST string myjob:="NewTry.job";
    VAR robtarget currentpos;
    CONST num gripper_max_distance:=25;
    CONST num Y_calibation_adjustment:=17;

  ! Without initial exposure time, the system will give an error during camera initialization
```

```
  ! The main program

   PROC MAIN()

! Gripper installation and calibration
        g_Init;
        g_Calibrate\Grip;

! Moving the robot's right arm linearly to initial position

        currentpos:=CRobT(\Tool:=Servo);
        MoveL Offs(currentpos,0,0,100),v100,z0,Servo\Wobj:=wobj0;

! Object detection and localization part
        MoveToDetectedObject;
        Stop;
   ENDPROC

        ! Camera Intilization and loading the Job file

   PROC Cam_init()
        CamSetProgramMode YumiCam_Left;
        CamLoadJob YumiCam_Left,myjob;
        CamSetRunMode YumiCam_Left;
   ENDPROC

        ! Snippet Predefiened tool for detection of the objects.

   PROC MoveToDetectedObject()
        VAR num exp_time;
        VAR num myscene:=1;
        VAR bool cam_res:=FALSE;
        VAR num num_of_results;
        cam_init;
        currentpos:=CRobT(\Tool:=Servo);
        MoveL Offs(currentpos,0,0,100),v100,z0,Servo\Wobj:=wobj0;

        WHILE TRUE DO
```

```
WaitTime\inpos,0;
g_GripIn;
! Move to side position before photo, otherwise the hand will disturb the picture!
MoveJ Side_position,v500,z0,Servo\Wobj:=wobj0;
WaitTime\inpos,0;
CamSetRunMode YumiCam_Left;
! Stop moving before photographing to get better picure quality
WaitTime\inpos,0;
WaitTime 1;
exp_time:=1;
CamFlush YumiCam_Left;
cam_res:=FALSE;
WHILE (NOT cam_res) AND exp_time<10 DO
    CamFlush YumiCam_Left;
    picture_done:=FALSE;
    CamSetExposure YumiCam_Left\ExposureTime:=exp_time;
    CamReqImage YumiCam_Left;
    ! Wait until the Cognex camera gets it's picture processed
    WaitTime 1.5;
    IF CamNumberOfResults(YumiCam_Left)>0 THEN
       cam_res:=TRUE;
    ELSE
        exp_time:=exp_time+1;
    ENDIF
ENDWHILE
picture_done:=TRUE;
camera_ready:=FALSE;
IF cam_res THEN
    num_of_results:=CamNumberOfResults(YumiCam_Left);
    WHILE num_of_results>0 DO
        CamGetResult YumiCam_Left,mycamtarget\MaxTime:=1;
        num_of_results:=num_of_results-1;
        ! Coordinate conversion to work object
        ! x-coordinate
        Pposition.trans.x:=380-mycamtarget.cframe.trans.x;
        ! y-coordinate
        Pposition.trans.y:=Y_calibation_adjustment-mycamtarget.cframe.trans.y;
        ! z-coordinate
```

```
Pposition.trans.z:=25;
! Pick-up position
Uposition.trans.x:=Pposition.trans.x;
Uposition.trans.y:=Pposition.trans.y;
Uposition.trans.z:=100;
TPWrite "target="\pos:=Pposition.trans;
MoveJ Start_position,v1000,z0,Servo\Wobj:=wobj0;
WaitTime\inpos,0;
! Upper position
MoveL Uposition,v100,z0,Servo\Wobj:=wobj0;
WaitTime\inpos,0;
g_MoveTo gripper_max_distance;
! Lower position
IF mycamtarget.name="Circle" THEN
    g_MoveTo gripper_max_distance/1.5;
    MoveL Offs(Pposition,0,0,0),v100,z0,Servo\Wobj:=wobj0;
ELSE
    MoveL Pposition,v100,z0,Servo\Wobj:=wobj0;
ENDIF
WaitTime\inpos,0;
g_GripIn;
!Back to upper position
MoveL Uposition,v100,z0,Servo\Wobj:=wobj0;
WaitTime\inpos,0;

IF mycamtarget.name="Circle" THEN
    MoveL adjustment_pos,v100,z0,Servo\Wobj:=wobj0;
    WaitTime\inpos,0;
    g_MoveTo gripper_max_distance;
    MoveL Offs(adjustment_pos,0,0,100),v100,z0,Servo\Wobj:=wobj0;
    WaitTime\inpos,0;
    ! For centering of the circle
    MoveL Offs(adjustment_pos,0,-22,100),v100,z0,Servo\Wobj:=wobj0;
    WaitTime\inpos,0;
    MoveL Offs(adjustment_pos,0,-22,0),v100,z0,Servo\Wobj:=wobj0;
    WaitTime\inpos,1;
    g_GripIn\targetPos:=gripper_max_distance-2;
ENDIF
```

```
            IF mycamtarget.name="Circle" THEN
              MoveL targetpos2,v100,z0,Servo\Wobj:=wobj0;
              WaitTime\inpos,0;
              g_MoveTo gripper_max_distance;
            ELSEIF mycamtarget.name="Cross" THEN
              MoveL targetpos3,v100,z0,Servo\Wobj:=wobj0;
              WaitTime\inpos,0;
              g_MoveTo gripper_max_distance;
            ELSE
              MoveL targetpos1,v100,z0,Servo\Wobj:=wobj0;
              WaitTime\inpos,0;
              g_MoveTo gripper_max_distance;
            ENDIF
          ENDWHILE
        ENDIF
      ENDWHILE
      Stop;
    ENDPROC

  ENDMODULE
```

Left Arm

```
MODULE LEFT_ARM
    PERS bool camera_ready:=TRUE;
    PERS bool picture_done:=TRUE;
    CONST robtarget Camera_Pose:=[[356.88,-3.34,546.30],[1.00161E-
05,0.707097,0.707117,-3.85405E-06],[-1,0,0,4],[-
178.065,9E+09,9E+09,9E+09,9E+09,9E+09]];
    PROC main()
        MoveJ Camera_Pose,v100,z0,Camera\Wobj:=wobj0;
        WHILE TRUE DO
        camera_ready:=TRUE;
        ENDWHILE
        Stop;
    ENDPROC
ENDMODULE
```