Optimal Design of a Flexible Fixtures System
Using Fuzzy C-means Clustering

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Abstract:- In modern day manufacturing, manual transfer of parts between press machines has been replaced with automatic transfer systems. Higher automation productivity calls for greater flexibility of transfer devices. This paper deals with ways of improving the flexibility of fixtures designed to transfer parts between press machines in press shop-3 in Irankhodro company (IKCO). A method has been proposed for the optimization of the number and arrangement of actuators for each fixture. Fuzzy C-means Clustering algorithm has been used for this purpose.

Key-Words:- Automation, Flexible Fixtures, Clustering, Fuzzy Logic, Optimization

1 Introduction

The daily increase of competition among part makers has necessitated a higher rate of productivity. Automation, as a major factor influencing productivity has had an undeniable role in the drive for higher quality and lower prices.

Press line automation including automatic transfer of parts between press machines is an automation trend recently adopted by a great number of manufacturers.

Two of the most important automatic transfer systems are loader and unloader systems and robots. The use of each system in a specific plant depends on a number of factors. Speed and reliability are two important factors usually considered for choosing between the two methods.

Transfer systems must be able to handle parts of various sizes. Therefore, to handle different parts, certain components of the system might need to be changed. In time, this causes the wearing down of system components and reduces speed and reliability. A flexible transfer system able to handle various parts without the need to change any component so increases speed and reliability considerably. (Figure 1)

This paper presents a method of optimal design of a flexible transfer system.

Figure 1- Press automation in Irankhodro Company (IKCO)

2 Loader and Unloader system

Research shows that Loader and Unloader systems are more suitable for rapid transfer of heavy parts than robots. These systems have three main parts. Two moving arms with a number of degrees of freedom act as the loader and unloader and a table containing the fixtures that moves between the press machines.
The unloading arm picks the part up from one press machine and places it on the table named shuttle. The moving table moves to the next press. (Figure 2)

The loading arm then picks the part up from the table and feeds the press. Different types of loader and unloader systems have been designed for different applications. [2], [3] In a typical loader and unloader system, change of production plan demands a change in the arrangement of fixtures. This in turn reduces production speed and wears the system down. (Figure 3)

To solve this problem, various methods, including a flexible design of fixtures have been proposed. [4], [5], [6] A flexible fixture design has also been proposed for the press shop at Iran Khodro Company. [7]

3 Flexible fixtures
Fixtures are among the most sensitive parts in a transfer system. Inaccurate operation of fixtures causes an incorrect positioning and results in the part scrapped. Therefore, a set of fixtures must be able to position a part precisely. On each part a number of points are designated for handling. (Figure 4) These points differ for various parts. Each part, therefore, demands fixtures at different points.

To increase flexibility and in order to use only one set of fixtures for every part produced, flexible fixtures must have movements in three directions relative to each other. (Figure 5) In the flexible fixturing design proposed at Iran Khodro, precise fixture movement has been made possible with the use of linear actuators. [7]
Linear actuators include Motor and ball screw drive, linear motors, hydraulic drives, pneumatic drives, etc. [8], [9], [10] In the aforementioned flexible fixturing design, linear motors have been chosen due to their high speed, precision, and controllability. [11]
Optimization of the arrangement and number of linear motors seems necessary taking into account their high prices.
In the present paper, Fuzzy C-means Clustering algorithm has been used.

4 Hard C-means Clustering
The C-means Clustering Algorithm is a pattern recognition method. In other words, the
algorithm searches for similarities in order to classify data.[12],[13]
In the present application, the criterion for similarity is the proximity of points that must be secured with a fixture. Similar points will be placed within one cluster. One pair of linear motors has been allocated to each cluster to provide fixture movements in both X and Y directions for every given point in the cluster’s rectangular area. Optimization, therefore, reduces to finding a number of rectangular areas of fixture locations so that the total number of linear motors used, i.e. the total periphery of rectangular clusters, is minimum. Such clustering provides the least-expensive arrangement of motors that are capable of moving fixtures to specific points.

The Hard C-means Clustering assumes an arbitrary cluster for points. The kth point belongs to the ith cluster if the corresponding matrix element $U_{ik}$ is one and does not if it is zero.

Then, the coordinates of the center of each rectangular cluster $(v_{xl}, v_{yl})$ is specified as follows:

$$v_{xl} = \frac{\sum_{k=1}^{n} U_{ik} x_k}{\sum_{k=1}^{n} U_{ik}}$$

$$v_{yl} = \frac{\sum_{k=1}^{n} U_{ik} y_k}{\sum_{k=1}^{n} U_{ik}}$$

The best clustering is one which has the least sum of rectangular cluster circumferences. Considering the fact that in addition to actuators in x and y directions, each fixture needs an actuator with a fixed length of $L=70$ in the z direction, the number of fixtures can not exceed a certain limit (one fixture has been allotted to each cluster of points). The following goal function must therefore be minimized for cluster optimization:

$$J(n,c) = \sum_{k=1}^{n} \sum_{i=1}^{c} (u_{ik} (|x_k - v_{xl}| + |y_k - v_{yl}| + L))$$

$n$ denotes the number of points and $c$ is the number of clusters.

In this way, the number of clusters that minimizes the function $J(n,c)$ will be obtained. The most suitable number and arrangement of fixtures will thus be found. The most widely used method employed for solving the mentioned optimization is the ISODATA algorithm. First, an assumed arrangement of clusters is identified and the center of each cluster found. The proximity of a given point to cluster centers is then used to specify what cluster that point belongs to. In the third step, the coordinates for the new clusters are calculated.

5 Fuzzy C-means Clustering

Pattern recognition problems, due to their inherent inaccuracy, demand Fuzzy modeling. Fuzzy modeling is more flexible in dealing with uncertainties and obscurities in structures.[12],[13],[14]

In Fuzzy clustering methods, instead of only the end points, the entire [0,1] range is used to determine whether a point is a member of a cluster ($U_{ik}$). In this way, each point can have relative membership to several clusters. On the other hand, due to continuity of functions, differentiation might be used to determine the proper search path. Goal function is defined as follows:

$$J_{n}(n,c) = \sum_{k=1}^{n} \sum_{i=1}^{c} (m u_{ik}^{-m} (|x_k - v_{xl}| + |y_k - v_{yl}| + L))$$

With $m$ a number greater than one.
It can be shown that $J_m(n,c)$ is minimum if:

$$
u_{ik} = \left[ \sum_{j=1}^{c} \left( \frac{|x_k - v_{i\alpha}| + |y_k - v_{j\beta}| + L}{m-1} \right) \right]^{-1}$$

(5)

Whereas,

$$v_{i\alpha} = \frac{\sum_{k=1}^{n} (u_{ik})^m x_k}{\sum_{k=1}^{n} (u_{ik})^m}$$

(6)

$$v_{j\beta} = \frac{\sum_{k=1}^{n} (u_{ik})^m y_k}{\sum_{k=1}^{n} (u_{ik})^m}$$

(7)

Therefore, clustering optimization for each $n$ may be pursued by updating the parameters above to the point where variation in $u_{ik}$ is less than an arbitrary value $\varepsilon$. It has been shown that the aforementioned algorithm converges to the correct solution.[16],[17]

The algorithm produces a $U_{c \times n}$ matrix with numbers between zero and one as its elements. To definitely determine boundaries for each cluster, the farthest point is found such that $u_{ik}|x_k - v_{i\alpha}|$ and $u_{ik}|y_k - v_{j\beta}|$ are maximum.

6 Simulation results

The data points for clustering algorithms have been taken from drawings for all 5 fixture systems handling the 15 different parts manufactured at Press Shop Number 3 at Iran Khodro Company.[7] In the Fuzzy Clustering algorithm, 1.2 has been assumed as the optimal value of $m$. A 1500*2500 square millimeter table carries the fixtures and motor length in $z$ direction is 700 mm.

The experimental arrangement of locators prior to optimization is such that each locator covers a quarter of the table.[7] It is thus necessary that each locator cover 1.25, 0.75, 0.7 meter in $x$, $y$, and $z$ directions respectively. A total length of 4.7 m is then needed for every locator. Figure 6 depicts total actuator lengths for 1 to 20 locators before and after optimization.

Experience has shown that 12 locators can handle a part correctly and without fixture redundancy.[7] Figure 7 shows the most suitable arrangement of these locators.

Figure 6- Total actuator length against the number of actuators before and after optimization

Figure 7- Fuzzy Clustering-optimized arrangement of 12 flexible fixtures

Considering the arrangement of locators before and after optimization, the total length of actuators is calculated at 56.4 meter and 21.2 meter respectively. Optimization has resulted in a 62.4% reduction in total linear motor length compared to the original fixture combination.

Figure 8 indicates that cluster centers converge in the optimum condition.
7 Conclusion
Flexible components are indispensable to increasing production speed and reliability in an automated system. Application of a flexible fixtures system and use of linear motors was found to be the best method of adding flexibility to the Loader and Unloader transfer system installed at Press Shop number 3 at Iran Khodro Company. Fuzzy Clustering algorithm produced good results despite the imprecise nature of the problem in hand, decreasing the total linear motor length necessary by 62.4%. Such reduction in motor length leads to substantial saving in production costs.

8 Acknowledgements
The authors wish to extend their utmost gratitude to engineers at the Production Engineering Department at Iran Khodro Company’s Press Shop 3, Messrs. Naqib-Kia, Fathalian, Rahimi, Mohammai and Rezapour for their help and guidance and support with this work.

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