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Minimum Time Algorithm for Gantry Travel

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Abstract

Surface mount technology is a method of applying lead solder to PCB pads to fix Surface Mount Device (SMD) components on PCBs. SMT facilitates the pickup of the electronic component and accurate placement on PCBs. Heads and nozzles for each axis use suction cups to pick up electronic components from tape feeders. The components are inspected before a vision camera to check pickup location and alignment, and then are moved to PCBs waiting on the conveyer for placement.

This paper presents an algorithm that identifies the shortest path from sLa to pLb without stopping before the camera for visual inspection. The simulations verified that the fly motion method reduced the time involved by 16% compared to the stop motion method.

***Keywords**: SMT, Surface Mount Device, Optimal Path Search*

1. Introduction

All electronic products are made by placing electronic components on PCBs. Electronic devices are being produced at an explosive rate with the emergence of personal electronic products such as mobile phones and wearable devices. High-performance fabrication equipment is required to meet the increasing demand, and extensive research has been performed to ensure optimal performance.

Surface mount technology is a method of applying lead solder to PCB pads to fix SMD components such as chips, semiconductors, switches and connectors onto PCBs. Once SMD components are placed on the PCBs, they are conveyed into an oven to harden the solder paste which holds the components in place [1].

Some methods of enhancing SMT include faster component pickup, using a more lightweight gantry for faster travel, faster vacuum breaking during placement, and utilizing easy-to-use equipment.

This study proposes a method of identifying the fastest path for components to be picked up at the feeder and to travel to PCBs for placement under a structure with a fixed gantry speed and acceleration.

2. Related Work

Productivity in SMT is expressed in terms of chips per hour (CPH), which is the number of chips placed on PCBs in an hour. Many studies have attempted to improve the pickup speed, the speed of visual inspection, and the placement speed of various SMT machines [2].

In general, the SMT placement process consists of the following:

① Pickup of electronic components
② Moving to camera position
③ Camera visual inspection
④ Moving to PCBs

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⑤ Offset adjustment based on visual inspection results
⑥ Placement of components
⑦ Moving to the next pickup position

Here, the proposed method of improving productivity in SMT machines is to shorten the existing overall time by combining ④ and ⑤.

Another method is to carry out ②, ③ and ④ at the same time.

In other words, visual inspection is performed while the components pass by the camera instead of stopping before the camera. The time saved by eliminating stopping contributes to higher productivity [2].

This study proposes a method of finding the fastest path, when the path is of the sLa-Camera-pLb type, as shown in Figure 1, without stopping before the camera for visual inspection.

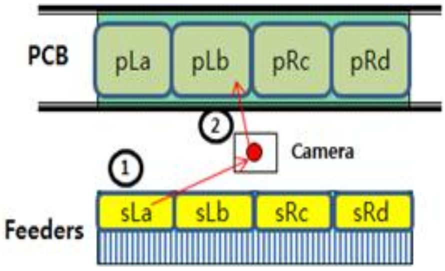

Figure 1. (Sla-Camera-Plb) Moving Path

2.1. Characteristics and Operating Conditions of (Sla-Camera-Plb)

The characteristics of the (sLa–camera-pLb) type are as follows.

① The direction of travel changes for the x-axis.

② The x-axis is longer than the y-axis for the distance from the pickup to the camera (x>y).

③ The y-axis is longer than the x-axis for the distance from the camera to placement (x < y).

The input conditions satisfying the (sLa–camera-pLb) type are shown in Table 1.

Table 1. Input Conditions

Item	X axis	Y axis	Unit
Max Velocity	2.0	2.0	m/sec
G Acceleration	3.0	2.0	g
G [m/sec^2]	9.81	9.81	m/sec^2
Max Acceleration	29.43	29.43	m/sec^2
Pickup Position	-300	-150	mm
Camera Position	0	0	mm
Place Position	-40	200	mm

2.2. Components Stopped Before Camera for Inspection (Stop-Motion)

The velocity graph of the stop-motion mode, which involves components stopping before the camera, is presented in Figure 2.

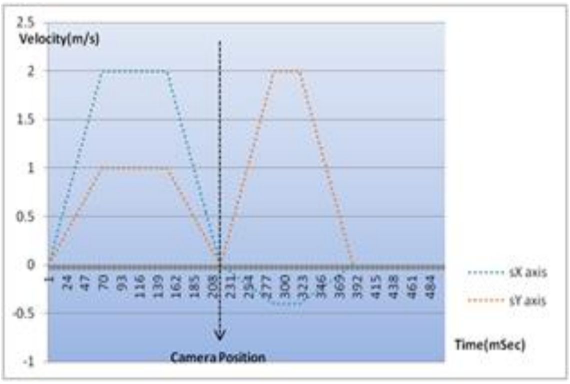

Figure 2. Velocity Graph of the Stop-Motion

From the moving path in Figure 3, we can see that the velocity of both axes becomes zero, and that the direction of velocity changes for the x-axis.

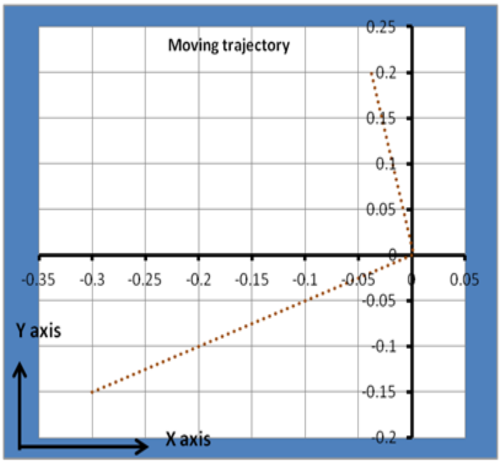

Figure 3. Moving Path of the Stop-Motion

The trajectory of the stop-motion path shows that the time taken to travel from component pickup to the camera is 0.218s. In this case, the x-axis takes a longer time than the y-axis. The time from the camera to placement is 0.168s, with the y-axis takes a longer time than the x-axis. As such, the total travel time is 0.386s.axes.

2.3. Components passed By Camera Considering Distance in X and Y Axes (Fly1-Motion)

Under the Fly1-Motion mode, the components pass by the camera without stopping. The velocity graph is shown in Figure 4, and the y-axis velocity exists since the components do not stop before the camera. The moving path of the Fly1-motion mode is presented in Figure 5 [13,14,15].

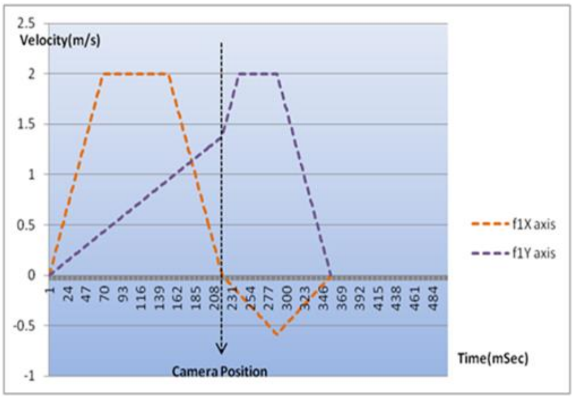

Figure 4. Velocity Graph of the Fly1-Motion

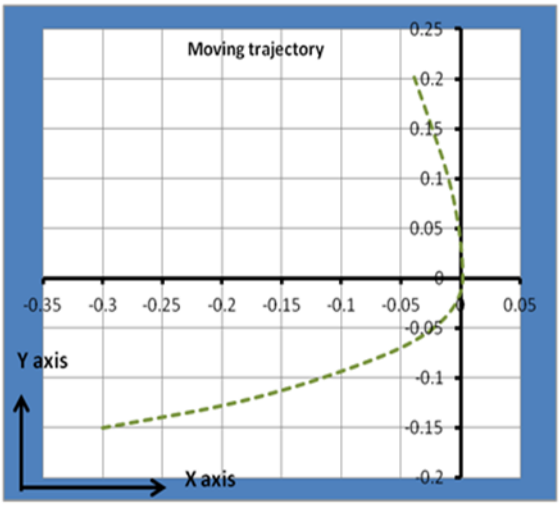

Figure 5. Moving Path of the Fly1-Motion

The time taken to travel from component pickup to the camera is determined by the x-axis, while the y-axis velocity is determined by the distance traveled and time. The time taken to travel from the camera to placement is determined by the y-axis. Since the y-axis velocity at the camera is not zero, this method is less time-consuming than the stop-motion mode, in which components accelerate from 0 at the camera position.

When s (distance traveled) = 0.15m and t (time) = 0.218sec, the y-axis velocity when passing the camera can be calculated as follows.

Since $s = h \cdot t/2$, h (velocity) = $2 \cdot s/t = 0.3/0.218 = 1.376147$m/s.

The y-axis time from the camera to placement is obtained by solving for t (time) using the given h (velocity) in Figure 6.

Here,

- s (distance traveled) = d + e + f
- v: maximum velocity
- j: acceleration
- h: final velocity

$$x \text{ (acceleration time)} = v/j \quad (1)$$
$$z = (v - h)/j \quad (2)$$

$$t = x + y + z \quad (3)$$
$$d = v \cdot x/2 \quad (4)$$
$$e = v \cdot y \quad (5)$$
$$f = h \cdot z + (v-h) \cdot z/2 \quad (6)$$
$$s = d + e + f \quad (7)$$
$$s = v \cdot x/2 + v \cdot y + h \cdot z + (v-h) \cdot z/2 \quad (8)$$
$$y = (s - v \cdot x/2 - h \cdot z - (v-h) \cdot z/2)/v \quad (9)$$

$s = 0.2m$
$j = 29.43m/s^2$
$v = 2m/s$
$h = 1.376147m/s$
$x = 2/29.43 = 0.68$
$z = (2 – 1.376147)/29.43 = 0.021$
$s = d + e + f$
When (4), (5) and (6) are substituted into the above, we get
$s = v \cdot x/2 + v \cdot y + h \cdot z + (v-h)z/2.$
Here,
$y = (s – v \cdot x/2 - h \cdot z - (v-h)z/2)/v = 0.048$
As such, t (time) = 0.137s.

The components take 0.168s when accelerating from 0 to travel 0.2 m, but 0.137 when beginning at a speed of 1.376147m/s. The Fly1-Motion mode shortens the overall time by 0.031s.

3. Fly2-Motion Method

The above comparison of the Stop-Motion mode and Fly1-Motion mode showed that less time is taken when components pass by the camera at a higher speed. A faster velocity can be obtained using m (distance) and t (time). Here, distance is a better variable since time is determined by the axis.

The velocity graph of the proposed Fly2-Motion mode is shown in Figure 6. This method obtains a higher speed within the given time by moving in the opposite direction. The resulting moving path of the Fly2-Motion mode is given by Figure 7.

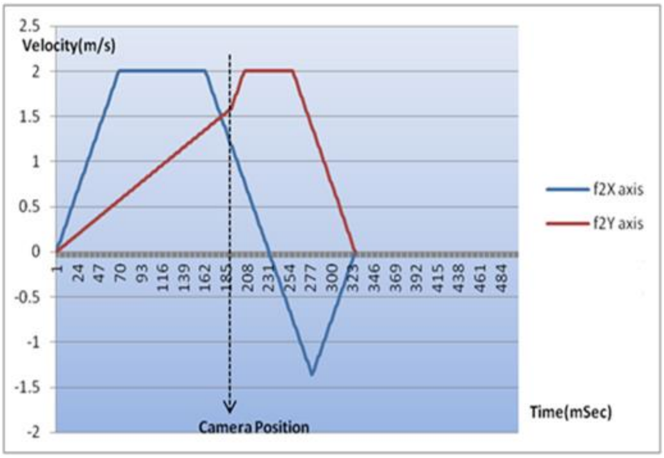

Figure 6. Velocity Graph of the Fly2-Motion

The time taken from pickup to the camera is 0.190s, and the time from the camera to placement is 0.135s, amounting to a total time of 0.325s.

When d (distance) = 40mm, h (initial speed) = 1.5831m/s, and t (time) = 135m/s, we can use the graph of [Figure 8] to calculate j (acceleration).

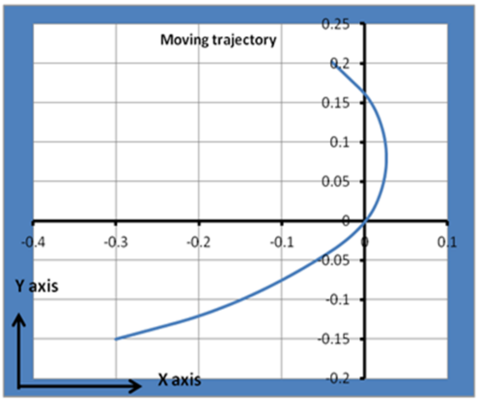

Figure 7. Moving Path of the Fly2-Motion

Input conditions:

- d (distance traveled) = -0.04m (opposite direction)
- t (time) = 0.135s
- h (initial velocity) = 1.176m/s

s and e have the same decelerating gradient.

- x = s (distance moved during x)
- y = e (distance moved during y)
- p = k/2 = h· y/2· x

$t = x + y$ (1)

$s = x \cdot h/2$ (2)

j (acceleration) = h/x (3)

$k = h \cdot y/x$ (4)

$p = k/2 = h \cdot y/2x$ (5)

$e = p \cdot y/2 = h \cdot y^2/4x$ (6)

$d = s - e$ (7)

By substituting (1) into (6),

$e = h \cdot y^2/4x$ (substitute ‘y = t–x’)

$= h(t - x)^2/4x$

$= (h \cdot t^2 - 2h \cdot t \cdot x + h \cdot x^2)/4x$

By substituting (2) into (7),

$d = s - e$

$= x \cdot h/2 - (h \cdot t^2 - 2h \cdot t \cdot x + h \cdot x^2)/4x$

The above is then solved for x.

$4d \cdot x = 2h \cdot x^2 - h \cdot t^2 + 2h \cdot t \cdot x - h \cdot x^2$

$h \cdot x^2 + (2h \cdot t - 4d) \cdot x - h \cdot t^2 = 0$

$\therefore\ x = (-(h \cdot t - 2d) + \sqrt{(h \cdot t - 2d)^2 + h^2 \cdot t^2})/h$

j (gradient) = $h/x (0 < x < t)$

$\therefore$ j (gradient) = 28.833m/s²

t (time) = 0.135s

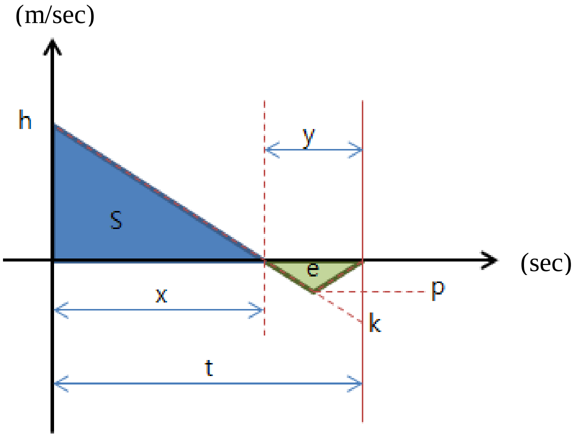

Figure 8. h Velocity Graph

Under the proposed Fly2-Motion mode, the x-axis has a velocity at the camera position, and components decelerate and pass the +0.026m point before returning. The time taken was 0.028 seconds faster with a speed of 190 m/s from pickup to the camera, and 0.002s faster with a speed of 135 m/s from the camera to placement.

4. Comparison of Three Methods

Using the conditions of Table 1, the three modes were compared, as shown in Table 2.

Table 2. Result of Fly2-Motion

Mode	Total Time (m/sec)	Difference (m/sec)	%	Velocity of Camera position	
				X	Y
Stop-Motion	386	-	-	0.00	0.00
Fly1-Motion	355	31	8	0.00	1.38
Fly2-Motion	325	61	16	1.19	1.58

The x-axis was longer than the y-axis when traveling from the pickup to the camera, and vice versa when traveling from the camera to placement. At the camera position, the y-axis velocity and x-axis velocity were 1.58 m/s and 1.19 m/s respectively, due to the opposite directions.

As such, the velocity from pickup to the camera improved by 28m/s to 190m/s, and from the camera to placement by 2m/s to 135m/s.

The Fly2-Motion mode was faster than the Fly1-Motion mode by 30m/s.

5. Conclusion and Future Work

This study found that the method of moving to the PCBs without stopping before the camera shortened the overall time by 8% compared to the Stop-Motion mode. The proposed Fly2-Motion method shortened the overall time by 16% compared to the Fly1-Motion mode.

If the proposed algorithm is applied to component pickup and placement, productivity can be enhanced by reducing traveling time to the shortest amount possible.

As future work, it is necessary to address the problems that may arise when applying the proposed method to surface mount devices, including vibration and motor heating.

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