







### Step (A2)-Generate one-dimensional object type combination

Each detected object composes Set<sub>O</sub>, which can be divided into one-dimensional object relation groups GP<sub>1y</sub>,  $y=1 \sim N(\text{Set}_O)$ , in other words, in one-dimensional object relation  $\text{GP}_O(1, y, 1) = \text{GP}_{1y}$ , and the object GP<sub>O</sub>(1, y, 1) in each group is ordered in its detected sequence. Since each object group in one-dimensional object relation has the only object GP<sub>O</sub>(1, y, 1), its corresponding object type combination G\_Type(1, y) is identified according to element's type of Set (Set<sub>P</sub>, Set<sub>G</sub>, Set<sub>A</sub>), the concept can be revealed in Eq.(2).

$$\begin{aligned} \text{IF}(\text{GP}_O(1, y, 1) \in \text{Set}_P) \text{ THEN } G\_Type(1, y) &= P \\ \text{IF}(\text{GP}_O(1, y, 1) \in \text{Set}_G) \text{ THEN } G\_Type(1, y) &= G \\ \text{IF}(\text{GP}_O(1, y, 1) \in \text{Set}_A) \text{ THEN } G\_Type(1, y) &= A \end{aligned} \quad (2)$$

Equation (2) indicates that in one-dimensional object relation, the corresponding object type combination of each object group are 'person', 'goods', or 'area'.

### Step (A3)-Generate two-dimensional object type combination

The object group in two-dimensional object relation is composed of any two objects detected by the RFID reader. Therefore, according to the total of detected objects, there are  $C_2^{N(\text{Set}_O)}$  two-dimensional object relation groups, and each object GP<sub>O</sub>(2, y, 1), GP<sub>O</sub>(2, y, 2) in group is ordered in its detected sequence. Since each object group in two-dimensional object relation has two elements GP<sub>O</sub>(2, y, 1), GP<sub>O</sub>(2, y, 2), the corresponding object type combination is identified according to the combination of its two elements' type of Set, and the order of the elements doesn't affect the type combination, the concept can be revealed in Eq.(3) and Eq. (4).

$$\begin{aligned} \text{IF}(\text{GP}_O(2, y, 1) \in \text{Set}_P) \text{ AND } \text{GP}_O(2, y, 2) \in \text{Set}_P \text{ THEN } G\_Type(2, y) &= PP \quad (3) \\ \text{IF}(\text{GP}_O(2, y, 1) \in \text{Set}_G) \text{ AND } \text{GP}_O(2, y, 2) \in \text{Set}_G \text{ THEN } G\_Type(2, y) &= GG \\ \text{IF}(\text{GP}_O(2, y, 1) \in \text{Set}_A) \text{ AND } \text{GP}_O(2, y, 2) \in \text{Set}_A \text{ THEN } G\_Type(2, y) &= AA \end{aligned}$$

$$\begin{aligned} \text{IF}(\text{GP}_O(2, y, 1) \in \text{Set}_P \text{ AND } \text{GP}_O(2, y, 2) \in \text{Set}_G) \text{ OR } (\text{GP}_O(2, y, 1) \in \text{Set}_G \\ \text{AND } \text{GP}_O(2, y, 2) \in \text{Set}_P) \text{ THEN } G\_Type(2, y) &= PG \quad (4) \\ \text{IF}(\text{GP}_O(2, y, 1) \in \text{Set}_G \text{ AND } \text{GP}_O(2, y, 2) \in \text{Set}_A) \text{ OR } (\text{GP}_O(2, y, 1) \in \text{Set}_A \\ \text{AND } \text{GP}_O(2, y, 2) \in \text{Set}_G) \text{ THEN } G\_Type(2, y) &= GA \\ \text{IF}(\text{GP}_O(2, y, 1) \in \text{Set}_P \text{ AND } \text{GP}_O(2, y, 2) \in \text{Set}_A) \text{ OR } (\text{GP}_O(2, y, 1) \in \text{Set}_A \\ \text{AND } \text{GP}_O(2, y, 2) \in \text{Set}_P) \text{ THEN } G\_Type(2, y) &= PA \end{aligned}$$

Equations (3) and (4) indicate that in two-dimensional object relation, the corresponding object type combination of each object group are 'person to person', 'goods to goods', 'area to area', 'person to good', 'person to area', and 'good to area'.

### Step (A4)-Generate three-dimensional object type combination

The object group GP<sub>3y</sub> in three-dimensional object relation is composed of any three objects detected by the

RFID reader. Therefore, according to the total of detected objects, there are  $C_3^{N(\text{Set}_O)}$  three-dimensional object relation groups, and each object GP<sub>O</sub>(3, y, 1), GP<sub>O</sub>(3, y, 2), GP<sub>O</sub>(3, y, 3) in group is ordered in its detected sequence. Since each object group in three-dimensional object relation has three elements GP<sub>O</sub>(3, y, 1), GP<sub>O</sub>(3, y, 2), GP<sub>O</sub>(3, y, 3), the corresponding object type combination G\_Type(3, y) is identified according to the combination of its three elements' type of Set, and the order of the elements doesn't affect the type combination, the concept can be revealed in Eq. (5).

$$\begin{aligned} \text{IF}(\text{GP}_O(3, y, 1) \in \text{Set}_P \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_P \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_G) \\ \text{OR } (\text{GP}_O(3, y, 1) \in \text{Set}_G \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_P \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_P) \\ \text{OR } (\text{GP}_O(3, y, 1) \in \text{Set}_P \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_G \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_P) \\ \text{THEN } G\_Type(3, y) &= PPG \\ \text{IF}(\text{GP}_O(3, y, 1) \in \text{Set}_P \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_P \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_A) \\ \text{OR } (\text{GP}_O(3, y, 1) \in \text{Set}_A \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_P \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_P) \\ \text{OR } (\text{GP}_O(3, y, 1) \in \text{Set}_P \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_A \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_P) \\ \text{THEN } G\_Type(3, y) &= PPA \\ \text{IF}(\text{GP}_O(3, y, 1) \in \text{Set}_G \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_G \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_P) \\ \text{OR } (\text{GP}_O(3, y, 1) \in \text{Set}_G \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_P \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_G) \\ \text{OR } (\text{GP}_O(3, y, 1) \in \text{Set}_P \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_G \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_G) \\ \text{THEN } G\_Type(3, y) &= PGG \\ \text{IF}(\text{GP}_O(3, y, 1) \in \text{Set}_G \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_G \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_A) \\ \text{OR } (\text{GP}_O(3, y, 1) \in \text{Set}_G \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_A \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_G) \\ \text{OR } (\text{GP}_O(3, y, 1) \in \text{Set}_A \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_G \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_G) \\ \text{THEN } G\_Type(3, y) &= GGA \\ \text{IF}(\text{GP}_O(3, y, 1) \in \text{Set}_A \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_A \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_G) \\ \text{OR } (\text{GP}_O(3, y, 1) \in \text{Set}_A \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_G \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_A) \\ \text{OR } (\text{GP}_O(3, y, 1) \in \text{Set}_G \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_A \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_A) \\ \text{THEN } G\_Type(3, y) &= GAA \\ \text{IF}(\text{GP}_O(3, y, 1) \in \text{Set}_P \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_G \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_A) \\ \text{OR } (\text{GP}_O(3, y, 1) \in \text{Set}_P \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_A \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_G) \\ \text{OR } (\text{GP}_O(3, y, 1) \in \text{Set}_G \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_A \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_P) \\ \text{OR } (\text{GP}_O(3, y, 1) \in \text{Set}_A \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_G \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_P) \\ \text{OR } (\text{GP}_O(3, y, 1) \in \text{Set}_A \text{ AND } \text{GP}_O(3, y, 2) \in \text{Set}_P \text{ AND } \text{GP}_O(3, y, 3) \in \text{Set}_G) \\ \text{THEN } G\_Type(3, y) &= PGA \end{aligned} \quad (5)$$

Equation (5) indicates that in three-dimensional object relation, the corresponding object type combination of each object group are 'person to person to person', 'goods to goods to goods', 'area to area to area', 'person to person to good', 'person to person to area', 'person to goods to goods', 'goods to goods to area', 'goods to area to area', and 'person to goods to area'.

#### (b) Object relationship identification

Since object type combination clarify all categories of object groups, the interactions between objects can be simply investigated based on each objects' target demands in the group and object relationship is then identified. In this sub-subsection, the methodology of object relationship identification is introduced, and the conceptual model of object relationship identification is shown in Figure 4.

### Step (B1)-Identify object relationships

Object relationship identification is based on object type combination, object's target demands and those of corresponding target attribute values. In the proposed model, there are eight types of object relationships, including 'MA', 'BLK', 'NI', 'NO', 'CFT', 'MIX', 'COI', 'SPT' and five types of target demands, including 'FID', 'CTL', 'AFM', 'BAN', 'AST'.

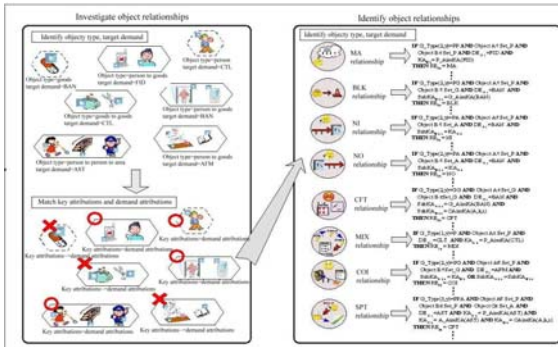


Fig. 4 The conceptual model of object relationship identification.

The methods for identifying eight types of object relationship are as follows:

- **MA-** The properties of object relationship ‘MA’ are: two-dimensional object relation, object type combination is ‘person to person’, ‘person to goods’, ‘person to area’, and when a ‘person’ object in the group with target demand ‘FID’, the attribute value of target demand ‘FID’ is equal to the key attribute of the other object in the group.
- **BLK-** The properties of object relationship ‘BLK’ are: two-dimensional object relation, object type combination is ‘person to goods’, and when a ‘person’ object in the group with target demand ‘BAN’, the attribute value of the target demand ‘BAN’ is equal to the particular sub-attribute ‘obstacle’ of the other ‘goods’ object in the group.
- **NI-** The properties of object relationship ‘NI’ are: two-dimensional object relation, object type combination is ‘person to area’, or ‘goods to area’, and when an object in the group with target demand of ‘BAN’, the object’s key attribute value is equal to the particular sub-attribute ‘NI condition’ of the other ‘area’ object in the group.
- **NO-** The properties of object relationship ‘NO’ are: two-dimensional object relation, object type combination is ‘person to area’, or ‘goods to area’, and when an object in the group with target demand of ‘BAN’, the object’s key attribute value is equal to the particular sub-attribute ‘NO condition’ of the other ‘area’ object in the group.
- **CFT-** The properties of object relationship ‘CFT’ are: two-dimensional object relation, object type combination is ‘goods to goods’, an object in the group with particular sub-attribute ‘CFT condition’, target demand of ‘BAN’, the object’s sub-key attribute value ‘CFT condition’ is equal to the attribute value of target demand ‘BAN’, and the sub-key attribute value of the other object in the group and the object with target demand is equal.
- **MIX-** The properties of object relationship ‘MIX’ are: one-dimensional object relation, object type combination is ‘person to goods’, and when an object in the group with target demand of ‘CTL’, the object’s key attribute value is equal to the attribute value of target demand ‘CTL’.
- **COI-** The properties of object relationship ‘COI’ are: two-dimensional object relation, object type combination is ‘person to goods’, ‘goods to goods’, ‘goods to area’, and when an object in the group with

target demand of ‘AFM’, the object’s sub-attribute value is equal to the key attribute or sub-attribute of the other object in the group.

- **SPT-** The properties of object relationship ‘SPT’ are: three-dimensional object relation, object type combination is ‘person to person to goods’, an object in the group with target demand of ‘AST’, the object’s key attribute value is equal to the attribute value of target demand ‘AST’, the ‘area’ object’s key attribute value is equal to the attribute value of target demand ‘AST’, and the other ‘person’ object’s key attribute value is equal to the sub-attribute value of the object with target demand.

### (c) Object guidance

After object type combination and object relationship identification, RFID-based system would send instructions to the related objects in the group and guiding the related objects to move quickly to complete the tasks. In object guidance, objects are firstly located via RFID; then the relative positions of related objects are obtained; finally, instructions are sent to the related objects for guidance on accomplishing or preventing something. In this sub-subsection, the methodology of object guidance is introduced, and the conceptual model of object guidance is shown in Figure 5.

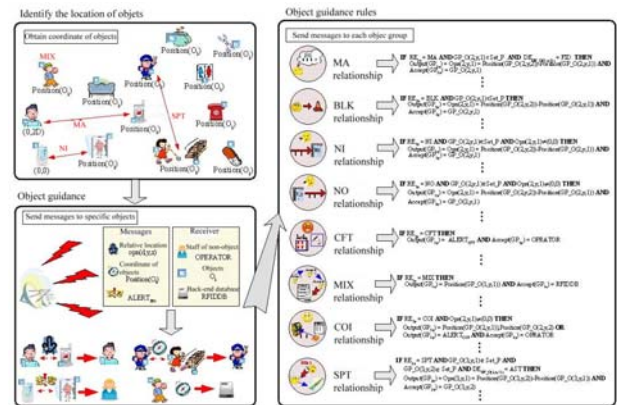


Fig. 5 The conceptual model of object guidance.

The distribution of RFID reader in this research is shown as Figure 6. The RFID readers are arranged along the parallel lines, the distance between adjacent line is  $D$ , the distance between RFID readers arranged in lines is  $2D$ , and the distance in horizontal direction between an RFID reader and another one in adjacent line is  $D$ . In this research, the location of an object is the center of current region. Therefore, the location of an object can be obtained based on the mean coordinate of RFID readers detecting it. While an object is detected by an only RFID reader, its location is the coordinate of the RFID reader, and if detected by two, the location of the object is the center of line passing through the two RFID readers. The details of the proposed object guidance are described as follows.

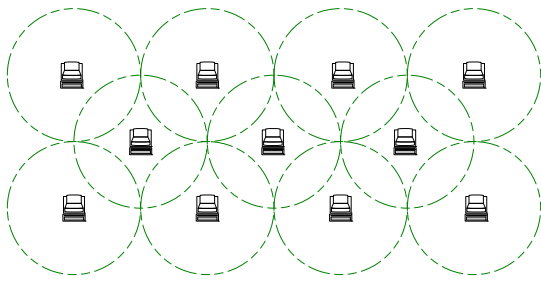


Fig. 6 The distribution of RFID readers.

**Step (C1)-Identify the location of objects**

In order to obtain the relative location of objects, the coordinates of objects need to be identified. First, obtain the ranks (Reader<sub>ab</sub>), coordinates (Location(a,b)) and total of RFID (CountR(O<sub>i</sub>)) that detect object O<sub>i</sub>, then the coordinate of objects (Position(O<sub>i</sub>)) can be obtained accordingly. While an object O<sub>i</sub> is detected by an only RFID reader (CountR(O<sub>i</sub>)=1), the location (Position(Reader<sub>1,1</sub>), Location(1,1)) of the RFID reader (Location(a,b)), and if detected by two, the location of the object is the center of line passing through the two RFID readers.

**Step (C2)-Send messages for object guidance**

After obtaining the location of objects, guidance messages are sent to the objects with identified object relationships. Since the interactions between objects are based on the object relationships; therefore, the sent messages are described according to the object relationships.

**4. DEVELOPMENT OF OBJECT RELATIONSHIP IDENTIFICATION AND GUIDANCE SYSTEM**

This study established an Object Relationship Identification and Guidance System (ORIGS) for object relationship identification, interaction determination and guidance. The ORIGS was based on Microsoft Pocket PC. VB.Net (Visual Basic.Net) was applied to develop the diverse system functions and operation interfaces. Besides, Microsoft SQL Server CE was applied for the back-end system to store and maintain the relevant data. The ORIGS is composed of Object Type Combination Module (OTC), Object Relationship Identification Module (ORI), Object Guidance Module (OG) and User Data Maintenance Module (UDM).

In the proposed ORIGS system, the system users can be distinguished into the common users and administrators. First, the administrator launches the RFID readers, and then starts the OTC and ORI module. Later, when the common user log into the system, he can perform the object relationship identification (Figure 8), object relationship query. Furthermore, it can provide guidance service for the users to complete the target demand according to the identified object relationship.

**5. CONCLUSIONS AND FUTURE WORK**

In this study, a general model demonstrating the interactions between objects and object relationships based on RFID technology is proposed. In brief, this study

generalizes eight object relationships to develop a novel methodology of object relationship identification, object localization, and guidance for completing interactions between objects. In the future, the distribution of RFID readers will be addressed. More precise object localization methods need to be found and analyzed to obtain more reliable results.



Fig 8. The interface of object relationship identification.

**REFERENCES**

- [1] Chumkamon, S., Tuvaphanthaphiphat, P. and Keeratiwintakorn, P., 2008, "A blind navigation system using RFID for indoor environments," *The 5th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology*, Vol. 2, pp. 765-768.
- [2] Huang, H.-P., Chen, C.-S. and Chen, T.-Y., 2006, "Mobile diagnosis based on RFID for food safety," *Proceedings of the 2006 IEEE International Conference on Automation Science and Engineering*, pp. 357-362.
- [3] Huang, K.-S. and Tang, S.-M., 2006, "RFID applications strategy and deployment in bike renting system," *The 10th International Conference on Advanced Communication Technology*, Vol. 1, pp. 660-663.
- [4] Hou, J.-L. Chen, T.-G. 2011, "An RFID-based Shopping Service System for retailers", *Advanced Engineering Informatics*, Vol. 25, pp. 103-115.
- [5] Järviluoma, M. and Heikkilä, T., "An ultrasonic multi-sensor system for object locating applications," *Mechatronics*, Vol. 5, No. 4, pp. 433-440. 1995.
- [6] J. M. Ko, C. Kwak, Y. Cho, and C. O. Kim, "Adaptive product tracking in RFID-enabled large-scale supply chain", *Expert Systems with Applications*, vol. 38, pp. 1583-1590. 2011.
- [7] Ji, W.-W. and Liu, Z., 2008, "Locating ineffective sensor nodes in wireless sensor networks," *IET Communications*, Vol. 2, No. 3, pp. 432-439.
- [8] K. C. Yeh, R. S. Chen, and C. C. Chen, "Intelligent service-integrated platform based on the RFID technology and software agent system", *Expert Systems with Applications*, vol. 38, pp. 3058-3068. 2011.
- [9] Larson, J. S., Bradlow, E. T. and Fader, P. S., 2005, "An exploratory look at supermarket shopping paths," *International Journal of Research in Marketing*, Vol. 22, No. 4, pp. 395-414.
- [10] M. Baum, B. Niemann, F. Abelbeck, D.H. Fricke, L. Overmeyer, "Radio frequency identification application in smart hospitals", *Proceedings of the 20th IEEE International Symposium on Computer-Based Medical Systems*, pp. 337-342. 2007.
- [11] R. Tesoriero, R. Tebar, J. A. Gallud, M. D. Lozano, and V. M. R. Penichet, "Improving location awareness in indoor spaces using RFID technology", *Expert Systems with Applications*, vol. 37, pp. 894-898. 2010.
- [12] S. W. Wang, W. H. Chen, C. S. ONG, L. Liu, Y.W. Chuang, "RFID applications in hospital: a case study on a demonstration RFID project in a Taiwan hospital", *Proceedings of the 39th Hawaii International Conference on System Sciences*, Vol. 8, pp.184a-184a. 2006.
- [13] T. C. Poon, K. L. Choy, H. K. H. Chow, H. C. W. Lau, F. T. S. Chan and K. C. Ho, "A RFID case-based logistics resource management system for managing order-picking operations in warehouses", *Expert Systems with Applications*, vol. 36, pp. 8277-8301. 2009.