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RFID Based People-Object Direction of Pass Detection

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Abstract. In the smart city context, more and more retailers are equipping their stores with state-of-the-art technologies to create smart spaces. A hot topic between retailers is the customer shopping behavior analysis to identify the hot spots within the space to enhance the novel shopping experience. Along the technologies in the Internet of Things (IoT) paradigm, the Radio-Frequency Identification (RFID) technology allows the exchange of sensor data between simple objects. We present two approaches of smart infrastructure to detect the direction of pass from passive RFID-labeled objects. The first approach is based on a phased array system and the second version is a tilted system. We perform diverse tests to aim a realistic scenario. Our results return the reliability of our approaches to achieve a smart space.

Keywords. radio-frequency identification, intelligent gate, beam control, direction of pass

1. Introduction

The Smart City context pursuits the increment and improvement of services by exchanging information between entities. The Internet of Things (IoT) technology is directly linked to the Smart City context thanks to its properties to interconnect intelligent entities (i.e. environmental sensors sending information to an analysis center). However, most simple objects cannot provide such information, since they lack of sensing capabilities. Radio-frequency identification (RFID) is a wireless technology which allows the unique identification of objects with non-line-of-sight. A common architecture is composed of a reader (or interrogator), antennas which transmit the electromagnetic signals, tags (or transponders) and a computing system to process the information. The ultra high frequency (UHF) RFID, defined in the Electronic Product Code Class 1 Generation-2 (EPC Gen2) [1], is *de facto* standard in retail. Many retailers already attach UHF RFID tags to their products, to monitor stock, speed up cash processes or detect people-object interactions. [2,3]. The analysis of customers' behavior within the store is becoming a hot-topic for retailers to improve the shopping experience. For instance, the amount of entering and leaving movements within the store, that is, the measurement of footfalls, can be obtained. Not only customers entering or leaving the store, but transit all around the store may be obtained: i.e. cash counter, fitting rooms, etc. Since each RFID tag can be uniquely identified from its EPC, each product can be detected and identified automatically. We envision an RFID-enabled retail store where people-object movements of entering and leaving can be correctly classified, providing valuable information to analyze the customers' behavior, hot-spots (areas where more traffic of customers are) and other profiling benefits. The overall goal of this work is to count the entering and leaving people-object movements by uniquely using RFID data. We provide the following contributions:

- A study of different methods to correctly classify the people-object direction of pass.
- A comparison of different state-off-the-art RFID antennas to increase the people-object direction of pass detection rate.
- An extensive empirical analysis of people-object direction of pass with multiple tags and events.

The remainder of this paper is organized as follows: Section 2 motivates our proposal including an overview of current state-of-the-art. The generation of RFID features and the people-object direction of pass detection methods are described in Section 3. Two approaches of direction of pass detection systems are introduced in Section 4. We empirically test our people-object direction of pass detection methods in Section 5. Finally, the paper is concluded in Section 6, also pointing out future work directions.

2. Related Work

Since decades, retailers pursuit to enhance their stores to increase the shopping experience to their customers [4]. Analyzing the customers' behavior is key to realize changes within their stores to attract new customers. For instance, by counting the entering and leaving movements along a shopping day, retailers might know the hottest points. Furthermore, by detecting the direction of pass in a gate, shoplifting can be avoided among other applications. Literature presents diverse approaches to detect the gate crossing detection. Chung et al. [5] present an audio/video system attached to a rail vehicle allowing a surveillance of the path while the train is operative. This approach detects intersection signals using frame analysis. However, an audio/video system is expensive and the correct frame analysis will depend on the quality of the image. Similar approach is described for Haring et al. [6] where intersections are recorded and is sent their location using global positioning system for a further review. Again, this approach requires expensive video surveillance equipment. Zeng et al. [7] use the electronic article surveillance (EAS) technology to deactivate security tags once they pass through the portal. The equipped antennas are capable of detecting tags crossing the gate. However, the EAS technology does not allow the identification of tags. Sakashita et al. [8] describe a compact magnetic field detector easing the installation process at the gate. Although their solution allows a higher freedom for installation, it cannot identify the product crossing the portal. A version using the Wi-Fi signal strength and an accelerometer sensor is presented by Ahmed et al. [9]. Their approach detects a passing event towards the gate from a smartphone user by a significant variance of the RSSI signal and the accelerometer values. This work only detects intelligent objects provided of Wi-Fi antenna and an accelerometer sensor, unfeasible to scale to item-level. Jae-Lee et al. [10] designed an RFID-enabled portal implementing wireless sensor networks based on Zigbee and the code division multiple access technology to detect the entrance of trucks and other vehicles. Their solution allows a 30% detection accuracy, and the identification of only entering trucks. Jiang et al. [11] propose a tag motion detection method based on the response rate from a multitag/multireader scenario. From their 1353 carried out experiments, they obtained a maximum detection accuracy of 94%. Nevertheless, their approach requires three RFID antennas located along different independent axes reducing the suitability in a real space where the antennas may block the users' movement. A phase difference of arrival based tag direction detection is presented by Nikitin et al. [12]. Their scenario consisted on a gate equipped with four RFID antennas where the radial speed projection is calculated. From that calculation, they can differentiate the entering/leaving direction from a tag with a distance under 1.5 meters, being a non common space dimensions (where distances are higher) and it may increase the multipath effects. Miesen et al. [13] use the phase data from three RFID antennas to calculate the radial velocity from labeled-objects. They can detect the direction of pass of unobstructive objects which it does not happen in real situations. Also, their approach is composed of three RFID antennas, increasing the cost of the system. Oikawa [14] describes a direction of pass detection system using three different methods with RF indicators extracted from passive RFID tags and two antennas: the tag read time, the time over a given threshold and a weighted time, respectively. The experiment consisted on crossing the read range generated by two RFID antennas in vertical position (perpendicular to the floor) of a box with 10 passive RFID tags stacked on it. Finally, uniquely the method 3 is evaluated obtaining a reading percentage of 79%. Nevertheless, those tags are not obstructive being a non-quotidian behavior where the labeled-product may infer in a direct line-of-sight. Moreover, his approach shows a read accuracy where RFID antennas were positioned perpendicular to the floor. These RFID antennas' placement may be difficult the free movement of customers entering/leaving the space.

Opposite to the works described above, we present two approaches of direction of pass detection system where multiple tags are identified even in an obstructive way, simulating a real situation by uniquely using the RFID technology. In addition, our solutions are composed of only two RFID antennas, decreasing the implementation's cost. Furthermore, by holding the RFID antennas on the ceiling, we do not block the entrance with uncomfortable devices removing barriers to customers and as a consequence their feeling of being controlled.

3. People-Object Movement Detection Principle

In this section, we describe our approach on detecting people-object direction of pass by correctly classifying the entering and leaving events in an IoT scenario, based on reasoning the RFID data from off-the-shelf equipment.

3.1. Measuring RFID Indicators to Detect Movements

In an UHF EPC Gen2 [1] RFID communication, antennas are interrogating passive RFID tags in a time-multiplexed manner. Those passive RFID tags within the read range backscatter the signal back to the RFID reader. The RFID reader not only can obtain those identifiers from RFID tags within its read range, but also high and low-level indicators are included in the backscattered signal. High-level indicators such as the identification code *EPC*, timestamp, antenna port and reader identifier can also be obtained. Each tag sample received by a state-of-the-art commercial RFID system is composed of high and low-level indicators, the following being the most relevant:

- High-level indicators
  - Identification code (96-bit typically)
  - Timestamp
  - Antenna port
  - Mux identifier
  - Reader identifier
  - Read count
- Low-level indicators
  - Received signal strength indicator (RSSI)
  - Radio frequency phase (PHASE)

The high-level indicators uniquely identify an object within a group of objects with a timestamp when each sample was captured. The antenna port indicator represents the RFID antenna which received the signal from a given tag in each inventory round. The read count provides the number of times a tag was identified along a *read time* period. The low-level indicators approximately measure the radio-frequency signal once it is backscattered to the RFID antenna. The RSSI indicator is modeled by the two-way radar equation for a mono-static transmitter while the PHASE is approximated by the combination of the round trip distance between the reader's antenna and the tag, plus the phase rotation introduced in the transmission, reception and at the tag itself. The intuition behind the people-object direction of pass detection is given by the antenna port identifier at each timestamp's sample. A tag detected within the antenna port 1 at timestamp equal 0 and at time t later for the antenna port 2, indicates the tag changed its position, meaning a movement event. Opposite, if a tag is read by the antenna port 1 at timestamp 0 and t, the tag remained static in the same position. Figure 1 shows a plot representing all the samples (x-axis) of the RSSI indicator in *dBm* (y-axis) from a product crossing the direction of pass detection system. The product initiates a dynamic event from the antenna port 2 (red triangles) where only this antenna can read it. Once the tag goes towards the system, both antenna port 1 (black circles) and 2 are reading it alternatively. Finally, the tag left behind the system but uniquely the antenna port 1 can read it. Figure 2 illustrates the principle of direction of pass in an intelligent space using a system composed of two RFID antennas. We established two event type of movement in a space: Entering and leaving. The entering event consists on an object getting inside the space. Opposite, when the object goes to the exterior of a space a leaving event occurred. The RFID-labeled book with the **A** identifier is inside the space at the instant it starts moving. At this instant, the RFID antenna 1 is reading it and before leaving the space it is read by the RFID antenna 2. That fact, allows to the RFID antenna 2 uniquely read the labeled book. On the other hand, the labeled-cup with identifier **B** proceeds to move from outside the space into it. That means, perform an entering event. In this case, the labeled-cup will be first read by the RFID antenna 2 and afterwards, by the RFID antenna 1.

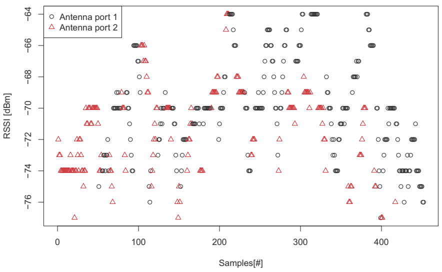

Figure 1. In a dynamic event, the tag is read from different antenna ports, the RSSI indicator shows the tag behavior

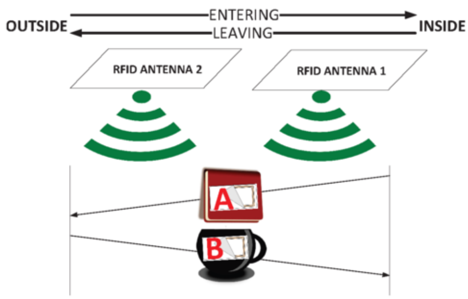

Figure 2. Representation of a direction of pass

3.2. Features' Generation

From the high and low-level indicators described above, we generate a richer set of six features based on RFID data. Table 1 describes the features used in our methods. Those features were generated after sorting the data by timestamp since most of them depend on a time-series progression.

Table 1. Summary of features based on RFID data.

1 - BEAM: Positive and negative numeric identifiers to tag each antenna lobe depending on their position.
2 - TIME: Interval of time in seconds between the first sample and the rest.
3 - AV_TIME: Mean of the feature TIME in seconds from each antenna port indicator.
4 - MINUS_TIME: Interval of time in seconds between the last sample and the rest.
5 - M1: Product of multiplying TIME per BEAM.
6 - M2: Product of multiplying MINUS_TIME per BEAM.

3.3. Methods

We implemented three different methods for a system which generates a time-series data. These methods are designed to detect the direction of pass by using the features described in Table 1. We defined the entering event as *IN* and the leaving as *OUT*. Following these methods are explained:

- **Slope:** This method is based on a lineal model [15] from the BEAM and TIME features. If the Slope value is positive an *IN* event occurred. Otherwise, this value would be negative.
- **Average Time:** It is based on the AV_TIME feature described in Table 1. The AV_TIME feature is a vector with length equal to the amount of antennas have read the tag. For instance, if two antennas read the product along the movement, the AV_TIME feature has a length of two. Then, the values from the first and last index of the AV_TIME vector are compared. If the mean time from the nearest antenna to the exit is higher than the other antenna, an *OUT* event happened. That is, because the time from the initial movement is lower than at the end of the movement.

- **Momentum:** This method is calculated from the features M1 and M2. If the M1 value is higher than the M2 feature, an *IN* event occurred. Opposite, the M2 value will be higher, being an *OUT* event.

Additionally, three weights are introduced to enhance the reliability on the methods described above. Table 2 shows the weights applied to each method for obtaining better results. By combining all three methods with and without those weights described in Table 2, a total of twelve methods are defined to evaluate our scenario.

Table 2. Summary of weights to apply in the methods based on RFID data.

1 - W1: It is the read count indicator. The intuition behind the read count is that the closer the tag to the antenna is, the higher the read count value is, thanks to a better signal reception.
2 - W2: Difference of a given RSSI indicator value and the minimum among all the samples.
3 - W3: Result of multiplying the weights W1 and W2.

4. Methodology

Different techniques are proposed to detect the direction of pass for a further customers' shopping behavior analysis. We simulated the gate from a retail store by holding an RFID-enabled system from the ceiling at 2.5 meters high. We present two approaches of direction of pass detection system: *tilted* and *phased array*. Both tilted and phased array system are composed of two RFID antennas. The tilted version is characterized by inserting an angle of 7° for separating the lobes. The phased array system concept is based on microwave components capable of shifting the phase of radio-frequency signals. Digital phase shifters provide a discrete set of phase states that are electronically controlled from an input RF signal. Thereby, the phase shifter splits an RF input into two outputs. For example, two RFID antennas connected to an RF phaser can generate four identifiable beams. Thus, a phased array system can be obtained by connecting a pair of antennas to a phaser device. Figure 3 represents the two described systems. The phased array system generates four identifiable and phased beams electronically by connecting two RFID antennas to a phase shifter. On the other hand, the separation of the beams is performed manually, by inserting an inclination to the RFID antennas in the case of the tilted system. Furthermore, we tested three different antennas to evaluate their performance under this scenario. The array 1x3 patch antenna is an array of three elements emitting a broadside beam of 90° and 40° to end-fire direction, providing a wide beam for a gate. The array 2x2 is composed of a matrix with four elements' array and it generates a radiation

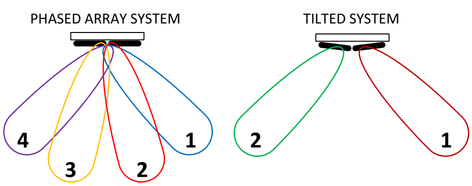

Figure 3. The phased array generates four identifiable beams and the tilted system separates the RFID antennas' beam by inserting an inclination

pattern characterized by a 60°/ 60° beamwidth being more efficient regarding directivity. Last, the array air 1x1 is composed of a slot aperture in the ground plane with a lobe of 68° / 68° beamwidth. We emulated a real retail event where customers enter and leaves the store with one or multiple tags (randomly oriented) inside a shopping bag. Each experiment procedure consisted on twenty passes under the direction of pass detection system with an RFID labeled-object in a shopping bag. Those twenty passes were initially defined with ten *IN* and ten *OUT* events. The first pass of the experiment started with an *IN* event, the second pass with an *OUT* event, and so on. The ground truth was determined by the odd and even number from the pass. Thus, odd passes corresponded with *IN* events and even passes with *OUT* events. Each pass has a duration of approximately five seconds. In order to differentiate passes in the post-processing, we had to wait seven seconds before performing the next pass. A good pass was considered when a minimum of two lobes read the labeled-object. Otherwise, the methods may not work since obtaining information from a single lobe the methods cannot be performed correctly. Table 3 reviews the different configurations tested along the performed experiments to achieve a multitag/multievent people-object direction of pass detection system. Since all combinations of configurations will required an extensive battery of tests, we plan a progressive election of configurations depending on the previous results. That fact, will reduce unnecessary tests to reach the same goal. Summarizing, all those configurations exposed in

Table 3. Review of the experiments performed based on RFID data.

RFID antennas: We compare the patch antennas array 1x3, 2x2 and air 1x1 since they perform differently.
Reading mode: Both sequential and autonomous mode offer diverse order for transmitting/receiving, changing the behavior of the system. The sequential mode establishes a numeric order being the antenna port 1, first to emit; the antenna port 2 the second; and so on. In sequential mode, a *read time* value is configured to allow each antenna the same time to inventory. The autonomous mode establishes the token's time for transmitting to each antenna in base to their reading. For instance, if the antenna port 1 is reading more tags than the antenna port 2, more priority will be given to the antenna port 1.
Antennas' position: Depending on the antennas' position (tilted and no tilted), their lobes placement also change.
Read power: The energy transmitted by the antennas will affect the response rate from the surrounding passive RFID tags.
Passive RFID tags: We test two different passive RFID tags. The Frog 3D which generates a 360 degrees of radiation pattern and a cheaper, smaller and most used tag, the Web G2iL. That last, allows a more realistic scenario.
Different products: The material and shape of the products affect on the readings, and as a consequence the performance of our approach.
Multitag: When several labeled-objects are grouped into the same space, they infer with each other by obstructing the signal.
Multievent: In a real situation, events such as products entering, leaving and static in a store occurred.

Table 3 pursuit the same goal, to achieve a direction of pass detection system suitable in real IoT spaces.

5. Experiments & Results

This section evaluates the accuracy in reading and detecting the direction of pass from passively labeled-objects with both tilted and phased array approach by uniquely using RF data.

5.1. Direction of Pass Evaluation

We evaluated all possible beams' combinations with all described patch antennas array 1x3, 2x2 and air 1x1 using the sequential reading mode.

As a result, the phased array 1x3 obtains a maximum of 95% accuracy with the beams' combination 2-4 and 3-4. With the phased array 2x2 and air array 1x1 system a 100% detection accuracy is obtained. In case of the array 2x2 with the combination of beams 1-3 and, with the air array 1x1 with the beams' combination 1-4, 2-3, 2-4, 3-4 and 1-2-3-4. For the following experiments, we are going to use the patch antenna array 2x2 and air array 1x1 due to they provide good results. Since a 100% detection can be obtained by using a phased array of RFID antennas with two beams, the next step can be the evaluation of two RFID antennas with and without tilt connected directly to the reader (without phase shifter). The no-tilted composition represents a common antenna location where it remains parallel to the surface. Figure 4 shows the evaluation of a single tag using both array 2x2 and air array 1x1 patch antenna, with and without tilting the antennas, and reading mode autonomous and sequential. The fact of tilting the antennas

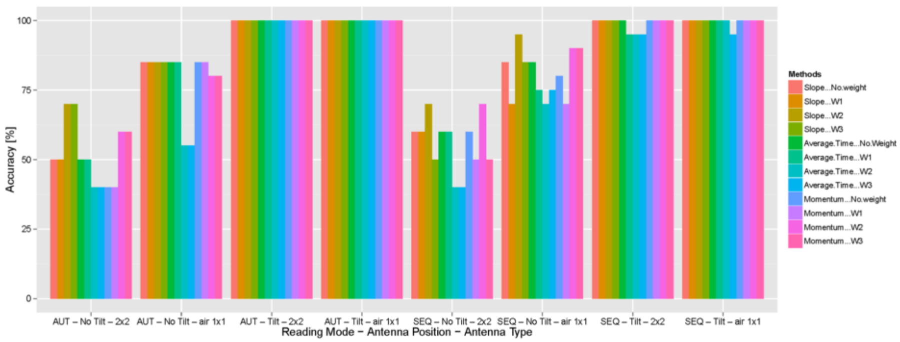

Figure 4. The tilted system returns the highest accuracy metric using both air 1x1 and 2x2 array in autonomous mode

allows a higher accuracy in reading the tag and detecting the correct direction of pass. We obtain a 100% accuracy using the patch antenna array 2x2 and air array 1x1. Otherwise, without tilting the RFID antennas the accuracy reaches a 95% in one case. However, the rest of cases the accuracy remains below 90%. Initially, the passive RFID tag Smartrac Frog 3D was used because its 360° radiation pattern. That means, the product can be read at any rotation. Nevertheless, its dimensions makes it difficult to fit in regular retail labels. Hence, we selected the passive RFID tag Smartrac Web G2iL thanks to its reduced dimensions. The experiments were carried out connecting two tilted RFID antennas array 2x2 directly to the reader and autonomous reading mode. Furthermore, we performed the tests with different *read power* values to analyze their performance. Although the Smartrac Frog 3D provides a 100% accuracy with both *read power* values 27 and 30 *dBm*, the Smartrac Web reaches also the 100% using the maximum power. Thus, the Smartrac Web tag will be used along the rest of experiments because its dimensions and price. The empirical tests were performed using the same labeled-object, a wool robe. Since retail stores provide different products, we performed tests using diverse products with different material, shape and dimensions. Thus, we tested six different products: a wool robe, a plastic doll, a plastic rainboot, a ceramic mug, a plastic bowl and a polyester dress. From all six products tested, four of them obtained an accuracy of 100% with the methods **Slope W2** and **Slope W3**. Despite we achieve a 100% accuracy by passing with a single labeled-object at time, a common behavior includes crossing spaces with few products. Hence, we carried out experiments by passing with groups of 2, 4 and 6 products in the same shopping bag. In two out of the three cases where a group of two products crossed the people-object direction of pass detection system, a 100% accuracy was achieved with all the products. By grouping the products in four units, a minimum of 80% accuracy is obtained. Finally, with six products passing at the same time, only one tag could not be read and detected due to the rotation of the tag. Nevertheless, a 100% accuracy was obtained in most of the cases with the methods **Slope** and **Average Time** with and without the weight **W1**. Finally, our empirical experiments included a real retail situation where multiple persons carrying labeled-objects are crossing the people-object direction of pass detection system with opposite directions at the same time and some products remain static near the gate within the antennas' beam. Figure 5 compares the accuracy on reading and detecting a given product's event. We defined three type events: *IN* when a product enters the store, *OUT* when a product exits the store and *static* when the product remains passive in a given location. The experiment consisted on two users passing across the loss prevention system with a bag with two products each. One of the users initiated the round of tests with an *IN* event and the second user in an *OUT* event. Meanwhile, the other two leftover products remain static. Our hypothesis is that a 100% accuracy may be achieved by reading the tag and the correct direction of pass for each dynamic product even with both *IN* and *OUT* event occurred simultaneously. Opposite, the static product does not return true passes indicating a false alarm was not detected. The intuition behind a false alarm from static products is because the users' body could reflect the signal to the incorrect antenna. For instance, if a static product is read continuously from the antenna port 1 and suddenly the antenna port 2 receives signal from that product, methods could consider it as a pass provoking a false alarm event. Indeed, our hypothesis was correct. All four dynamic products were read and

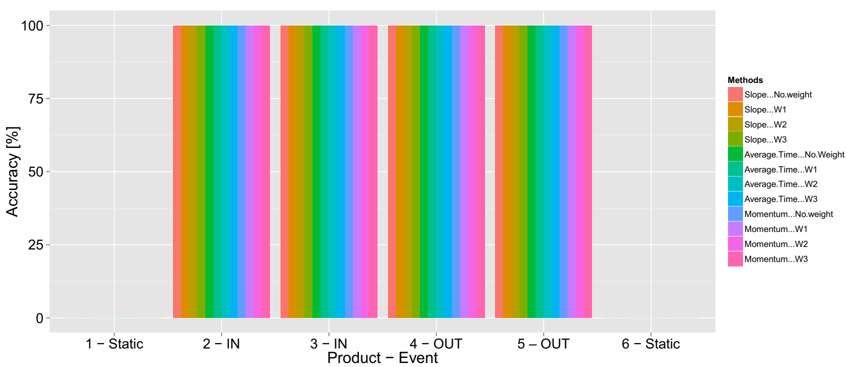

Figure 5. Both dynamic and static products are classified correctly

detected correctly by the people-object direction of pass detection system achieving a 100% accuracy without provoking false alarms from the static products. In average, the **Slope** method provides the highest accuracy metrics. Summarizing, our approaches of people-object direction of pass detection demonstrated a high reliability by uniquely using RFID data from only two off-the-shelf antennas.

6. Conclusion

We presented two approaches of people-object direction of pass detection using uniquely RFID data and off-the-shelf antennas. We demonstrated how both tilted and phased array approach achieved a 100% accuracy on reading and detecting the direction of pass of passively labeled-objects. Our experiments confirmed the reliability of our methods, making them suitable for people-object direction of pass detection using a single product, including the detection of multiple tags and events. That fact, increases the value of our proposal being a suitable solution for real retail store environments. As a future work, we intend to explore the following challenges:

- Test in autonomous mode the phased array approach.
- Increase the number of products for each event: IN, OUT and static.
- Study the performance of our approaches with other products material, size, shape, etc. and antennas[16].
- Implement our approaches in a real retail store environment.

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