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An Accuracy and Repeatability of a Robot made with V-Slot Extrusion with built-in Linear Rails

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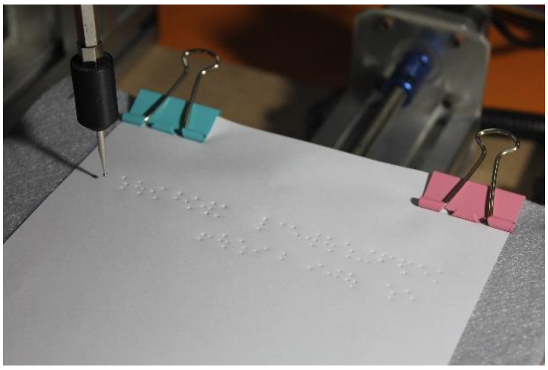
Abstract. Recently, aluminum extrusion with a built-in V-rail linear bearing draws increasing attention, especially among the hobbyist and makers, and is applied into many of their projects. The aluminum extrusion is an open source, light weight, and coming with extensive accessory. This significantly reduces cost and gives flexibility to their projects. Its performance is reasonable and adequate for operations among hobbyist and university's projects. However, the precise accuracy of this kind of robot is usually unavailable. Accordingly, the purpose of this paper is to investigate and analyse performance of the V-Slot extrusion with built-in linear rails robot in terms of accuracy and repeatability. The tools, in this investigation, can be obtained within the ecosystem and the process can be done by the user. This performance result will help general users to define the scope of the operation that can be achieved with reasonable result when using this robot. The methodology, in this experiment, is Trajectory analysis approach that commands the robot to move in both linear and circular, with various travel distances, in a single run, and determine the defects. Effects of travel speed are also investigated. From experimental result, the accuracy of the experimental robot is 0.45 mm in the entire range of motion. This methodology can be applied to other machines with their accuracy not better than 0.1 millimetre due to the precision of tools that are used.

1. Introduction

Since 1980, industrial robots were designed with high accuracy by using high-grade materials [1], intricate assembly process, and advanced controller. They are comparatively expensive among automation devices. By the technological advancement, robot's performance is enhanced, while its cost continues to decrease. As the robot's cost to perform ratio reduces, the robots have been widely introduced into new applications. Recently, aluminum extrusion with a built-in V-rail linear bearing catches more attention, especially among the hobbyist and makers, as it can be seen in many activities; 3D printer (1), Farmbot (2), Braille Printer in Figure 1. The aluminum extrusion is an open source, light weight, low cost, and coming with extensive accessory. Its ecosystem is very interesting. This gives flexibility to both the design and how we source parts, which can be obtained by various vendors. The performance of this robots also appropriates for daily activities which only sub-millimetre precision is adequate. Though, for this robot, its resolution is usually given by provider, its accuracy and repeatability are usually missing and cannot be exactly identified since the robot was fabricated under ecological communication. The international standard ISO 9238 [2], that is used to determine the accuracy and repeatability of an industrial robot [3], requires precision, expensive tools and time-consuming process, is not applicable for the user in aluminum extrusion's ecosystem. Furthermore, the accuracy and repeatability are for the robots, not the task. This paper focuses on the investigation of accuracy and repeatability of aluminum extrusion robots while it is performing on specific tasks – gripping and moving-- by using trajectory analysis approach. Trajectory analysis approach is designed to be a simplified method that requires only ecological equipment and lessens performing time, which is accessible by user. Trajectory analysis approach is the accuracy and repeatability investigating method focusing on the shifting of value between desired trajectory and actual performing trajectory of the robot.



(a) Braille Printed on Paper

(b) Demonstration

Figure 1. Braille Printer

2. The Cartesian robotic system

The robot used in this experiment is fabricated by Thai StartUp company "Easy Builds". The components of robot shown in Figure 2 are built with 3030 V-Slot aluminium Extrusion profile, a feed screw and rollers. The thread of the screw is 1 mm. Each axis is driven by NEMA stepper motor with micro stepping drive and Arduino board that can give the resulting velocity up to 50 mm/s for X and Y axes and 10 mm/s for the Z axis with 0.0025 mm resolution. The workable space is $150 \times 150 \times 150$ mm^3. The controller board is RUMBO 3D printer control board with Repetier firmware.

3. Design of experiment

To investigate the accuracy and repeatability of the experimental Cartesian robot in moving and gripping task, trajectory analysis approach has been assigned. The Z-axis of this experimental robot is in vertical direction against gravity field while X- and Y-axis are in horizontal plane. Thus, the characteristic of motion robot's arm in XY-plane will be differ from the motion in Z-axis. Furthermore, the G-code [4], which is the ISO standard language used to control the machine, commands the motion with linear or circular trajectory. It is noted that G01 is for linear movement, G02 and G03 for clockwise and counter clockwise circular curve respectively, G04 for time delay which could stop the motion of all axes for a given amount of time. For the accuracy investigation, we command the robot to move in circular motion with various radius, e.g. 10,20,30,40,50,60 mm and radial motion with various directions. E.g. and each set up of the robot is commanded with two velocity, high and low velocity. In this designed moving pattern, both linear and circular trajectories are investigated in a single run. For the repeatability test, we command the robot to move repeatedly in circular motion for 30 mm in an entire workspace in horizontal plane. In the task, the robot grips a pen in its hand and draws lines on the paper. A 0.5 mm felt-tip pen is used. For the image processing process, scanning ink trace graphical is result in a resolution of 300 dots per inch (about 0.085 mm resolution) to measure all necessary dimensions in sub-millimetre tasks; the circle's radius, length of the line. Moreover, for an accuracy investigation, constructing the circumferential band that cover the ink trace to represent the minimum and maximum radius of the ink trajectory; the width of the band will represent the accuracy. The repeatability of the robot can be obtained by the maximum deviation between desired trajectories and ink trajectories. The effect of length and velocity are investigated.

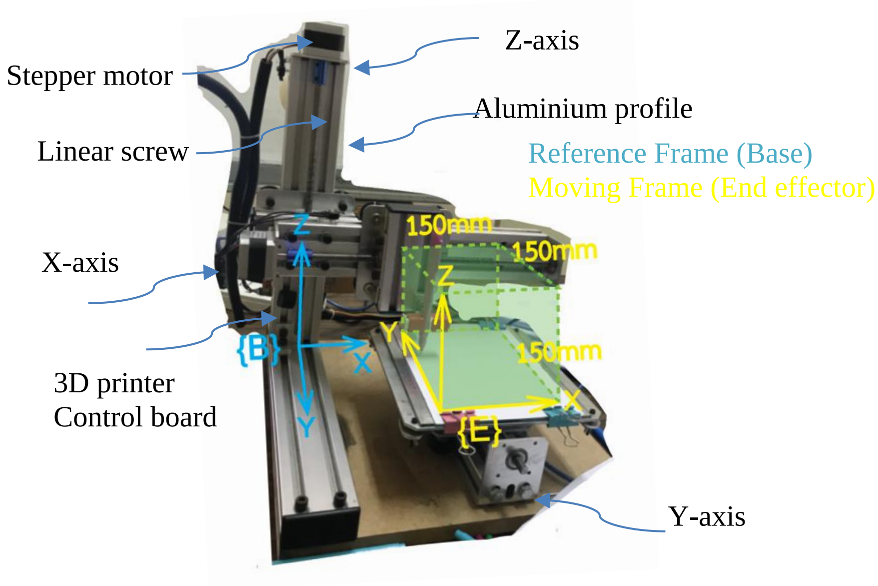
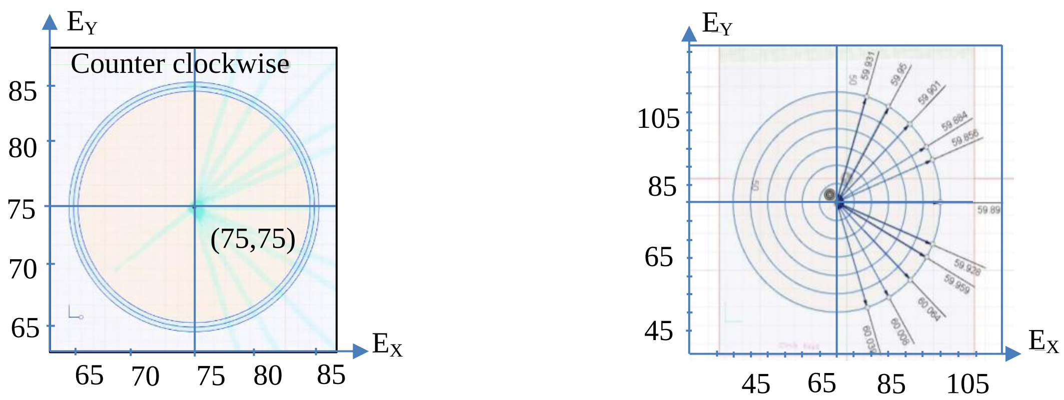


Figure 2. Cartesian Robot made with aluminium extrusion

4. Experimental result

The experimental accuracy is demonstrated in Figure 3. From the experiment, in the work space of 150x150x150 m^3, the accuracy, as analysed in Table 1, of this robot is 0.45 millimetre under the entire range of travel velocity. The accuracy linearly degrades as the robot's travel velocity increases. If the travel velocity is too high (2400 mm/min in the repeatability test, as in Figure 4 and summarized in Table 2), the repeatability degrades quickly. The tools, that are used in the proposed technique, give the variation of result around 0.1 millimetre which could be used to examine the accuracy at about 0.5-millimetre resolution. This is sufficient for this type of robot that its accuracy is about 0.5 millimetre and for our case that the resulting accuracy is only 0.45 millimetre. The effect of travel's distance also linearly degrades the accuracy. This could be corrected at the step/millimetre in the controller's firmware. The accuracy is better when the robot travels along its hardware's axis, in X-direction in this case, and slightly poorer in the incline direction. The linear trajectory gives better accuracy. These preliminary results may be used to design the task's trajectory for a better accuracy.

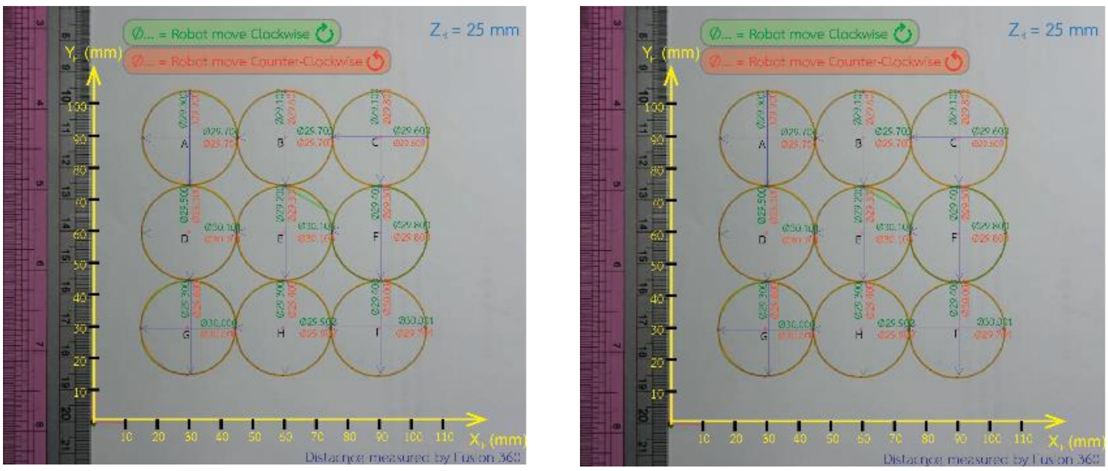


(a) Circular trajectory (b) Linear trajectory

Figure 3. Accuracy analysis in the horizontal plane

Table 1. Accuracy analysis

(a) circular trajectory (G02 G03 command)							(b) linear trajectory (G01 command)		
velocity	Circle label	Commanded distance (mm)	Band radius (mm) Inner band	Band radius (mm) Outer band	accuracy (mm)	Max accuracy (mm)	Degree (°)	Radius got (mm)	Accuracy (mm)
300 mm/min	A	10	9.8718	10.128	0.128		73	60.356	0.356
	B	20	19.835	20.165	0.165		60	60.286	0.286
	C	30	29.775	30.225	0.225		45	60.318	0.318
	D	40	39.703	40.297	0.297		30	60.178	0.178
	E	50	49.758	50.242	0.242		22.5	60.154	0.154
	F	60	59.593	60.407	0.407	0.407	0	60.075	0.075
							-22.5	60.135	0.135
							-30	60.262	0.262
							-45	60.283	0.283
							-60	60.142	0.142
							-73	60.262	0.262
600 mm/min	A	10	9.9088	10.091	0.091		73	59.931	0.069
	B	20	19.873	20.127	0.127		60	59.95	0.05
	C	30	29.798	30.202	0.202	0.251	45	59.901	0.099
	D	40	39.841	40.159	0.159		30	59.884	0.116
	E	50	49.826	50.174	0.174		22.5	59.856	0.144
	F	60	59.749	60.251	0.251		0	59.89	0.11
							-22.5	59.928	0.072
							-30	59.959	0.041
							-45	60.064	0.064
							-60	60.008	0.008
							-73	60.039	0.039
600 mm/min time delay 2s	A	10	9.8418	10.158	0.158		73	60.278	0.278
	B	20	19.877	20.123	0.123		60	60.227	0.227
	C	30	29.854	30.146	0.146	0.302	45	60.208	0.208
	D	40	39.777	40.223	0.223		30	60.148	0.148
	E	50	49.784	50.216	0.216		22.5	60.184	0.184
	F	60	59.698	60.302	0.302				



(a)Velocity 2400 mm/min (b)Velocity 200 mm/min

Figure 4. Repeatability test

Table 2. Repeatability test

Circle label	Diameter of circle [mm]			
	Velocity 200 mm/min		Velocity 2400 mm/min	
	X	Y	X	Y
A	29.900	29.601	29.704	29.300
	29.900	29.601	29.704	29.900
B	29.900	29.701	30.101	29.500
	29.900	29.701	30.101	30.300
C	30.001	29.601	30.000	29.300
	30.001	29.601	30.000	29.800
D	29.604	30.000	29.703	30.601
	29.604	30.000	29.703	29.102
E	30.001	30.003	30.103	29.200
	30.001	30.003	30.103	30.300
F	29.900	30.001	29.902	29.300
	29.900	30.001	29.902	30.400
G	29.804	29.702	29.600	29.100
	29.804	29.702	29.600	29.800
H	30.004	29.800	29.800	29.401
	30.004	29.800	29.800	30.301
I	29.902	29.900	30.001	29.400
	29.902	29.900	30.001	30.000
Repeatability	0.296		0.753	

5. Conclusion
In this investigation, the robot with V-slot extrusion with 150x150x150 m^3 workspace, give the resulting task accuracy of 0.45 millimetre under the entire range of motion. This task accuracy is a lot lower than 0.0025 mm resolution of the robot actuation system. However, this performance is enough to accomplish most of operation in hobbyist's works and university's projects which are only sub-millimetre tasks. The travel's distance and speed also affect the accuracy of the robot. If the circular trajectory is too big, the robot may degrade its accuracy quickly. The effect of travel speed is observed in the repeatability test as we test the robot with lower and higher velocity, compared to in the accuracy test. The repeatability degrades as the robot moves faster.

6. Notes
(1) "3-in-1 3D printer". https://www.snapmaker.com (accessed 25 November 2018)
(2) "FarmBot". https://farm.bot (accessed 28 November 2018)
(3) "OX CNC machine". https://openbuilds.com (accessed 28 November 2018)

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[3] Şirinterlikçi A, Bird A, Harris A and Kweder K 2009 Repeatability and Accuracy of an Industrial Robot: Laboratory Experience for a Design of Experiments Course, the *Technology Interface Journal*
[4] Daniel N 2016 *G-Code to RAPID translator for Robot-Studio*

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