Zagazig University, Faculty of Engineering,
Mechatronics Program

# ZuKa

## Deployment of industrial KUKA robot in CNC machining and visual servoing through Kinect interfacing on ROS

*Graduation project for the degree Bachelor of Science (B.Sc.) submitted to Mechatronics Program, Faculty of Engineering, Zagazig University, Egypt*

**by**

Ahmed Emam
Ahmed Saeed
Donna Mustafa
Dua'a Samir
Hoda Mahmoud
Reeham Mohamed

**Supervisors**

*Asst. Prof. Dr.Ing.*
**Mohammed Nour A. Ahmed**
*Computer and Systems Engineering Dept.*

*Asoc. Prof. Dr.*
**Ahmed Hamdy Hassanien**
*Mechanical Engineering Dept.*

Faculty of Engineering, Zagazig University, Zagazig, Egypt

July, 2017

Graduation Project Report submitted to
**Zagazig University, faculty of Engineering, Mechatronics Program**, Zagazig, Egypt
in partial fulfillment of the requirements for the degree
Bachelor of Science in Engineering (**B.Sc.**)
©2017



**Date of Presentation**
16. July 2017

**Project Team Memebers**

| | |
|---|---|
| Ahmed Emam | Ahmed Saeed |
| Donna Mustafa | Dua'a Samir |
| Hoda Mahmoud | Reeham Mohamed |

**Supervisors**
Asst. Prof. Dr.Ing. **Mohammed Nour A. Ahmed**
*Computer and Systems Engineering Department,*
*Faculty of Engineering, Zagazig University, Egypt*

Asoc. Prof. Dr. **Ahmed Hamdy Hassanien**
*Mechanical Engineering Department,*
*Faculty of Engineering, Zagazig University, Egypt*

**Defense Commete**

| | |
|---|---|
| Prof. Dr. **Nabil H. Mostafa**<br>*Mechanical Engineering Dept., Faculty of Engineering, Zagazig University* | ...................................<br>signature |
| Asoc. Prof. Dr. **Mohamed Talat**<br>*Electric Power Engineering Dept., Faculty of Engineering, Zagazig University* | ...................................<br>signature |
| Asst. Prof. Dr.Ing. **Mohammed Nour A. Ahmed**<br>*Computer and Systems Engineering Dept., Faculty of Engineering, Zagazig University* | ...................................<br>signature |
| Asoc. Prof. Dr. **Ahmed Hamdy Hassanien**<br>*Mechanical Engineering Dept., Faculty of Engineering, Zagazig University* | ...................................<br>signature |

Revision SVN.198.50.20170712

# Abstract

The first industrial revolution marked the transition to new manufacturing processes in eighteenth century, which is arguably similar to the transition introduced by the use of robotic manipulators in different industrial aspects in the late twentieth century. This project is motivated by the major developments in the industrial sector thanks to robots, especially in machining processes. Robots offer more flexibility, cost reduction and higher level of details, all of which are essential characteristics to any successful industry. Although these characteristics can be obtained by conventional CNC machines, however, the level and rate of production differ on larger scales, in favor of the robots.

The main problem can be summarized in Four points; accuracy, ease of use, flexibility and safety, and the solution to these problems defines the scope of our project. As for accuracy, it is obtained by implementing the robot itself, which offers multiple-axes movement, enabling the possibility for higher level of details than the conventional CNC machines. Ease of use is demonstrated in the user-friendly robot interface that enables the implementation of projects easily and without the need to multiple machines or tasks to deliver the final results. Flexibility is provided through the multiple programmable interfaces that offer multiple methods of control; Inline programming through KUKA's smartPAD, offline programming through converting G-codes from CAD files into KRL and ROS. Safety is increased in the work space of the robot by introducing a vision based safety system that reduces the robot's operating speed when someone enters this work space.

The results of the aforementioned methods and applications are diverse, offering milling in multiple dimensions and thus widening the scope of final products. In addition to introducing further control methods, which opens up new doors towards further developments and applications that were not applicable earlier.

# Acknowledgements

This graduation project consumed huge amount of work, research and dedication. Still, accomplishment would not have been possible if we did not have a support of many individuals. Therefore we would like to extend our sincere gratitude to all of them.

First of all, we would like to sincerely thank our advisors Dr.Ing. Mohammed Nour and Dr Ahmed Hamdy. They gave us the opportunity to work on great ideas with great people . When needing someone for the discussion of any problem, ..... was always there and also solved a lot of .......... problems for/with us.

we are also grateful to our friends and colleagues, XYZ, ABC, and UVW. For getting into the basics of this project, we had a lot of support by XYZ who raised our first interest during the initial part of this work. ABC helped us a lot with the ......... and experiments. UVW helped so much in ......... We are indebted to ........... for making ............ easier to understand and to introduce ........ to us.

we express our warm thanks to ......, ............, and ............ for making the ............ robot available to us and the time they spend assisting us to carry out the field experiments. Without their superior knowledge and experience, the experiments would not have that like in quality of outcomes, and thus their support has been essential. In addition, we wish to express our sincere gratitude to ............ for helping when we had questions as well as frustrations.

We would like to thank all the numerous people in the internet who ask questions and provide answers for programming problems (specifically in ROS) and for the very useful code and tools they share with others.

we would like to most importantly acknowledge the effort of our families, who encouraged us to pursue higher education and support us through the difficulties associated with such a goal even when we was not sure we would make it through.

Last but not least, we would like to thank our friends for always encouraging us onwards. We can never thank them enough for their love and faith.

This work was supported by a financial aid from Zagazig University. We would like to thank the funders. They had no role in study design, data collection and analysis, decision to publish, or preparation of this work.

# Contents

# List of Figures

# List of Tables

# List of Algorithms

*"There is nothing more difficult to take in hand, more perilous to conduct or more uncertain in its success than to take the lead in the introduction of a new order of things."*

*— Niccolo Machiavelli, (Italian writer and statesman, Florentine patriot, author of 'The Prince', 1469-1527)*

# Chapter 1 Introduction

Industrial robots are reshaping the present and future of most, and very soon all, industrial aspects. They are currently used in a broad spectrum of industries, some of which include car parts assembly as in BMW and Mercedes factories, industrial automation as in Yaskawa factories, metal industries that include welding and machining processes and many others. While there is a controversial part in replacing humans with robots in factories, it, nevertheless, offers more accuracy and higher production rate with more space for development. The growth of the Global Industrial Robotics Market is driven by many factors, of which the need to reduce manufacturing cost in industries is one of the main drivers. Industrial robotics aids companies in reducing the cost due to product failure and product wastage.

Some of the pioneering companies in the Industrial robotics market are ABB Ltd., Fanuc Corp., Yaskawa Electric Corp., Apex Automation and Robotics, Mistubishi Electric Corp. and KUKA AG. We had the opportunity to work with the latter, KUKA AG, on the implementation of our project (*ZuKa: Deployment of the industrial KUKA robotic manipulator in CNC machining and visual servoing through Kinect interfacing on ROS*). Over the course of our final year, this project helped increase our knowledge, not only on the main topic, machining and visual servoing, but also on the KUKA platform itself, which is considered an advanced platform widely used in today's industries.

The project is inspired by the aforementioned development in the industrial sector. The scope of the project can be summarized in the following three points; firstly, the commissioning and operation of the KUKA KR6 R900 sixx robotic manipulator, which included the installation of the related software and creating a network that facilitates communications with the robot. In addition to software commissioning, hands-on experience with the KUKA robot language (KRL) platform was achieved through learning the basic and advanced forms of KRL, which later helped in the development of software tools that facilitates the main objective of the project; the milling process.

Secondly, the design and manufacturing of a base to support the robot during heavy duty operation, this included performing mathematical calculations based on the robot's weight and forces to obtain the optimal dimensions and weight for the base, besides performing CAD studies on the manipulator's body to support the results of the mathematical analysis.

Finally, the development of various software tools to achieve the purposes of remotely controlling the robot and milling. These tools include an Inkscape extension for converting 2D G-code to KRL, directly using sketches from Inkscape, an independent toolkit for converting 3 axis G-code to KRL. In addition to Python tools; one Python class for reading and writing system variables, and a Python library for controlling the arm motions from pc. The development also included editing openni_tracker for publishing uncalibrated person's depth and creating ROS nodes for safety operation distance and visual servoing (hand guiding) for the robot.

Initially, the project scope was limited to the milling process in addition to minor ideas in the smart development of the workspace, however, over the course of the semester we encountered many problems that required extended research in all the previously mentioned aspects, which eventually led to broadening the scope of the project to include these development tools, both relevant and irrelevant to milling.

## 1.1 Project Contributions

The results of the project studies and implementation include, but not limited to;

- The manufacturing of the robot's base, with mathematically calculated data endorsed by CAD studies, contributing in a stable, secure and robust base that can support the weight of the robot and tolerate the forces resulting from the robot's motion without major failure or errors.
- The attachment and operation of a pneumatic gripper, leading to the development and implementation of software tools for drawing and palletizing.
- The development of different software tools to obtain the appropriate KRL codes used in the milling process.
- The development of a safety system in the robot's workspace, similar to KUKA AG's own Collision detection, which stops thee robot from moving when it hits a solid surface. However, being more efficient and safe, in terms that it does not require actual contact or collision but significantly reduced the operation speed of the robot when someone enters a defined perimeter of the robot's workspace. This is achieved using a Microsoft Kinect device for obtaining visual input of the workspace.

The results of the work exceeded both the preset expectations and goals for the project, resulting in a wide variety of applications and an extension in our own knowledge base, which is the most important achievement.

just some text for text

## 1.2 overview

some data

### 1.2.1 Flower Power

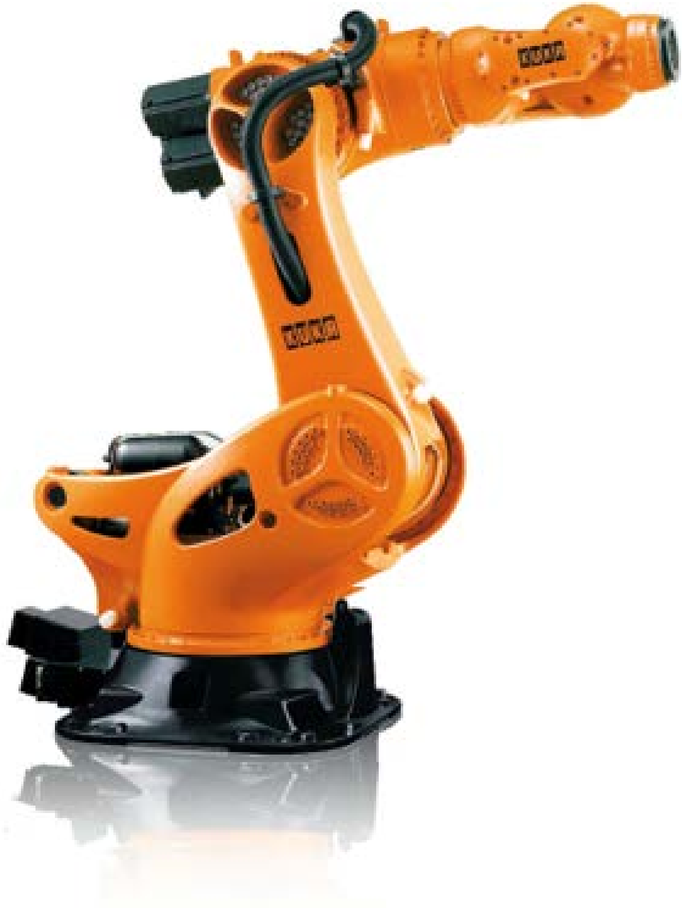

**Figure 1.1:** This is a test figure. You can use it as a template for your figures

*"It is impossible for us, who live in the latter ages of the world, to make observations in criticism, morality, or in any art or science, which have not been touched upon by others. We have little else left us but to represent the common sense of mankind in more strong, more beautiful, or more uncommon lights."*

*— Joseph Addison, (English essayist, poet, and politician, 1672–1719), Spectator, No. 253*

# Chapter 2
# State of the Art

*"A computer would deserve to be called intelligent if it could deceive a human into believing that it was human."*

*— Alan Turing, (British pioneering computer scientist, cryptanalyst,$\cdots$, and philosopher, 1912–1954)*

# Chapter 3
# Architecture Overview

*"Be sure you put your feet in the right place, then stand firm."*

*— Abraham Lincoln, (American $16^{th}$ President, 1809–1865)*

# Chapter 4

# Robot Programming

## 4.1 Cartesian–Axis Specific Coordinate System

### 4.1.1 Coordinate systems in conjunction with robots

The following Cartesian coordinate systems are defined in the robot controller:

**WORLDCoordinate System** Fixed, rectangular coordinate system whose origin is located at the base of the robot. It is the root coordinate system for the ROBROOT and BASE coordinate systems. By default, the WORLD coordinate system is located at the robot base.

**ROBROOT Coordinate System** Fixed, rectangular coordinate system whose origin is located at the base of the robot. It is the root coordinate system for the ROBROOT and BASE coordinate systems. By default, the WORLD coordinate system is located at the robot base.

**BASE Coordinate System** Fixed, rectangular coordinate system whose origin is located at the base of the robot. It is the root coordinate system for the ROBROOT and BASE coordinate systems. By default, the WORLD coordinate system is located at the robot base.

**TOOL Coordinate System** a Cartesian coordinate system which is located at the tool center by default, the origin of the TOOL coordinate system is located at the flange center point. The TOOL coordinate system is offset to the tool center point by the user

## 4.2 KUKA Robot Language (KRL) Quick Guide

KRC 4 controller uses KRL KUKA programming language.

kuka_coordinate_system.jpg

**Figure 4.1:** KUKA robot coordinate systems

### 4.2.1 Variables and Declarations

All system variables start with $ sign, mind not starting any "user-defined" name with this sign to avoid syntax errors.

**Names in KRL**

- Can have a maximum length of 24 characters
- Can consist of letters(A - Z), numbers(0 - 9) and the special characters '$'.
- Must not begin with a number.
- Must not be a keyword.

**Declaration and initialization of variables**

- Variables (simple and complex) must be declared in the SRC file before the INI line and initialized after the INI line
- Variables can optionally also be declared and initialized in a local or global data list.
- Every variable is linked to specific data type.
- The data type must be declared before use.
- The keyword for the declaration is DECL. It can be omitted in case of the four simple data type
  - In order to place syntax before the INI line, the DEF line must be activated: **Open file >Edit >View >DEF line**

```
DEF programName()
    DECL data type user defined variable
    ;declaration section of  variables
    INI
    ;Initialization section of user defined variables.
    ...
    ;Instruction Section
    ...
END
```

#### Simple Data types

| Data Type | Keyword | Meaning | Range | Example |
|---|---|---|---|---|
| Integer | INT | integer number | $-2^{3}1\ldots2^{3}1-1$ | 2 |
| Real | REAL | floating point number | $\pm1.1E-38\cdots\pm3.4E+38$ | 4.23 |
| Boolean | BOOL | logic state | TRUE, FALSE | TRUE |
| Character | CHAR | character | ASCII character | C |

**Table 4.1:** KRL Data Types

**Structure Types**

- AXIS: A1 to A6 are angle values (rotational axes) or translation values (translational axes)

  Axis: A1 .., A2 .., A3 .., A4, A5 .., A6 ..

- FRAME: X, Y, and Z are space coordinates, while A, B, and C are the orientation of the coordinate system.

  FRAME: X .., Y .., Z .., A .., B .., C ..

- POS and E6POS: S (Status) and T (Turn) define axis positions unambiguously

  POS: X .., Y .., Z .., A .., B .., C .., S ..., T

## 4.3 Motion Programming

### 4.3.1 Motion Types

The robot can move in various motion types. Paths are created according to the operation of each axis. Thus, the robot can be controlled to create either linear or circular path.

#### 4.3.1.1 Axis-specific motion

The robot guides the TCP along the fastest path to the end point. The fastest path is generally not the shortest path and is thus not a straight line. The first motion in the program must be PTP as status and turns are only evaluated here. The coordinates of the end point are absolute.

**characteristics**

- smooth motion
- Robot can move from start to end singularity free. As long as both the starting and ending points are in the working envelope, the robot will get to the end point without collision or sudden movement.
- Control is much simpler than continuous path control.

**Figure 4.2:** PTP Motion

ptp.png

#### 4.3.1.2 CP motion

**LIN Motion** Motion at a defined velocity and acceleration along a straight line. This motion requires the programmer to “teach” one point. The robot uses the point defined in the previous move as the start point and the point defined in the current command as the end point and interpolates a straight line in between the two points.

**Figure 4.3:** LIN Motion

LINmotion.png

**CIRC Motion** Motion at a defined velocity and acceleration along a circular path or a portion of a circular path. This motion requires the programmer to “teach” two points, the mid-point and the end point.

Using the start point of the robot (defined as the end point in the previous motion command) the robot interpolates a circular path through the mid-point and to the end point.

**Figure 4.4:** CIRC Motion

CIRCmotion.png

### 4.3.2 Approximate Positioning

Approximate positioning of motion means that the next programmed point will not be exactly reached. This can help to shorten cycle times

**Figure 4.5:** Speed Profile:
a) If all points approached exactly
b)In case of approximate positioning of the points

approximateAdv.png

**Figure 4.6:** Approximate positioning of an auxiliary points

apppos.png

#### 4.3.2.1 PTP-PTP approximate positioning

For the purposes of PTP approximate positioning,the controller calculates the distances the axes are to move in the approximate positioning range, and plans velocity profiles for each axis which ensure tangential transition from the individual instructions to the approximate positioning contour.

System Variable, $APO.CPTP enables the start of approximate positioning to be specified as a percentage of these maximum values. The approximate positioning of a point is displayed in the PTP command by adding the key word C_PTP:

```
$ APO.CPTP = 80
PTP HOME C_PTP
```

The greater this value the, the more path is rounded.

**Status and Turns** The position of x,y,z and orientation A,B,C values of TCP are not sufficient to define the robot position ,as different axis positioning are possible for the same TCP . Status and turns serve to define the position that can be achieved with different axis positions.

ST.png

**Figure 4.7:** Same TCP, different axis position

### 4.3.3 User Programming

Inline forms are available in the KSS for frequently used instruction. They simplify programming and facilitates user interface with controller without the need of knowing detail information about KUKA programming Language

### 4.3.4 Expert Programming

In the Expert interface, can achieve advanced programming using the KRL programming language and perform complex application programs including subprograms, interrupt programming, loops, and program branches.

*"Look up at the stars and not down at your feet. Try to make sense of what you see, and wonder about what makes the universe exist. Be curious."*

*— Stephen Hawking, (British theoretical physicist, and cosmologist*

# Chapter 5

# Short–Range Embodied Terrain Classification

*"I think setting a goal, getting a visual image of what it is you want. You've got to see what it is you want to achieve before you can pursue it."*
*— Chuck Norris, (American martial artist, actor, film producer and screenwriter)*

# Chapter 6

# Long–Range Visual Terrain Classification

*"You have brains in your head. You have feet in your shoes. You can steer yourself in any direction you choose. You're on your own, and you know what you know. And you are the guy who'll decide where to go."*

*— Dr. Seuss, (American writer and cartoonist, 1904–1991)*

# Chapter 7

# Path Planning and Following

*"It doesn't matter how beautiful your theory is, it doesn't matter how smart you are. If it doesn't agree with experiment, it's wrong."*
— *Richard P. Feynman, (American theoretical physicist, 1918–1988)*

# Chapter 8

# Experiments and Results

*The true function of philosophy is to educate us in the principles of reasoning and not to put an end to further reasoning by the introduction of fixed conclusions.*

*— George Henry Lewes, ( English philosopher and critic of literature, 1817–1878)*

# Chapter 9

# Conclusions and Future Outlook

# Bibliography

[Byrd and de Vries, 1990] Byrd, J. and de Vries, K. A. (1990). six-legged telerobot for nuclear applications development. *Int. J. Robot*, 9:43–52. []

[Cousins, 2011] Cousins, S. (2011). Exponential growth of ros [ros topics]. *IEEE Robotics Automation Magazine*, 18(1):19–20. []

[Digia, 2017] Digia (2017). Qt project. `http://qt-project.org`. []

[Ding et al., 2010] Ding, X., Rovetta, A., Zhu, J. M., and Wang, Z. (2010). Locomotion analysis of hexapod robot. *INTECH Open Access Publishe*. []

[Dynamics, 2015a] Dynamics, B. (2015a). Dedicated to the science and art of how things move, Boston dynamics. []

[Dynamics, 2015b] Dynamics, B. (2015b). *Boston Dynamics*. Boston dynamics. []

[Dürr et al., 2004] Dürr, V., Schmitz, J., and Cruse, H. (2004). “behaviour-based modeling of hexapod locomotion: linking biology and technical application”. *Arthropod Structure & Development*, 33:237–250. []

[G.M.Nelson, 1997] G.M.Nelson, R. (1997). Design & simulation of a crockroach like-hexapod robot. In *the IEEE international conference on Robotics & automation*, New Mexico. IEEE. []

[Gurfinkel et al., ] Gurfinkel, V., Gurfinkel, E., Devjanin, E., Efremov, E., Zhicharev, D., Lensky, A., Schneider, A., and Shtilman, L. I. o. r. In six-legged walking model of vehicle with supervisory control; nauka press: Moscow, russia, 1982;. *p*, pages 98–147. []

[KanYoneda, 2007] KanYoneda (2007). Light weight quadruped with nine actuators. *journal of robotics & mechatronics*, 19(2). []

[Lewinger and MartinReekie, 2011] Lewinger, W. A. and MartinReekie, H. (2011). A hexapod robot modeled on the stick insect carausius-morosus. In *the 15th international conference on advanced robotics*, Tallinn. []

[Lewinger and Quinn, 2010] Lewinger, W. A. and Quinn, R. D. (2010). A hexapod walks over irregular terrain using a controller adapted from an insects nervous system. In *the IEEE/RSJ international conference on intelligent robots & systems (IROS)*, pages 18–22, Taiwan. IEEE/RSJ. []

[Manoiu-Olaru et al., 2011] Manoiu-Olaru, S., Nitulescu, M., and Stoian, V. (2011). Hexapod robot. mathematical support for modeling and control. In *System Theory, Control, and Computing (ICSTCC), 15th International Conference on*, pages 1–6. []

[McGhee, 1977] McGhee, R. (1977). Control of legged locomotion systems. *In Proceedings of the*, 18:205–215. []

[Mehdigholi&SaeedAkbarnejad, 2012] Mehdigholi&SaeedAkbarnejad, H. (2012). " optimization of watt's six-bar linkage to generate straight& parallel leg motion" in the journal of humanoids. *ISSN*, pages 1996–7209. []

[MohdDaud and KenzoNonami, 2012] MohdDaud and KenzoNonami (2012). Autonomous walking over obstacles by means of lrf for hexapod robot comet-iv. *robotics & Mechatronics*, 24(1). []

[Moore and Buehler, 2001] Moore, E. Z. and Buehler, M. (2001). Stable stair climbing in a simple hexapod robot. Technical report, DTIC Document. []

[Okhotsimski and Platonov, 1973] Okhotsimski, D. and Platonov, A. (1973). Control algorithm of the walking climbing over obstacles.

In *Proceedings of the 3rd International Joint Conference on Artificial Intelligence*, CA, USA, 20. Stanford. []

[Peternella and Salinari, 1973] Peternella, M. and Salinari, S. (1973). Simulation by digital computer of walking machine control system. In Genova, I., editor, *Proceedings of the 5th IFAC Symposium on Automatic Control in Space of the Conference*. []

[Saranlı, 2002] Saranlı, U. (2002). *Dynamic locomotion with a hexapod robot*. PhD thesis, The University of Michigan. []

[Schneider and Schmucker, 2006] Schneider, A. and Schmucker, U. (2006). Force sensing for multi-legged walking robots: Theory and experiments part 1: Overview and force sensing. In Intelligence, M. and Buchli, J., editors, *Mobile Robotics*, pages 125–174. Germany; Austria, ; Pro Literatur Verlag ARS. []

[Seljanko, 2011] Seljanko, F. (2011). ”hexapod walking robot gait generation using genetic gravitational hybrid algorithm” in the 15th international conference on advanced robotics, estonia, june 20-23. 2011. []

[Tedeschi and Carbone, 2014] Tedeschi, F. and Carbone, G. (2014). Designissues for hexapod walking robots. *Robotics*, 3(2):181–206. []

[terrain hex-limbed extra-terrestrial explorer, ] terrain hex-limbed extra-terrestrial explorer, N. A. 2009. []