Faculty of Electrical and Electronic Engineering Technology

DEVELOPMENT OF G-CODE TO ROBOTSTUDIO RAPID TARGET WITH QUATERNION ORIENTATION FORMAT

EZRASIEFRITZ JANTIN ANAK JAMES

Bachelor of Electrical Engineering Technology (Industrial Automation & Robotics) with Honours

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DEVELOPMENT OF G-CODE TO ROBOTSTUDIO RAPID TARGET WITH QUATERNION ORIENTATION FORMAT

EZRASIEFRITZ JANTIN ANAK JAMES

A project report submitted
in partial fulfillment of the requirements for the degree of
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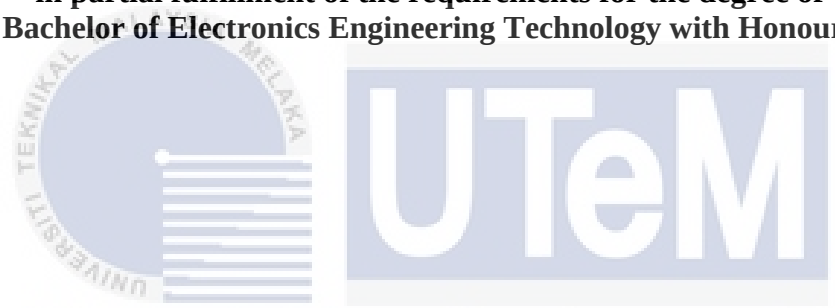

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Disahkan oleh:

TS. MOHAMED AZMI BIN SAID
Pensyarah Kanan
Jabatan Teknologi Kejuruteraan Elektrik
Fakulti Teknologi Kejuruteraan Elektrik dan Elektronik
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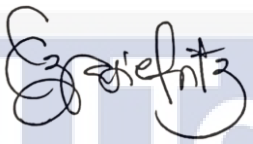
Signature : 

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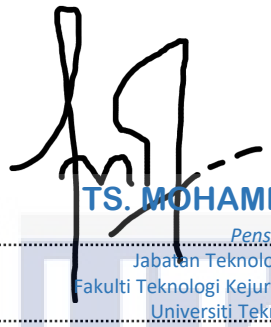
Signature : 

Supervisor Name : TS. MOHAMED AZMI BIN SAID
Pensyarah Kanan
Jabatan Teknologi Kejuruteraan Elektrik
Fakulti Teknologi Kejuruteraan Elektrik dan Elektronik
Universiti Teknikal Malaysia Melaka

Date : 11 JAN 2022

ABSTRACT

Every robot manufacturer has developed their own proprietary language since there are no standardizations for G-Code. Furthermore, to execute a complex milling required a competency of the operator in reading the instructions command and controlling the levers as it consists of thousand lines of command code. Hence, by develop an effective application for IRB 120 to be able to conduct milling process by using of Quaternion Orientation Format as it encodes information about an axis-angle rotation about an arbitrary axis. Based on previous version, the translation angle of Z-axis coordinates was fixed. Thus, by apply the Quaternion Orientation Format shall replacing the fixed Euler Orientation. Result show that by stimulate the Rapid Target with Quaternion Orientation Format provides a convenient mathematical notation for representing spatial orientations and rotations of elements in three-dimensional space in ABB RobotStudio.

ABSTRAK

Setiap pengeluar robot telah membangunkan bahasa proprietari mereka sendiri kerana tiada penyeragaman untuk G-Code. Tambahan pula, untuk melaksanakan pengilangan kompleks memerlukan kecekapan pengendali dalam membaca arahan arahan dan mengawal tuas kerana ia terdiri daripada ribuan baris kod arahan. Oleh itu, dengan membangunkan aplikasi yang berkesan untuk IRB 120 untuk dapat menjalankan proses pengilangan dengan menggunakan Format Orientasi Kuaternion kerana ia mengekod maklumat tentang putaran sudut paksi tentang paksi sewenang-wenangnya. Berdasarkan versi sebelumnya, sudut terjemahan koordinat paksi-Z telah ditetapkan. Oleh itu, dengan mengaplikasikan Format Orientasi Kuaternion bagi menggantikan Orientasi Euler tetap. Keputusan menunjukkan bahawa dengan merangsang Sasaran Pantas dengan Format Orientasi Kuaternion menyediakan tatatanda matematik yang mudah untuk mewakili orientasi spatial dan putaran unsur dalam ruang tiga dimensi dalam ABB RobotStudio.

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LIST OF ABBREVIATIONS

ABB	-	Robot Company
CAD	-	Computer Aided Design
CAM	-	Computer Aided Manufacturing
CIL	-	Common Intermediate Language
CLR	-	Common Language Runtime
CNC	-	Computer Numerical Control
C++	-	Programming Language
C#	-	Programming Language
DLL	-	Dynamic Link Library
FTP	-	File Transfer Protocol
G-Code	-	Geometric Code
GUI	-	Graphic User Interface
IRB	-	Industrial Robot Arm
JIT	-	Just-In-Time
KRL	-	KUKA Robot Language
MoveC	-	Move Circular
MoveJ	-	Move Joint
MoveL	-	Move Link
TCP	-	Tool Center Point

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CHAPTER 1

INTRODUCTION

1.1 Background

Due to a lack of uniformity in converting G-Code to other robot programming languages, each industrial robot has developed its own programming language. As a result, a G-Code to ABB RobotStudio Rapid Target conversion tool is necessary to correctly execute the robot program.

The IRB 120 will be able to mill any work object in ABB RobotStudio using CAD G-Code generated by graphical design software, which will then be converted to Rapid Target code. The conversion application will solely serve as a third-party utility. To convert G-Code to Rapid Target Code, the user must first build a work object in SolidWorks software, which then generates a G-Code by using CARTIA software that can be imported into this application.

Furthermore, due to the constraints of contemporary CNC machines compared to milling robots, despite the fact that both have similar processes, milling robots have more flexibility and diversity of operations. As a result, adopting an industrial robot for the milling process would provide a lot more benefits in terms of producing higher-quality final products.

1.2 Problem Statement

CNC machines are commonly used in the milling process in the manufacturing business. In terms of prototype size, axis movement, and drill bit size, each CNC machine

has its unique set of limitations. For a certain CNC machine to execute a specific sort of work product, it requires a different size and type of CNC machine. The specific CNC was less appealing due to the necessity to complete a complicated operation involving several axes of orientation and a substantially greater cost. Furthermore, the more specialized the CNC Machine, the more difficult it is to set up.

An industrial robot arm can now replace a CNC machine in the production sector since industrial mechanical robots can perform numerous tasks such as picking and positioning things, painting, assembly work objects, welding, machining, and other industry needs. A machining industrial robot serves the same goal as a specialized CNC machine in that it can perform any dimension and sophisticated machining involving multiple axes of rotation.

1.3 Project Objective

The main aim of this project is to propose a systematic and effective third-party application to convert G-code to RobotStudio Rapid Target Code with multiple axis of orientation. Specifically, the objectives are as follows:

a) Develop an effective application for IRB 120 to perform a milling process by using mathematical algebra of Quaternion Orientation Format.

b) Apply the use of compact, efficient, and numerically stable rotation matrices of Quaternion Orientation Format by replacing fixed rotation of Euler Orientation Format for industrial robot milling's conversion software.

c) Test the application through RobotStudio Emulation by using Rapid Target Code along with Quaternion Orientation Format to perform multiple axis of orientation for milling's process.

1.4 Scope of Project

The scope of this project are as follows:

a) Graphical User Interface (GUI) of third-party conversion application will be developed by using Microsoft Visual Studio's software of Window Forms App (.NET Framework).

b) SolidWorks software will be used to design the work object and CARTIA will be used to generate the G-Code.

c) Only the milling procedure will be performed after converting generated G-Code to RobotStudio Rapid Target with Quaternion Orientation Format.

d) The user will manually enter the values for yaw (Rz), pitch (Ry), and roll (Rx), as well as the velocity, zone, work object, and tool, to determine the appropriate rotation angle and speed for the ABB IRB 120 to perform milling operation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

An industrial robot arm is the most common robot in the manufacturing industry since it improves not only the speed but also the accuracy and precision of the manufacturing process. An industrial robot arm is a technical marvel since it is a combination of controller and software that resembles a human arm. Aside from that, milling is one of the most common uses for an industrial robot arm. Robotic milling's ability to manufacture high-quality complicated and unusual shapes was the cause for its replacement of CNC machines, as robot milling can do manufacturing and sculpting on a massive scale. Robot milling systems are designed with tooling and cutting system adaptability at a high level, allowing them to accommodate to various material removal processes.

Because there are no standardizations for G-Code, each robot maker has developed their own proprietary language. Furthermore, because a complicated milling comprises of thousands of lines of command code, the operator must be capable of deciphering the instructions and controlling the levers. As a result, third-party application software to translate G-Code to robot language is offered by every major robot manufacturer. As a result, creating a conversion from G-Code to RobotStudio Rapid Target Code with Quaternion Orientation Format ensures that robot milling operations and G-Code programming are as simple as possible.

This chapter will go over the existing G-Code converter solutions. As a result, the ABB RobotStudio, Microsoft Visual Studio, G-Code, Rapid Target Code, and C# programming languages used in development will be thoroughly described. Moreover, by

completing the development will aid in achieving the goal and resolving the problem that has plagued industrial manufacturing.

Aside from that, the objective of authoring this chapter is to serve as a reference or guide, as it will be based on research, articles, user manuals, theses, journals, and other types of published knowledge relevant to the project's theme.

2.2 Type of Programming Languages

A standardized programming language is still not used by robots today. Currently, each vendor is reliant on their own control system. The structure of the code between ABB and KUKA differs significantly. The user can specify a starting block in the KRL language for KUKA robots that determines several settings, such as the tool.

Furthermore, the tool is defined for each movement command in the Rapid Target code, thus this isn't necessary to define in the movement commands. Another distinction between these companies is that the KUKA robotics control system uses x, y, and z coordinates for translation and Roll, Pitch, and Yaw for defining rotational angles in degrees.

According to Bolmsjö, the roll, pitch, and yaw ways of representing rotation are the same movements that an airplane makes, where roll denotes a rotation along the hand's longitudinal axis, the pitch is a horizontal axis rotation that causes the end effector to rotate up and down while the yaw denotes a rotation along a vertical axis in relation to the hand longitudinal axis, causing the end effector to rotate from side to side.

Moreover, ABB robotics uses x, y, and z coordinates to determine translation and quaternions to define rotational angles[1].

2.2.1 G-Code Programming Language

G-Code is an operational language for CNC machining which tells numerically controlled lathes and machining centers on how to move tools in order to perform various cutting operations. It is a language that can be quite complex at times and would vary from machine to machine.

Moreover, G-Code come in group with each group can be replaced by another code in the same group. Hence, programmer be able to establish mode of operation. G-Code fits somewhere between conversational control, where an operator describes the part and how it should be machined, and CAM programs, where software develops the necessary toolpaths, feed rates that been needed for CNC machine to cut the material into end products[2].

Furthermore, G-Code is best to illustrate as a combination of geometric code and variation of the alpha numeric pattern such as, N (Line number), G(Motion), X (Horizontal position), Y (Vertical position), Z(Depth), F (Feed rate), S (Spindle speed), T (Tool selection, Miscellaneous function), I and J (Incremental center of an arc), R (Radius of an arc). While the alpha numeric codes are used for defining motion and function (G##), Declare a position (X## Y## Z##), Set a value (F## or S##), Select a tool (T##), Switching coolant on and off (M##)[3].

2.2.2 RobotStudio Rapid Target

Rapid Target is a robot programming language that been used to program ABB's industrial robots in RobotStudio that rely on three different types of motions[1]. First is, MoveL is a linear motion which forces the robot to move in a straight line between two points that been defined by the programmer.

Second type of motion is, MoveJ is a point-to-point motion that lets the robot move to the second point in the easiest way. Moreover, the benefit of letting the robot decide the

easiest way as it also capable to avoid collusion whenever the robot wanted to move to opposite side of the layout as it will create a circular motion around the base since it travel along a non-linear path[4]. Thus, MoveJ is often required in the beginning of the robot path in order to let the robot to configure itself without the constraint of following a specific path.

Third type of motion is MoveC where it is used to move the TCP circularly to a given destination. Furthermore, it will create an arc motion that doesn't need to be circular as the orientation normally remains unchanged relative to the circle[4].

2.2.3 C# Programming Language

C# is a modern object-oriented, general-purpose programming language, created and developed by Microsoft together with the .NET platform. It is simple yet powerful language primarily aimed at developer for creating various types of applications, for example web, windows, console applications, or other types of applications using Microsoft Visual Studio at a large scale[5].

Furthermore, C# is syntactically similar to Java and C++ as it's also a high-level language which consists of a set of definitions in classes that contain methods while the methods contain program logic (instructions that will be executed by computer)[6]. Moreover, C# programming language was not considered as a standalone product as is a part of Microsoft .NET framework which consists of an environment for development and execution of programs.

Microsoft .NET Framework is a software development framework for building and running an application such as website, providing a service, desktop apps on Windows. Other than that, two main components of .NET Framework are Class Library which acts as a provider to provide a set of APIs and types for common functionality such as strings, dates,

number, and Common Language Runtime (CLR) which acts as an execution engine for handling running applications[7].

In a nutshell, Microsoft .NET Framework applications are written in C# programming language code. The code been compiled into Common Intermediate Language (CIL) which then stored in assemblies file (.dll or exe file extension). When a user runs an application, Common Language Runtime CLR shall analyze the assembly's file and uses a JIT to turn into machine code to be executed on the specific architecture of the computer.

2.3 Grasshopper

Grasshopper is a software for Rhinoceros CAD system. Rhinoceros is a CAD software for surface modeling. Grasshopper is an add-in that enables the user to create parametric structures without the need of knowing how to write scripts. Instead, Grasshopper uses a visual scripting tool where the user can drag lines between different 8 blocks with different functions where the coding is embedded in the block so that the user doesn't need to write the code. The principle of the usage is the same as for many other visual scripting tools such as the, to engineers more commonly known software LabVIEW, and Simulink for Matlab[8].

2.4 HAL

HAL robot programming tool is an add-on framework for Grasshopper. HAL could be used to create robot paths with visualization directly in the CAD software. The software supports ABB IRC5 controllers which make it possible to simulate the robot motions. The premium version also has the possibility to directly create robot code in the HAL software that is executable on the robot controller. The software is also capable of importing G-code

and translate the code into paths. The software is mainly focusing on architectural applications[9].

2.5 ABB Machining Pac

The ABB machining PowerPac is ABB's own add-in software for ABB Robot Studio. The software makes it possible for the user to create machining paths by importing CAD geometries directly into Robot Studio. The software does support path generation from G-Code. It also features to act as a CAM software and calculate the tool path in the off-line programming software. The benefits of using ABB's own software are that the user is guaranteed that if the path is executable in the simulation, it will also be executable on the robot. A feature that other software's does not have. A drawback with the software is that it is closed source and it is therefore not possible for the user to customize the software for their specific needs[10].

2.6 Boot the Bot

This is a Java-based software that enables the user to import points and additional data and export valid RAPID code from Boot the Bot. Since the software is built in Java it is designed to have cross-platform support. The software is able to automatically calculate the best-suited configuration for the robot. It also allows for FTP (file transfer protocol) connection to the robot, which allows for remote upload of robot programs and remote robot control[11]. The software also gives the user a full simulation of the workflow in the program. It is designed to enable a more creative freedom for the designer and is primarily targeting users working as architectures and artists.

2.7 RISE from RoboMaster

A full offline programming software that is also able to import CAD geometries and create robot paths for multiple vendors of robots. The software has an in-built CAD engine that makes it possible to create and edit CAD models within the software. It has the capability to import CAM data from 2-5 axis machines and translate it into robot code. And it is able to handle configuration problems and singularities[12].

2.8 Types of Software

In the development for this project several software were considered to be used, due to it is a software development project. Microsoft Visual Studio serve as a major role in C# programming language for the conversion application to be achieved. Moreover, the design of the work object along with robot tool will be done in SolidWorks. Thus, the generated G-Code will be generated by using CARTIA. Furthermore, simulation will be done in ABB 10 RobotStudio along with the execution of Rapid Target code that been converted from generated G-Code.

2.8.1 RobotStudio 6.05

RobotStudio is an offline programming tool for the setup of ABB Robots which allow robot programmer to generate more accurate robot programs. It also capable to help the designers to visualize and determine the layouts before the robot been install. Furthermore, designers be able to perform a simulation based on a real time simulation and optimization without disturbing the production as it uses ABB Virtual Robot Technology.

Thus, the offline programming approached by ABB RobotStudio also display the best way to maximize return on investment on robot systems[1]. There are several benefits

of RobotStudio which are, Auto Reach feature that will automatically analyze reachability for user to verify and optimize the overall layout.

Next, Path Optimization which will automatically detect and warn about programs that targets can be improved to make the robot move in the most efficient way. Furthermore, the most valuable benefit using ABB RobotStudio is Virtual Flex Pendant feature which is a graphical representation of the real Flex Pendant which indicate that everything that could be done in Virtual Flex Pendant will be able to perform in real Flex Pendant[13].

2.9 Quaternion Orientation Format

Versors, or unit quaternions, are a useful mathematical notation for representing spatial orientations and rotations of items in three dimensions[14]. They encode information about an axis-angle rotation along an arbitrary axis in particular. Computer graphics, computer vision, robotics, navigation, molecular dynamics, flight dynamics, satellite orbital mechanics, and crystallographic texture analysis all use rotation and orientation quaternions[15].

Unit quaternions are also known as rotation quaternions because they represent the 3D rotation group when used to express rotation. They are called orientation quaternions or attitude quaternions when they are used to describe an orientation (rotation relative to a reference coordinate system). The quaternion (C,XS,YS,ZS) signifies a spatial rotation about a fixed point of theta radians along a unit axis (X,Y,Z) that denotes the Euler axis, where $C=\cos(\theta/2)$ and $S=\sin(\theta/2)$[16].

Quaternions are more compact, economical, and numerically stable than rotation matrices. They are easier to construct than Euler angles and avoid the problem of gimbal lock. They are not, however, as obvious, or as simple to comprehend as Euler angles. Furthermore, due to the periodic nature of sine and cosine, rotation angles that differ