Non-restraint Human Authentication Using MIMO Array

Shoichi Iizuka[1], Takeshi Nakayama[1], Dai Sasakawa[2], and Naoki Honma[2]

[1] Apliances Company, Panasonic Corporation, Kadoma, Japan
`iizuka.shoichi@jp.panasonic.com`
[2] Graduate School of Engineering, Iwate University, Morioka, Japan

Abstract. We have studied the human authentication system using the time-variant channel measured with multi-input multi-output (MIMO) array. However, the system needs to authenticate the subject under restraint because it uses the positional relation between the subject and array, and this is not suitable for a daily living space. We propose the human authentication system without strict position restraint by using the bistatic MIMO radar. In this paper, we evaluate the robustness of the human authentication system for the subject's position, and the precision of the human radar to evaluate the practicability of proposed system. The experimental results showed that our human authentication technique successfully works without restraining the subject if the subject presents exactly at the pre-determined location, and the recognition rate of this case was 95%.

Keywords: human identification · human positioning · MIMO.

1 Introduction

Developments in the internet of things (IoT) are driving a growing demand for non-contact, easy-to-use and unconscious human authentication. Human authentication is a technology for identifying an individual by comparing their distinctive and quantifiable characteristics with a database. Authentications are categorized into those based on physiological characteristics and those based on behavioral characteristics. The former one exploits the shape of the human body: common examples are fingerprints, hand veins and face shapes [1]. The latter one uses to the unique patterns of a person's movements: these include signature [1], gait [2] and tracking [3]. Some studies have proposed authentications using video cameras [4] and ultrasonic sensors [5] for use in living spaces. However, any system that uses video cameras [4] risks violating privacy and applicable situation is restricted. Ultrasonic-based system [5] uses only the height of the subject, but the recognition rate declines when the number of subjects increased. To solve the above problems, non-contact, easy-to-use and unconscious human authentication using a microwave system has been proposed [6]. However, because the most of the conventional microwave sensors use excessively wide bandwidth, these systems are difficult to use in parallel with other wireless communication channels.

The authors have studied a human authentication system using a microwave [7], where this system only uses a narrow bandwidth, i.e. CW signal. This method uses multiple-input multiple-output (MIMO) array to measure reflection and scattering characteristics and distinctive vital sign. Spatial and temporal reflection characteristics are used for identification. However, the system requires the subject to be under restraint, making it unsuitable for use in daily living situations.

We propose a human authentication system that uses human radar [8], to eliminate strict positional restraint. This human radar estimates the subject's position using the time-variant MIMO channel.

We evaluate here the robustness of this human authentication system [7] for the subject's position, and investigate the degree of precision of the human radar [8] to evaluate the practicability of the proposed system.

2 Review of Authentication Using MIMO Array

In this section, we briefly describe human authentication using the MIMO array for the better understanding of the following discussion. This study assumes the use of a MIMO array consisting of an M_r element array receiver and an M_t element array transmitter around the subject. Fig. 2 shows the positional relationship between the subject, array receiver and array transmitter. We measure the $M_r \times M_t$ time-variant MIMO channel

$$\boldsymbol{H}(t) = \begin{pmatrix} h_{11}(t) & \dots & h_{1M_t}(t) \\ \vdots & \ddots & \vdots \\ h_{M_r1}(t) & \dots & h_{M_rM_t}(t) \end{pmatrix}, \tag{1}$$

for every registrant. h_{ij} is complex channel response from the j-th transmitter element to the i-th receiver element, and t represents the observation time. We store this channel as a reference channel $\boldsymbol{H}_D(t,q)$ in the database. q represents the q-th registrant of the database. Next, we measure a test channel $\boldsymbol{H}_T(t)$ for authentication under the same settings as the reference channels. The direct current (DC) component of the observed channel degrades the recognition performance. The DC component therefore needs to be excluded, so we define the DC-suppressed test channel and the reference channel respectively as $\boldsymbol{H}_{De}(t,q)$ and $\boldsymbol{H}_{Te}(t,q)$.

The evaluation function $\rho(p,q)$ which represents the sliding correlation between the test channel and the reference channel is defined as,

$$\rho(p,q) = \frac{\left|\sum_{t_k=0}^{N_T-1}\sum_{j=1}^{M_t}\sum_{i=1}^{M_r}\boldsymbol{H}_{Te}(t_k,q)\boldsymbol{H}_{De}^{H}(p,q)\right|}{\sqrt{\sum_{t_k=0}^{N_T-1}\sum_{j=1}^{M_t}\sum_{i=1}^{M_r}\left|\boldsymbol{H}_{Te}(t_k,q)\right|^2\sum_{k=0}^{N_T-1}\sum_{j=1}^{M_t}\sum_{i=1}^{M_r}\left|\boldsymbol{H}_{De}(p,q)\right|^2}}, \tag{2}$$

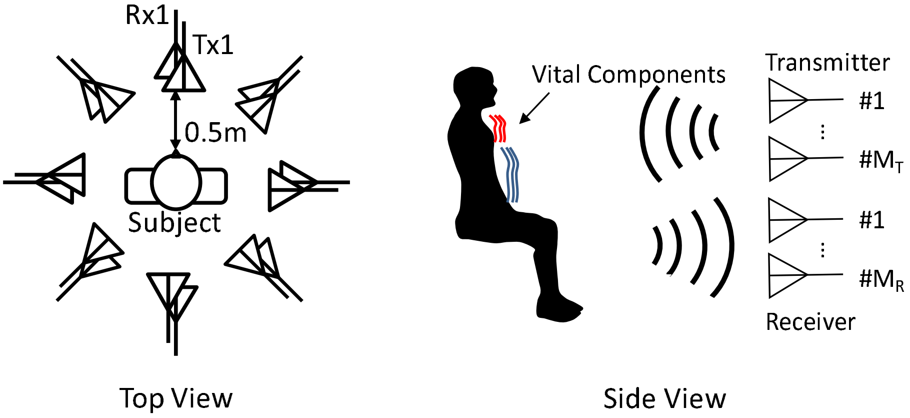

Fig. 1. The positional relation between the subject and arrays in [7]

$$p = 1, 2, \ldots, N_D - N_T + 1,$$

where N_T and N_D represent the number of snapshots of the test channel and reference channel, and p is the number of the iteration applied in calculating the sliding correlation. $(\cdot)^H$ represents complex conjugate transposition. After calculating the evaluation function (2) for every registrant, the maximum value of $\rho_{max}(p, q)$ and the argument of the maximum value s is calculated. The authentication system [7] then recognize the subject as the s-th registrant.

In [7], the recognition rate is 87.8% using an 8 × 8 MIMO array. However, the position of the subject is restricted to the center of the array which is 1m radius, and the authentication of the subject in other locations is not evaluated.

3 Non-restraint Human Authentication Using a MIMO Array

Human authentication [7] requires a subject to be under restraint, making it unsuitable for use in actual living spaces. In this section, we discuss a human authentication system without this strict positional requirement by using the human radar [8] technique that we also proposed.

This study groups the elements of the array into M_{array} antenna arrays and uses M_t/M_{array} transmit antenna arrays and M_t/M_{array} receive array antennas. The element separation in the array antennas is half a wavelength. For example, in the case of $M_t = M_r = 16$ and $M_{array} = 4$, we assume 16 × 16 MIMO array consisting of 4 transmit antennas that have 4 elements and 4 receive array antenna that also have 4 elements. This antenna setting enables human radar [8] to be used to estimate the position of subject X.

During authentication [7], the position of the subject is restraint. If the position of the subject changes, the measured MIMO channel also changes due to the change in positional relationship between the subject and the array. Therefore, the test channel must be measured with the subject in the same position as the reference channel to be able to use authentication [7] in a non-restraint setting. If the position of the subject can be estimated precisely by using human radar [8], it will be possible to authenticate a person by using the reference channel that measured the subject while in the same position as when detected using the test channel.

In the registration step, the authentication system measures the reference channel and estimates the subject's position. The pair of the reference channel and the subject's position is stored in a database. In the authentication step, the system estimates the subject's position using the test channel, and searches the reference channel with the same subject's position in the database.

In an authentication system using human radar [8] without the strict positional restraint, the area inside which human authentication [7] allows the subject to move needs to be larger than the relative error of human radar [8]. 'Relative error' means the distance between the average estimated position and each estimated position, when the human radar system repeatedly estimates the position of the subject. If the relative error is greater than the area inside which the system [7] can achieve correct authentication, the system [7] uses a reference channel that is outside of this area causing the results of authentication to lose accuracy. We evaluated the area within which the system [7] can achieve correct authentication, and the relative error of the human radar system [8]. If the position estimated with the test channel and position estimated with the reference channel is the same, human authentication [7] can authenticate correctly even if the estimated position is different from the true position due to the multi-path effect. The index of the degree of precision of human radar in this evaluation is therefore relative error.

4 Experiment

In this section, to evaluate the practicability of our proposed system, we describe the experiments carried out to evaluate the positional robustness of the system [7], and to test the precision of human radar.

4.1 Robustness of the Human Authentication System

Fig. 2 and Fig. reffig:setting shows the overview of the measurements made and the subject's position. The 16 × 16 MIMO configuration, which consists of 4 receive and 4 transmit patch antenna arrays, where each of them has 4 antenna elements, was used. The height of the receive array was 0.8 m, and the transmitter array was set above the receiver element at a distance of 1 wavelength.

The element separation of array antennas is 0.5 wavelength. Each array antenna was placed in the corner of a 4 m × 4 m area. A continuous wave signal at 2.47125 GHz was used, and transmitted power at the antennas was +0.15

dBm. In Fig. 2, a Single-Pole 64 Throw (SP64T) switch was used at the transmitting side. The CW signal was split to the receiver side as well since accurate synchronization between transmitting and receiving sides is required. At the receiver side, the received signals were input to a down-converter unit by way of a low-noise amplifier (LNA). The down-converted baseband signals (I_1, $Q_1 \sim I_{16}$, Q_{16}) were digitized by a data-acquisition unit (DAQ). The rate for taking a snapshot of the MIMO channel was set to 100 Hz.

The reference channel measurement time was 10 seconds and the test channel measurement time was 3 seconds. The number of registrants was 4 and the reference channel of each registrant was measured at position A in Fig. 3. The test channel took 10 measurements for each position. Table 1 shows the individual and total recognition rate of each position. This illustrates the total recognition rate where the distance from position A of 5cm is degraded and lower than 50% in some positions. The recognition rate of position M and O is different in spite of the symmetrical antenna position. This is because the human body is asymmetric and the angle of reflection is different at each position. The asymmetry of human body seems to be one of the causes that the recognition rate of each subject is different in Table 1.

The relative error of the human radar system must therefore be smaller than 5cm.

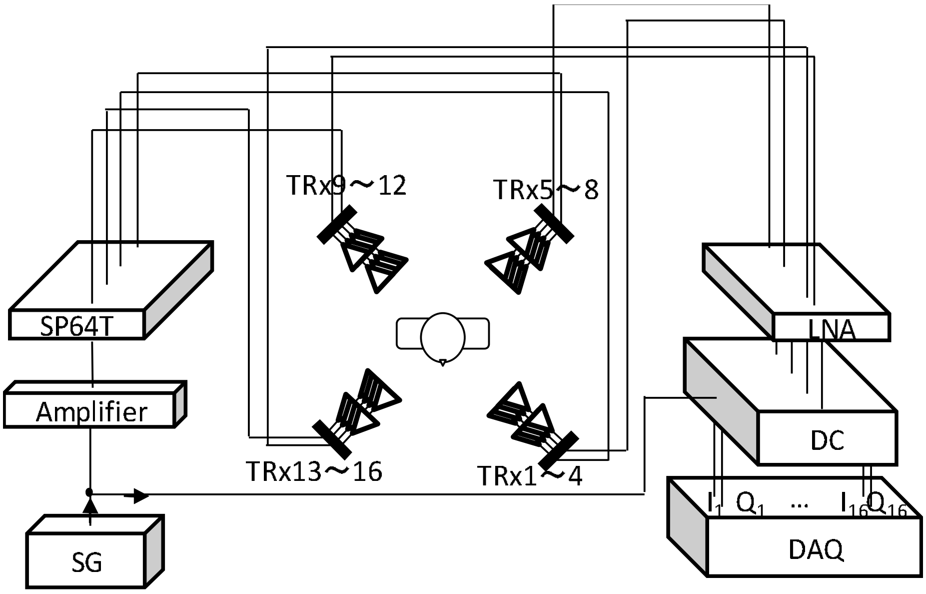

Fig. 2. Measurement overview.

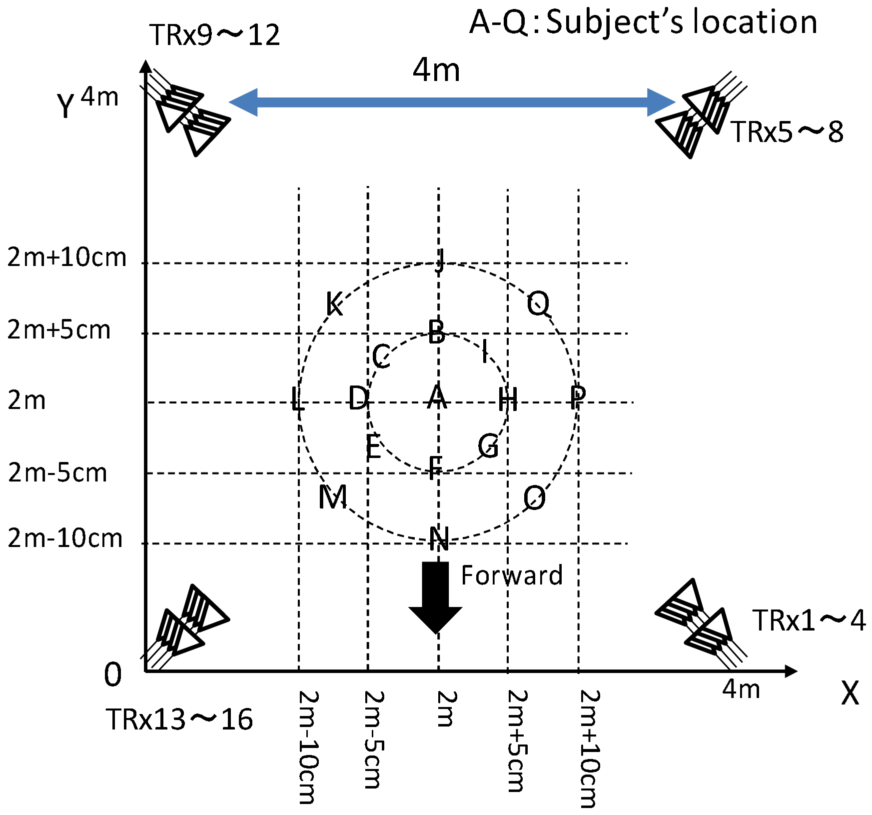

Fig. 3. Subject's position.

Table 1. Recognition rate of each position.

Position	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Distance from center [cm]	0	5	5	5	5	5	5	5	5	10	10	10	10	10	10	10	10
Recognition rate of the subject a[%]	80	100	100	100	100	90	100	100	100	80	70	100	70	90	80	90	100
Recognition rate of the subject b[%]	100	0	40	0	10	0	0	90	60	100	0	100	10	80	80	80	10
Recognition rate of the subject c[%]	100	100	90	30	100	10	0	0	80	100	100	0	0	0	100	0	0
Recognition rate of the subject d[%]	100	70	30	0	10	0	20	10	20	20	0	40	30	0	10	0	50
Total recognition rate[%]	95	67.5	65	32.5	55	25	30	50	65	75	42.5	60	27.5	42.5	67.5	42.5	40

4.2 Relative Error of Position Estimation

We evaluated the precision of the human radar system [8]. The precision target was that the relative error should be smaller than 5cm. The channel employed is the same as that employed in subsection 4.1. The number of people was 4, occupying 17 positions, occupying each position 10 times. Table 2 shows the relative error of each position, and Fig. 4 shows the cumulative distribution function (CDF) calculated from all the measurement results. The 50% point of CDF was 5cm, which falls short of the target.

Table 2. Relative error of each position.

Position	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Distance from center [cm]	0	5	5	5	5	5	5	5	5	10	10	10	10	10	10	10	10
Error [cm]	4.4	5.0	8.2	3.1	3.3	3.3	6.1	22.1	8.4	15.8	33.3	2.6	6.5	10.0	11.2	7.8	4.8

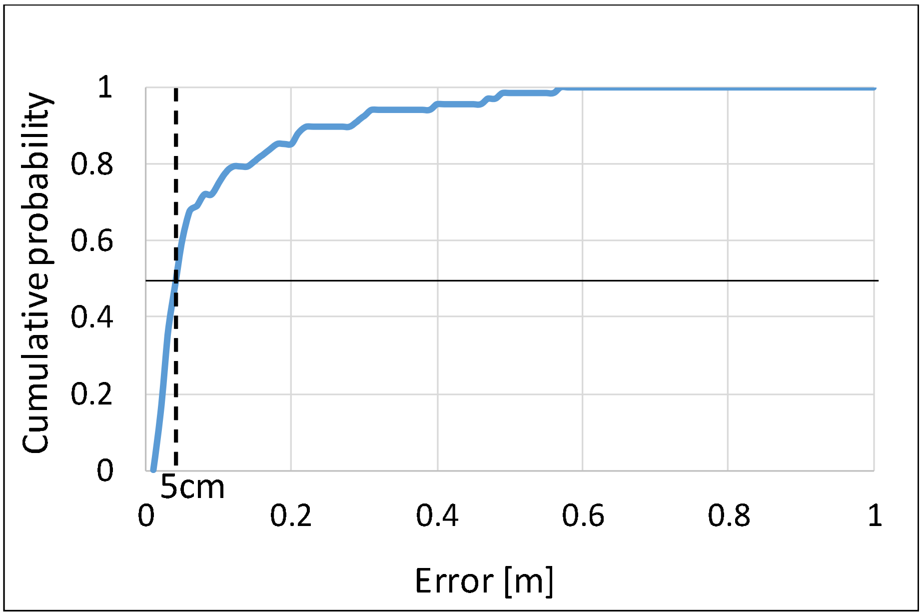

Fig. 4. CDF of relative error of the human radar [8]

5 Conclusion

This paper presented the performance of the non-restraint human authentication system, and its robustness against the positional error was investigated. The experimental results showed that our human authentication technique successfully works without restraining the subject if the subject presents exactly at the pre-determined location, and the recognition rate of this case was 95%.

References

1. A. K. Jain, A. Ross, and S. Prabhakar, “An introduction to biometric recognition,” IEEE Trans. Circuits Syst. Video Technology Special Issue Image- and Video-Based Biomet., vol. 14, no. 1, pp. 4-20, Jan. 2004.
2. M. S. Nixon, T. N. Tan, and R. Chellappa, “Human identification based on gait,” New York, NY, US:Springer, Vol. 4, 2010.
3. Q. Hao, F. Hu, and Y. Xiao, “Multiple human tracking and identification with wireless distributed pyroelectric sensor systems,” IEEE Systems Journal, Vo. 3, No. 4, Dec. 2009.
4. J. Krumm, S. Harris, B. Meyers, B. Brumitt, M. Hale, and S. Shafer, “Multi-camera multi-person tracking for easy living,” Proc. IEEE Int’l Workshop Visual Surveillance, pp. 3-10, 2000.
5. V. Srinivasan, J. Stankovic, and K. Whitehouse, “Using height sensors for biometric identification in multi-resident homes,” Pervasive Computing, pp. 337-354, 2010.
6. G. Mokhtari, Q. Zhang, C. Hargrave, and J. C. Ralston, “Non-wearable UWB sensor for human identification in smart home,” IEEE Sensors Journal, Vol.17, No.11, pp. 3332-3340, Jun. 2017.
7. D. Sasakawa et al. “Human identification using MIMO array,” in IEEE Sensors Journal, vol. 18, no. 8, pp. 3183-3189, 15 April15, 2018.
8. D. Sasakawa et al. “Evaluation of fast human localization and tracking using MIMO radar in multi-path environment,” 2016 IEEE 27th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC), Valencia, 2016, pp. 1-6.