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A Fuzzy Implementation for Optimization of Storage Locations in an Industrial AS/RS

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***Abstract*—**Warehousing is commonly used in factories for the storage of products until delivery of orders. As the amount of products stored increases it becomes tedious to be carried out manually. In recent years, the manual storing has converted into fully or partially computer controlled systems, also known as Automated Storage and Retrieval Systems (AS/RS). This paper discusses an ASRS system, which was designed such that the best storage location for the products is determined by utilizing a fuzzy control system. The design maintains the records of the products to be/already in store and the storage/retrieval times along with the availability status of the storage locations. This paper discusses on the maintenance of the above mentioned records and the utilization of the concept of fuzzy logic in order to determine the optimum storage location for the products. The paper will further discuss on the dynamic splitting and merging of the storage locations depending on the product sizes.

***Keywords*—**ASRS, fuzzy control systems, MySQL database, dynamic splitting and merging.

I. Introduction

AUTOMATED Storage and Retrieval Systems (ASRS) are computer controlled storage systems that can automatically store and retrieve loads with high throughput [1]. Other major advantages of automating a storage and retrieval system are the efficient use of space, high reliability and improvement of safety [2]. In an ASRS, computers and software activate the operation of the S/R machines enabling the reduction of workers yet dealing with a large number of storage and retrieval operations due to the speed and accuracy.

In recent days, the ASRS systems are at the most sophisticated level, in which the operations are totally automated and computer controlled [3]. Research is carried on for the optimization of these systems to minimize the travelling distance and travelling time of the S/R machines. Hence these computer controlled systems are made intelligent by utilizing optimization methods such as genetic algorithm and fuzzy C means clustering and fuzzy logic to determine the best storage location for the products or to determine the optimum path for the S/R machine to travel in order to reduce the traveling time.

In [4] a genetic algorithm based on Pareto optimal solution was adopted for the optimization for automated warehouse. To improve the efficiency of storage and retrieval operations of automated warehouse, three scheduling policies were proposed. Application of the solution indicated that it could be used in warehouse assignment problem.

The main objective of this paper is to utilize an optimization method to determine the optimum storage location for the items being stored in an ASRS system. Hence for the purpose of determining the best storage location, the concept of a fuzzy control system is utilized. Lofti Zadeh (1965) the master of fuzzy logic defined the term fuzzy logic as [5]:

"Fuzzy logic is determined as a set of mathematical principles for knowledge representation based on degrees of membership rather than on crisp membership of classical binary logic."

II. Research Scope

The designed ASRS system allows storing and retrieving of a batch of products. The storage locations are not designed as dedicated storage locations for each product. The system is programmed in *Visual Basic 2005* [6] such that the optimum location for the product is determined using a fuzzy control system, only at the time the product is to be stored. The locations can be dynamically split and merged as the products are stored and retrieved respectively depending on the product dimensions. The fuzzy expert system was initially designed in MATLAB Fuzzy Toolbox and was later converted into Visual Basic Coding.

The records of the activities of the ASRS system is maintained in a MySQL database which is updated at the storing and retrieving of items in the system. A graphical user interface was created to allow the user to store and retrieve products. It also enables the user to view the records in the MySQL database via VB in spite of their knowledge on MySQL.

This paper does not focus on physical configuration of a warehouse system that includes the layout of the racks, number of I/O ports, appropriate transportation systems and space utilization [7] or other hardware that is involved in an ASRS. The main objective is to design a software application which is compatible with small or large scale warehouse systems, different product types with varying attributes such as the dimensions, weight and activity times. For the purpose of testing the system, product details from a FESTO catalogue was used with part numbers and product names. The number

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of storage locations for the system was taken as 100 in which there are 10 rows and 10 columns.

The system integration consists of the serial communication of PLC Hardware (PC is used for the purpose of demonstration) and RFID reader interface to obtain part number of item upon storing.

A. Database of the System

MySQL [8] is a database system which allows the communication between databases and tables within a database. MySQL was utilized for this project to create a database which consists of several tables that are linked together by an initially defined primary key for each table. The database named as "ASRS" consist of the following tables with corresponding attributes as columns:

- Productinfo table – the name, part number (primary key), weight, length, width, height and S/R times of the products to be stored and already in storage. The records of this table are utilized to obtain the inputs to the fuzzy control system.
- Storageinfo table – the name, part number, type, storage location (primary key) of the products already in storage. The records of this table are updated accordingly with the storing and retrieving of the items.
- Availability table – the storage locations (primary key), and the availability status of each location. The availability table contains records of all the storage locations in the warehouse and is updated with the storing and retrieving of items. Upon storage, the storage location of the product being stored is updated in the availability table such that the STATUS of that particular location is set as 'OCCUPIED.' If all the items of the storage location is retrieved, the STATUS column in the availability table is set to 'AVAILABLE.'
- Activity table – the part number, date and time of storage/retrieval. Activity table contains records of all the storing and retrieving activities of the warehouse through a unit period of time (one month) allowing relevant personnel to view the activities and detect possible areas in which the system could be improved.

A communication link between the software Visual Basic 2005 and MySQL database was obtained in order to retrieve relevant data for the execution of the fuzzy control system and to update the MySQL tables accordingly with the storing and retrieval of items.

B. Dynamic Splitting/Merging of Storage Locations

It is important to utilize the Rack space intelligently in a warehouse. Therefore the concept of dynamic splitting and merging of shelves was employed in this system to maximize the space utilization.

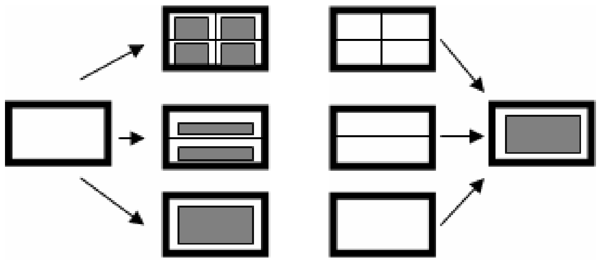


Fig. 1 (a) the storage location is dynamically split into 1, 2 or 4 for storage. (b) the storage location is merged once all the cells are emptied upon retrieval

The program is designed such that storage locations can be split dynamically into 2 or 4 depending on the dimensions of the product. If the dimensions are small the location will be split into 4 locations (type 4), if medium the location will be split into 2 locations (type 2) else the location will not be split (type 1). Once the products in all of the split cells of the previously split storage location are retrieved, the split location will be merged once again allowing the same or different number of splits.

C. Naming Conventions of the Storage Location

The storage location was given as an array with two elements store_vert and store_horiz. Store_vert and store_horiz is the column number (vertical component) and the row number (horizontal component) of the storage location, respectively. The numbering is a multiple of 10 allowing the splitting and merging of the locations.

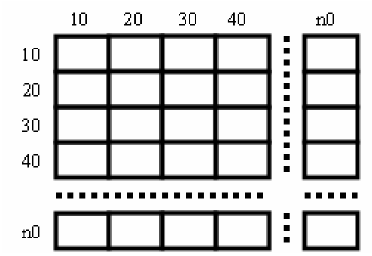


Fig. 2 Naming convention of storage location

The Fig. 3 takes one storage location with column number 20 and row number 10 (20,10) shown in Fig. 2 above as an example in order to describe the naming conventions of the split cells. From Fig. 3 it is clear that originally when the locations are not split the numbering of the storage locations are simply the number of the column and the number of row multiplied by 10. Once the locations are split, '1' and '2' are added to the row and column number depending on the number of splits.

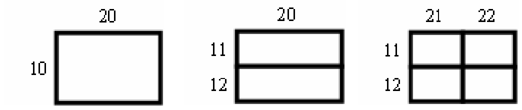


Fig. 3 Naming convention of storage location (20, 10) (a) with no splits (type 1), (b) with 2 splits (type 2) and (c) with 4 splits (type 4)

D. Fuzzy Control System

The project utilizes the concept of fuzzy logic in order to determine the optimum storage location for a product that is to be stored.

The inputs to the fuzzy control system is the activity times (the number of storing and retrieving times for a unit time) of the products and the weight of the product. The output of the fuzzy control system consists of two components, the horizontal and vertical components of the optimum storage location. The control system is designed such that the weight has an effect only on the horizontal component while the activity time has an effect only on the vertical component.

To maximize the throughput of an ASRS, many researches follow the strategy of class based storage. It is the process of identifying the mostly accessed items (higher activity time) and clustering these items in a storage location closer to the I/O port, to minimize the travelling time of the S/R machine [9].

For this project, the Pareto analysis [4] was considered in the case of determining the activity time of the products. The activity times of the 'productinfo' table was divided into three classes as follows:

- A – 20% items leads to 80% S/R activity
- B – 30% items leads to 15% S/R activity
- C – 50% items leads to 5% S/R activity

Fuzzy rules are required to obtain the effect of the inputs on the outputs of the fuzzy control system. For the designed fuzzy control system, seven rules were considered such that products with a high activity rate (class A) will be stored near to the I/O station than those with low activity rates (class B and class C respectively) and the products that are heavy will be stored at the bottom and those with light weights at the top.

The product items of the same kind are assumed to be placed inside pallets before storing. Hence when a pallet is retrieved from the warehouse in order to collect items for delivery, the quantity in the pallet will decrease in turn reducing the weight, which leads to the change of the optimum storage location for the pallet. Therefore the system is designed such that the fuzzy control system will execute each time there a pallet is been stored.

E.g : a pallet is in store with initially 10 items. The pallet is retrieved from the warehouse in order to collect 5 items in the pallet. Once the 5 items are collected, the weight of the pallet will be reduced; hence it is possible to place it in a higher location than the previous. Hence the fuzzy control system will determine the optimum storage location once again.

The fuzzy control system was initially designed with the fuzzy logic toolbox offered by MATLAB and later ported to Visual Basic code. When converting in to Visual Basic code, five basic steps were followed to obtain the fuzzy control system [10].

1. Determine the inputs and the outputs fuzzy sets
2. Rule evaluation
3. Aggregation of rule outputs
4. Defuzzification

The input and output fuzzy sets were assigned the parameter values of that defined in MATLAB Fuzzy Toolbox.

In order to map a given crisp input to the output fuzzy set for a given rule, the triangular membership and the trapezoidal membership function were utilized. The degree of membership (DOM) of the output fuzzy set for a given crisp input, when the output fuzzy set is a triangular membership function, can be determined by the following equation:

$$f(x,a,b,c) = \max\left(\min\left(\frac{x-a}{b-a}, \frac{c-x}{c-b}\right), 0\right) \quad (1)$$

Where x is the crisp input and a, b, c are the input parameters for the particular fuzzy set.

Similarly the degree of membership was determined for the trapezoidal membership function by utilizing (2).

$$f(x,a,b,c,d) = \max\left(\min\left(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}\right), 0\right) \quad (2)$$

After the evaluation of all the rules for the system the rules are summed in order to obtain the fuzzy output. Since an output cannot be given as a fuzzy set, defuzzification is performed to evaluate a crisp output.

$$\frac{(q1+q2+q3)*A+(q4+q5+q6)*B+(q7+q8+q9)*C}{A*n1+B*n2+C*n3} \quad (3)$$

The crisp output is calculated utilizing (3), in which A, B and C are the degrees of membership for each fuzzy output calculated from (1) and (2) while q1, q2…. q9 are fuzzy output parameters of fuzzy output set. For instance one fuzzy output set which is a triangular membership function will have three parameters, which are the values of the three corners of the triangular. n1, n2 and n3 are the number of membership functions for the corresponding fuzzy sets with degree of membership A, B and C respectively.

The results of both MATLAB Fuzzy Toolbox and Visual Basic coding were compared to determine if there are significant differences in the two results.

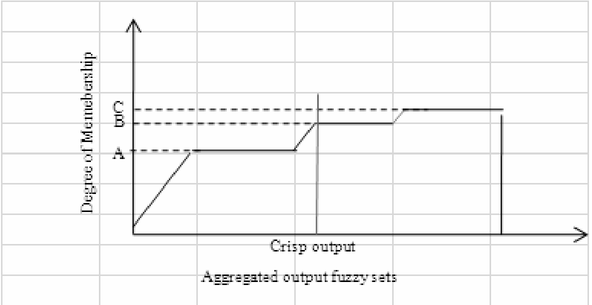


Fig. 4 Determination of a crisp output from aggregated output fuzzy sets

E. Serial Communication

In the ASRS system designed, it is required for both the RFID reader and the S/R controller to communicate with the program in both storage and retrieval activities. The information of the part number of the items being stored and the storage locations of the items to be stored/retrieved are to be transferred from RFID reader to PC and PC to SR/machine respectively.

Each pallet which is stored is assumed to have a unique part number. The RFID reader reads this part number on the pallet to be stored, when it is moving in the conveyor, and displays in the GUI. In order for this event to occur it is required for the program and the RFID reader to communicate with each other and transfer information. This connection was established by the use of an RS232 cable which supports serial communication. The RFID reader used for the purpose of this project was Mifare (MF5) RFID card reader.

When a product is being stored or retrieved it is essential to inform the S/R controller to perform the activity of storing or retrieving. The S/R controller should also receive the storage location of the item to be stored/retrieved. When storing a product the S/R controller should also be informed on the number of splits of the storage location. The paper does not cover the implementation of an ASRS model. Hence for the purpose of demonstation the program communicates to another PC instead of the S/R controller.

The storing and retrieving signals were sent via RS232 cable to another PC in the following string format.

- Storing - (10, 11), [2], 1
- Retrieving - (10, 11), 0

'(10,11)' the storage location
'[2]' in the case of storing indicates the storage type (split into two)
'1' indicates store and '0' indicates retrieval.

F. Graphical User Interface

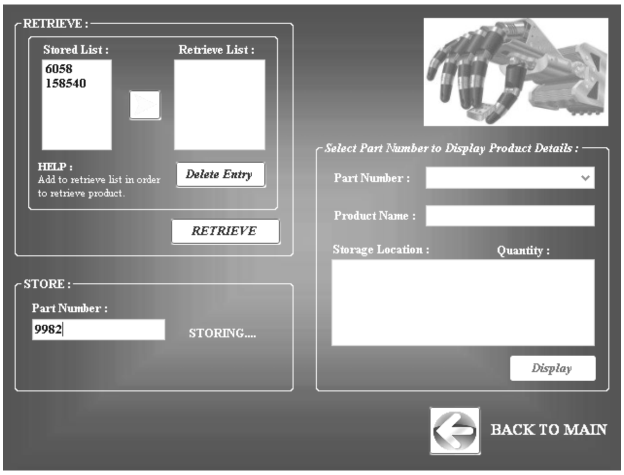
A graphical user interface (GUI) was created such that the user can view all the details of the products in storage and the availability of the storage locations. The user can also retrieve any item in store once the part number and the quantity to be retrieved is inserted in to the system.

The GUI allows the user to access the records in MySQL in a user friendly manner without the requirement of the knowledge on MySQL. All the records of the ASRS system are displayed to the user in a data grid view and can be accessed any time. The GUI is designed using the Visual Basic 2005 software and VB is linked to MySQL in order to obtain the records in the MySQL databases.

Part_name	Part_number	quantity	store_vert	store_horiz	type
Clevis foot mounti...	6058	10	21	11	4
Clevis foot	6058	10	21	12	4
Clevis foot mounti...	6059	10	21	71	4
Clevis foot	6058	10	22	11	4
Clevis foot mounti...	6058	10	22	12	4
Double Acting	158540	10	50	70	1

Fig. 5 Details of the products that stored in the warehouse including the storage location and the type of the location

Fig. 6(a) displays the GUI that is available to the user. The part number of the product which is being stored is displayed in the GUI. Once the system has completed the storing activity, the user is notified by an acknowledgement as in Fig.6(b).



(a)

(b)

Fig. 6 (a) GUI when a product with part number 9982 is stored (b) Acknowledgement when the product is stored

In order to link MySQL Database with Visual Basic, a Data Provider is utilized which consist of the common utility classes the connection, command, parameter, Data Adapter and Data Reader.

The connection string contains the password, username and the name of the database and provides the connection to communicate with the data source (MySQL Database). The command is used to perform certain actions on the data source, such as reading, updating or relating relational data.

G. Displaying the Layout of the Storage Locations in Excel

The storage locations are stored in an Excel sheet as shown in Fig. 7 which is available for the user viewing. This serves as a back up and can be utilized for manual retrieval in case of a hardware failure. The available cells and the occupied cells are clearly distinguished by the fill color of the occupied cells being 'purple.' The Part stored on each of these locations is available as a separate list.

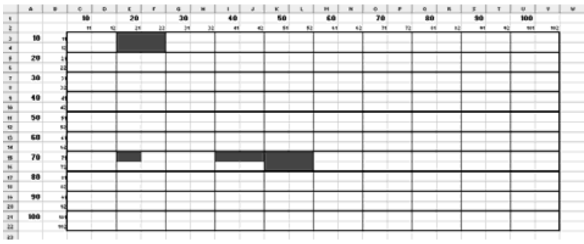


Fig. 7 Layout of the storage shelves

H. MIS Layer

A MIS layer works on top of the MySQL DB layer and all the data is available in tables. A sample DB schema for the developed application is shown below in Fig. 8.

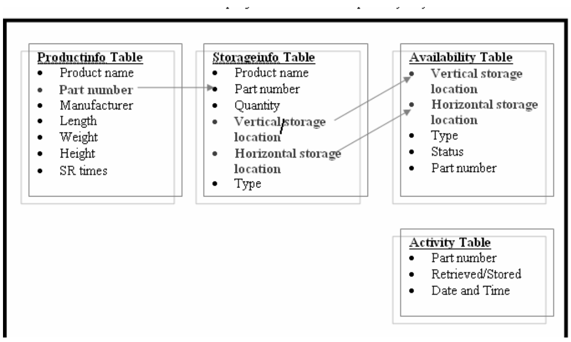


Fig. 8 Data Base schemas

I. E-Mail function

The ASRS system designed was integrated with an E-mail function which automatically e-mails the activity details to the relevant personnel each month. The activity details are obtained from the MySQL 'activity' table and converted in to an Excel application, and attached to an E-mail and mailed via Outlook.

III. OVERALL SYSTEM ARCHITECTURE

The overall system as shown in Fig. 9 consists of MySQL database management, GUI development, integration of VB software and MySQL database, integration of MiFare RFID reader with VB, communication of S/R controller and PC and integration of MS office applications with VB.

For storing, when a part number is detected by the RFID reader, it will communicate with the designed VB application by a serial port and send the part number as a string to the GUI. VB will then communicate with the MySQL database in order to retrieve the input parameters (weight and activity times) for the fuzzy control system. The fuzzy control system will then determine the optimum storage location and the number of splits. VB will then send the storage location, type of location and '1' to indicate storing, to the S/R controller through a RS232 cable. MySQL database will be updated such that the availability table will update STATUS to 'occupied' for the relevant storage location, the 'storageinfo' table will be updated with the details of the item stored and the activity table will be updated with the storing activity time and date.

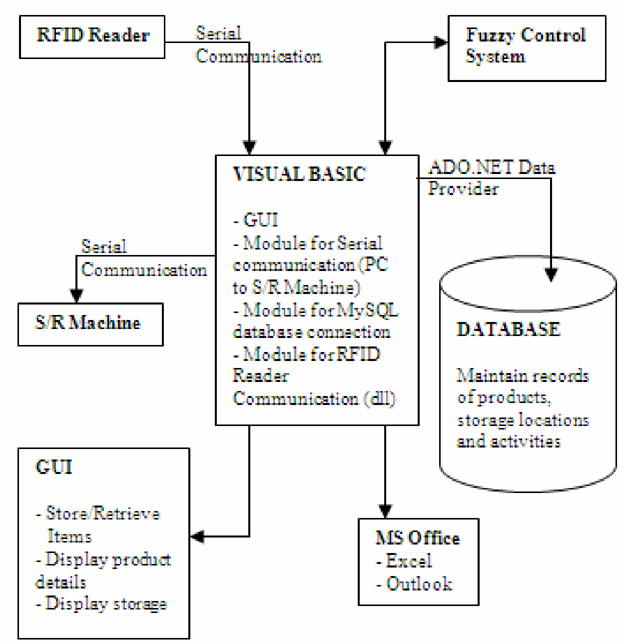


Fig. 9 Overview of the system architecture

When retrieving an item, the user will enter the item and quantity to be retrieved in the GUI, which will in turn communicate with the MySQL database to check if the inserted details are valid. If such item exists with the required quantity, VB communicates with the S/R controller to notify that an item is to be retrieved from a particular storage location. The MySQL database tables will be updated accordingly.

IV. RESULTS

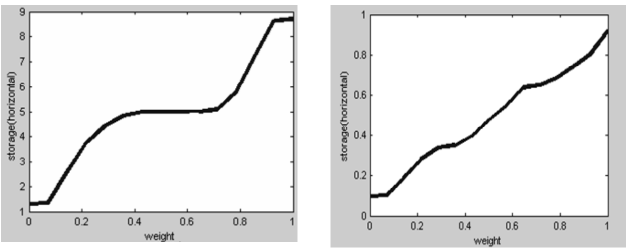
Results obtained from the development of the system are as follows:

- Dynamic splitting/merging of storage locations when stored/retrieved respectively.

- Various fuzzy control systems were designed each with varying membership functions and the optimum control system was chosen.
- Optimum locations for the products were determined by the chosen fuzzy control system.
- Successful conversion of coding of the fuzzy control system from MATLAB to Visual Basic.
- Creating a database in MySQL with several tables linked together and the successful management of this database.
- Linking the created database to Visual Basic and the successful manipulation of these tables through VB.
- GUI allows user to insert the quantity of product being stored and the selection of part numbers and the quantity required to retrieve of a particular item.
- GUI enables the user to view information of the products and the storage locations (graphical representation in Excel).
- Successful serial communication from PC to ASRS module and vice versa, allowing storage and retrieval and reading of Bar code and RFID tags through Readers.
- Integrated email function allowing automatic emailing of the activity table periodically.

V. Discussion

A number of fuzzy control systems each with varying number of membership functions (MFs) were taken in to consideration when choosing the best fuzzy control system.



(a) (b)

Fig. 10 The effect of the weight on the horizontal component of the storage locations are compared in fuzzy logic Toolbox with differing number of MFs (a) 3 MFs, (b) 4 MFs

The Fig. 10(a) the horizontal component of the storage location remains the same for a much larger range of weights while for Fig. 10(b) the horizontal component changes with only a small weight change. Hence the fuzzy control system with four membership functions was chosen as the optimum fuzzy control system for the purpose of this work.

The Fuzzy control system implemented utilizing the MATLAB fuzzy logic toolbox was converted into Visual Basic to avoid Schedule lag due to the integration of software and hardware issues during the application development. The results from the MATLAB Fuzzy Logic Toolbox and the results from the fuzzy control system coded in Visual basic were compared in order to determine the difference of the results.

Testing was done to compare the results between results obtained from VB application and MATLAB. There were no significant changes in the results and the small differences were due to calculation methods utilized in the defuzzification method in MATLAB Fuzzy Logic Toolbox and the Visual Basic Coding.

VI. Conclusion/ Future Work

We utilized the concept of a fuzzy control system in order to determine the optimum storage location for the products in a warehouse system. The system was programmed and implemented such that it is compatible for large or small warehouses.

Further work is in progress to model and optimize the results for determining the best storage location for items. Future work will include a rearranging function of the products at off-peak hours which improve the readiness of the system for the next peak hour thus maximizing the throughput of the ASRS system. The system can be made more intelligent by analyzing the Logs which contain details such as the activity times, List of the items and the S/R frequency as the system is on the run for a couple of months. As the activity table records the storing and retrieval of items every month, the system can store in locations further optimized through learning.

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