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The International Journal of Artificial Intelligence and Expert Systems (IJAE) is an effective medium for interchange of high quality theoretical and applied research in Artificial Intelligence and Expert Systems domain from theoretical research to application development. This is the *Fifth* Issue of Volume *Two* of IJAE. The Journal is published bi-monthly, with papers being peer reviewed to high international standards. IJAE emphasizes on efficient and effective Artificial Intelligence, and provides a central for a deeper understanding in the discipline by encouraging the quantitative comparison and performance evaluation of the emerging components of Expert Systems. IJAE comprehensively cover the system, processing and application aspects of Artificial Intelligence. Some of the important topics are AI for Service Engineering and Automated Reasoning, Evolutionary and Swarm Algorithms and Expert System Development Stages, Fuzzy Sets and logic and Knowledge-Based Systems, Problem solving Methods Self-Healing and Autonomous Systems etc.

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TABLE OF CONTENTS

Volume 2, Issue 5, November / December 2011

Pages

- | | |
|-----------|---|
| 195 - 207 | Efficient Mining of Association Rules in Oscillatory-based Data
<i>Mohammad Saniee Abadeh, Mojtaba Ala</i> |
| 208 - 228 | Position Control of Robot Manipulator: Design a Novel SISO Adaptive Sliding Mode Fuzzy PD Fuzzy Sliding Mode Control
<i>Farzin Piltan, N. Sulaiman, Sadeq Allahdadi, Mohammadali Dialame, Abbas Zare</i> |

Efficient Mining of Association Rules in Oscillatory-based Data

Mohammad Saniee Abadeh

*Assistant professor, Faculty of Electrical and Computer Engineering
Tarbiat Modares University
Tehran, 14115-143, Iran*

saniee@modares.ac.ir

Mojtaba Ala

*Computer Engineering Department
Payame Noor University
Tehran, Iran*

mojtaba.ala@gmail.com

Abstract

Association rules are one of the most researched areas of data mining. Finding frequent patterns is an important step in association rules mining which is very time consuming and costly. In this paper, an effective method for mining association rules in the data with the oscillatory value (up, down) is presented, such as the stock price variation in stock exchange, which, just a few numbers of the counts of itemsets are searched from the database, and the counts of the rest of itemsets are computed using the relationships that exist between these types of data. Also, the strategy of pruning is used to decrease the searching space and increase the rate of the mining process. Thus, there is no need to investigate the entire frequent patterns from the database. This takes less time to find frequent patterns. By executing the MR-Miner (an acronym for "Math Rules-Miner") algorithm, its performance on the real stock data is analyzed and shown. Our experiments show that the MR-Miner algorithm can find association rules very efficiently in the data based on Oscillatory value type.

Keywords: Data Mining, Association Rules, Frequent Patterns, Stock.

1. INTRODUCTION

Association rules mining is an important problem in the data mining field which deals with exploring the association and hidden relationships between itemsets within a transaction [2]. For example, an association rule may be like this: "If the stock prices of Transfo and Parsian go down, at 80% of probability, the price of Iran Khodro goes down". This rule is seen in 40% of the transactions. In this example, the probability posed is called "confidence" and the percentage of the transactions cover this rule is called "support".

Several algorithms have been proposed for mining association rules. Among these, the best approaches are including: Apriori approach [1], [2], which was first introduced by Agrawal in 1993. This approach operates on the basis of the candidate generation; and, searching {there} is done through the method of breadth-first so that the network of itemsets is searched from one level to another one. Eclat's approach was presented by Zaki et al. in 1997 [5]. FP-growth approach was presented by Han et al. four years later [4]. In this approach (FP-growth), discovering frequent patterns is done without candidate generation through using FP-tree where searching is done by depth-first. Recently, several algorithms have also been introduced for this purpose such as [3], [12] which were presented by Borgelt et al.

Mining association rules is very useful in the financial issues and the capital market such as the stock market [7], [8], [9], [10], [11]. Data such as stock data include the oscillatory value type. In this paper, an effective method about the data with the oscillatory value type is presented in which, unlike the available algorithms that all frequent itemsets are mined from the database, just a few numbers of the counts of itemsets are searched from the database, and the counts of the

rest of itemsets are computed using the relationships that exist between these types of data. The method consists of two important stages. In the first stage, the frequencies of some patterns is searched via a database; and, in the second stage, the other frequent patterns are computed by the frequencies of the patterns which was obtained in the first stage.

The remainder of the paper is organized as follows: In section 2, issues related to mining association rules are described in the data with the oscillatory value type. In Section 3, the MR-Miner algorithm is introduced; the experiments results are presented in Section 4; and, Section 5 includes the conclusion of this paper.

2. DEFINITIONS

In this section, some concepts associated with mining association rules in the data with the oscillatory value type are described. Before doing so, we will first give some definitions.

Definition 1 Let $u(i)$ and $v(j)$ be two "items", in this case $u(i) = v(j)$, where $(i = j$ and $u = v)$.

Definition 2 Let $\alpha = \{u_0(i), u_1(i), \dots, u_k(i)\}$ and $\beta = \{v_0(j), v_1(j), \dots, v_k(j)\}$ be two "patterns" for $k \geq 1$. $\alpha = \beta$, where $u_m(i) = v_m(j)$ for $0 \leq m \leq k$.

Definition 3 In a transaction database D , the number of transactions is shown by $|D|$. Let α be a pattern, the frequency of α is shown by $count(\alpha)$ and the support of α is shown by $sup(\alpha) = count(\alpha)/|D|$. If $sup(\alpha)$ is less than the user-specified minimum support, "minsup", α will be called a "frequent pattern".

Definition 4 The number of items in a pattern is called the *length* of the pattern. A pattern with the length of k is called "k-pattern" (or k-itemset).

Example The length of $\{a(1), b(2), c(2), d(2)\}$ is equal to 4.

Definition 5 The number of items in a transaction is called the length of the transactions. The length of transactions is shown by L .

Definition 6 An association rule is like $\alpha \rightarrow \beta$, where: (1). Both α and $\alpha \cup \beta$ are frequent patterns; (2). $\alpha \cap \beta = \emptyset$; and, (3). $conf(\alpha \rightarrow \beta)$ is not less than the user-specified minimum confidence. The confidence of a rule is defined as $sup(\alpha \cup \beta) / sup(\alpha)$.

Oscillatory value: the value of an attribute in a transaction represents an increase or decrease in it. In the analysis of association on this type of data, only increase or decrease, are important in the numerical values showing the oscillation. Therefore, the numerical values turn into the "Up" or "Down".

TID/date	Attribute/stock symbol		
	ALBZ	DLGM	INFO
20100903	Up	Down	Up
20100904	Up	Down	Down
20100905	Down	Up	Down
20100906	Up	Up	Up

TABLE 1: Stock market data

Taking stock market database as an example, association rule mining can be used to analyze the share price movement. The stock prices variation in the stock market database is the oscillatory value type. As it is shown in Table 1, several trades are considered in the stock market database

of a transaction every day and the date of that day is used as its transaction ID (TID). Each attribute is the changes in stock price of a company accepted in a stock market which has two values: "Up" or "Down". "Up" indicates the increase of price in one stock, and "Down" indicates the decrease of price in one stock, which are shown briefly with the numbers of 1 and 2, respectively.

3. THE MR-MINER ALGORITHM

In this section, the MR-Miner algorithm is presented and the details of the method are shown step by step. The MR-Miner algorithm is made of the combination of four major functions of the Candidate, SeekDB, Prune2 and Compute. The Algorithm and its functions are shown in Figures 1, 3, 4, 6.

3.1. The MR-Miner Algorithm

To discover frequent itemsets, the main idea in this method is in such a way that: first, $(2^L - 1) * 2^{L-2}$ of the candidate itemsets are generated; then, the other 3 itemsets are generated by each of these k-itemsets for $k \geq 2$. There is a relationship between the counts of all obtained 4 itemsets so that by finding the frequency of 1 itemset from the database, the counts of the other 3 itemsets can be computed by Equation 6, with no need to the database. Of course, some of these candidate itemsets are pruned by the Prune2 function according to Figure 4.

Algorithm: MR-Miner(transaction database D , $minsup$)

```

F = Candidate(D);
F1 ← SeekDB(F1, D);
F1 ← Compute(F1, |D|);
For( k = 2; Fk ≠ ∅; k++ )
    if(k>=3)
        Prune2(Fk, Fk-1);
    end if
    Fk ← SeekDB(Fk, D);
    Fk ← Compute(Fk, Fk-1);
    for (each itemset i in Fk-1 )
        if (i.Count < minsup)
            Delete i from Fk-1;
        end if
    end for
    F ← Fk;
end for
Output All Frequent Patterns F;

```

FIGURE 1: The MR-Miner algorithm

In general, the MR-Miner algorithm consists of the following four phases.

- PHASE I: Determination of candidate itemsets
- PHASE II: Pruning based on the candidate frequent itemsets
- PHASE III: Counting some itemsets via the database
- PHASE IV: Computing the rest of itemsets, with no need to the database

The following presents the detailed method phase by phase.

3.2. PHASE I: Determination of Candidate Itemsets

First, the candidate patterns are generated in two stages: In the first stage, all itemsets $\alpha = \{u_0(i), u_1(i), \dots, u_k(i)\}$ are generated for $i = 1$. To do this, 1-itemsets are generated by the available attributes in the transaction database corresponding to Figure 1; then, 2-itemsets are generated by joining 1-itemsets; similarly, the k-itemsets are generated by joining (k-1)-itemsets. All the generated itemsets include items with value of 1 (up). In the second stage, using each generated k-itemsets ($k \geq 2$), $2^{k-2} - 1$ of the other itemsets are generated. To generate these

itemsets, the value of 2 is used in $k-2$ of their first items. The generated itemsets, in these two stages, are called candidate itemsets.

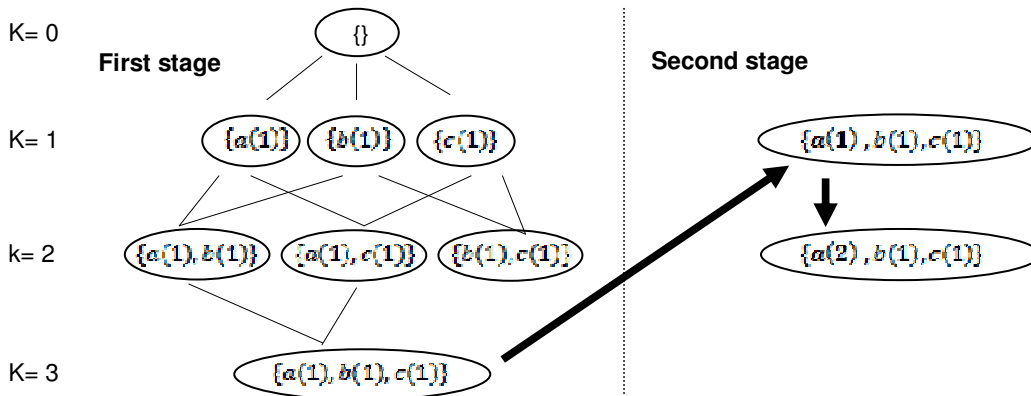


FIGURE 2: Generation of the candidate itemsets.

To generate candidate 1-itemsets $\{u(1)\}$, we need to have the attributes u from the database which are considered as the input of the Candidate function, and the Join function which is similar to the function of candidate generation in Apriori approach, has generated k -itemsets for $k \geq 2$ by joining $(k-1)$ -itemsets. Finally, for each generated itemset, $2^{k-2} - 1$ other itemsets are generated by $k - 2$ of the first items. Figure 3 shows the Candidate function.

```

Function: Candidate(transaction database  $D$ )


---


 $C_0 = \emptyset$ ;
for (each attribute  $a$  of  $D$ )
    Generate 1-Itemset  $c$  by  $a(1)$ ;
     $C_1 \leftarrow \{c\}$ ;
end for
for ( $k = 2$ ;  $F_{k-1} \neq \emptyset$ ;  $k++$ )
     $C_k = \text{Join}(C_{k-1})$ ;
end for
if ( $k > 2$ )
    for (each Itemset  $c$  in  $C_k$ )
        Generate all  $c'$  by  $c: c \ni c' = \{u_i(j) \mid \forall 1 \leq i \leq k-2$ 
        then  $j$  is optional element from  $\{1, 2\}$  and
         $\forall k-1 \leq i \leq k$  then  $j=1\}$ 
         $C_k \leftarrow \{c'\}$ ;
    end for
end if
return Candidate Patterns  $C$ ;


---



```

FIGURE 3: The candidate itemset generation function

3.3. PHASE II: Pruning Based on the Candidate Frequent Itemsets

In the MR-Miner algorithm, the strategy of pruning is used to decrease the searching space and increase the rate of the mining process. Considering that all subsets of frequent k -itemsets are frequent, if the $(k-2)$ -subset from any candidate frequent k -itemsets is not frequent, this candidate itemset and $2^2 - 1$ other itemsets which should be made by that, will also not be frequent and will be deleted in this stage.

The code that is shown in Figure 4, with a survey of itemsets in the level of $k-1$ and $k-2$ delete a number of infrequent k -patterns and in this way the searching space will decrease.

Function: Prune2(k -Itemsets F_k , $(k-1)$ -Itemsets F_{k-1} , $minsup$)

```

for (each itemset  $i$  in  $F_k$ )
  find  $(k-2)$ -subset  $s$  of  $i$  in  $F_{k-2}$ 
  if ( $s \notin F_{k-2}$  or  $s.Count \leq minsup$ )
    Delete  $i$  in  $F_k$ 
  else
    find  $(k-1)$ -subset  $s$  of  $i$  in  $F_{k-1}$ 
    if ( $s \notin F_{k-1}$  or  $s.Count \leq minsup$ )
      Delete  $i$  in  $F_k$ 
    end if
  end if
end for
Return Patterns  $F_k$ 

```

FIGURE 4: The Prune2 function

3.4. PHASE III: Counting Some Itemsets Via the Database

In this phase, some itemsets are counted via the database and their frequent patterns available are determined. This section of the algorithm, the database T and the candidate itemsets F_k with the length of k are received as input and the counts of patterns return as output. This is done by the SeekDB function. Similar to Apriori algorithm, this stage has searched the database once at any level.

3.5. PHASE IV: Computing the Rest of Itemsets, With no Need to the Database

The itemset $\{u(2)\}$ is generated for each candidate itemset $\{u(1)\}$ with the length of 1. To simplify, it can be assumed $x_1 = \{u(1)\}$, $x_2 = \{u(2)\}$.

Considering that each attribute u is one of the two values of increase or decrease, and the number of whole values of one attribute is equal to the number of the whole transactions, we have for each attribute u :

$$count(x_1) + count(x_2) = |D| \tag{1}$$

So, we have for each 1-itemset x_2 :

$$count(x_2) = |D| - count(x_1) \tag{2}$$

So, to calculate the counts of the itemsets with the length of 1, all x_1 are searched from the database and all x_2 can be computed by Equation 2.

Also, for each candidate itemset with the length of higher than 1, there is $2^2 - 1$ other itemsets which should be generated, and their frequency should be computed.

For $k = 2$, $2^2 - 1$ other itemsets are generated by each of candidate 2-itemsets according to the Figure 5. There is a shared 1-itemset for all two 2-itemsets shown in Figure 5.

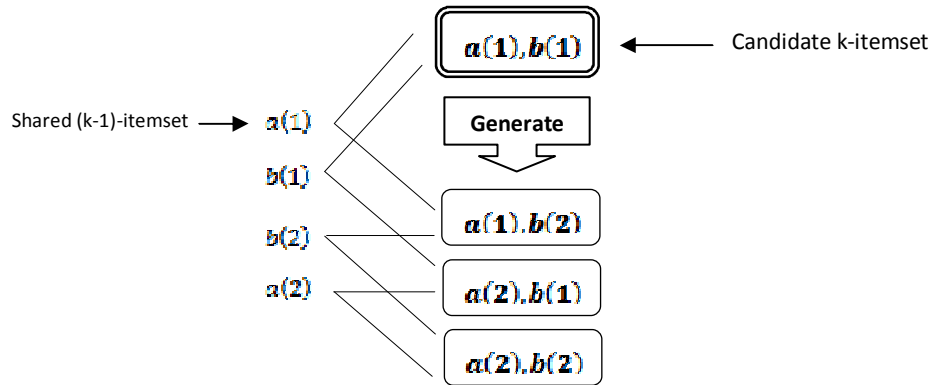


FIGURE 5: Relationship between 2-itemsets

Considering the available relationships in Figure 5, we have:

$$\begin{aligned}
 \{a(1), b(1)\} \cap \{a(1), b(2)\} &= \{a(1)\} \\
 \{a(1), b(1)\} \cap \{a(2), b(1)\} &= \{b(1)\} \\
 \{a(1), b(2)\} \cap \{a(2), b(2)\} &= \{b(2)\}
 \end{aligned}
 \tag{3}$$

We can extend Equation 3 for itemsets with the length more than 2. Let x_i be the itemset generated by a candidate itemset x_1 with the length of k such that $i = 2, 3, 4$ and let y_j be the itemset with the length of $k - 1$ such that $j = 1, 2, 4$. Regarding Equation 3, we have:

$$\begin{aligned}
 x_1 \cap x_2 &= y_1 \\
 x_1 \cap x_3 &= y_2 \\
 x_2 \cap x_4 &= y_4
 \end{aligned}
 \tag{4}$$

So, for their counts, we have:

$$\begin{aligned}
 count(x_1) + count(x_2) &= count(y_1) \\
 count(x_1) + count(x_3) &= count(y_2) \\
 count(x_2) + count(x_4) &= count(y_4)
 \end{aligned}
 \tag{5}$$

Finally, to compute the counts of k-itemsets x_2, x_3, x_4 , we have:

$$\begin{aligned}
 count(x_2) &= count(y_1) - count(x_1) \\
 count(x_3) &= count(y_2) - count(x_1) \\
 count(x_4) &= count(y_4) - count(x_2)
 \end{aligned}
 \tag{6}$$

Thus, by any candidate k-itemsets $x_1 (k \geq 2)$, 3 k-itemsets $x_i (i = 2, 3, 4)$ are generated which, at every level, by searching the frequency of the itemset x_1 from the database, the counts of the itemsets x_2, x_3, x_4 via Equation 6, are computed. Figure 6 shows the Compute function.

```

Function: Compute( $F_k, F_{k-1}, |D|$ )


---


    for (each k-itemset i in  $F_k$ )
         $X_1 = i$ ;
        if (k = 1)
             $X_2.Count = |D| - X_1.Count$ ;
             $F_k \leftarrow X_2$ ;
        else
            Find  $y_1, y_2, y_3$  in  $F_{k-1}$ 
            Generate  $x_2, x_3, x_4$  by  $X_1$ 
             $x_2.Count = y_1.Count - X_1.Count$ ;
             $x_3.Count = y_2.Count - X_1.Count$ ;
             $x_4.Count = y_3.Count - X_1.Count$ ;
             $F_k \leftarrow x_2, x_3, x_4$ ;
        end if
    end for
    Return  $F_k$ 

```

FIGURE 6: The Compute function

4. PERFORMANCE STUDY

We evaluated the performance of the MR-Miner algorithm on two synthetic datasets and three real datasets with various parameters. The data of Tehran Stock Exchange were collected from Tehran Securities Exchange Technology Management Company (TSETMC). We compared proposed algorithm with the Apriori algorithm. Apriori algorithm is a very useful and well-known algorithm and has been used in many articles related to mining association in exchange data in the recent years [8], [9], [10]. All experiments were running on a computer with a Pentium 3.06GHz processing, 1GB of main memory, 500GB of hard disk capacity and the operating system of Microsoft Windows XP. Both algorithms have been implemented using C# in the environment of Microsoft Visual Studio 2008.

Parameters	Real-life datasets			Synthetic datasets	
	Dataset 1	Dataset 2	Dataset 3	Dataset 4	Dataset 5
Number of transaction	2000	2000	2000	5000	10000
Length of transaction	6	10	16	10	10

TABLE 2: Sets of the parameters for 5 datasets

We generated two synthetic datasets, dataset 4 and dataset 5, using the parameters shown in Table 2, and, the first three are real stock data.

4.1. Experiment on Synthetic Data

In this section, we compare the MR-Miner algorithm with the Apriori Algorithm by varying one parameter, which maintaining the other parameter at the default values shown in Table 2.

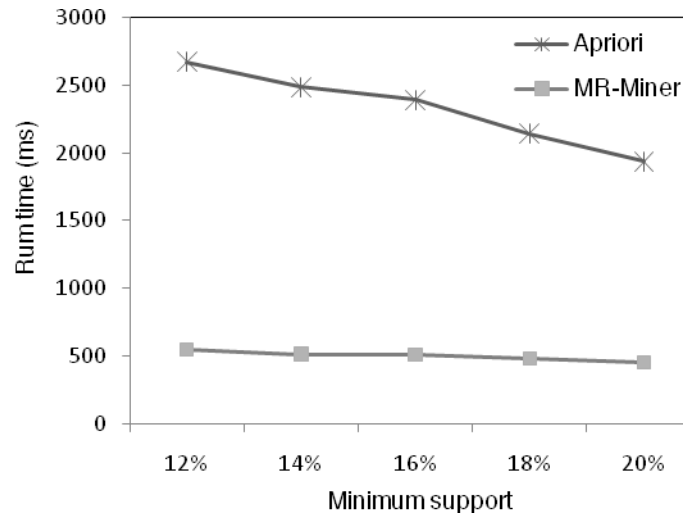


FIGURE 7: Minimum support versus run time, Dataset 4

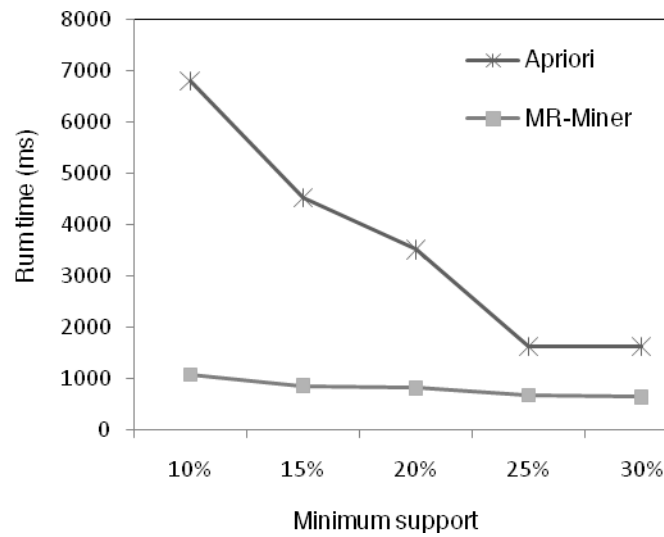


FIGURE 8: Minimum support versus run time, Dataset 5

Figures 7, 8 and 9 have shown the minimum support versus the run time. In Figure 8, the minimum support was investigated versus the run time with the lower minimum support for dataset 5. In this case, more itemsets were mined. By decreasing the amount of minimum support, the proposed algorithm had much less linear increase compared to the Apriori algorithm. Also, by increasing the minimum support, the run time on the dataset 4 is shown in Figures 7 and 9.

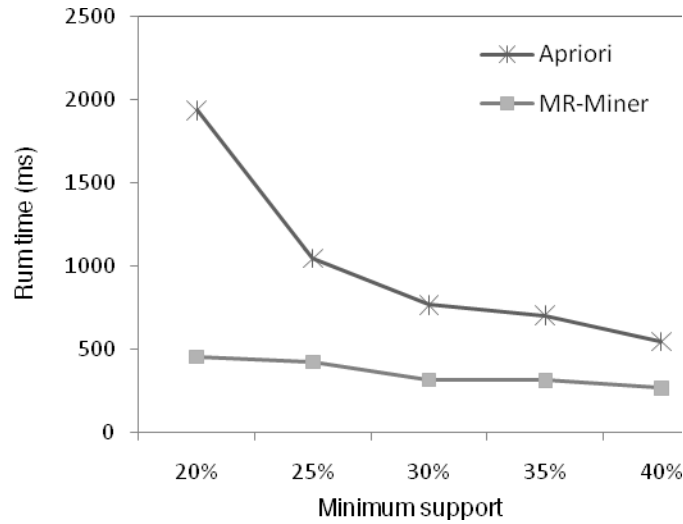


FIGURE 9: Minimum support versus run time, Dataset 4

Figure 10 shows the effect of increasing the number of transactions versus the run time on the dataset 2, 4 and 5. 2000, 5000 and 10000 were considered as the numbers of transactions. The minimum support of 20% was used for all datasets. The run time of both algorithms will increase versus increasing the number of transactions, so that the proposed algorithm will need 3 times less run time than the Apriori algorithm.

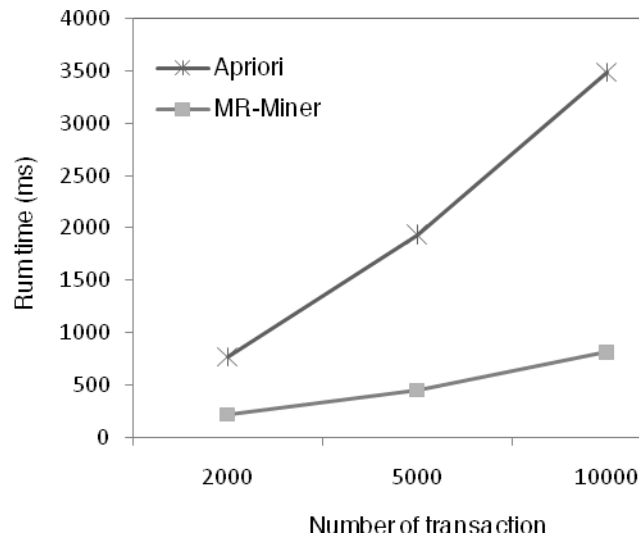


FIGURE 10: Number of transactions versus run time, with *minsup* = 20%

We also investigated the effect of the length of a transaction on both algorithms. The results are shown in Figure 11. In both algorithms, the run time had increased by increasing the length of transaction. Therefore, under the same support, more itemsets would be generated if the length of transactions increased. So, more candidate itemsets should be generated. In the proposed algorithm, since computing the entire frequent itemsets from database is not needed, by increasing the length of transactions, 3 times less time is needed than the Apriori algorithm.

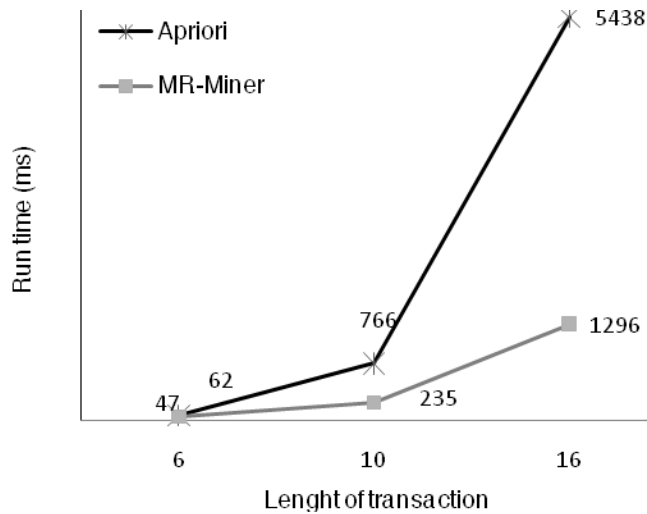


FIGURE 11: Length of transactions versus run time, with *minsup* = 16%

4.2. Experiments on Real Data

We now compare the MR-Miner algorithm and Apriori algorithm by mining three datasets 1, 2, 3. The datasets are included the stock price changes of eight companies: Iran Khodro, Jaber Ebne Hayyan Pharmacy, Tehran Cement, Mines & Metals Development, Isfahan Petrochemicals, Iran Transfo, Kashan Amirkabir Steel and Parsian Bank. The data were related to the trading days from March 2001 to June 2011.

Figures 12 to 14, illustrate the run time versus the minimum support for Dataset 2 and Dataset 3. The MR-Miner algorithm runs 3-4 times faster than the Apriori algorithm for real data.

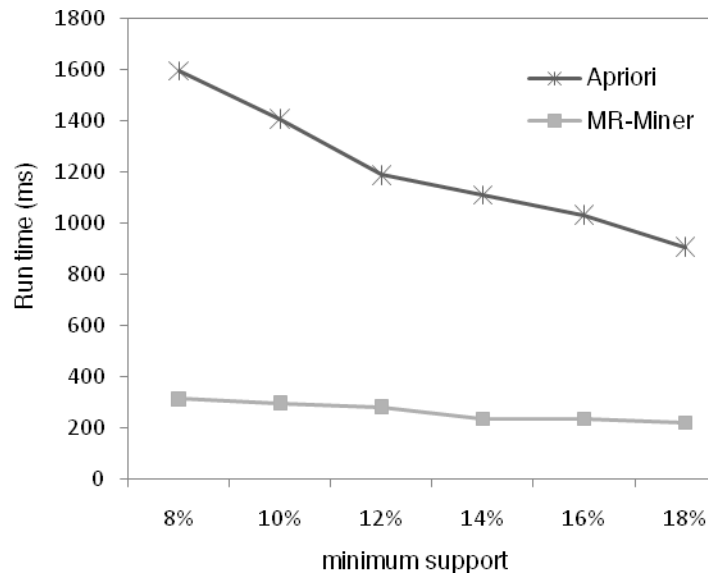


FIGURE 12: Minimum support versus run time, Dataset 2

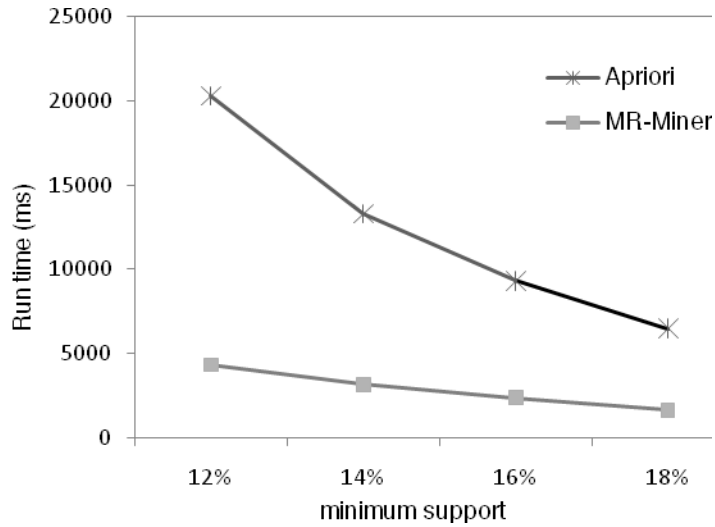


FIGURE 13: Minimum support versus run time, Dataset 3

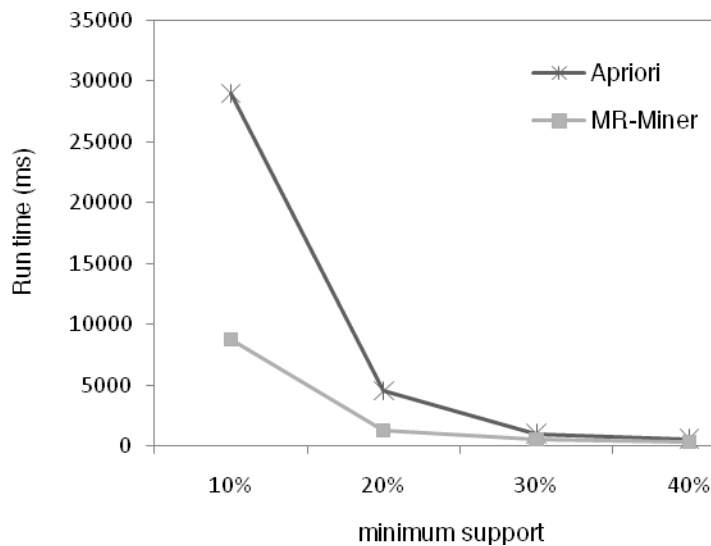


FIGURE 14: Minimum support versus run time, Dataset 3

In summary, the proposed algorithm was implemented faster than the Apriori algorithm on all datasets. The results had shown that the MR-Miner algorithm had operated better than the Apriori algorithm in all cases. Considering that the presented algorithm is an absolute algorithm and does not use the sampling methods, the accuracy of this algorithm likes that of the Apriori algorithm is 100%.

When mining the Tehran stock exchange data, some interesting rules were found. For Dataset 3, a sample rule found was “BTRNS(2), BPAR(2) → STEH(2)”. That is, if Transfo and Parsian fall, then Tehran Cement will fall with support =22% and confidence=75%. Also a sample rule found was “IKCO(1), BTRNS(2) → STEH(2)”. That is, if Iran Khodro rise, and Transfo falls, then Tehran Cement will fall with support=19% and confidence 67%. It should be noted that the association rules have a lower support on this type of attributes.

No	Rules	Support	Confidence
1	DBJR(1)--> STEH(2)	30%	61%
2	PESF(2)--> STEH(2)	33%	73%
3	BTRNS(2)--> STEH(2)	39%	66%
4	BPAR(2)--> STEH(2)	34%	71%
5	DBJR(1), PESF(1)--> IKCO(1)	21%	71%
6	BTRNS(2), FAJR(2)--> STEH(2)	24%	68%
7	BTRNS(2), BPAR(2)--> STEH(2)	22%	75%
8	FAJR(2), BPAR(2)--> STEH(2)	23%	75%
9	BTRNS(2), BPAR(2) --> MADN(2)	23%	77%
10	IKCO(1), DBJR(1)--> MADN(1)	19%	61%
11	DBJR(1), MADN(1)--> IKCO(1)	19%	75%
12	MADN(1), FAJR(1)--> IKCO(1)	18%	73%
13	PESF(1), MADN(1)--> BPAR(1)	18%	65%
14	MADN(1), FAJR(1)--> BPAR(1)	19%	75%
15	DBJR(1), STEH(2)--> IKCO(1)	18%	61%
16	IKCO(1), BTRNS(2)--> STEH(2)	19%	67%
17	PESF(1), STEH(2)--> BTRNS(2)	19%	63%

TABLE 3: Some of the association rules extracted from real data of Tehran stock exchange

Table 3 shows more association in decreasing the stock prices of the analyzed companies on the Tehran exchange data, such as rules 2, 3, 4, 6, 8 and 9 in Table 3 which can be seen with a more powerful support whereas the associations of stock price increase can be seen with a less support, such as rules 5, 10, 11, 12, 13 and 14.

5. CONCLUSION AND FUTURE WORK

In this paper, using the available relationship between the counts of itemsets inside the data with the oscillating value type, a new algorithm was implemented on the basis of generation of the candidate patterns. In the MR-Miner algorithm, based on relationship between the counts of itemsets in this type of data, many counts of itemsets were computed via the counts of other itemsets and with no need to searching the database. On the other hand, pruning strategy was used to reduce the searching space effectively. Thus, much less time was spent to find frequent patterns. By conducting experiments on the real data and synthetic data, it was shown that the presented algorithm had operated much faster than the basic Apriori algorithm.

Although we have shown that the proposed algorithm can efficiently mine association rules on the data with the oscillatory value type, there are still some issues that should be addressed in future researches, as we may extend the proposed algorithm from the frequent patterns to the closed frequent patterns. In order to have more decrease on the search space, a more effective function of prune can be implemented.

ACKNOWLEDGMENTS

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REFERENCES

- [1] R. Agrawal, T. Imieliński and A. Swami. "Mining Association Rules between Sets of Items in Large Databases", in Proc. Management of Data, 1993, pp 207–216.
- [2] R. Agrawal, R. Srikant, "Fast Algorithm for Mining Association Rules", in Proc. VLDB, Santiago de Chile, 1994.
- [3] C. Borgelt and X. Yang, "Finding Closed Frequent Item Sets by Intersecting Transactions", in Proc. 14th Int. Conf. on Extending Database Technology (EDBT 2011, Uppsala, Sweden), 2011.

- [4] J. Han, H. Pei and Y. Yin, "Mining Frequent Patterns without Candidate Generation". In Proc. the Management of Data (SIGMOD'00, Dallas, TX), New York, NY, USA, ACM Press, pp. 1-12, 2000.
- [5] M. Zaki, S. Parthasarathy, M. Ogihara and W. Li, "New Algorithms for Fast Discovery of Association Rules", In Proc. 3rd Int. Conf. on Knowledge Discovery and Data Mining (KDD'97, Newport Beach, CA), AAAI Press, pp. 283-296, 1997.
- [6] Claudio Lucchese, Salvatore and Raffaele Perego, "Fast and Memory Efficient Mining of Frequent Closed Itemsets", in Proc Knowledge and Data Engineering, pp. 21-36, 2006.
- [7] Anthony J.T. Lee and Chun-Sheng Wang, "An Efficient Algorithm for Mining Frequent Inter-Transaction Patterns", Information Sciences 177, pp. 3453-3476, 2007.
- [8] Shu-hsien Liao, Pei-hui Chu and Tzu-kang Teng, "Mining the co-movement in the Taiwan Stock Funds Market", Expert Systems with Applications, Volume 38, Issue 5, pp. 5276-5288, 2011.
- [9] Sung Hoon Na and So Young Sohn, "Forecasting Changes in Korea Composite Stock Price Index (KOSPI) using Association Rules", Expert Systems with Applications, Volume 38, Issue 7, pp. 9046-9049, 2011.
- [10] Hulyi Tan Cai and H.J. Yong Li, "Frequent Patterns of Investment Behaviors in Shanghai Stock Market", Science and Software Engineering, Volume 04, pp. 325-328, 2008.
- [11] Vladimir Boginski, Sergiy Butenko and Panos M. Pardalos, "Mining Market Data: A Network Approach", Computers & Operations Research, Volume 33, Issue 11, pp. 3171-3184, 2006.
- [12] Borgelt, C., Yang, X., Nogales-Cadenas, R., Carmona-Saez, P., Pascual-Montano, A. "Finding Closed Frequent Item Sets by Intersecting Transactions", In. 14th. Extending Database Technology, ACM Press, New York, pp. 367-376, 2011.

Position Control of Robot Manipulator: Design a Novel SISO Adaptive Sliding Mode Fuzzy PD Fuzzy Sliding Mode Control

Farzin Piltan

Department of Electrical and Electronic Engineering,
Faculty of Engineering, Universiti Putra Malaysia 43400
Serdang, Selangor, Malaysia

SSP.ROBOTIC@yahoo.com

N. Sulaiman

Department of Electrical and Electronic Engineering,
Faculty of Engineering, Universiti Putra Malaysia 43400
Serdang, Selangor, Malaysia

nasri@eng.upm.edu.my

Sadeq Allahdadi

Industrial Electrical and Electronic Engineering
SanatkadeheSabze Pasargad. CO (S.S.P. Co), NO:16,
PO.Code 71347-66773, Fourth floor Dena Apr, Seven Tir
Ave, Shiraz, Iran

SSP.ROBOTIC@yahoo.com

Mohammadali Dialame

Industrial Electrical and Electronic Engineering
SanatkadeheSabze Pasargad. CO (S.S.P. Co), NO:16,
PO.Code 71347-66773, Fourth floor Dena Apr, Seven Tir
Ave, Shiraz, Iran

SSP.ROBOTIC@yahoo.com

Abbas Zare

Industrial Electrical and Electronic Engineering
SanatkadeheSabze Pasargad. CO (S.S.P. Co), NO:16,
PO.Code 71347-66773, Fourth floor Dena Apr, Seven Tir
Ave, Shiraz, Iran

SSP.ROBOTIC@yahoo.com

Abstract

This research focuses on design Single Input Single Output (SISO) adaptive sliding mode fuzzy PD fuzzy sliding mode algorithm with estimates the equivalent part derived in the Lyapunov sense. The stability of the closed-loop system is proved mathematically based on the Lyapunov method. Proposed method introduces a SISO fuzzy system to compensate for the model uncertainties of the system and eliminate the chattering by linear boundary layer method. This algorithm is used a SISO fuzzy system to alleviate chattering and to estimate the control gain in the control law and presented a scheme to online tune of sliding function. To attenuate the chattering phenomenon this method developed a linear boundary layer and the parameter of the sliding function is online tuned by adaptation laws. This algorithm will be analyzed and evaluated on robotic manipulators and design adaption laws of adaptive algorithms after that writing Lyapunov function candidates and prove the asymptotic convergence of the closed-loop system using Lyapunov stability theorem mathematically. Compare and evaluate proposed method and sliding mode algorithms under disturbance. In regards to the former, we will be looking at the availability of online tuning methodology and the number of fuzzy if-then rules inherent to the fuzzy system being used and the corresponding computational load. Our analysis of the results will be limited to tracking accuracy and chattering.

Keywords: Sliding Mode Algorithm, Adaptive Sliding Mode Fuzzy PD Fuzzy Sliding Mode Algorithm, Estimator, Lyapunov Method, Model Uncertainties, Linear boundary Layer Method, Chattering Phenomenon.

1. INTRODUCTION

Dynamic of robotic manipulators have strong nonlinear and time variant characteristic [1, 6]. Conventional linear control technologies are not quite gratifying to control robotic manipulators [1-6]. Nonlinear control technologies can arrangement with highly nonlinear equations in dynamic parameters. Conventional nonlinear control strategies cannot provide good robustness for controlling robotic manipulators. The control system designer is often unsure of the exact value of the manipulator parameters that describe the dynamic behavior of the manipulator. Sliding mode control methods can manage uncertainties in the dynamic parameters of the robotic manipulator. Sliding mode controllers are robust controllers for controlling uncertain plant. Classical sliding mode control is robust to control model uncertainties and external disturbances. A sliding mode method with a switching control law guarantees the stability of the certain and/or uncertain system, but the addition of the switching control law introduces chattering into the system. One way to reduce or eliminate chattering is to insert a boundary layer method [1-15] inside of a boundary layer around the sliding surface. Chattering phenomenon can cause some problems such as saturation and heats the mechanical parts of robot manipulators or drivers. To reduce or eliminate the chattering, various papers have been reported by many researchers which classified into two most important methods: boundary layer saturation method and estimated uncertainties method [9-20]. In boundary layer saturation method, the basic idea is the discontinuous method replacement by saturation (linear) method with small neighborhood of the switching surface. This replacement caused to increase the error performance against with the considerable chattering reduction. Slotine and Sastry have introduced boundary layer method instead of discontinuous method to reduce the chattering[21]. Slotine has presented sliding mode with boundary layer to improve the industry application [22]. R. Palm has presented a fuzzy method to nonlinear approximation instead of linear approximation inside the boundary layer to improve the chattering and control the result performance[23]. Moreover, C. C. Weng and W. S. Yu improved the previous method by using a new method in fuzzy nonlinear approximation inside the boundary layer and adaptive method[24]. As mentioned [24]sliding mode fuzzy controller (SMFC) is fuzzy controller based on sliding mode technique to simple implement, most exceptional stability and robustness. Conversely above method has the following advantages; reducing the number of fuzzy rule base and increasing robustness and stability, the main disadvantage of SMFC is need to define the sliding surface slope coefficient very carefully. To eliminate the above problems control researchers have applied artificial intelligence method (e.g., fuzzy logic) in nonlinear robust controller (e.g., sliding mode controller) besides this technique is very useful in order to implement easily. Estimated uncertainty method used in term of uncertainty estimator to compensation of the system uncertainties. It has been used to solve the chattering phenomenon and also nonlinear equivalent dynamic part which it is in classical sliding mode controller. If estimator has an acceptable performance to compensate the uncertainties, the chattering is reduced. Research on estimated uncertainty to reduce the chattering is significantly growing as their applications such as industrial automation and robot manipulator. For instance, the applications of artificial intelligence, neural networks and fuzzy logic on estimated uncertainty method have been reported in [25-28]. Wu et al. [30] have proposed a simple fuzzy estimator controller beside the discontinuous and equivalent control terms to reduce the chattering. Their design had three main parts i.e. equivalent, discontinuous and fuzzy estimator tuning part which has reduced the chattering very well. Elmali et al. [27]and Li and Xu [29]have addressed sliding mode control with perturbation estimation method (SMCPE) to reduce the classical sliding mode chattering. This method was tested for the tracking control of the first two links of a SCARA type HITACHI robot. In this technique, digital controller is used to increase the system's response quality. Conversely this method has the following advantages; increasing the controller's response speed and reducing dependence on dynamic system model by on-line control, the main disadvantage are chattering phenomenon and need to improve the performance.

Classical sliding mode control method has difficulty in handling unstructured model uncertainties. One can overcome this problem by combining a sliding mode controller and artificial intelligence (e.g. fuzzy logic).

Zadeh [31] introduced fuzzy sets in 1965. After 40 years, fuzzy systems have been widely used in different fields, especially on control problems. Fuzzy systems transfer expert knowledge to mathematical models. Fuzzy systems used fuzzy logic to estimate dynamics of proposed systems. Fuzzy controllers including fuzzy if-then rules are used to control proposed systems. Conventional control methods use mathematical

models to controls systems [31-40]. Fuzzy control methods replace the mathematical models with fuzzy if then-rules and fuzzy membership function to controls systems. Both fuzzy and conventional control methods are designed to meet system requirements of stability and convergence. When mathematical models are unknown or partially unknown, fuzzy control models can use fuzzy systems to estimate the unknown models. This is called the model-free approach [31-40]. Conventional control models can use adaptive control methods to achieve the model-free approach. When system dynamics become more complex, nonlinear systems are difficult to handle by conventional control methods. From the universal approximation theorem, fuzzy systems can approximate arbitrary nonlinear systems. In practical problems, systems can be controlled perfectly by expert. Experts provide linguistic description about systems. Conventional control methods cannot design controllers combined with linguistic information. When linguistic information is important for designing controllers, we need to design fuzzy controllers for our systems. Fuzzy control methods are easy to understand for designers. The design process of fuzzy controllers can be simplified with simple mathematical models. Research on applied fuzzy logic methodology in sliding mode controller (FSMC) to reduce or eliminate the high frequency oscillation (chattering), to compensate the unknown system dynamics and also to adjust the linear sliding surface slope in pure sliding mode controller considerably improves the robot manipulator control process [41-47]. H.Temeltas [46] has proposed fuzzy adaption techniques for SMC to achieve robust tracking of nonlinear systems and solves the chattering problem. Conversely system's performance is better than sliding mode controller; it is depended on nonlinear dynamic equation. C. L. Hwang *et al.* [47] have proposed a Tagaki-Sugeno (TS) fuzzy model based sliding mode control based on N fuzzy based linear state-space to estimate the uncertainties. A multi-input multi-output FSMC reduces the chattering phenomenon and reconstructs the approximate the unknown system has been presented for a robot manipulator [42].

Adaptive control uses a learning method to self-learn the parameters of systems. For system whose dynamics are varying, adaptive control can learn the parameters of system dynamics. In traditional adaptive control, we need some information about our system such as the structure of system or the order of the system. In adaptive fuzzy control we can deal with uncertain systems. Due to the linguistic characteristic, adaptive fuzzy controllers behave like operators: adaptively controlling the system under various conditions. Adaptive fuzzy control provides a good tool for making use of expert knowledge to adjust systems. This is important for a complex unknown system with changing dynamics. Investigation on applied sliding mode methodology in fuzzy logic controller (SMFC) to reduce the fuzzy rules and refine the stability of close loop system in fuzzy logic controller has grown specially in recent years as the robot manipulator control [23, 48-50]. Lhee *et al.* [48] have presented a fuzzy logic controller based on sliding mode controller to more formalize and boundary layer thickness. Emami *et al.* [51] have proposed a fuzzy logic approximate inside the boundary layer. H.K.Lee *et al.* [52] have presented self tuning SMFC to reduce the fuzzy rules, increase the stability and to adjust control parameters control automatically. We divide adaptive fuzzy control into two categories: direct adaptive fuzzy control and indirect adaptive fuzzy control. A direct adaptive fuzzy controller adjusts the parameters of the control input. An indirect adaptive fuzzy controller adjusts the parameters of the control system based on the estimated dynamics of the plant. This research is used fuzzy indirect method to estimate the nonlinear equivalent part in order to used sliding mode fuzzy algorithm to tune and adjust the sliding function (direct adaptive).

In this research we will highlight the SISO adaptive sliding mode fuzzy PD fuzzy sliding mode algorithm with estimates the equivalent part derived in the Lyapunov sense. This algorithm will be analyzed and evaluated on robotic manipulators. Section 2, serves as an introduction to the classical sliding mode control algorithm and its application to a two degree of-freedom robot manipulator, describe the objectives and problem statements. Part 3, introduces and describes the methodology algorithms and proves Lyapunov stability. Section 4 presents the simulation results of this algorithm applied to a 2 degree-of-freedom robot manipulator and the final section is describe the conclusion.

2. OBJECTIVES, PROBLEM STATEMENTS AND SLIDING MODE ALGORITHM

When system works with various parameters and hard nonlinearities design linear controller technique is very useful in order to be implemented easily but it has some limitations such as working near the system operating point[2-20]. Sliding mode controller is used in wide range areas such as in robotics, in control process, in aerospace applications and in power converters because it has an acceptable control performance and solve some main challenging topics in control such as resistivity to the external

disturbance. Even though, this controller is used in wide range areas but, pure sliding mode controller has the following disadvantages: chattering problem; which caused the high frequency oscillation in the controllers output and equivalent dynamic formulation; calculate the equivalent control formulation is difficult because it depends on the dynamic equation [20]. Conversely pure FLC works in many areas, it cannot guarantee the basic requirement of stability and acceptable performance[30-40]. Although both SMC and FLC have been applied successfully in many applications but they also have some limitations. The linear boundary layer method is used to reduce or eliminate the chattering and fuzzy estimator is used instead of dynamic equivalent equation to implement easily and avoid mathematical model base controller. To reduce the effect of uncertainty in proposed method, self tuning sliding mode fuzzy method is applied in fuzzy sliding mode controller in robot manipulator in order to solve above limitation.

The dynamic equation of an n-link robot manipulator is define as [53-62]

$$M(q)\ddot{q} + c(q, \dot{q}) + G(q) = \tau \tag{1}$$

Where $q \in R^n$ is the vector of joint position, $M(q) \in R^{n \times n}$ is the inertial matrix, $C(q, \dot{q}) \in R^n$ is the matrix of Coriolis and centrifugal forces, $G(q) \in R^n$ is the gravity vector and $\tau \in R^n$ is the vector of joint torques. This work focuses on two-degree-of-freedom robot manipulator (Figure 1)

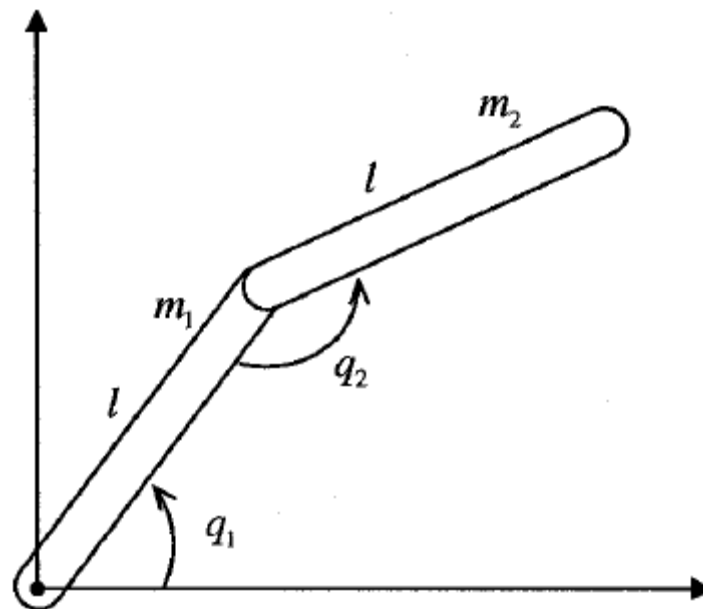


FIGURE 1: Two-link robotic manipulator

The dynamics of this robotic manipulator is given by [1, 6, 9-14]

$$\tau = M(q)\ddot{q} + B(q)[\dot{q} \dot{q}] + C(q)[\dot{q}]^2 + G(q) \tag{2}$$

Where

$$M(q) = \begin{bmatrix} m_1 l^2 + 2m_2 l^2 + 2m_2 l^2 \cos q_2 & m_2 l^2 + m_2 l^2 \cos q_2 \\ m_2 l^2 + m_2 l^2 \cos q_2 & m_2 l^2 \end{bmatrix} \tag{3}$$

$$C(q, \dot{q}) = \begin{bmatrix} -2m_2 l^2 \dot{q}_1 \dot{q}_2 \sin q_2 - m_2 l^2 \dot{q}_2^2 \sin q_2 \\ m_2 l^2 \dot{q}_1^2 \sin q_2 \end{bmatrix} \tag{4}$$

Our target is to track the desired trajectories q_d of the robotic manipulators (2) by using a sliding mode controller. We extract \ddot{q} from $C(q, \dot{q})$ in (2) and rewrite (2) as

$$\tau = M(q)\ddot{q} + c(q, \dot{q})\dot{q} \tag{5}$$

Where

$$C(q, \dot{q}) = \begin{bmatrix} -m_2 l^2 \dot{q}_2 \sin q_2 - m_2 l^2 \dot{q}_1 \sin q_2 - m_2 l^2 \dot{q}_2 \sin q_2 \\ m_2 l^2 \dot{q}_1 \sin q_2 & 0 \end{bmatrix} \tag{6}$$

We define the tracking error as

$$e = q - q_d \tag{7}$$

Where $q = [q_1, q_2]^T$, $q_d = [q_{1d}, q_{2d}]^T$. The sliding surface is expressed as

$$s = \dot{e} + \lambda e \tag{8}$$

Where $\lambda = \text{diag}[\lambda_1, \lambda_2]$, λ_1 and λ_2 are chosen as the bandwidth of the robot controller.

We need to choose τ to satisfy the sufficient condition (9). We define the reference state as

$$\frac{1}{2} \frac{d}{dt} s^2(x, t) = S \cdot \dot{S} = [f - \hat{f} - K \text{sgn}(s)] \cdot S = (f - \hat{f}) \cdot S - K|S| \tag{9}$$

$$\dot{q}_e = \dot{q} - s = \dot{q}_d - \lambda e \tag{10}$$

Now we pick the control input τ as

$$\tau = M^{\hat{}} \ddot{q}_r + C_1^{\hat{}} \dot{q}_r - A s - K \text{sgn}(s) \tag{11}$$

Where $M^{\hat{}}$ and $C_1^{\hat{}}$ are the estimations of $M(q)$ and $C_1(q, \dot{q})$; $A = \text{diag}[a_1, a_2]$ and $K = \text{diag}[k_1, k_2]$ are diagonal positive definite matrices. From (7) and (11), we can get

$$M \dot{s} + (C_1 + A) s = \Delta f - K \text{sgn}(s) \tag{12}$$

Where $\Delta f = \Delta M \ddot{q}_r + \Delta C_1 \dot{q}_r$, $\Delta M = M^{\hat{}} - M$ and $\Delta C_1 = C_1^{\hat{}} - C_1$. We assume that the bound $|\Delta f_i|_{\text{bound}}$ of Δf_i ($i = 1, 2$) is known. We choose K as

$$K_i \geq |\Delta f_i|_{\text{bound}} \tag{13}$$

We pick the Lyapunov function candidate to be

$$V = \frac{1}{2} s^T M s \tag{14}$$

Since M is positive symmetric definite, $V > 0$ for $s \neq 0$. Take the derivative of M with respect to time in (6) and we get

$$\dot{M} = \begin{bmatrix} -2 m_2 l^2 \dot{q}_2 \sin q_2 & -m_2 l^2 \dot{q}_2 \sin q_2 \\ -m_2 l^2 \dot{q}_2 \sin q_2 & 0 \end{bmatrix} \tag{15}$$

From (11) and (15) we get

$$\dot{M} - 2C_1 = \begin{bmatrix} 0 & 2m_2 l^2 \dot{q}_1 \sin q_2 + m_2 l^2 \dot{q}_2 \sin q_2 \\ -2m_2 l^2 \dot{q}_1 \sin q_2 - m_2 l^2 \dot{q}_2 \sin q_2 & 0 \end{bmatrix} \tag{16}$$

Which is a skew-symmetric matrix satisfying

$$s^T (\dot{M} - 2C_1) s = 0 \tag{17}$$

Then \dot{V} becomes

$$\begin{aligned} \dot{V} &= s^T M \dot{s} + \frac{1}{2} s^T \dot{M} s \\ &= s^T (M \dot{s} + C_1 s) \\ &= s^T [-A s + \Delta f - K \text{sgn}(s)] \\ &= \sum_{i=1}^2 (s_i [\Delta f_i - K_i \text{sgn}(s_i)]) - s^T A s \end{aligned} \tag{18}$$

For $K_i \geq |\Delta f_i|$, we always get $s_i [\Delta f_i - K_i \text{sgn}(s_i)] \leq 0$. We can describe \dot{V} as

$$\dot{V} = \sum_{i=1}^2 (s_i [\Delta f_i - K_i \text{sgn}(s_i)]) - s^T A s \leq -s^T A s < 0 \quad (s \neq 0) \tag{19}$$

To attenuate chattering problem, we introduce a saturation function in the control law instead of the sign function in (9). The control law becomes

$$\tau = M^s \ddot{q}_r + C_1^s \dot{q}_r - As - Ksat(s/\Phi) \tag{20}$$

In this classical sliding mode control method, the model of the robotic manipulator is partly unknown. To attenuate chattering, we use the saturation function described in (20). Our control law changes to

$$\tau = M^s \ddot{q}_r + C_1^s \dot{q}_r - As - Ksat(s) \tag{21}$$

The main goal is to design a position controller for robot manipulator with acceptable performances (e.g., trajectory performance, torque performance, disturbance rejection, steady state error and RMS error). Robot manipulator has nonlinear dynamic and uncertain parameters consequently; following objectives have been pursuit in the mentioned study.

- To develop a chattering in a position pure sliding mode controller against uncertainties.
- To design and implement a position fuzzy estimator sliding mode controller in order to solve the equivalent problems in the pure sliding mode control.
- To develop a position sliding mode fuzzy adaptive fuzzy sliding mode controller in order to solve the disturbance rejection.

Figure 2 is shown the classical sliding mode methodology with linear saturation function to eliminate the chattering.

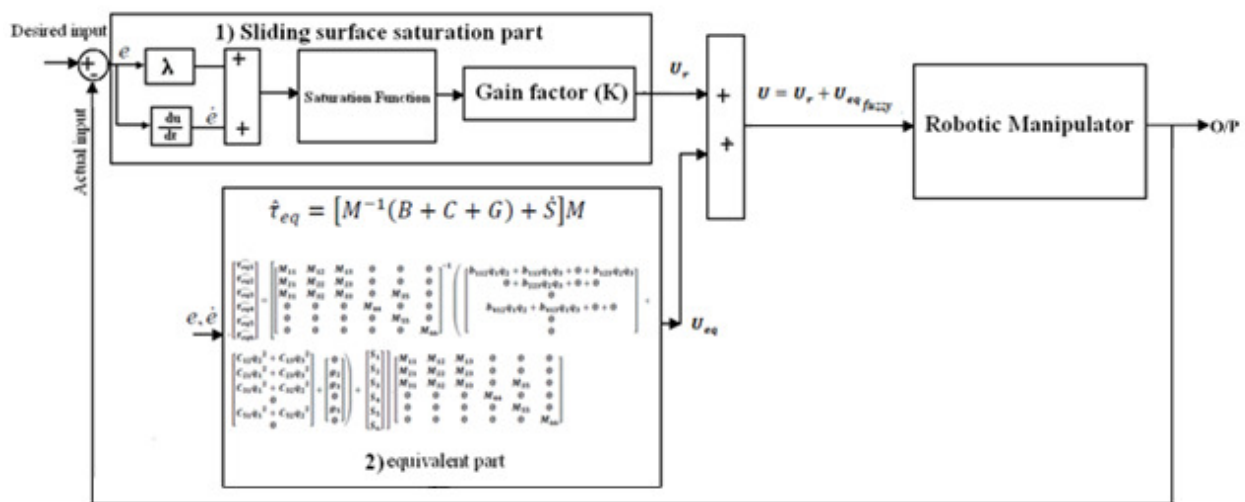


FIGURE 2: Classical sliding mode controller: applied to two-link robotic manipulator

3. METHODOLOGY: DESIGN A NOVEL SISO ADAPTIVE SLIDING MODE FUZZY PD FUZZY ESTIMATE SLIDING MODE CONTROL

First part is focuses on design chattering free sliding mode methodology using linear saturation algorithm. A time-varying sliding surface $s(x, t)$ is given by the following equation:

$$s(x, t) = \left(\frac{d}{dt} + \lambda\right)^{n-1} \tilde{x} = 0 \tag{22}$$

where λ is the constant and it is positive. The derivation of S, namely, \dot{S} can be calculated as the following formulation [5-16, 41-62]:

$$\dot{S} = (\tilde{x} - \tilde{x}_d) + \lambda(\tilde{x} - \tilde{x}_d) \tag{23}$$

The control law for a multi degrees of freedom robot manipulator is written as:

$$U = U_{eq} + U_r \tag{24}$$

Where, the model-based component U_{eq} is the nominal dynamics of systems and it can be calculate as follows:

$$U_{eq} = [M^{-1}(B + C + G) + \dot{S}]M \tag{25}$$

Where $M(q)$ is an inertia matrix which it is symmetric and positive, $V(q, \dot{q}) = B + C$ is the vector of nonlinearity term and $G(q)$ is the vector of gravity force and U_r with minimum chattering based on [9-16] is computed as;

$$U_r = K \cdot (\mu u + b) \left(\frac{S}{\phi} \right) \tag{26}$$

Where $\phi_{sa} = \mu u + b = \text{saturation function}$ is a dead zone (saturation) function and, u and b are unlimited coefficient, by replace the formulation (5) in (3) the control output can be written as;

$$U = U_{eq} + K \cdot (\mu u + b) \left(\frac{S}{\phi} \right) = \begin{cases} U_{eq} + K \cdot \text{sgn}(S) & , |S| \geq \phi \\ U_{eq} + K \cdot \frac{S}{\phi} & , |S| < \phi \end{cases} \tag{27}$$

Where the function of $\text{sgn}(S)$ defined as;

$$\text{sgn}(s) = \begin{cases} 1 & s > 0 \\ -1 & s < 0 \\ 0 & s = 0 \end{cases} \tag{28}$$

Second part is focuses on design fuzzy estimator to estimate nonlinear equivalent part. However the application area for fuzzy control is really wide, the basic form for all command types of controllers consists of;

- Input fuzzification (binary-to-fuzzy[B/F]conversion)
- Fuzzy rule base (knowledge base)
- Inference engine
- Output defuzzification (fuzzy-to-binary[F/B]conversion) [30-40].

The basic structure of a fuzzy controller is shown in Figure 3.

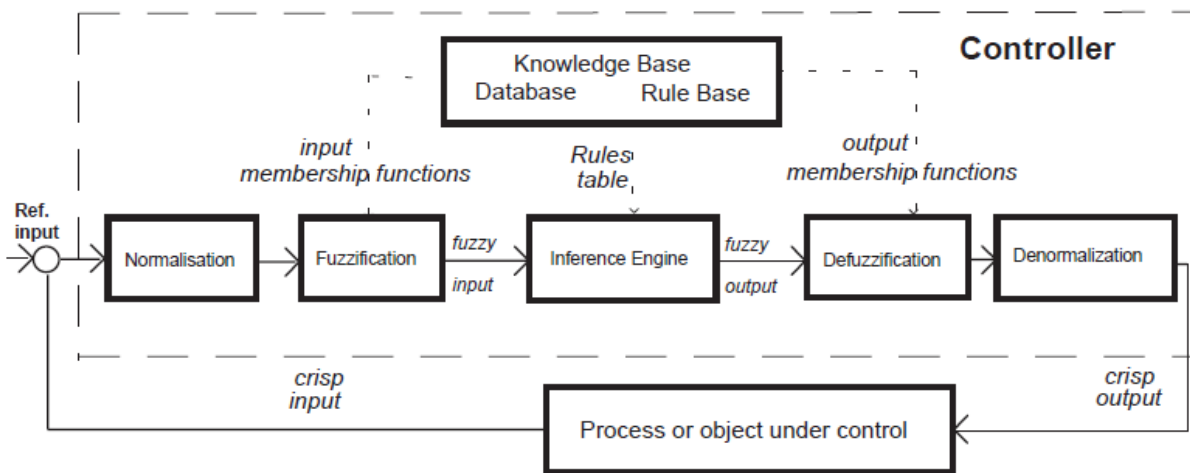


FIGURE 3: Block diagram of a fuzzy controller with details.

The fuzzy system can be defined as below [38-40]

$$f(x) = U_{fuzzy} = \sum_{i=1}^M \theta^i \zeta^i(x) = \psi(S) \tag{29}$$

where $\theta = (\theta^1, \theta^2, \theta^3, \dots, \theta^M)^T, \zeta(x) = (\zeta^1(x), \zeta^2(x), \zeta^3(x), \dots, \zeta^M(x))^T$

$$\zeta^1(x) = \frac{\sum_i \mu_i(x) x_i}{\sum_i \mu_i(x)} \tag{30}$$

where $\theta = (\theta^1, \theta^2, \theta^3, \dots, \theta^M)$ is adjustable parameter in (8) and $\mu_{A_j^l}$ is membership function. error base fuzzy controller can be defined as

$$U_{fuzzy} = \psi(S) \tag{31}$$

In this work the fuzzy controller has one input which names; sliding function. Fuzzy controller with one input is difficult to implementation, because it needs large number of rules, to cover equivalent part estimation [16-25]. Proposed method is used to a SISO fuzzy system which can approximate the residual coupling effect and alleviate the chattering. The robotic manipulator used in this algorithm is defined as below: the tracking error and the sliding surface are defined as:

$$e = q - q_d \tag{32}$$

$$s = \dot{e} + \lambda_e \tag{33}$$

We introduce the reference state as

$$\dot{q}_r = \dot{q} - s = \dot{q}_d - \lambda_e \tag{34}$$

$$\ddot{q}_r = \ddot{q} - \dot{s} = \ddot{q}_d - \lambda \dot{e} \tag{35}$$

The control input is given by

$$\tau = M^* \ddot{q}_r + C_1^* \dot{q}_r - As - K \tag{36}$$

Where $A = \text{diag}[a_1, \dots, a_m]$ and a_1, \dots, a_m are positive constants; $K = [k_1, \dots, k_m]^T$ and K_j is defined as the fuzzy gain estimated by fuzzy systems.

The fuzzy if-then rules for the j th joint of the robotic manipulator are defined as

$$R^{(l)}: \text{if } s_j \text{ is } A_j^l \text{ , then } y \text{ is } B_j^l \tag{37}$$

Where $j = 1, \dots, m$ and $l = 1, \dots, M$.

We define K_j by

$$K_j = \frac{\sum_{l=1}^M \theta_j^l [\mu_{A_j^l}(s_j)]}{\sum_{l=1}^M [\mu_{A_j^l}(s_j)]} = \theta_j^T s_j(s_j) \tag{38}$$

Where

$$\varepsilon_j(s_j) = [\varepsilon_j^1(s_j), \varepsilon_j^2(s_j), \dots, \varepsilon_j^M(s_j)]^T, \tag{39}$$

$$\varepsilon_j^l(s_j) = \frac{\sum_{i=1}^M \mu_{A_j^i}(s_j)}{\sum_{i=1}^M [\mu_{A_j^i}(s_j)]} \tag{40}$$

The membership function $\mu_{A_j^l}(s_j)$ is a Gaussian membership function defined in bellows:

$$\mu_{A_j^l}(s_j) = \exp \left[- \left(\frac{s_j - \alpha_j^l}{\delta_j^l} \right)^2 \right] \quad (j = 1, \dots, m). \tag{41}$$

The Lyapunov function candidate is given by

$$V = \frac{1}{2} s^T M s + \frac{1}{2} \sum_{j=1}^m \frac{1}{\gamma_{sj}} \phi_j^T \phi_j \tag{42}$$

Where $\phi_j = \theta_j^* - \theta_j$. The derivative of V is

$$\dot{V} = s^T M \dot{s} + \frac{1}{2} \dot{s}^T M s + \sum_{j=1}^m \frac{1}{\gamma_{sj}} \phi_j^T \dot{\phi}_j \tag{43}$$

Since $\dot{M} - 2C_1$ is a skew-symmetric matrix, we can get $s^T M \dot{s} + \frac{1}{2} s^T \dot{M} s = s^T (M \dot{s} + C_1 s)$. From (2) and (36), we get

$$\tau = M(q)\ddot{q} + c(q, \dot{q})\dot{q} + G(q) = M^{\hat{}} \ddot{q}_r + C_1^{\hat{}} \dot{q}_r + G^{\hat{}} - A s - K \tag{44}$$

Since $\dot{q}_r = \dot{q} - s$ and $\ddot{q}_r = \ddot{q} - \dot{s}$ in (43) and (42), we get

$$M \dot{s} + (C_1 + A) s = \Delta F - K \tag{45}$$

Where $\Delta F = \Delta M \ddot{q}_r + \Delta C_1 \dot{q}_r + \Delta G$, $\Delta M = M^{\hat{}} - M$, $\Delta C_1 = C_1^{\hat{}} - C_1$ and $G = G^{\hat{}} - G$, then \dot{V} becomes

$$\begin{aligned} \dot{V} &= s^T (M \dot{s} + C_1 s) + \sum_{j=1}^m \frac{1}{\gamma_{sj}} \phi_j^T \dot{\phi}_j^1 \\ &= -s^T (-A s + \Delta f - K) + \sum_{j=1}^m \frac{1}{\gamma_{sj}} \phi_j^T \dot{\phi}_j^1 \\ &= \sum_{j=1}^m [s_j (\Delta f_j - K_j)] - s^T A s + \sum_{j=1}^m \frac{1}{\gamma_{sj}} \phi_j^T \dot{\phi}_j^1 \\ &= \sum_{j=1}^m [s_j (\Delta f_j - \theta_j^T \varepsilon_j(s_j))] - s^T A s + \sum_{j=1}^m \frac{1}{\gamma_{sj}} \phi_j^T \dot{\phi}_j^1 \\ &= \sum_{j=1}^m [s_j (\Delta f_j - (\theta_j^*)^T \varepsilon_j(s_j) + \phi_j^T \varepsilon_j(s_j))] - s^T A s + \sum_{j=1}^m \frac{1}{\gamma_{sj}} \phi_j^T \dot{\phi}_j^1 \\ &= \sum_{j=1}^m [s_j (\Delta f_j - (\theta_j^*)^T \varepsilon_j(s_j))] - s^T A s + \sum_{j=1}^m \left(\frac{1}{\gamma_{sj}} \phi_j^T [\gamma_{sj} s_j \varepsilon_j(s_j) + \dot{\phi}_j^1] \right) \end{aligned}$$

We choose the adaptation law $\dot{\theta}_j = \gamma_{sj} s_j \varepsilon_j(s_j)$. Since $\dot{\phi}_j = -\dot{\theta}_j = -\gamma_{sj} s_j \varepsilon_j(s_j)$, \dot{V} becomes

$$\dot{V} = \sum_{j=1}^m [s_j (\Delta f_j - (\theta_j^*)^T \varepsilon_j(s_j))] - s^T A s \tag{46}$$

We define the minimum approximation error as

$$\omega_j = \Delta f_j - (\theta_j^*)^T \varepsilon_j(s_j) \tag{47}$$

Then \dot{V} change to

$$\begin{aligned} \dot{V} &= \sum_{j=1}^m s_j \omega_j - s^T A s \\ &\leq \sum_{j=1}^m |s_j| |\omega_j| - s^T A s \\ &= \sum_{j=1}^m (|s_j| |\omega_j| - a_j s_j^2) \\ &= \sum_{j=1}^m (|s_j| (|\omega_j| - a_j |s_j|)) \end{aligned} \tag{48}$$

According to Universal Approximation theorem in sliding mode algorithm, the minimum approximation error ω_j is as small as possible. We can simply pick a_j to make $a_j |s_j| > |\omega_j|$ ($s_j \neq 0$). Then we get $\dot{V} < 0$ for $s \neq 0$.

The fuzzy division can be reached the best state when $s \cdot \dot{s} < 0$ and the error is minimum by the following formulation

$$\theta^* = \arg \min [Sup_{x \in U} | \sum_{i=1}^M \theta^T \zeta(x) - U_{equ} |] \tag{49}$$

Where θ^* is the minimum error, $sup_{x \in U} | \sum_{i=1}^M \theta^T \zeta(x) - \tau_{equ} |$ is the minimum approximation error.

suppose K_j is defined as follows

$$K_j = \frac{\sum_{i=1}^M \theta_j^i [\mu_A(S_j)]}{\sum_{i=1}^M [\mu_A(S_j)]} = \theta_j^T \zeta_j(S_j) \tag{50}$$

Where $\zeta_j(S_j) = [\zeta_j^1(S_j), \zeta_j^2(S_j), \zeta_j^3(S_j), \dots, \zeta_j^M(S_j)]^T$

$$\zeta_j^1(s_j) = \frac{\mu_{(A_j)^1}(s_j)}{\sum_i \mu_{(A_j)^1}(s_j)} \tag{51}$$

where the γ_{sj} is the positive constant.

According to the nonlinear dynamic equivalent formulation of robot manipulator the nonlinear equivalent part is estimated by (8)

$$[M^{-1}(B + C + G) + \dot{S}]M = \sum_{l=1}^M \theta^l \zeta(x) - \lambda S - K \tag{52}$$

Based on (3) the formulation of proposed fuzzy sliding mode controller can be written as;

$$U = U_{eqfuzzy} + U_r \tag{53}$$

Where $U_{eqfuzzy} = [M^{-1}(B + C + G) + \dot{S}]M + \sum_{l=1}^M \theta^l \zeta(x) + K$

Figure 4 is shown the proposed fuzzy sliding mode controller.

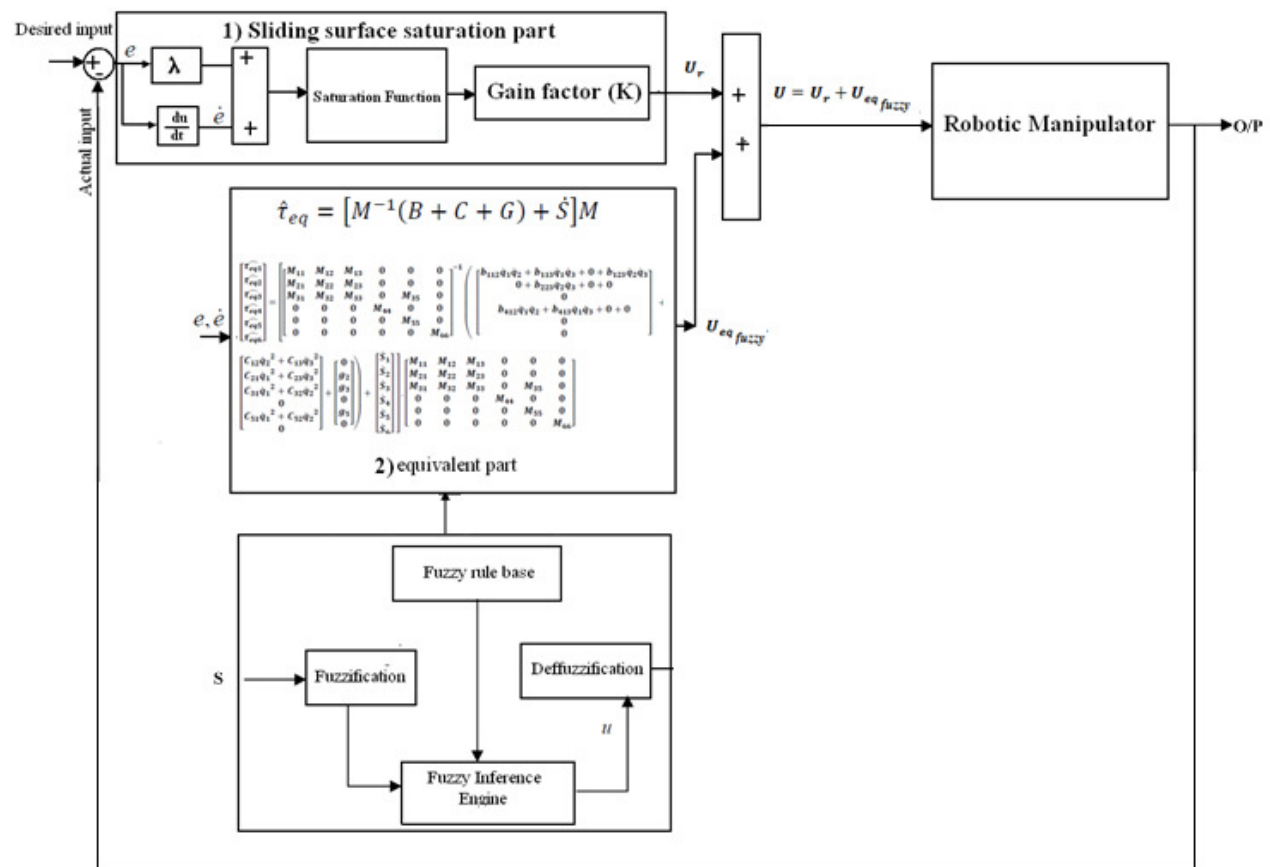


FIGURE 4: Proposed fuzzy estimator sliding mode algorithm: applied to robot manipulator

Third part is focuses on design sliding mode fuzzy adaptive algorithm for fuzzy estimator to estimate nonlinear equivalent part. Adaptive control uses a learning method to self-learn the parameters of systems. For system whose dynamics are varying, adaptive control can learn the parameters of system dynamics. In traditional adaptive control, we need some information about our system such as the structure of system or the order of the system. In adaptive fuzzy control we can deal with uncertain systems. Due to the linguistic characteristic, adaptive fuzzy controllers behave like operators: adaptively controlling the system under various conditions. Adaptive fuzzy control provides a good tool for making use of expert knowledge

to adjust systems. This is important for a complex unknown system with changing dynamics. The adaptive fuzzy systems is defined by

$$f(x) = \sum_{i=1}^M \theta^i \varepsilon^i(x) = \theta^T \varepsilon(x) \tag{54}$$

Where $\theta = (\theta^1, \dots, \theta^M)^T$, $\varepsilon(x) = (\varepsilon^1(x), \dots, \varepsilon^M(x))^T$, and $\varepsilon^i(x) = \prod_{l=1}^n \mu_{A_l^i}(x_l) / \sum_{i=1}^M (\prod_{l=1}^n \mu_{A_l^i}(x_l))$ define in the previous part. $\theta^1, \dots, \theta^M$ are adjustable parameters in (50). $\mu_{A_1^1}(x_1), \dots, \mu_{A_n^M}(x_n)$ are given membership functions whose parameters will not change over time.

The second type of fuzzy systems is given by

$$f(x) = \frac{\sum_{i=1}^M \theta^i \left[\prod_{l=1}^n \exp \left(- \left(\frac{x_l - \alpha_l^i}{\delta_l^i} \right)^2 \right) \right]}{\sum_{i=1}^M \left[\prod_{l=1}^n \exp \left(- \left(\frac{x_l - \alpha_l^i}{\delta_l^i} \right)^2 \right) \right]} \tag{55}$$

Where θ^i , α_l^i and δ_l^i are all adjustable parameters.

From the universal approximation theorem, we know that we can find a fuzzy system to estimate any continuous function. For the first type of fuzzy systems, we can only adjust θ^i in (50). We define $f^*(x|\theta)$ as the approximator of the real function $f(x)$.

$$f^*(x|\theta) = \theta^T \varepsilon(x) \tag{56}$$

We define θ^* as the values for the minimum error:

$$\theta^* = \arg \min_{\theta \in \Omega} \left[\sup_{x \in U} |f^*(x|\theta) - g(x)| \right] \tag{57}$$

Where Ω is a constraint set for θ . For specific x , $\sup_{x \in U} |f^*(x|\theta^*) - f(x)|$ is the minimum approximation error we can get.

The fuzzy system can be defined as below

$$f(x) = \tau_{fuzzy} = \sum_{l=1}^M \theta^l \zeta(x) = \psi(\theta, \xi) \tag{58}$$

where $\theta = (\theta^1, \theta^2, \theta^3, \dots, \theta^M)^T$, $\zeta(x) = (\zeta^1(x), \zeta^2(x), \zeta^3(x), \dots, \zeta^M(x))^T$

$$\zeta^1(x) = \frac{\sum_l \mu(x_l) x_l}{\sum_l \mu(x_l)} \tag{59}$$

where $\theta = (\theta^1, \theta^2, \theta^3, \dots, \theta^M)$ is adjustable parameter in (58) and $\mu(x_l)$ is membership function.

error base fuzzy controller can be defined as

$$\tau_{fuzzy} = \psi(\theta, \xi) \tag{60}$$

According to the formulation sliding function

$$if \ S = 0 \ then \ -\dot{e} = \lambda e \tag{61}$$

the fuzzy division can be reached the best state when $S \cdot \dot{S} < 0$ and the error is minimum by the following formulation

$$\theta^* = \arg \min [\sup_{x \in U} | \sum_{l=1}^M \theta^l \zeta(x) - \tau_{equ} |] \tag{62}$$

Where θ^* is the minimum error, $\sup_{x \in U} | \sum_{l=1}^M \theta^l \zeta(x) - \tau_{equ} |$ is the minimum approximation error. The adaptive controller is used to find the minimum errors of $\theta - \theta^*$.

suppose K_j is defined as follows

$$K_j = \frac{\sum_{i=1}^M \theta_j^i [\mu_A(S_j)]}{\sum_{i=1}^M [\mu_A(S_j)]} = \theta_j^T \zeta_j(S_j) \tag{63}$$

Where $\zeta_j(S_j) = [\zeta_j^1(S_j), \zeta_j^2(S_j), \zeta_j^3(S_j), \dots, \zeta_j^M(S_j)]^T$

$$\zeta_j^1(S_j) = \frac{\mu_{(A)}^1(S_j)}{\sum_i \mu_{(A)}^i(S_j)} \tag{64}$$

the adaption law is defined as

$$\dot{\theta}_j = \gamma_{sj} S_j \zeta_j(S_j) \tag{65}$$

where the γ_{sj} is the positive constant.

According to the formulation (63) and (64) in addition from (60) and (58)

$$M(q)\ddot{q} + V(q, \dot{q})\dot{q} + G(q) = \sum_{i=1}^M \theta^T \zeta(x) - \lambda S - K \tag{66}$$

The dynamic equation of robot manipulator can be written based on the sliding surface as;

$$M\dot{S} = -VS + M\dot{S} + VS + G - \tau \tag{67}$$

It is supposed that

$$S^T(M - 2V)S = 0 \tag{68}$$

it can be shown that

$$M\dot{S} + (V + \lambda)S = \Delta f - K \tag{69}$$

where $\Delta f = [M(q)\ddot{q} + V(q, \dot{q})\dot{q} + G(q)] - \sum_{i=1}^M \theta^T \zeta(x)$

as a result \dot{V} is became

$$\begin{aligned} \dot{V} &= \frac{1}{2} S^T \dot{M} S - S^T V S + \sum \frac{1}{\gamma_{sj}} \phi_j^T \dot{\phi}_j \\ &= S^T (-\lambda S + \Delta f - K) + \sum \frac{1}{\gamma_{sj}} \phi_j^T \dot{\phi}_j \\ &= \sum_{j=1}^m [S_j (\Delta f_j - K_j)] - S^T \lambda S + \sum \frac{1}{\gamma_{sj}} \phi_j^T \dot{\phi}_j \\ &= \sum_{j=1}^m [S_j (\Delta f_j - \theta_j^T \zeta_j(S_j))] - S^T \lambda S + \sum \frac{1}{\gamma_{sj}} \phi_j^T \dot{\phi}_j \\ &= \sum_{j=1}^m [S_j (\Delta f_j - (\theta_j^*)^T \zeta_j(S_j) + \phi_j^T \zeta_j(S_j))] - S^T \lambda S + \sum \frac{1}{\gamma_{sj}} \phi_j^T \dot{\phi}_j \\ &= \sum_{j=1}^m [S_j (\Delta f_j - ((\theta_j^*)^T \zeta_j(S_j))] - S^T \lambda S] + \sum (\frac{1}{\gamma_{sj}} \phi_j^T [\gamma_{sj} \zeta_j(S_j) S_j + \dot{\phi}_j]) \end{aligned}$$

where $\dot{\theta}_j = \gamma_{sj} S_j \zeta_j(S_j)$ is adaption law, $\dot{\phi}_j = -\dot{\theta}_j = -\gamma_{sj} S_j \zeta_j(S_j)$,

consequently \dot{V} can be considered by

$$\dot{V} = \sum_{j=1}^m [S_j \Delta f_j - ((\theta_j^*)^T \zeta_j(S_j))] - S^T \lambda S \tag{70}$$

the minimum error can be defined by

$$e_{mj} = \Delta f_j - ((\theta_j^*)^T \zeta_j(S_j)) \tag{71}$$

\dot{V} is intended as follows

$$\begin{aligned}
 \dot{V} &= \sum_{j=1}^m [S_j \dot{e}_{mj}] - S^T \lambda S \\
 &\leq \sum_{j=1}^m |S_j| |e_{mj}| - S^T \lambda S \\
 &= \sum_{j=1}^m |S_j| |e_{mj}| - \lambda_j S_j^2 \\
 &= \sum_{j=1}^m |S_j| (|e_{mj}| - \lambda_j S_j)
 \end{aligned} \tag{72}$$

For continuous function $g(x)$, and suppose $\varepsilon > 0$ it is defined the fuzzy logic system in form of (56) such that

$$\text{Sup}_{x \in U} |f(x) - g(x)| < \varepsilon \tag{73}$$

the minimum approximation error (e_{mj}) is very small.

$$\text{if } \lambda_j = \alpha \text{ that } \alpha |S_j| > e_{mj} (S_j \neq 0) \text{ then } \dot{V} < 0 \text{ for } (S_j \neq 0) \tag{74}$$

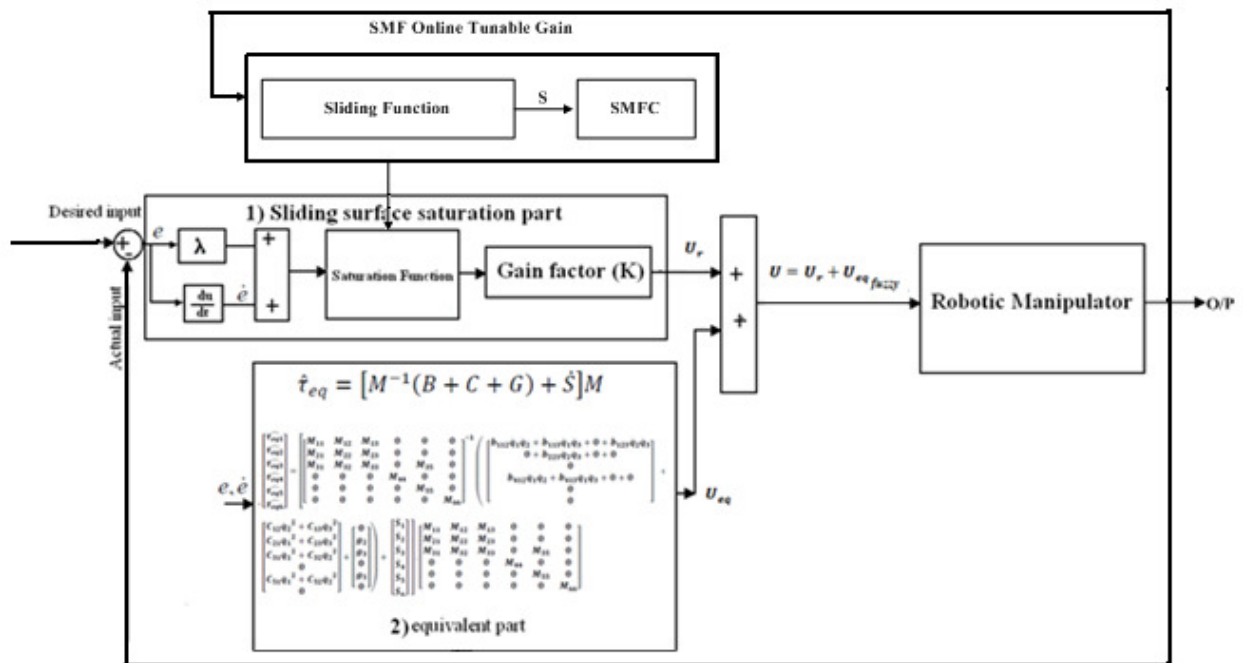


FIGURE 5: Sliding mode fuzzy adaptive proposed fuzzy estimator sliding mode algorithm: applied to robot manipulator

4. SIMULATION RESULTS

PD sliding mode controller (PD-SMC) and SISO proposed adaptive sliding mode fuzzy algorithm Fuzzy Estimate Sliding Mode Controller (AFESMC) were tested to sinus response trajectory. This simulation applied to two degrees of freedom robot arm therefore the first and second joints are moved from home to final position without and with external disturbance. The simulation was implemented in Matlab/Simulink environment. Trajectory performance, torque performance, disturbance rejection, steady state error and

RMS error are compared in these controllers. It is noted that, these systems are tested by band limited white noise with a predefined 40% of relative to the input signal amplitude which the sample time is equal to 0.1. This type of noise is used to external disturbance in continuous and hybrid systems.

Tracking performances

Figure 6 is shown tracking performance for first and second link in SMC, and AFESMC without disturbance for sinus trajectories. By comparing sinus response trajectory without disturbance in SMC and AFESMC it is found that the SMC's overshoot (8%) is higher than AFESMC (0%), although all of them have about the same rise time.

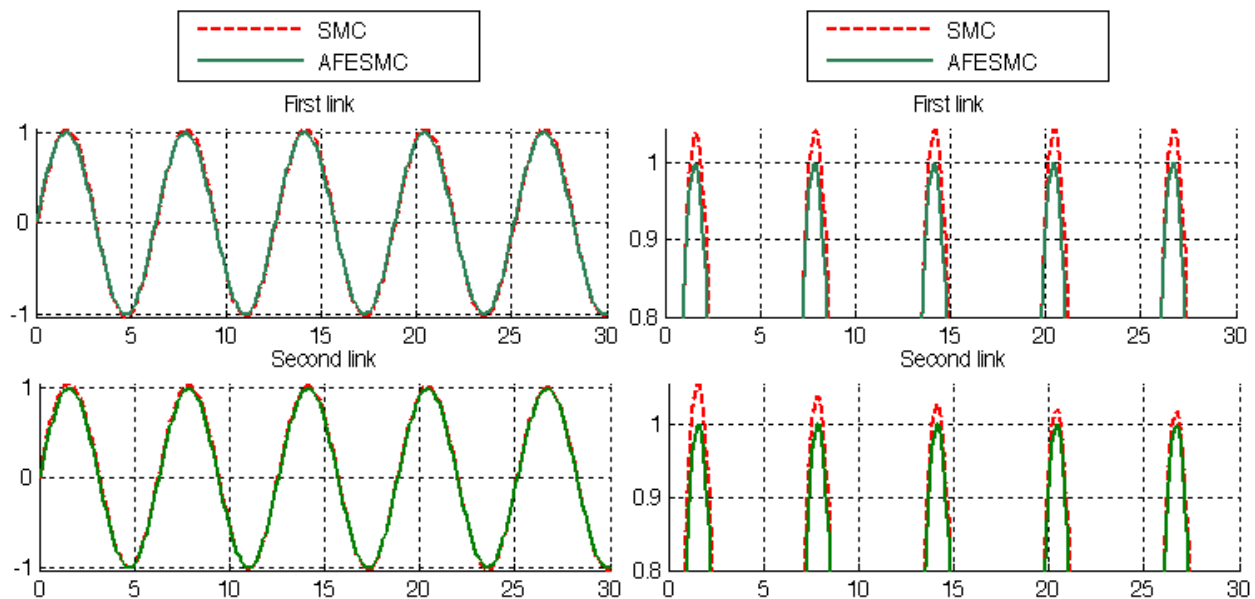


FIGURE 6: AFESMC and SMC trajectory: applied to robot manipulator.

Disturbance Rejection

Figure 7 has shown the power disturbance elimination in SMC and AFESMC. The main target in these controllers is disturbance rejection as well as reduces the chattering. A band limited white noise with predefined of 40% the power of input signal is applied to above controllers. It found fairly fluctuations in SMC trajectory responses.

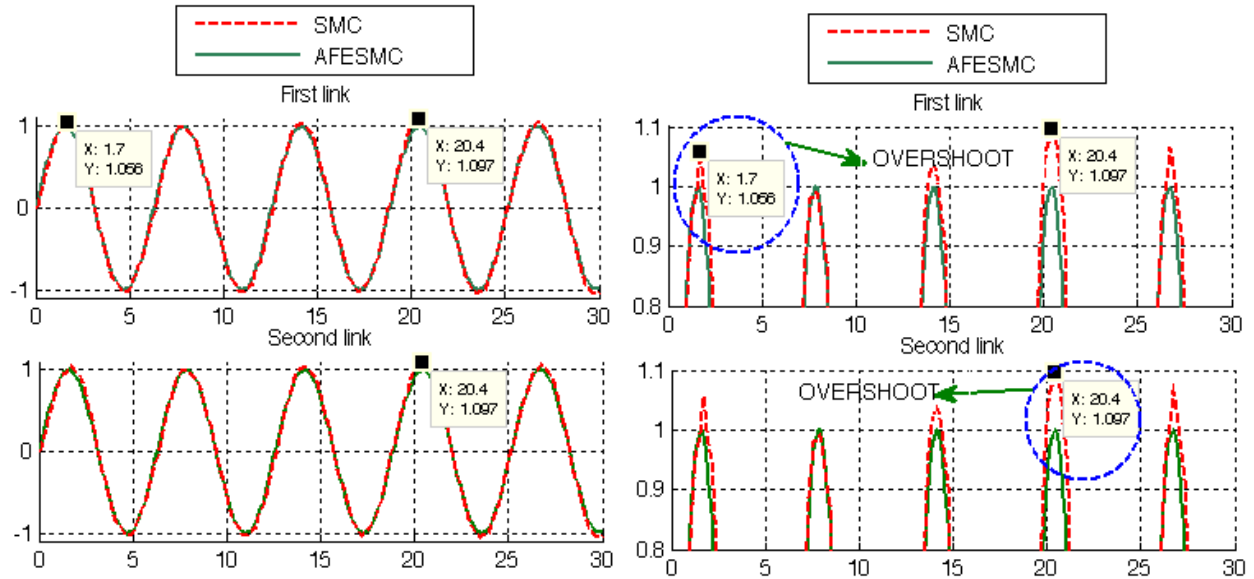


FIGURE 7: AFESMC and SMC trajectory with external disturbance: applied to robot manipulator

Among above graph relating to trajectory following with external disturbance, SMC has fairly fluctuations. By comparing some control parameters such as overshoot and rise time it found that the SMC's overshoot (10%) is higher than AFESMC (0%).

Torque Performance

Figure 8 has shown the torque performance in presence of unstructured uncertainties in SMC and AFESMC. The main target in these controllers is chattering free in proposed method in presence of external disturbance.

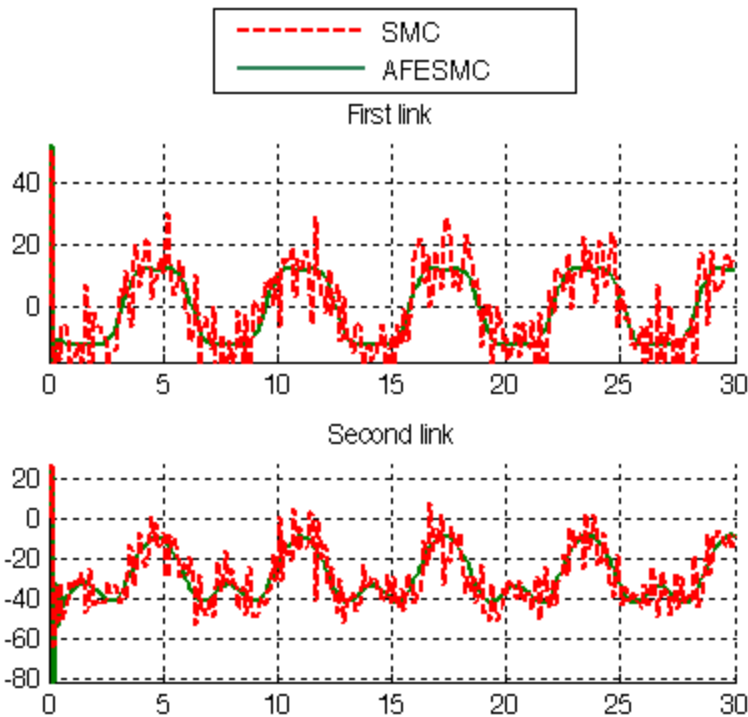


FIGURE 8: AFESMC and SMC torque performance with external disturbance: applied to robot manipulator

Error Calculation: Figure 9 and Table 1 are shown error performance in SMC and AFESMC in presence of external disturbance. SMC has oscillation in tracking which causes chattering phenomenon. As it is obvious in Table 2 FSMC is a SMC which estimate the equivalent part so FSMC have acceptable performance with regard to SMC in presence of certain and uncertainty and AFESMC also is fuzzy estimate sliding mode controller which online tuning by sliding mode fuzzy algorithm. Figure 9 is shown steady state and RMS error in SMC and AFESMC in presence of external disturbance.

TABLE 1: RMS Error Rate of Presented controllers

<i>RMS Error Rate</i>	SMC	FSMC	AFESMC
Without Noise	1e-3	0.9e-3	0.6e-6
With Noise	0.012	0.0012	0.65e-6

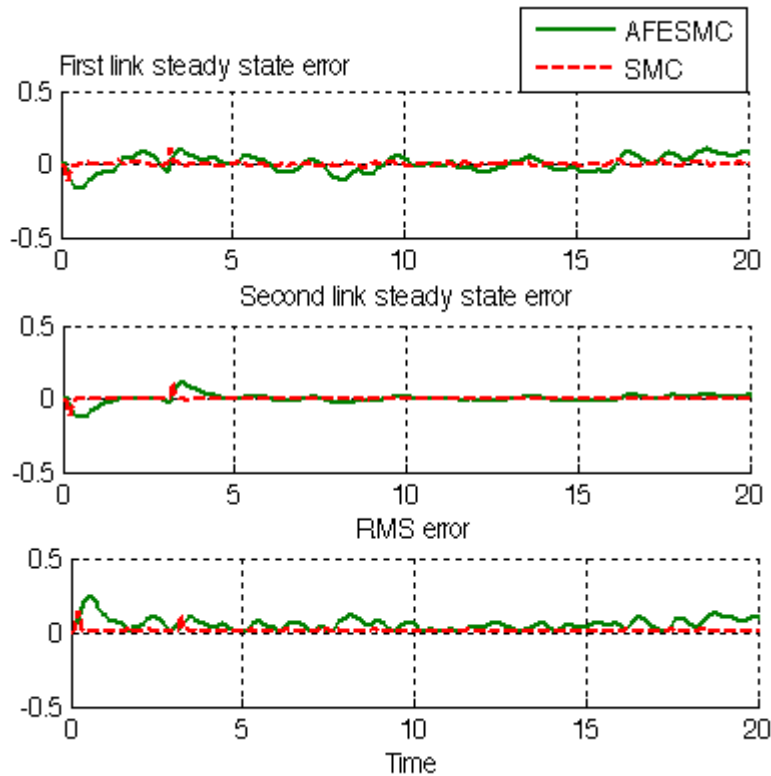


FIGURE 9: AFESMC and SMC error performance with external disturbance: applied to robot manipulator

In these methods if integration absolute error (IAE) is defined by (75), table 2 is shown comparison between these two methods.

$$IAE = \int_0^{\infty} |e(t)| dt \tag{75}$$

TABLE 2: Calculate IAE

Method	Traditional SMC	Fuzzy Estimator SMC	AEFSMC
IAE	490.1	406	208

5. CONCLUSIONS

In this work, a SISO sliding mode fuzzy adaptive fuzzy estimate sliding mode controller is design, analysis and applied to robot manipulator. This method focuses on design AFSMC algorithm with the adaptation laws derived in the Lyapunov sense. The stability of the closed-loop system is proved mathematically based on the Lyapunov method. The first objectives in proposed method is remove the chattering which linear boundary layer method is used to solve this challenge. The second target in this work is compensate the model uncertainty by SISO fuzzy inference system, in the case of the m-link robotic manipulator, if we define k_1 membership functions for each input variable, the number of fuzzy rules applied for each joint is R_1 which will result in a low computational load. In finally part sliding mode fuzzy algorithm with minimum rule base is used to online tuning and adjusted the sliding function and eliminate the chattering with minimum computational load. In this case the performance is improved by using the advantages of sliding mode algorithm, artificial intelligence compensate method and adaptive algorithm while the disadvantages removed by added each method to previous method. Fuzzy logic method by adding to the sliding mode controller has covered negative points in fuzzy and sliding algorithms.

REFERENCES

- [1] T. R. Kurfess, *Robotics and automation handbook*: CRC, 2005.
- [2] J. J. E. Slotine and W. Li, *Applied nonlinear control* vol. 461: Prentice hall Englewood Cliffs, NJ, 1991.
- [3] Piltan, F., et al., "Design sliding mode controller for robot manipulator with artificial tunable gain," *Canadian Journal of pure and applied science*, 5 (2): 1573-1579, 2011.
- [4] L. Cheng, *et al.*, "Multi-agent based adaptive consensus control for multiple manipulators with kinematic uncertainties," 2008, pp. 189-194.
- [5] J. J. D'Azzo, *et al.*, *Linear control system analysis and design with MATLAB*: CRC, 2003.
- [6] B. Siciliano and O. Khatib, *Springer handbook of robotics*: Springer-Verlag New York Inc, 2008.
- [7] I. Boiko, *et al.*, "Analysis of chattering in systems with second-order sliding modes," *IEEE Transactions on Automatic Control*, vol. 52, pp. 2085-2102, 2007.
- [8] J. Wang, *et al.*, "Indirect adaptive fuzzy sliding mode control: Part I: fuzzy switching," *Fuzzy Sets and Systems*, vol. 122, pp. 21-30, 2001.
- [9] Farzin Piltan, A. R. Salehi and Nasri B Sulaiman., "Design artificial robust control of second order system based on adaptive fuzzy gain scheduling," *world applied science journal (WASJ)*, 13 (5): 1085-1092, 2011
- [10] F. Piltan, *et al.*, "Artificial Control of Nonlinear Second Order Systems Based on AFGSMC," *Australian Journal of Basic and Applied Sciences*, 5(6), pp. 509-522, 2011.
- [11] Piltan, F., et al., "Design Artificial Nonlinear Robust Controller Based on CTLC and FSMC with Tunable Gain," *International Journal of Robotic and Automation*, 2 (3): 205-220, 2011.
- [12] Piltan, F., et al., "Design Mathematical Tunable Gain PID-Like Sliding Mode Fuzzy Controller with Minimum Rule Base," *International Journal of Robotic and Automation*, 2 (3): 146-156, 2011.
- [13] Piltan, F., et al., "Design of FPGA based sliding mode controller for robot manipulator," *International Journal of Robotic and Automation*, 2 (3): 183-204, 2011.
- [14] Piltan, F., et al., "A Model Free Robust Sliding Surface Slope Adjustment in Sliding Mode Control for Robot Manipulator," *World Applied Science Journal*, 12 (12): 2330-2336, 2011.
- [15] Harashima F., Hashimoto H., and Maruyama K, 1986. Practical robust control of robot arm using variable structure system, *IEEE conference*, P.P:532-539
- [16] Piltan, F., et al., "Design Adaptive Fuzzy Robust Controllers for Robot Manipulator," *World Applied Science Journal*, 12 (12): 2317-2329, 2011.
- [17] V. Utkin, "Variable structure systems with sliding modes," *Automatic Control, IEEE Transactions on*, vol. 22, pp. 212-222, 2002.
- [18] R. A. DeCarlo, *et al.*, "Variable structure control of nonlinear multivariable systems: a tutorial," *Proceedings of the IEEE*, vol. 76, pp. 212-232, 2002.
- [19] K. D. Young, *et al.*, "A control engineer's guide to sliding mode control," 2002, pp. 1-14.

- [20] O. Kaynak, "Guest editorial special section on computationally intelligent methodologies and sliding-mode control," *IEEE Transactions on Industrial Electronics*, vol. 48, pp. 2-3, 2001.
- [21] J. J. Slotine and S. Sastry, "Tracking control of non-linear systems using sliding surfaces, with application to robot manipulators†," *International Journal of Control*, vol. 38, pp. 465-492, 1983.
- [22] J. J. E. Slotine, "Sliding controller design for non-linear systems," *International Journal of Control*, vol. 40, pp. 421-434, 1984.
- [23] R. Palm, "Sliding mode fuzzy control," 2002, pp. 519-526.
- [24] C. C. Weng and W. S. Yu, "Adaptive fuzzy sliding mode control for linear time-varying uncertain systems," 2008, pp. 1483-1490.
- [25] M. Ertugrul and O. Kaynak, "Neuro sliding mode control of robotic manipulators," *Mechatronics*, vol. 10, pp. 239-263, 2000.
- [26] P. Kachroo and M. Tomizuka, "Chattering reduction and error convergence in the sliding-mode control of a class of nonlinear systems," *Automatic Control, IEEE Transactions on*, vol. 41, pp. 1063-1068, 2002.
- [27] H. Elmali and N. Olgac, "Implementation of sliding mode control with perturbation estimation (SMCPE)," *Control Systems Technology, IEEE Transactions on*, vol. 4, pp. 79-85, 2002.
- [28] J. Moura and N. Olgac, "A comparative study on simulations vs. experiments of SMCPE," 2002, pp. 996-1000.
- [29] Y. Li and Q. Xu, "Adaptive Sliding Mode Control With Perturbation Estimation and PID Sliding Surface for Motion Tracking of a Piezo-Driven Micromanipulator," *Control Systems Technology, IEEE Transactions on*, vol. 18, pp. 798-810, 2010.
- [30] B. Wu, *et al.*, "An integral variable structure controller with fuzzy tuning design for electro-hydraulic driving Stewart platform," 2006, pp. 5-945.
- [31] L. A. Zadeh, "Toward a theory of fuzzy information granulation and its centrality in human reasoning and fuzzy logic," *Fuzzy Sets and Systems*, vol. 90, pp. 111-127, 1997.
- [32] L. Reznik, *Fuzzy controllers*: Butterworth-Heinemann, 1997.
- [33] J. Zhou and P. Coiffet, "Fuzzy control of robots," 2002, pp. 1357-1364.
- [34] S. Banerjee and P. Y. Woo, "Fuzzy logic control of robot manipulator," 2002, pp. 87-88.
- [35] K. Kumbla, *et al.*, "Soft computing for autonomous robotic systems," *Computers and Electrical Engineering*, vol. 26, pp. 5-32, 2000.
- [36] C. C. Lee, "Fuzzy logic in control systems: fuzzy logic controller. I," *IEEE Transactions on systems, man and cybernetics*, vol. 20, pp. 404-418, 1990.
- [37] R. J. Wai, *et al.*, "Implementation of artificial intelligent control in single-link flexible robot arm," 2003, pp. 1270-1275.
- [38] R. J. Wai and M. C. Lee, "Intelligent optimal control of single-link flexible robot arm," *Industrial Electronics, IEEE Transactions on*, vol. 51, pp. 201-220, 2004.

- [39] M. B. Menhaj and M. Rouhani, "A novel neuro-based model reference adaptive control for a two link robot arm," 2002, pp. 47-52.
- [40] S. Mohan and S. Bhanot, "Comparative study of some adaptive fuzzy algorithms for manipulator control," *International Journal of Computational Intelligence*, vol. 3, pp. 303–311, 2006.
- [41] F. Barrero, *et al.*, "Speed control of induction motors using a novel fuzzy sliding-mode structure," *Fuzzy Systems, IEEE Transactions on*, vol. 10, pp. 375-383, 2002.
- [42] Y. C. Hsu and H. A. Malki, "Fuzzy variable structure control for MIMO systems," 2002, pp. 280-285.
- [43] Y. C. Hsueh, *et al.*, "Self-tuning sliding mode controller design for a class of nonlinear control systems," 2009, pp. 2337-2342.
- [44] R. Shahnazi, *et al.*, "Position control of induction and DC servomotors: a novel adaptive fuzzy PI sliding mode control," *Energy Conversion, IEEE Transactions on*, vol. 23, pp. 138-147, 2008.
- [45] C. C. Chiang and C. H. Wu, "Observer-Based Adaptive Fuzzy Sliding Mode Control of Uncertain Multiple-Input Multiple-Output Nonlinear Systems," 2007, pp. 1-6.
- [46] H. Temeltas, "A fuzzy adaptation technique for sliding mode controllers," 2002, pp. 110-115.
- [47] C. L. Hwang and S. F. Chao, "A fuzzy-model-based variable structure control for robot arms: theory and experiments," 2005, pp. 5252-5258.
- [48] C. G. Lhee, *et al.*, "Sliding mode-like fuzzy logic control with self-tuning the dead zone parameters," *Fuzzy Systems, IEEE Transactions on*, vol. 9, pp. 343-348, 2002.
- [49] Lhee. C. G., J. S. Park, H. S. Ahn, and D. H. Kim, "Sliding-Like Fuzzy Logic Control with Self-tuning the Dead Zone Parameters," *IEEE International fuzzy systems conference proceeding*, 1999, pp.544-549.
- [50] X. Zhang, *et al.*, "Adaptive sliding mode-like fuzzy logic control for high order nonlinear systems," pp. 788-792.
- [51] M. R. Emami, *et al.*, "Development of a systematic methodology of fuzzy logic modeling," *IEEE Transactions on Fuzzy Systems*, vol. 6, 1998.
- [52] H.K.Lee, K.Fms, "A Study on the Design of Self-Tuning Sliding Mode Fuzzy Controller. Domestic conference," *IEEE Conference, 1994*, vol. 4, pp. 212-218.
- [53] Z. Kovacic and S. Bogdan, *Fuzzy controller design: theory and applications*: CRC/Taylor & Francis, 2006.
- [54] F. Y. Hsu and L. C. Fu, "Nonlinear control of robot manipulators using adaptive fuzzy sliding mode control," 2002, pp. 156-161.
- [55] R. G. Berstecher, *et al.*, "An adaptive fuzzy sliding-mode controller," *Industrial Electronics, IEEE Transactions on*, vol. 48, pp. 18-31, 2002.
- [56] V. Kim, "Independent joint adaptive fuzzy control of robot manipulator," 2002, pp. 645-652.
- [57] Y. Wang and T. Chai, "Robust adaptive fuzzy observer design in robot arms," 2005, pp. 857-862.

- [58] B. K. Yoo and W. C. Ham, "Adaptive control of robot manipulator using fuzzy compensator," *Fuzzy Systems, IEEE Transactions on*, vol. 8, pp. 186-199, 2002.
- [59] H. Medhaffar, *et al.*, "A decoupled fuzzy indirect adaptive sliding mode controller with application to robot manipulator," *International Journal of Modelling, Identification and Control*, vol. 1, pp. 23-29, 2006.
- [60] Y. Guo and P. Y. Woo, "An adaptive fuzzy sliding mode controller for robotic manipulators," *Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on*, vol. 33, pp. 149-159, 2003.
- [61] C. M. Lin and C. F. Hsu, "Adaptive fuzzy sliding-mode control for induction servomotor systems," *Energy Conversion, IEEE Transactions on*, vol. 19, pp. 362-368, 2004.
- [62] Jordanov, H. N., B. W. Surgenor, 1997. Experimental evaluation of the robustness of discrete sliding mode control versus linear quadratic control, *IEEE Trans. On control system technology*, 5(2):254-260.

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