***British Journal of Applied Science & Technology***
***5(6): 547-555, 2015, Article no.BJAST.2015.053***
***ISSN: 2231-0843***

**SCIENCEDOMAIN** ***international***
*www.sciencedomain.org*

SCIENCEDOMAIN

# Nonparametric Analysis of Two Distributed Motion Control Algorithms

**Francisco Javier Lopez-Jaquez[1*], Sandra Elena Ramirez-Jara[2] and Lazaro Rico-Perez[1]**

*[1]Department of Industrial and Manufacturing Engineering, Universidad Autonoma de Ciudad Juarez, Av. Del Charro 450 Norte, C.P. 32310 Chihuahua, Mexico.*
*[2]Department of Computer Science, Universidad Autonoma de Ciudad Juarez. Av. Del Charro 450 Norte, C.P. 32310 Chihuahua, Mexico.*

### *Authors' contributions*

*This work was carried out in collaboration between all authors. Author FJLJ designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Authors FJLJ, SERJ, LRP managed the analyses of the study and literature searches. All authors read and approved the final manuscript.*

### *Article Information*

DOI: 10.9734/BJAST/2015/13429
Editor(s):
(1) Chien-Jen Wang, Department of Electrical Engineering, National University of Tainan, Tainan, Taiwan.
(2) Rodolfo Dufo Lopez, Electrical Engineering Department, University of Zaragoza, Spain.
Reviewers:
(1) Anonymous, University of Maribor, Slovenia.
(2) Lei Wang, School of Computer Science and Technology, Henan Polytechnic University, Jiaozuo 454000, China.
(3) Anonymous, University of São Paulo, Brazil.
(4) Anonymous, Xidian University, China.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=763&id=5&aid=6972

***Original Research Article***

***Received 16th August 2014***
***Accepted 6th November 2014***
***Published 15th November 2014***

## ABSTRACT

This paper presents the results obtained during the development and implementation of two distributing motion control algorithms as part of an X-Y cutting table. One algorithm issues commands to the motor drivers on every sample cycle while the other does it only when a control point is reached. Both algorithms have the same input data set, control points that define the required path for the cutting torch. The analysis included two tests: A Wilcoxon rank sum test to find if the outcomes of the algorithms were different and a sign test to find if algorithms were able meet the design specifications. The analysis included four predefined specifications from the specimens, metal parts. All tests were based on a sample size seven, a .05 significance level and a two-tailed test. We found that algorithms outcomes were different and one of the algorithms was able to meet the design specifications of a part used as the test specimen.

---

**Corresponding author: E-mail: frlopez@uacj.mx;*

*Keywords: Distributed motion control; Wilcoxon rank sum test; location test; interpolation; path following.*

## 1. INTRODUCTION

This experiment took place on a piece of equipment, an XY plasma cutting table. The cutting table uses a plasma torch to cut sheet metal parts. There are two motor drivers and a computer interconnected on a RS-485 network. The computer is the master that sends commands to the motor drivers, the slaves, as required to generate the desired motion of the cutting torch to produce a part. The XY plasma cutting table is a piece of equipment under research and development that covers design and integration of components. The motion control software is a development that we are able to change, recompile and test but only this paper focus is in the performance evaluation of the implementation of the path following algorithms. Previous work can be found in [1,2,3].

There are two hypotheses: One is that both algorithms produce equal trajectories. A Wilcoxon rank sum test (WRST) was applied to prove this claim against the alternative hypothesis that algorithms outcomes are different. Another hypothesis was that both algorithms were able to meet the required specifications; A sign test was used in this case [4].

The cutting path is obtained from the required sheet metal part design; in this case, the part is a circular plate with an ear to attach a handle in a later assembly operation to obtain the final product. The specifications used for this test are indicated on Fig. 1, along with a sample test specimen.

The motion of the cutting torch is accomplished through a pair of motor drivers able to operate in four different movement modes; Un-profiled stepping velocity, position un-profiled, position profile and velocity profile mode. This paper focus is on the un-profiled stepping velocity mode where a load trajectory command consist of a header byte, motor driver address byte, load trajectory command byte (lower nibble is the load command identification number and upper nibble is the additional data bytes required by the un-profiled stepping velocity mode, in this case four additional data bytes; One control byte, two bytes for the initial timer count and one byte for the closest velocity. Finally, there is the 8-bit checksum byte [5].

Algorithm 1 interpolates every sample cycle. This algorithm interpolates based on elapsed time from last sampling cycle, it calculates the initial time count for both axis, determines direction, prepares the command packets and sends them to motor drivers. Algorithm 2 checks every sampling cycle if it has arrived to the destination vertex and if it is the case it goes to similar sequence of operations as algorithm 1 but it does not interpolate, it goes from control point to control point until reaching final vertex of the trajectory.

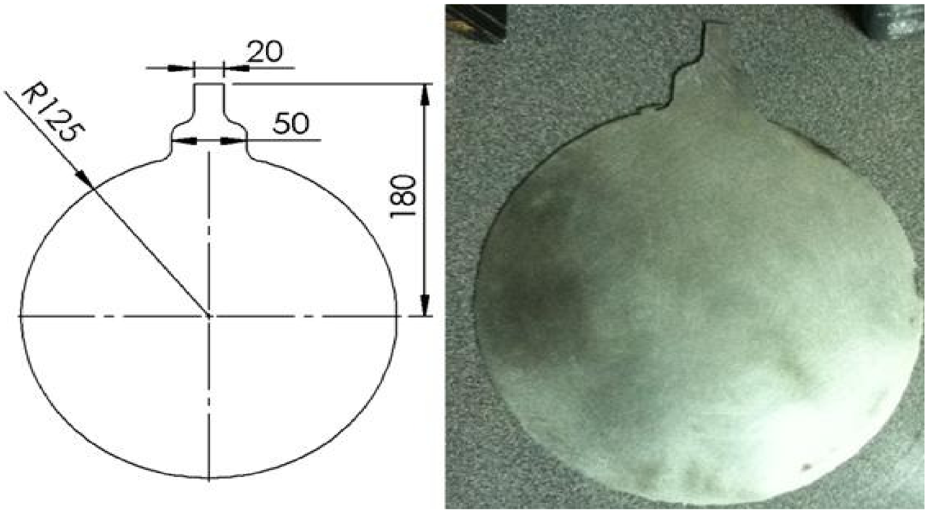


**Fig. 1. Design sketch and specimen sample part (dimensions are in millimeters)**

The main difference between both algorithms is that algorithm 1 is computer intensive because it interpolates and issues commands to the motor drivers every sampling cycle, a timer is set to run algorithm 1 every 20 milliseconds. Algorithm 2 does not interpolate, it issues move commands to motor drivers every time a control point is reached but it also goes through a 20 milliseconds sampling cycle to find when a control point has been reached, then it issues commands to the motor drivers. Fig. 2 and 3 illustrates the flow diagrams of both algorithms.

In the case of algorithm 1 it has the flexibility to change velocity every 20 milliseconds, if required. In the other hand, algorithm 2 is not able to change velocity until reaching next control point on the list.

Fig. 3 is a pictorial representation of how both algorithms managed to go from one control point to next control point. Four control points are included in Fig. 4. The interpolation window is used by algorithm 1 to generate linear interpolation points using the Lagrange interpolation based on a time increment [6,7]. The control points signal the start and end positions of an interpolation window and when an end position is reached it becomes the start of next interpolation window. The generated interpolation points act as a signal to keep the cutting torch on the path calculating the velocity components and issue them to the motor drivers every time an interpolation point is generated. It is possible to change to high degree of interpolation but at present time our experiment includes only linear interpolation.

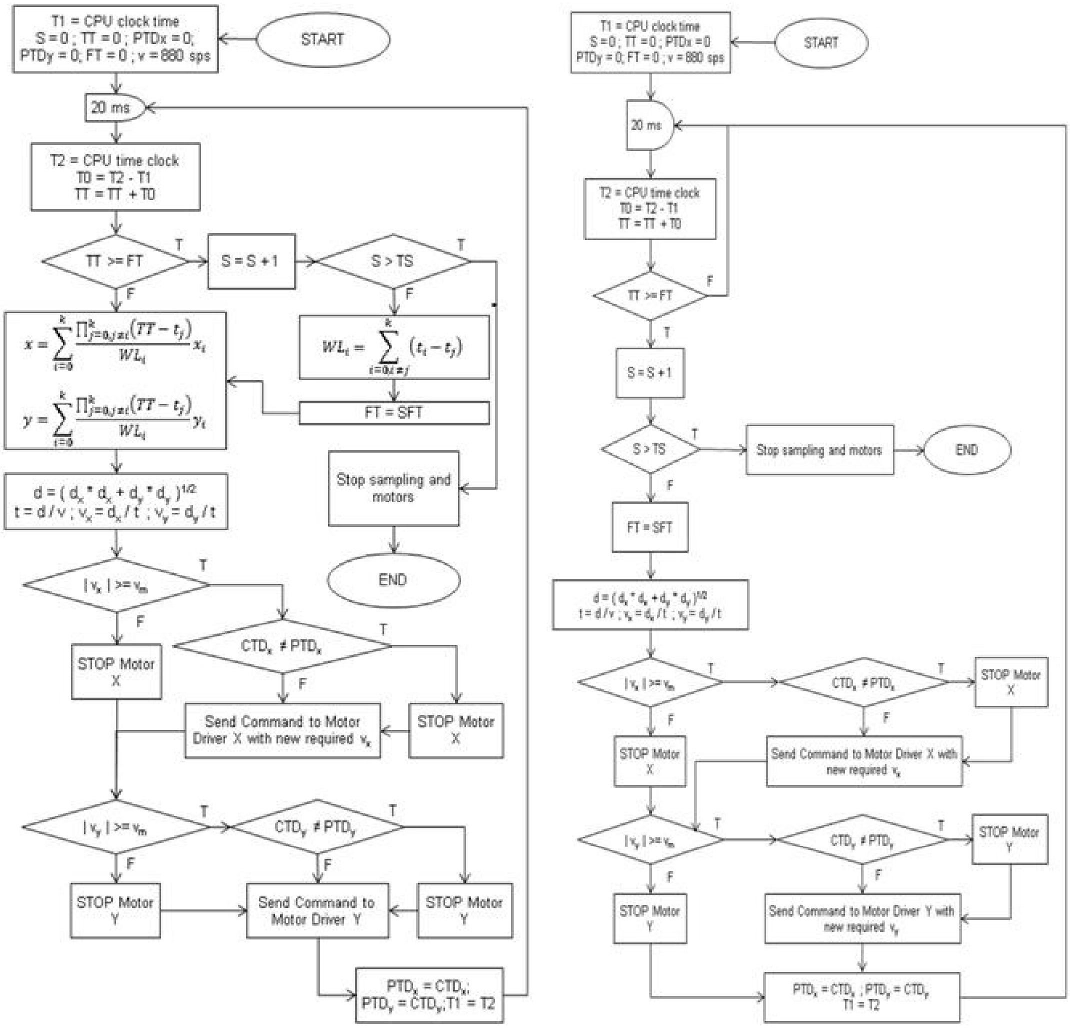


**Fig. 2. Flow diagrams for algorithm 1 and algorithm 2**

Both algorithms are based on time increment and it is possible to stop and continue the trajectory traversing at any moment during the cutting process.

The trajectory traversing is set at constant speed, 880 steps per second in this case. The velocity components $v_x$ and $v_y$ are computed when a control point is reached, in the case of algorithm 2, while algorithm 1 generates interpolation points based on first order Lagrange polynomial interpolation, i.e., the velocity components $v_x$ and $v_y$ are computed every sample cycle. The sampling rate was set to 20 milliseconds. The small dots on Fig. 3 represent vertices generated using interpolation.

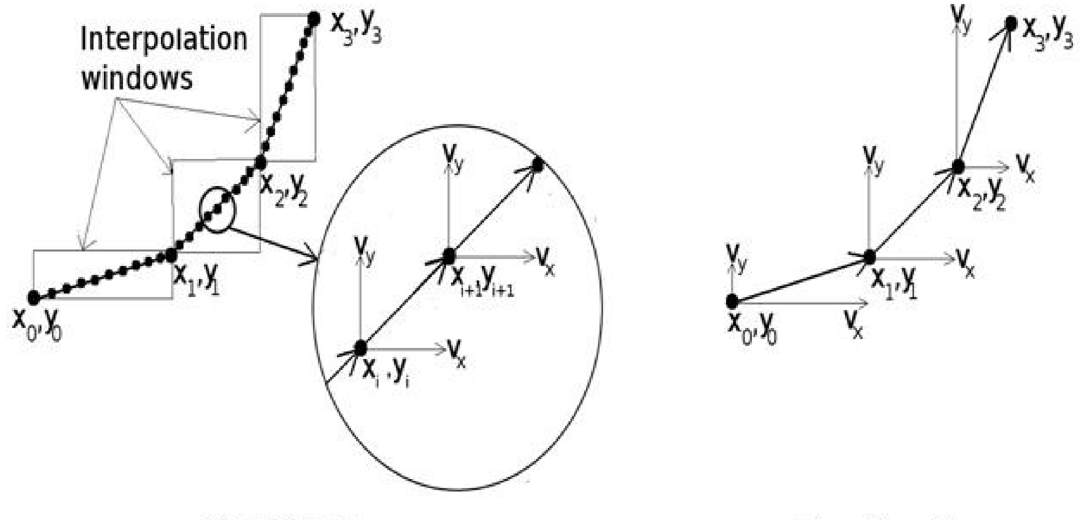
## 2. EXPERIMENTAL DETAILS

We have created specimens from pieces of mild steel sheet 27.0x45.5x0.12cm (gage 18), a total of 14 were produced; Seven using algorithm 1 and seven using algorithm 2. We set cutting speed to 880 steps per second. We measure the radius using an electronic caliper at a random direction from the center of the circular segment. A random number between 0 to 359 degrees was generated, excluding values from 75 to 105 degrees, Fig. 4 shows a specimen with marks on it ready to take measurements.

We placed a cross hair mark on the sample item to signal the center of the radius for reference. We use a glass plate with mesh lines on it as the reference to center the specimen and mark the center, horizontal and vertical reference axes. Data fall short to the specifications because the plasma cutting operation removes material from the metal sheet and the value used for the test was obtained adjusting the specifications to compensate the amount of material removed during the cutting operation.

A set of control points were generated from the drawing of the part and we used the same set to run both algorithms. The torch moves to initial position, makes a perforation and then starts to move while firing the plasma until reaching final control point.

The motion control system consist of a pair of stepper motors (1.4 degrees per step) connected to a motor drivers SL-146 with a 1/8 micro stepping setup, one motor driver for each stepper motor. The motor drivers are interconnected through an RS-485 network. Stepper motors axes are direct connected to a torque spline screws with a 3.81 cm linear displacement per revolution. The algorithms were implemented as part of the motion control running on a laptop connected to the RS-485 network. The laptop is the master that generates commands and issues them to the motor drivers, the slaves, accordingly to the input set of control points.



Algorithm 1

Algorithm 2

Fig. 3. Velocity components $v_x$ and $v_y$ computation during trajectory traversing

**Fig. 4. Specimen samples made during the experimentation**

## 3. NONPARAMETRIC ANALYSIS OF TWO INDEPENDENT SAMPLES

The data set obtained to calculate dimension A from the experiment is listed in Table 1. Column A-S is the Algorithm-Specimen identification. Column A is the average calculated from the five measurements $A_i$ of each specimen obtained at angle $\alpha_i$. The random angles where generated using an electronic spreadsheet with a function int (rand()*360). A list of random values was generated then values were assigned to $\alpha_1$, $\alpha_2$,$\alpha_3$, $\alpha_4$ and$\alpha_5$. The values from 75 to 105, where the circular section of the part does not feature a reference to get a measurement for dimension A, were ignored during the assignation. Measurements are in degrees for angles, $\alpha_i$, and centimeters for all $A_i$ and the A dimensions.

The first analysis is to prove the null hypothesis that both algorithms produce similar outcomes against the alternative that outcome from algorithms are different. Table 2 lists the data for this first analysis. Column A is the average of the measurements for the circular section of the part, as mentioned above. Columns B, C and D show the other measurements from the design specifications, one for each specimen. The target value is shown next to the specification in parentheses adjusted to take into account the average material removed during the cutting operation [6]. All dimensions are in centimeters.

We used the Wilcoxon rank sum test (WRST) to compare the two distributions, the one that comes out from using algorithm 1 and the other using algorithm 2. There is one test for each specification. The level of significance for all the tests was .05 and two tails test. (Tables 3 and 4) list the values computed accordingly to the WRST procedure [3]. First two columns are the algorithm and outcome, in ascending sorted by outcome. The R column lists the associated value according to the WRST procedure. In this case, because all the outcome values are different, it goes from 1 to 14. $R_1$ and $R_2$ list the associated rank values for each algorithm.

The WRST procedure requires to rank the observations from both samples and then compute the rank sums associated to each sample, algorithm in this case. The test statistic T will be equal to the sum of values for columns $R_1$ or $R_2$, either sum can be used because the sample sizes are equal, $n = 7$ for both algorithms. From (Table 2) we are able to find, adding all the values from column $R_1$ that $T = 28$ and, from column $R_2$, $T = 67$. The null hypothesis will be rejected if the test statistic T is $\leq T_L$ or $T \geq T_U$, where: $T_L$ and $T_U$ are the critical values obtained from the WRST (Table 3). In this case the critical values are $T_L = 37$ and $T_U = 68$, based on sample size seven, for both algorithms, 0.05 significance level and a two-tailed test [3]. In this case, we rejected the null hypothesis, because T is lower than $T_L$ ($28 < 37$). Similar conclusion can be done if T is calculated using rank 2 but this time if T is higher than $T_U$ ($77 > 68$) there is enough evidence to reject the null hypothesis.

In the case of dimension B, the critical $T_L$ and $T_U$ values are the same as in dimension A. in fact, critical and test values are equal for both tests. This leads to similar result; reject the null hypothesis. Algorithm 1 and 2 are yielding products with significant difference on specification B.

In the case of dimension C, the WRST critical values are $T_L = 37$ and $T_U = 68$, respectively. If we select the test value $T_1 = 61$ then $T_1$ is not lower or at least equal than $T_L$, this leads to say that there is not enough evidence to reject the null hypothesis. Both algorithms are producing similar results regarding specification C. The same is true if we had compared $T_2 = 34$ against $T_U = 68$ but this time we say that due to $T_2$ is not greater or equal than TU the null hypothesis cannot be rejected.

In the case of dimension D, the WRST critical values are $T_L = 37$ and $T_U = 68$, respectively. If we select the test value $T_1 = 36$ then $T_1$ is lower than $T_L$, this leads to say that there is enough evidence to reject the null hypothesis because the outcomes of the algorithms show a significant difference on measurements for specification D.

Fig. 5 shows the errors of both algorithms. The error was calculated by subtracting the required dimension from the median value of the outcome. The analysis takes into account an average cut width of 0.2cm, the width of cut of the plasma stream. In the case of specification A, we have compensated, as mentioned before, by 0.2cm, half the width of the cutting stream, giving a target value of 12.3 cm. We applied the same adjustment to requirement B and our new target was 17.8 cm instead of 18.0 cm. For requirements C and D we applied an adjustment of 0.4cm because measurements were taken from edge to edge [8]

**Table 1. Measurements from dimension A**

| A-S | $\alpha_1$ | $A_1$ | $\alpha_2$ | $A_2$ | $\alpha_3$ | $A_3$ | $\alpha_4$ | $A_4$ | $\alpha_5$ | $A_5$ | $A = \frac{1}{5}\sum_{i=1}^{5} A_i$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-1 | 7 | 12.3 | 29 | 12.3 | 204 | 12.1 | 68 | 12.5 | 70 | 12.4 | 12.32 |
| 1-2 | 315 | 12.6 | 159 | 12.2 | 345 | 12.5 | 8 | 12.3 | 264 | 12.4 | 12.40 |
| 1-3 | 339 | 12.4 | 40 | 12.0 | 332 | 12.4 | 39 | 11.9 | 235 | 12.5 | 12.24 |
| 1-4 | 2 | 12.2 | 74 | 12.2 | 181 | 12.1 | 65 | 12.2 | 303 | 12.5 | 12.24 |
| 1-5 | 323 | 12.3 | 105 | 12.4 | 109 | 12.4 | 311 | 12.3 | 220 | 12.2 | 12.32 |
| 1-6 | 259 | 12.2 | 74 | 12.0 | 16 | 12.2 | 222 | 12.2 | 214 | 12.2 | 12.16 |
| 1-7 | 284 | 12.5 | 257 | 12.3 | 56 | 12.1 | 4 | 12.4 | 263 | 12.3 | 12.32 |
| 2-1 | 211 | 11.6 | 43 | 11.7 | 321 | 11.6 | 166 | 11.9 | 316 | 11.8 | 11.72 |
| 2-2 | 226 | 11.7 | 335 | 11.9 | 147 | 12.0 | 65 | 11.7 | 231 | 11.7 | 11.80 |
| 2-3 | 254 | 12.0 | 125 | 11.8 | 169 | 11.7 | 138 | 11.9 | 214 | 11.7 | 11.82 |
| 2-4 | 18 | 11.6 | 291 | 12.1 | 62 | 11.8 | 37 | 11.7 | 200 | 11.1 | 11.66 |
| 2-5 | 42 | 11.7 | 146 | 11.9 | 189 | 11.6 | 161 | 11.9 | 192 | 11.6 | 11.74 |
| 2-6 | 261 | 11.5 | 246 | 11.7 | 320 | 12.0 | 125 | 11.8 | 184 | 11.7 | 11.76 |
| 2-7 | 33 | 12.0 | 5 | 11.9 | 233 | 11.5 | 345 | 12.1 | 352 | 12 | 11.90 |

**Table 2. Experiment data outcome**

| Algorithm | Specimen | A = 12.3 | B = 17.8 | C = 1.6 | D = 4.6 |
|---|---|---|---|---|---|
| 1 | 1 | 11.72 | 17.29 | 1.60 | 4.50 |
| 1 | 2 | 11.80 | 17.02 | 1.59 | 4.45 |
| 1 | 3 | 11.82 | 17.19 | 1.66 | 4.51 |
| 1 | 4 | 11.66 | 17.10 | 1.65 | 4.56 |
| 1 | 5 | 11.74 | 17.28 | 1.67 | 4.53 |
| 1 | 6 | 11.76 | 17.12 | 1.59 | 4.51 |
| 1 | 7 | 11.90 | 17.24 | 1.62 | 4.50 |
| 2 | 8 | 12.37 | 17.84 | 1.61 | 4.60 |
| 2 | 9 | 12.40 | 17.78 | 1.60 | 4.63 |
| 2 | 10 | 12.25 | 17.54 | 1.67 | 4.66 |
| 2 | 11 | 12.32 | 17.60 | 1.64 | 4.50 |
| 2 | 12 | 12.34 | 17.66 | 1.56 | 4.51 |
| 2 | 13 | 12.21 | 17.57 | 1.57 | 4.67 |
| 2 | 14 | 12.35 | 17.51 | 1.51 | 4.59 |

**Table 3. WRST data analysis for specifications A and B**

| A = 12.3 cm | | | | | B = 17.8 cm | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Algorithm** | **Outcome** | **R** | **R1** | **R2** | **Algorithm** | **Outcome** | **R** | **R1** | **R2** |
| 1 | 11.66 | 1 | 1 | 0 | 1 | 17.02 | 1 | 1 | 0 |
| 1 | 11.72 | 2 | 2 | 0 | 1 | 17.10 | 2 | 2 | 0 |
| 1 | 11.74 | 3 | 3 | 0 | 1 | 17.12 | 3 | 3 | 0 |
| 1 | 11.76 | 4 | 4 | 0 | 1 | 17.19 | 4 | 4 | 0 |
| 1 | 11.80 | 5 | 5 | 0 | 1 | 17.24 | 5 | 5 | 0 |
| 1 | 11.82 | 6 | 6 | 0 | 1 | 17.28 | 6 | 6 | 0 |
| 1 | 11.90 | 7 | 7 | 0 | 1 | 17.29 | 7 | 7 | 0 |
| 2 | 12.21 | 8 | 0 | 8 | 2 | 17.51 | 8 | 0 | 8 |
| 2 | 12.25 | 9 | 0 | 9 | 2 | 17.54 | 9 | 0 | 9 |
| 2 | 12.32 | 10 | 0 | 10 | 2 | 17.57 | 10 | 0 | 10 |
| 2 | 12.34 | 11 | 0 | 11 | 2 | 17.60 | 11 | 0 | 11 |
| 2 | 12.35 | 12 | 0 | 12 | 2 | 17.66 | 12 | 0 | 12 |
| 2 | 12.37 | 13 | 0 | 13 | 2 | 17.78 | 13 | 0 | 13 |
| 2 | 12.40 | 14 | 0 | 14 | 2 | 17.84 | 14 | 0 | 14 |

**Table 4. WRST data analysis for specifications C and D**

| C = 1.6 cm | | | | | D = 4.6 cm | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Algorithm** | **Outcome** | **R** | **R1** | **R2** | **Algorithm** | **Outcome** | **R** | **R1** | **R2** |
| 2 | 1.51 | 1 | 0 | 1 | 1 | 4.45 | 1 | 1 | 0 |
| 2 | 1.56 | 2 | 0 | 2 | 1 | 4.50 | 3 | 3 | 0 |
| 2 | 1.57 | 3 | 0 | 3 | 1 | 4.50 | 3 | 3 | 0 |
| 1 | 1.59 | 4.5 | 4.5 | 0 | 2 | 4.50 | 3 | 0 | 3 |
| 1 | 1.59 | 4.5 | 4.5 | 0 | 1 | 4.51 | 6 | 6 | 0 |
| 1 | 1.60 | 6.5 | 6.5 | 0 | 1 | 4.51 | 6 | 6 | 0 |
| 2 | 1.60 | 6.5 | 0 | 6.5 | 2 | 4.51 | 6 | 0 | 6 |
| 2 | 1.61 | 8 | 0 | 8 | 1 | 4.53 | 8 | 8 | 0 |
| 1 | 1.62 | 9 | 9 | 0 | 1 | 4.56 | 9 | 9 | 0 |
| 2 | 1.64 | 10 | 0 | 10 | 2 | 4.59 | 10 | 0 | 10 |
| 1 | 1.65 | 11 | 11 | 0 | 2 | 4.60 | 11 | 0 | 11 |
| 1 | 1.66 | 12 | 12 | 0 | 2 | 4.63 | 12 | 0 | 12 |
| 1 | 1.67 | 13.5 | 13.5 | 0 | 2 | 4.66 | 13 | 0 | 13 |
| 2 | 1.67 | 13.5 | 0 | 13.5 | 2 | 4.67 | 14 | 0 | 14 |

## 4. NONPARAMETRIC ANALYSIS FOR DISTRIBUTION LOCATION

We already found that algorithms are different but now our focus is to find how well each of the algorithms performs to meet the required specifications. It is easy to observe that almost all the observations are lower than the specifications. A sign test (ST) can be applied to probe if this deviation is enough evidence to reject the null hypothesis that algorithm is able to meet the specification [9].

It can be observed that algorithm 2 meets the requirements in three out of the four requirements while algorithm 1 only meets one of the requirements, the small one, then the error starts to show a tendency to grow (negatively) as the dimension increases.

Algorithm 1 shows a deviation of 0.09 cm from dimension target requirement D = 4.6 cm, on the median. In this comparative test we used the sign test for one sample being compared to a target value, the compensated required dimension. The procedure is to count how many of the observations fall lower ($S_L$), equal ($S_E$) and higher ($S_U$) than the target value [9]. The test statistic S is the larger of $S_L$ and $S_U$. Table 5 lists the values for this analysis.

The null hypothesis is that there is not difference between the outcome median and the required target requirement. The alternative hypothesis is that they are different. The null hypothesis will be rejected if the level of significance is greater than the probability of observing x number of values greater or equal than S from a binomial distribution with parameters n = 7 and *p* = .5 [9].

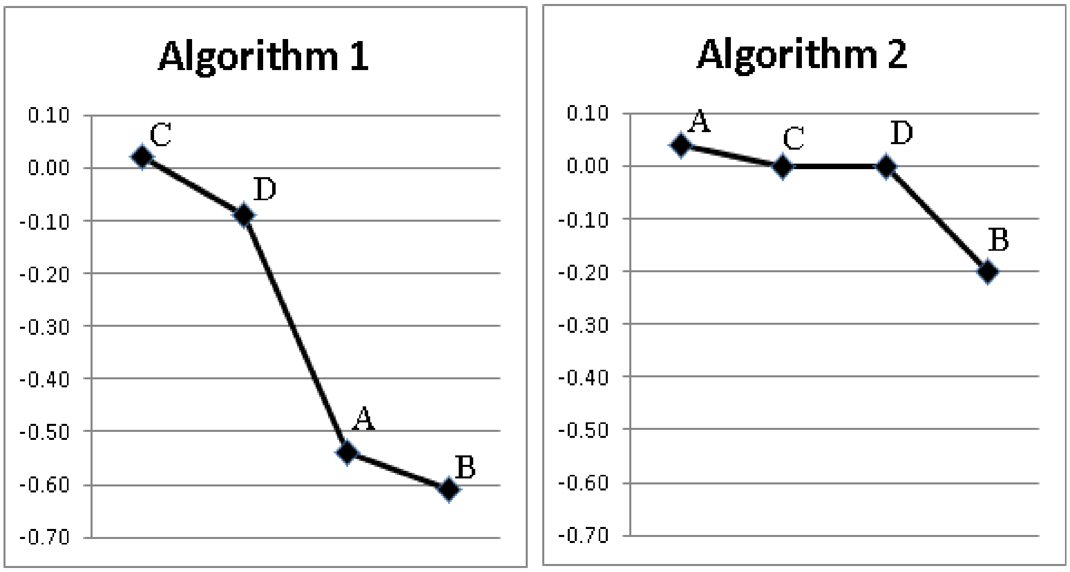


**Fig. 5. Error observed from the outcome of both algorithms**

**Table 5. Sign test analysis**

| Algorithm | A = 12.3 cm | | | B = 17.8 cm | | | C = 1.6 cm | | | D = 4.6 cm | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $S_L$ | $S_E$ | $S_U$ | $S_L$ | $S_E$ | $S_U$ | $S_L$ | $S_E$ | $S_U$ | $S_L$ | $S_E$ | $S_U$ |
| 1 | 7 | 0 | 0 | 7 | 0 | 0 | 2 | 1 | 4 | 7 | 0 | 0 |
| 2 | 2 | 0 | 5 | 6 | 0 | 1 | 3 | 1 | 3 | 3 | 1 | 3 |
| 1 | S = 7<br>*P*-value = .01 | | | S = 7<br>*P*-value = .01 | | | S = 4<br>*P*-value = .50 | | | S = 7<br>*P*-value = .01 | | |
| 2 | S = 5<br>*P*-value = .23 | | | S = 6<br>*P*-value = .06 | | | S = 3<br>*P*-value = .77 | | | S = 3<br>*P*-value = .77 | | |

Considering a level of significance of .05 then algorithm 1 is not able to meet requirements A, B and D because the level of significance is greater than the *P*-value associated to these requirements. But, it is able to meet requirement C. Using same level of significance of 0.05 then algorithm 2 is able to meet all requirements A, B, C and D because in all cases the level of significance is not greater than the *P*-value associated to those requirements.

## 5. CONCLUSION

Regarding the hypothesis to find if the outcomes of the algorithms were different, we found that for specifications A, B and D that there is evidence to say that algorithms 1 and 2 produce different outcome. But in the case of specification C we could not find enough evidence to reject the null hypothesis that both algorithms produce equal outcomes and the differences observed are probably due to random.

In the case of the first hypothesis to find if both algorithms were able to meet the specifications. We found evidence that algorithm 2 was able to meet the specifications while algorithm 1 was not able.

We suspect that there is a threshold value for length from where difference becomes of significance, but this will require more research to determine this value; If dimension length is small like in this case 2 cm the outcome will be equal for both algorithms but if length is higher like 5 cm or 12.3 cm then the outcome shows a significant difference between the algorithms.

Both algorithms were run without any feedback during the trajectory traversing and perhaps this could be a factor that leads to the outcome from the experiments. This will require future research to include feedback during the processes instead of the simple open loop motion control where Algorithm 2 showed more able to meet with the specifications of the part.

We focus to test if the algorithm produce difference in the outcome and we could say that there is enough evidence, at least in three of the specifications used in the test.

When considering the width of material removed by the plasma stream algorithm 2 is able to meet the specifications. It is recommended to generate control points based on a sketch considering the amount of material that is going to be removed during the process or to make sure the cutting torch width of cut goes to the outside of the path.

Algorithm 1 has flexibility to generate first or n-order polynomial interpolation for the same set of control points, but more research need to be conducted to find why it fall short to meet the requirements. Algorithm two was able to meet the requirements for the part used during the experiment.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

1. Lopez-Jaquez FJ, Ramirez-Jara SE. Distributed motion control real-time contouring algorithm implementation and performance test. Int J of Compu, Inf, Mech, SystSci and Eng. 2013;7(9):42-47.
2. Lopez-Jaquez FJ. Converting pixels of Jordan curves into motion control commands on a plasma cutting machine process. Proceedings of the 16th Annual International Conference on Industrial Engineering Theory, Applications and Practice. 2011;1(1):317-322.
3. Lopez-Jaquez FJ, Hon B. Computer modeling of an XY table. Advances in Manufacturing Technology -XX, First edition. Edit. Springer-Liverpool JMU. 2006;20:1:313-318.
4. Logosol Inc. Logosol Intelligent Microstepping driver LS-146, Accessed 14 August 2014. Available: http://www.logosolinc.com/files/downloads/Distributed%20Control/Intelligent%20Stepper%20Drives/ls-146.pdf
5. William M, Terry S. Comparing two populations: Independent random samples— In statistics for engineering and the sciences, editorial Prentice Hall. Upper Saddle River, New Jersey. 2007;762-767:Fifth edition.
6. Jean-Paul Berrut, Lloyd N. Trefethen. Barycentric lagrange interpolation. Society for Industrial and Applied Mathematics. 2004;46(3):501–517.
7. Khalid Ali Hussien. The lagrange interpolation polynomial for neural network learning. International Journal of Computer Science and Network Security. 2011;11(3):255-261.
8. Automated plasma cutting system-operating manual. Thermadyne Corporation, New Hampshire, USA. 2006;1:0-4642 Rev.AB.
9. William M, Terry S. Testing for location of a single population— in Statistics for Engineering and the Sciences, editorial Prentice Hall, Upper Saddle River, New Jersey. 2007;Fifth edition:757-759.

*Peer-review history:*
*The peer review history for this paper can be accessed here:*
*http://www.sciencedomain.org/review-history.php?iid=763&id=5&aid=6972*