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WSNs Based- L4L Rule for Fuzzy Inventory Control Decision Making (WSN-FL4L)

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Abstract:

Inventory control is one of the most important tasks for industrial companies. Inventory control systems play an important role in inventory monitoring. Wireless Sensor Networks (WSNs) technology has been taken into great attention in the field of inventory control because it is considered as an efficient, low-cost technology to control inventories. This paper proposes an intelligent inventory control system depending on WSNs and fuzzy logic to control the dependent demand items effectively under MRP system and L4L lot sizing rule. to be used to solve the industrial problems. A numerical example of a 5 drawers - chest of drawers product has been experimented.

The advantage of the proposed WSN-FL4L system could be represented in its ability to make decisions in different inventory states. Different cases of replenishment were investigated depending on the (IF-THEN rules) statement of fuzzy logic. Ultrasonic - distance sensor has been programmed to compute the number of items' pieces, depending on the thickness of each piece. ASP.net web application and C# programming language based on SQL database server are applied.

Keywords: Inventory Control; Lot Sizing; MRP; Wireless Sensor Networks; Fuzzy Logic.

الخلاصة

تعد وظيفة السيطرة على الخزين واحدة من اهم الانشطة التي تقوم بها الشركات الصناعية . تلعب انظمة السيطرة على الخزين دور كبير في ضمان الرقابة التامة على عناصر المخزون. من جهة ثانية، نال استخدام تقنية شبكات الاستشعار اللاسلكية اهتماماً كبيراً من حيث تطبيقها في حقل السيطرة على الخزين كونها تقنية كفوءة و رخيصة الثمن و سهلة التنصيب . اقترح البحث الحالي نظام سيطرة مخزنية ذكي بالاعتماد على تقنية الاستشعار اللاسلكي و المنطق المضبب، بالاعتماد على قاعدة حجم الدفعة المكافيء للاحتياج ضمن نظام تخطيط الاحتياجات المادية ليمكن استخدامه لحل اغلب المشاكل الصناعية. تم تطبيق النظام المقترح على حالة افتراضية لمنتوج يمثل قطعة من الاثاث الخشبي خماسي الدواليب الجرارة.

تكمن فائدة النظام المقترح في قدرته على المساعدة في اتخاذ قرارات المخزون في ظل حالات مختلفة فقد تم اختبار حالات متعددة لاعادة تعزيز المخزون بالاعتماد على قاعدة (اذا – عند ذلك) من المنطق الضبابي. تم نشر وبرمجة حساسات لقياس المسافة لغرض حساب عدد قطع مفردات المخزون بالاعتماد على قياس سمك القطعة.. تم اعتماد تقنية ASP.net و لغة C# بالاعتماد على قاعدة بيانات في الخادم الرئيس.

الكلمات الدالة: السيطرة على المخزون، تحديد حجم الدفعة، نظام تخطيط الاحتياجات المادية، انظمة الاستشعار اللاسلكية، المنطق المضبب.

1. Introduction

Inventory is a major component of any production system, it could be raw materials, parts, sub-assemblies, or finished goods. Material Requirements Planning (MRP) is one of the inventory control systems, it is a computer-based system which concerns with dependent demand items [Krajewski et. al., 2013]. MRP includes many inputs which considered as decision rules to determine the economic quantity of dependent demand items.

Wireless Sensor Network (WSN) is one of the most promising technologies. It could be programmed to be used in smart applications due to its characteristics (tiny size and cheap cost).

WSNs can serve many important areas by deploying them in a physical region and get data from sensors remotely over local network or internet [Zheng and Jamalipour, 2009]. WSNs technology has been used in intelligent applications such as in intelligent buildings, smart home, intelligent care of health and etc [Yick, et. al., 2008]. Fuzzy set theory provides a framework for considering parameters with values that are unclearly defined or may be determined based on subjective beliefs of individuals. Some researches concerned with studies that applying fuzzy logic to determine uncertainties in demand, order quantity, re-order point, and lead time [Tanthatemee and Phruksaphanrat, 2012]. The idea behind fuzzy logic is similar to the human being's feelings and inference process [Bai and Wang, 2005]. It is also known as possibility theory. It was proposed by Lotfi Zadeh in1965 as an alternative to traditional two-value logic and probability theory [Han and Kamber, 2006] .

2. Methodology and Related Works:

2.1 The problem of the study: many problems face the industrial organizations when they aim to maintain lowest possible levels of inventory and ensure efficient replenishment systems. Availability of materials and components, ensure safety and security in the work environment, protecting inventory from shortages, damage, or other poor storage circumstances are the most popular problems. Traditional systems will not be able to handle such problems without being integrated with appropriate technologies during planning and production phases.

2.2 The aim of the study: The main aim of this paper is to design a WSNs Based Fuzzy Inventory Control System to control the dependent demand items effectively based on L4L rule under MRP system depending on the fuzzy logic (IF-THEN rules) statement. This proposal will bridge the gap between theory and practice since there is a lake in researches that deal with the application of such systems in real life practices especially in industrial field.

2.3 Related works: many works in literatures deal with the applications of WSN and fuzzy logic in inventory control: **Tanthatemee and Phruksaphanrat, (2012)** proposed a fuzzy inventory control system for a single item continuous control system, The model can deal with both uncertain demand and availability of supply using fuzzy logic control system depending on Economic Order Quantity Lot - Sizing method (EOQ). The proposed Fuzzy Inventory Control (FIC) system describes the demand and availability of supply by linguistic terms and fuzzy rules to extract the fuzzy order quantity and the fuzzy reorder point continuously. The proposed fuzzy system is more flexible than the traditional approach in term of order quantity and determining the reorder point [Tanthatemee and Phruksaphanrat, 2012]. **Khan et. al. (2012)** developed a fuzzy interface based system for inventory replenishment decision making to determine inventory levels, reorder point, reorder quantity, etc. Input variable for the proposed system were demanding, inventory on hand, lead time, and the price of raw material. Several rules are also developed for each input and output variables combinations to make decisions based on the opinion of experts [Khan et. al., 2012]. **Sen and Malakar (2015)** discussed the costs involved in inventory shortages as fuzzy numbers. They developed the work of **Dutta and Kumar (2012)** which considered a fuzzy inventory model without shortages, by extending the model for purchasing inventory model with shortages using trapezoidal fuzzy numbers for different costs and signed distance method for defuzzification, and then for the same purchasing inventory model. They approved that the optimal values are improved in fuzzy environment as compared to that of in a crisp environment [Sen and Malakar, 2015].

3. Fuzzy Logic:

The identification of fuzzy model is considered as a problem of representing (IF-THEN) rules from input and output data. These could be proceeds through two steps as below:

1) Clustering**:** Clustering algorithms are used extensively not only to organize and categorize data, but are also useful for constructing models [Vaidehi et. al., 2008].

2) Specification of input-output relations (IF-THEN) rules: (If-Then) rule statements are used to formulate the conditional statements that comprise fuzzy systems which consider the Fuzzy sets as the subjects and verbs of its logic. A single fuzzy (If-Then) rule assumes the form:

If x is A_1 Then y is B_2 ،

If A_1 Then B_2 or $A_1 \rightarrow B_2$

Where A_1 and B_2 are linguistic variables defined by fuzzy sets on the ranges X and Y respectively. The If-part of the rule 'x is A_1' is called the antecedent or premise and the Then-part of the rule 'y is B_2' is called the consequent. In other words, the conditional statement can be expressed in a mathematical form [Siddique and Adeli, 2013] [Vaidehi et. al., 2008].

4. L4L - Lot Sizing Rule

MRP logic could be represented in a record depending on the following equations [Al-Bayati and Alrawi, 2005] and [Kareem et. al., 2017].

Gross Requirement (GR): GRt = TQit * QR …. (1)

Scheduled Receipts (SR): SR = GR+SS-POHt-1 …. (2)

Projected On Hand Inventory (POH): POHt = (POHt-1 + SRt + PRt) – GRt .... (3)

Net Requirement (NR): NRt = (GRt + SS) - (SRt+POHt-1) …. (4)

Planned Receipts (PR): PR= by lot sizing technique …. (5)

Planned Order Releases (POR): PORt = PRt – L.T …. (6)

Where:

TQ_{it} = total quantity required from part (i) in the week (t)

QR = quantity required from the child item to produce one unit of the parent item.

MRP used to determine the dependent demand items, such as parts, components, and materials needed to produce a product (end item), its logic helps to determine what, when, and how many of each part, component, subassemblies and final products are required. Lot – sizing rules (LSTs) achieving the balance between meeting the requirements and reducing inventory size and cost. LSTs determine the timing and size of order quantities, the choice of lot-sizing technique is important because they determine the number of setups or orders required. Lot of Lot (L4L) rule is considered as one of the replenishment systems, it operates under MRP logic. Algorithm (1) represents MRP logic to replenish inventory levels using L4L rule.

Algorithm (1): MRP Logic using L4L rule.
Input: child items, SR, SS, POH_{t-1}, TQ_{it}, QR, L.T Output: parent item (planning state)

Process:
Begin
Step1: for all child items in BOM do
Step2**:**For t = 1 To 10
Begin
Step 2.1: $GR_t = TQ_{it} * QR$
Step 2.2: $SR = GR+SS-POH_{t-1}$
Step 2.3: $POH_t = (POH_{t-1} + SR_t + PR_t) - GR_t$.
Step 2.4: $NR_t = (GR_t + SS)$ -(SRt+POHt-1)
Step 2.5: PR=NR
Step 2.6: $POR_t=PR_t - L.T$
End for
Step2: Inventory replenishment Under constraints of L4L
Step3: Process the child items (planning state)
End

5. The proposed System Topology and Design:

In this paper, a L4L and WSNs Based Fuzzy Inventory Control System (WSN-FL4L) is proposed. It's built using the ultrasonic sensor (distance sensor), which can measure the distance when arranging the inventory items' pieces in a predetermined order. This system will sensing any shortage could be occurred in inventory items by measuring the differences in distances. The replenishment system could make decisions to replenish the inventory depending on this proposed system as shown in figure (1), which represents an example of three cases to determine the number of pieces on shelfs. Assuming that the shelf height is 40 cm, and piece height is 10 cm. The distance sensor will measure the distance of free space in order to calculate the number of pieces need to be replenished. This process is done based on the following equations:

$Pn = (Lr - La) / Ptk$ ……….. (7)

$La = Lr - (TPn * Ptk)$ ………. (8)

Where Pn = number of pieces, Lr = length of rack, La = available length, Tpn = total number of pieces, and Ptk = thickness of piece

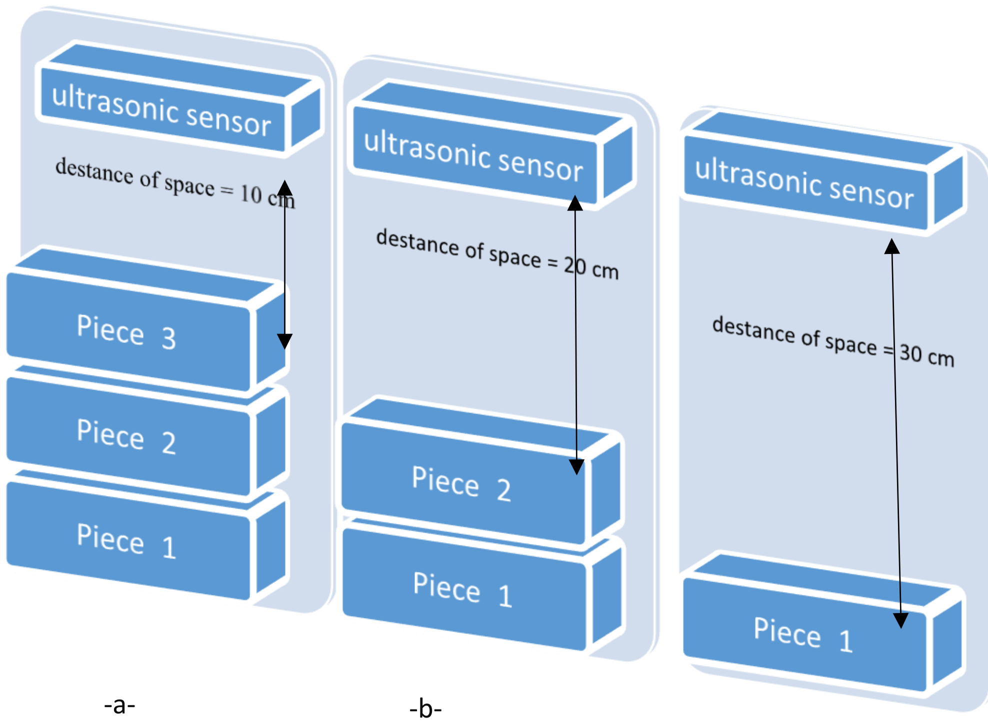

Figure (1): distance sensor works as a counter: (a) in this case the rack has three pieces. (b) in this case the rack has two pieces. And (c) in this case the rack has one piece.

The star topology is suitable to be used in WSNs on the indoor principles. This system has multi types of sensors and server, the wireless sensor network could be built with two structures by using access point (AP) device to ensure connecting between sensor and server, and WLAN card that installed on server device as in figure (2).

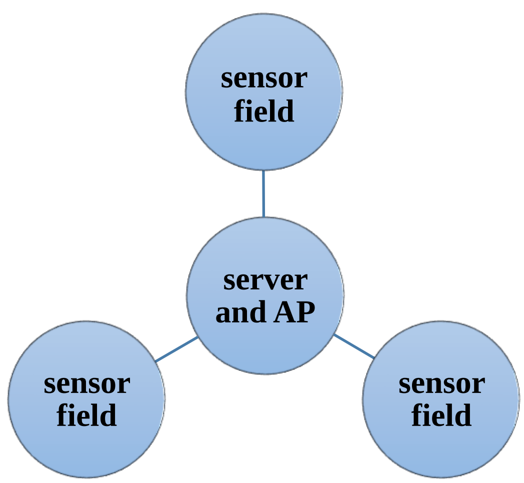

Figure (2): The Proposed Star Topology

The ultrasonic - distance sensor has been programmed to compute the number of items' pieces in each shelf depending on the thickness of each piece. In this case the sensor part acts as alarm and observer of the Projected on hand inventory (POH) and safety stocks (SS) levels. The sensor system operates according to algorithm (2) below.

```
Algorithm (2): Sensor-Interaction Algorithm
Input: Length of Rack (LR), Thickness of Piece (THP), Number of
       Pieces in L4L (NP)
Output: parent item (production State) for level (0,1)
Process:
Begin
   Step1: read sensor signal (Dist);
   Step2: NPr←NPr - (Dist/THP);
   Step3: If not end(pPlan) then
    Begin
      Step3.1:  If (NPr < NP) then
           Sensor_Msg (replenishment)
       Step3.1:    Else
           Begin
              Step3.1.1: Sensor_status (idle)
              Step3.1.2: Until piece removed ()
             Step3.1.3:  Go to Step1
            End if
     End if
```

6. Experiments and Results of the WSN-FL4L System

A numerical example of a factory of wooden furniture produces several products has been experimented. One of its products is the 5 drawers - chest of drawers (COD). This product has many parts and sub-assemblies as shown in its BOM in table (1) and figure (3). This factory applying a make – to – order strategy and uses the L4L rule.

Table (1): BOM of the (COD).

Symbol	Part description	Number of pieces	Thickness /cm	Width /cm	Length /cm	Lumber kind	Cost /$
A	Top	1	2	40	40	Oak	5
B	Sides	2	2	40	100	Oak	25
C	Back	1	1	40	100	Oak	6
D	Drawer rail	5	2	36	40	Oak	22
E	Drawer front	5	2	20	40	Oak	12
F	Drawer sides	10	1	20	40	Oak	12
G	Drawer back	5	1	20	36	Oak	6

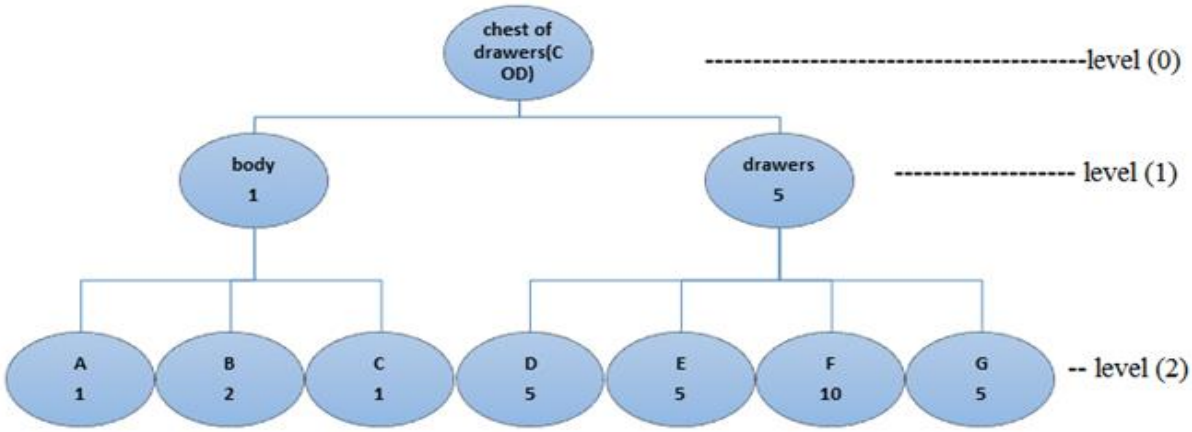

Figure (3): Bill of Material for (COD).

Table (2) shows the gross requirements (GR) for (COD) product at a level (0) which derived from the production plan. The planning horizon considered is (10) weeks. Lead time is (1) week which results in Planned Order Releases (POR) as mentioned in Step 2.6 in algorithm (1).

Table (2): production plan (in units) for (COD)

Weeks	١	٢	٣	٤	٥	٦	٧	٨	٩	١٠
GR	٠	٥٠	٦٠	٠	٦٠	٤٥	٢٥	٣٠	٣٠	١٠
POR	٥٠	٦٠	٠	٦٠	٤٥	٢٥	٣٠	٣٠	١٠	٠

6.1 Sensor Part:

MRP logic will compute the Net Requirements (NR) necessary to complete the MRP record for each dependent demand item. Sensors installed in inventory stores determine the quantities of Safety stock (SS), Projected on hand Inventory at the beginning of the planned horizon (POH t-1), and Scheduled receipts (SR) that are required for MRP logic as in table (3). Then L4L rule computes the Planned Receipts (PR) and Planned Order Releases (POR) for each parent item to determine Gross Requirements (GR) for its Child items.

Table (3) shows how the sensor will calculate the available length (La) and number of pieces (Pn) as in equations (7) and (8) respectively, for the child item (A) which has a unique shelf of (10000) cm (10 meters).

Table (3): MRP Record for Item A Based on Distance Sensor.

Lot size technique: L4L Item: A*1												
Safety stock (SS)= 50		**L. t = 1**										
Weeks		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Gross requirements		**50**	**60**	**0**	**60**	**45**	**25**	**30**	**30**	**10**	**-**	
Scheduled receipts		**100**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**		
Projected on hand	**0**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	
Net requirements		**0**	**60**	**0**	**60**	**45**	**25**	**30**	**30**	**10**		
Planned order receipts		**0**	**60**	**0**	**60**	**45**	**25**	**30**	**30**	**10**		
Planned order releases		**60**	**0**	**60**	**45**	**25**	**30**	**30**	**10**			

6.2 Fuzzy Logic (If-Then) Rules Part:

The proposed system is depending on the fuzzy logic by investigating to identify the statements of (IF-THEN) rules from child items input to generate output data predicatively. This could be done through Clustering and Specification of input-output relations steps (IF-THEN rules) as mentioned in section (2). Clustering concerns with the deployment of sensors at the beginning of each shelf. In the regular storage method, each child items have unique shelf, the shelf which customized for a particular element. Specification of input-output relations steps (IF-THEN rules) are conducted as below and shown in table (4).

IF X =X – QR THEN Y=Y+1
IF X =X – QR AND X1 =X1 – QR1 ……. AND Xn =Xn – QRn THEN Y=Y+1

Where QR = quantity required from the child item to produce one parent item unit, X= item on the shelf , Y = child item , and P = parent item .

Table (4): generate Body, Drawers and COD

IF		**AND IF**		**THEN**
IF	**THEN**	**IF**	**THEN**	
A	Body	D	Drawers	COD
50	0	250	0	0
49	1	245	1	1
48	2	240	2	2
47	3	235	3	3
.	.	.	.	.
.	.	.	.	.
٠	٥٠	٠	٥٠	٥٠

The advantages of the proposed WSN-FL4L system represented in its ability to make decisions in the following inventory states as mentioned in table (5) depending on two factors: fuzzy set and knowledge base. The fuzzy set factor consists of different inventory cases and the production planning stages. The second factor investigates different production cases.

6.2.1 Fuzzy Set:

State 1 = the inventory is decreased (child items).

State 2 = the inventory is increased (parent items).

State 3 = No changes in inventory state (in the both parent and child items).

State 4 = No enough inventory on the shelf (shortage).

State 5 = production line is stop

State 6 = SS is decreased.

The production plan could be in the stages below:

Stage 1 = beginning (the production plan is started).

Stage 2 = work-in-process (WIP).

Stage 3 = End (production plan is finished).

6.2.2 Knowledge base: different cases could be investigated from the proposed system:

-IF production line is stop AND inventory demand is in process (WIP) THEN start next interval.

- IF production line is stop AND the inventory is increased (parent items) AND End (production plan is finished) THEN the demand ready.

-IF production line is stop AND No changes in the inventory state (in both parent and child items) AND Under process (the item demand in production plan is) THEN Sudden stop in the production line.

-IF no change in the inventory state (in both parent and child items) AND Start (the production plan is started) THEN production line ready to start.

-IF the inventory is decreased (child items) AND the inventory is increased (parent items) AND No inventory enough in the rack AND item in process (WIP) THEN Replenishing the inventory.

-IF SS is decrease AND (WIP) THEN Replenishing the SS.
-IF production line is stop AND No enough inventory on shelf AND End (production plan is finished) THEN the planning is finished and the production line ready to a new plan

Table (5): WSN-FL4L Decision-Making Procedures.

IF		THEN
State 5	Stage 2	Decision 1: start next interval
State 5 AND state 2	Stage 3	Decision 2: the demand ready
State 5 AND state 3	Stage 2	Decision 3: Sudden stop in the production line
State 3	Stage 1	Decision 4: production line ready to start
State 1 AND state 2 AND state 4	Stage 2	Decision 5: Replenishing the inventory
State 6	Stage 2	Decision 6: Replenishing the SS
State 5 AND state 4	Stage 3	Decision 7: the planning is finished and the production line ready to new plan

7 Conclusions

The main goals of (LSTs) are achieving the balance between meeting the customer requirements and reducing inventory size and cost, determine the timing and size of order quantities, and controlling inventory replenishment. (L4L) rule is considered as one of the replenishment systems, it operates under MRP logic. For this reason, a WSNs Based Fuzzy L4L Inventory Control System (WSN-FL4L) is designed to control the dependent demand items effectively.

The advantages of the proposed WSN-FL4L system proposed in this paper, represented in its ability to make decisions different inventory states depending on two factors: fuzzy set and knowledge base. The fuzzy set factor consists of different inventory cases and the production plan stages. The knowledge base factor investigates different production cases.

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