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Method of compensation between the powers of the received signals for the localization of a Wi-Fi node inLOS/NLOSEnvironments

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ABSTRACT :*This article explores a technique based on the compensation between the powers of the received signals in order to estimate the geographical position of a Wi-Fi node in an external environment.Two cases were considered: the propagation in line-of-sight (LOS) and nonline-of-sight (NLOS). The technique admits five phones with Wi-Fi interfaces, of which four are represented as base stations (BSs) and are equipped with software called Wi-Fi Analyzer. One of the phones is configured in Hot-Spot mode and is regarded as the target. Although these phones are located in 2-D, the antennas used are omnidirectional. The technique succeeds in delimiting the position of the target inside a restricted geographical area.This technique was applied to the multilateration to confirm its precision. The results of simulations show that this technique gives better results than the other conventional methods of localization such as the hyperbolic technique and the traditional (classic) multilateration, using the received signal strength (RSS) to identify the position of the target inside of an area of reduced uncertainty.*

KEYWORDS:*BSs, LOS, NLOS, Multilateration, Wi-Fi.*

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I. INTRODUCTION

In global navigation satellite systems (GNSS), the receiver, which might be near or on the ground, receives measurements from one or more satellites, and then estimates its position, provided enough line of sight (LOS) satellites are available. One of the most popular systems is the global positioning system (GPS), operated by the US government. GPS was initially used for military applications and has now been used for over two decades by civilians. The GPS system has several disadvantages: the battery demand of GPS devices is high, making it unsuitable for several low-power devices, and the performance of GPS systems is degraded in indoor locations or dense urban areas where the GPS signal is weak or unavailable. Due to such limitations, it becomes necessary inseveral applications to rely on a ground-based network to find the position of radio-frequency (RF) devices more accurately. These are denoted as network-based localization or wireless geolocation systems [1].

Wireless communication has enjoyed explosive growth over the past decade. With the increasing need for location-based services and applications, mobile positioning will be one of the most exciting features of the next generation wireless systems. With this technique, a mobile device can either gather the information about its position or it can be localized from elsewhere [2]. Location based services (LBSs) are a significant sought-after technology and becoming a vital part of life. Within the field of wireless communication networks, LBSs broadly exist from the short-range communication to the long-range telecommunication networks. LBSs refer to the applications that depend on a user's location to provide services in various categories including navigation, tracking, healthcare, and billing. However, demand for its performance is increasing with new ideas and advances in the mobile phone market. The core of LBSs is the positioning technology used to find the motion activity of the mobile client. After detection, this information is passed to the mobile client on the move at the right time and the right location. So, positioning technologies have a major influence on the performance, reliability, and privacy of LBS systems and applications [3].

One of the most important applications of mobile positioning is personal safety, such as in the emergency localization (E-911 service). Automatic location identification (ALI) will be a system requirement for wireless operators in the near future. Mobile location systems can also be used by advanced user hand-off schemes, and potentially many user services for which a GPS is impractical. Other applications are automatic billing and fraud detection for cellular providers, accident reporting, law enforcement, cargo tracking, and intelligent transportation systems [2, 4].

In the literature, many terms are used for location finding, such asposition location, geolocation, location sensing, or localization [2, 5]. There are various existing location estimation approaches [6-10], such as received signal strength (RSS), time of arrival (TOA), time difference of arrival (TDOA), frequency difference of arrival (FDOA), and angle of arrival (AOA). These comprise the most popular types of measurements.

In this correspondence, we focus on mobile positioning using the RSS information. The advantage of the RSS technique is in fairly low cost, since power measurements are already made by hand-sets (part of the handoff algorithm). If a propagation model is known, power measurement can be mapped to a distance measurement. If the distance from the mobile terminal to three or more base stations is known, the mobile terminal position can be calculated. Unfortunately, RSS estimation error is higher than the other localization methods. Also, the mobile terminal is usually in motion, resulting in rapid fading due to multipath propagation, which causes significant errors.

The goal of this correspondence is to propose and evaluate the compensation technique between the powers of the signals received in multilateration for the estimate of the geographical position of a wireless fidelity (Wi-Fi)node in LOS/NLOS environment. This technique was proposed for the first time by Janaswamy in Ref. [11] in the localization of a radio frequency identification (RFID) node in the LOS environment. To achieve this goal, we will evaluate the performance of the method and compare it with the conventional methods using RSS.The body of the paper is organized as follows: In section II we present background on the interest of Wi-Fi technology in radiolocation. We describe the RSS measurement model in section III. Then the Wi-Fi propagation model is explained in section IV. The simulation results are presented in section V and the conclusion is drawn in section VI.

II. INTEREST OF THE WI-FI TECHNOLOGY IN RADIOLOCATION

The Wi-Fi technology is based on the standard 802.11, which specifies the medium access control (MAC)layer and the physical layer. This standard of the local area network called wireless local area network(WLAN),functioning in the medical scientific instrumentation (ISM)band of 2.4 GHz, became very popular with public hotspots and companies over these last several years. With a binary rate of 11.54 Mbps or 108 Mbps and a range of 50 to 100 m, the standard IEEE 802.11 currently dominates the local area network without wire. Consequently, the use of its existing infrastructure for the goal of interior or external localization constitutes an opportunity**.** Wi-Fi is integrated today into many types of equipment and in particular into mobile equipment such as smart phones, desktop computers and portable computers. This technology allows a coupling of localization and simultaneous communications (bidirectional communications, multi-media flow,…etc.) [12]. Just like the geolocalization by global system of mobile communication, a Wi-Fi terminal can be localized with the help of the Cell ID (Identification by cell) method. In this case, it is the identifier of the Wi-Fi terminals which is detected. Applications were developed to facilitate the localization of the users possessingthe Wi-Fi terminals. The precision of the WLAN positioning systems using data on the power of the received signalis approximatively of 3 to 30 m, with a refresh frequency of about a few seconds.

Thus, the low cost of the implementation and proliferation of Wi-Fi terminals has aroused the interest of many researchers in utilizing this technology [13-16]. Several methods, for which the principal metric is the receiver signal strength indicator (RSSI), are used in the localization by Wi-Fi: triangulation**,** trilateration, fingerprinting, the identification of the cells, etc. By using a similar approach to the one used in GPS, it is possible to expand Wi-Fi technology beyond its main use to accomplish radiolocation.

III. DESCRIPTION OF THE RSS MEASUREMENT MODEL

The RSS is one of the most widespread types of measurements, as used in Ref. [1]. The RSS of a device travelling between two transceivers is a signal parameter that contains information related to the distance between them. This RSS can be used in conjugation with a suitable attenuation model and shadowing effect to estimate distance. The shadowing effect is commonly modelled as a zero mean Gaussian random variable with a variance of σ^2in the logarithmic scale. Therefore, the received power $P(d)$ in dB can be expressed as [1]:

$$P(d) = P_0 - 10\alpha log_{10}\left(\frac{d}{d_0}\right) + \gamma, \quad (1)$$

where $\alpha$is the path loss exponent that takes on values between 1 and 5, $P_0$is the received power in dBm at a short reference distance d_0, and a normal distribution,$\gamma \approx N(0, \sigma^2)$, which describes the random shadowing effects. Note that this model can be used in both line-of-sight (LOS) and non-line-of-sight (NLOS) scenarios with an appropriate choice of channel parameters. However, it is very difficult to find a suitable choice of parameters in multipath and NLOS environments and therefore RSS measurements cannot be converted to a distance range accurately.

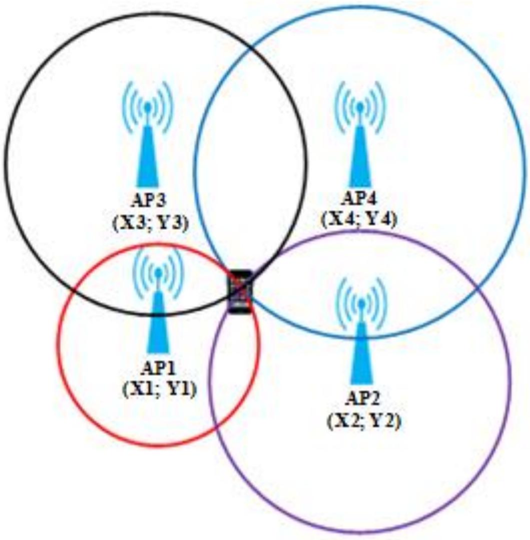

Figure 1 Localization in a 2-D plane

An RSS estimate at a receiver (base station/sensor) determines the position of a transmitter (a mobile station/target) on a circle in the error-free case. Figure 1 shows the intersection of range circles formed by four base stations and a mobile terminal, which is referred to as multilateration.

IV. WI-FI PROPAGATION MODEL

The radio signal propagation of Wi-Fi access reference points (APs) can be used to estimate the mobile terminal position in areas where the signal is distributed. This is accomplished by measuring the received signal strength intensity (RSSI) value within the path loss model, because the signal characteristically decreases with the distance between the transmitter and the receiver. This signal attenuation can be modelled by using a function of the logarithm-distance path loss model as follows:

$$P_{rx}(d) = P_{do} - 10\alpha \log_{10}\left(\frac{d}{d_o}\right) - wallLoss, \quad (2)$$

where $P_{rx}$is the receiver power in decibels (dBm), P_{do} is the received power at a reference distance or the initial RSSI value at the 1st meter distance, $\alpha$is the path loss exponent, which can vary from 2 to 6 depending on the propagation environment [17], $d_0$is the breakpoint distance and $d$is the Euclidean distance between transmitter and receiverin unit of meters. Finally,*wallLoss* is the sum of the losses introduced by each wall. This factor depends on the building layout, construction material, moving objects and numerous reflecting surfaces.

V. RESULTS AND INTERPRETATION

Wi-Fi terminals continuously emit signals which can be captured and analysed in order to determine the movements of their carriers. We currently focus on the emergence of systems of Wi-Fi radiolocation which provide broad scale displacements of mobile terminals. These systems are used to provide statistics on the presence of individuals or objects in zones of interest. By using access points as points of reference and by evaluating the distances with the help of the power of the received signals, we can determine the position of a Wi-Fi terminal.

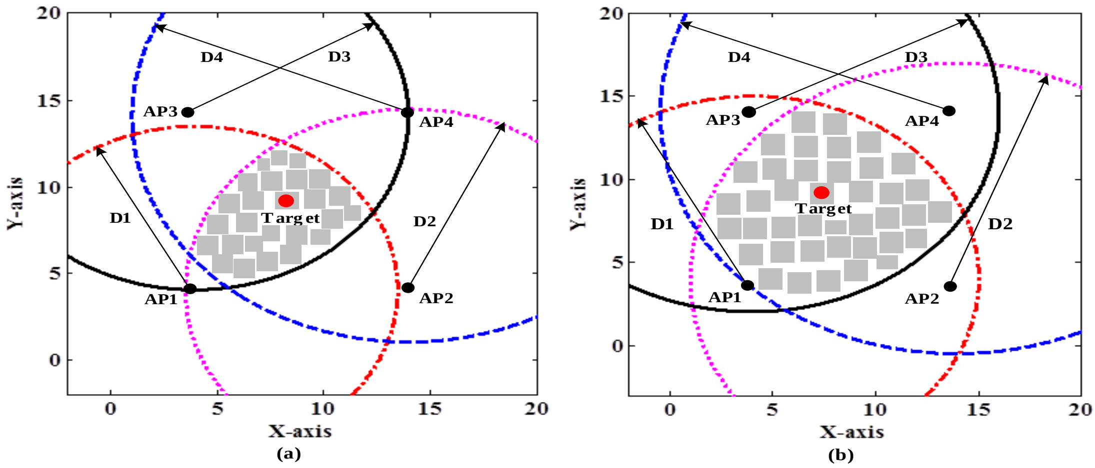

Figure 2 Illustration of the technique of traditionalmultilaterationin (a) LOS and (b) NLOS.

Figure 2(a) presents the results of the simulation in a LOS environment for a traditional multilateration. Based on the equations of the circles, the traditional technique of multilateration uses the distance separating the AP and the target to generate a radius of coverage. The target is located either in the zone of coverage, or on its border. Each AP becomes the center of a radius of coverage and the intersection of these four circles delimits the zone in which the target is located. The simulation was carried out for the configuration presented in Figure 1. In this configuration, we have deployed four fixed nodes, with (4, 4), (14, 4), (4, 14) and (14, 14) representing their coordinates (x, y) in meters of the APs. These have, respectively, received the following powers from the target: -53 dBm, -56 dBm, -54 dBm, -58 dBm, which represent the average values of the power of reception. The intersection of their respective circles of coverage delimits the zone of detection of the target. The parameters used are: a frequency of 2412 MHz, a distance from reference$d_0 = 1\,m$, a path loss exponent $\alpha = 2.69$, a standard deviation of the shadowing effect of $\sigma = 3.43$, an effective isotropic radiated power (EIPR) of 17 dBmand a rate of confidence $C = 0.93$. The analysis of the numerical results shows that the traditional technique of multilateration reduced the initial surface to 38.17 m^2, i.e., a reduction of 61.83 % compared to the initial surface, which was 100 m^2.

Figure 2(b) presents numerical results in NLOS for a traditional multilateration. Here, the only difference is that the conditions of propagation make the powers received by AP1, AP2, AP3 and AP4 -58 dBm, -62 dBm, -59 dBmand -63 dBm, respectively. The parameters used are the same, except the path loss exponent $\alpha = 3.12$, the shadowing variance $\sigma = 5.62$,and the rate of confidence $C = 0.92$. In comparison with the data and conditions of propagation, we note that in NLOS, the traditional technique of multilateration gives a greater zone of uncertainty of 120.10 m^2, i.e., 20% more than the initial zone, which is 100 m^2.

The technique of hyperbolic estimation uses the hyperbolic limits generated by the pairs of APs, respectively, (AP1, AP4) and (AP2, AP3). These two pairs will produce intervals limited by a min and max value, forming the zone in which the target is located. The hyperbolas denoted $[H14^-, H41^-]$ and $[H23^-, H32^-]$ are generated by the pairs of access points (AP1, AP4) and (AP2, AP3), respectively. These terminals are calculated with the help of the difference of the distances generated by each member of the pair, either by taking into account the minimum capacity, or of the maximum power which a phone can emit. We note that the determination of these terminals is a function of the possible combinations that we can make in the pair. However, the only combinations that should be retained are those which produce a small interval (in terms of value). These terminals translate into hyperbolas generated by each member of the pair. Taking the difference between the hyperbolas, we find useful variations generated by each pair to delimit the zone in which the target is located. The hyperbolas traced and represented in Fig. 3(a) are made under the same conditions as the traditional multilateration.This reveals that starting from 100 m^2, we obtain an area with 19.13 m^2, i.e., a reduction of 80.87% compared to the initial area. The hyperbolic technique in the NLOS scenario gives a reduction of the initial area down to 11.16%, with a rate of confidence of 92% ($z = 1.66$), as shown in Figure 3(b). This technique gives an error of ±1.73m relative to the real position of the target. It is significant to note that contrary to the propagation in LOS, the estimation of the area requires the determination of which terminals are the APs.

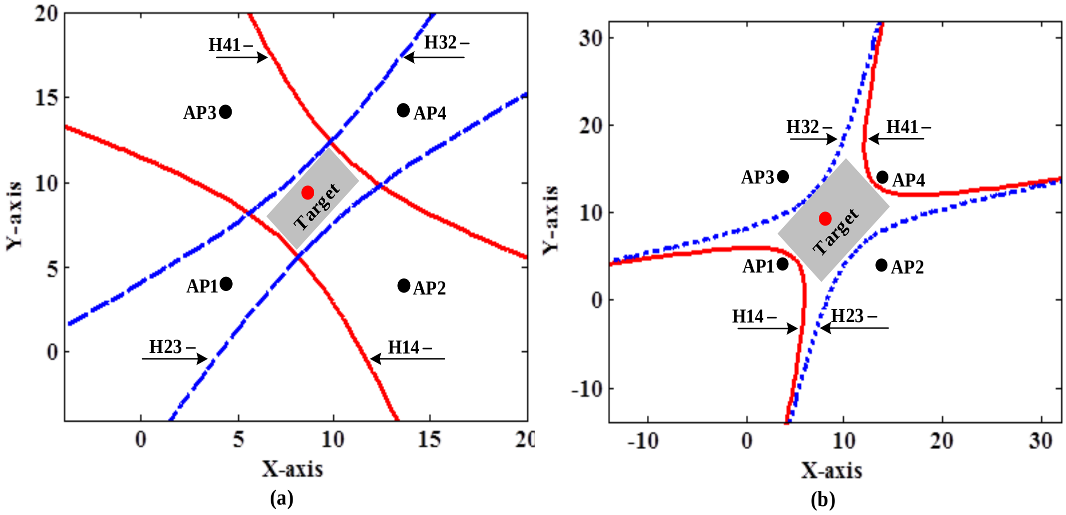

Figure 3 Illustration of the hyperbolic technique in (a) LOS and (b) NLOS.

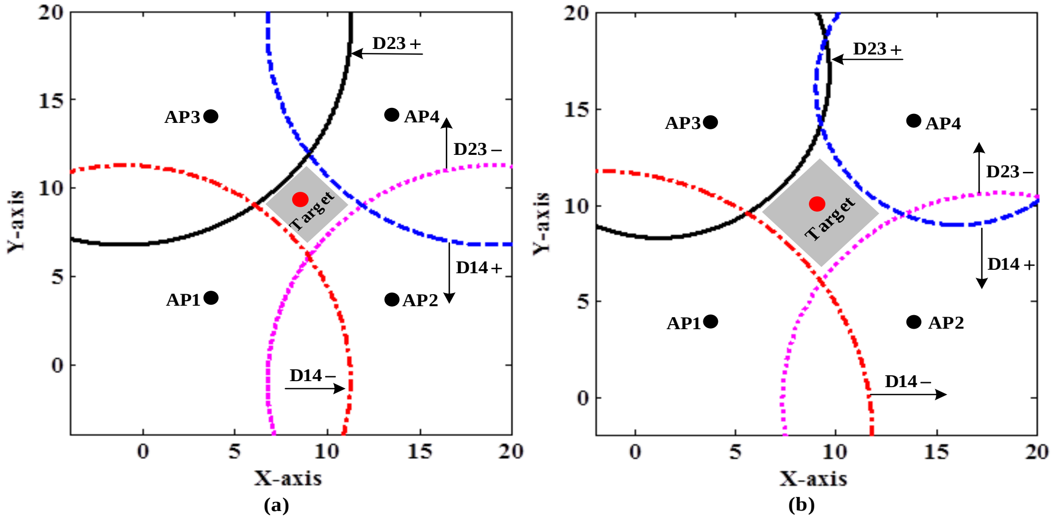

Figure 4 Illustration of the multilaterationtechnique by using the algorithm of compensation of the power of signals received in (a) LOS and (b) NLOS environment**.**

Figure 4(a) is obtained on the basis of the multilateration technique by using the compensation algorithm of the received power, called modified multilateration. Starting with a surface of 100 m^2, after application of the algorithm we manage to reduce the initial zone to a surface of 10.23 m^2, i.e., a reduction of 89.77% in the surface area. It is necessary to note that the real position of the target is at (10, 10) and the center of the reduced surface is at (9.5, 10), giving an error of 0.48 m between the real position and that given by the algorithm. We also note that during the application of this technique, the location of the access points must be such that the receiver which receives the smallest power has the smallest coordinates. If this is not respected, the calculated zone of intersection may not contain the target. The results obtained are valid for any type of targeted space (rectangular or square). The analysis of the numerical results shows that the application of the compensation algorithm of the strengths of the signals received to the multilateration procedure gives a rate of confidence of 92% (z = 1.66) in locating the target. This process is done by reducing as well as possible the initial surface compared to both the traditional multilateration process and the hyperbolic technique, as shown in Table 1 below.

Traditional Multilateration	HyperbolicTechnique	ModifiedMultilateration
38.47 m^2	18.13 m^2	11.36 m^2

Table 1 Comparison of the reduced surface of each technique in LOS.

Moreover, it is noted that the multilateration process gives an average error of 0.47 m according to the rate of confidence; the maximum value of this error is 0.53 m with a rate of confidence of 92% $(z = 1.66)$, 96% $(z = 1.99)$ and 99% $(z = 2.44)$. In the NLOS scenario, the ratio used in the compensation technique necessitates more attention. For this technique, we are able to give a good ratio to better reduce the surface area of the target location. It is also necessary to choose the pair of receivers in an ideal way. This consists in forming pairs of receivers that are opposite to one another in a diagonal way. Then, we find the permutation in the pair which gives a better result. In our case, as in LOS/NLOS the formed pairs are (AP1, AP3) and (AP2, AP4); the ratios selected are also $\left(\frac{d_1}{d_4}\right)and\left(\frac{d_2}{d_3}\right)$. These ratios made it possible to obtain the results in Fig. 4(b). In view of this figure, we find that this technique allows a reduction of the initial surface by up to 75.02%, with a rate of confidence of 92%.

Traditional Multilateration	HyperbolicTechnique	ModifiedMultilateration
$120.10 m^2$	$88.8311\ m^2$	$24.9838\ m^2$

Table 2 Comparison of the reduced surface of each technique in NLOS.

Thus, we can conclude that in LOS as in NLOS, the compensation algorithm provides an improvement in the technique of localization by multilateration. Table 2 shows that the modified multilateration gives the best results in terms of reduction of the initial surface of the target location compared to traditional multilateration and the hyperbolic technique.On the other hand, concerning the level error in location, we see a variation of this error as a function of the rate of confidence, as illustrated in Fig. 5.

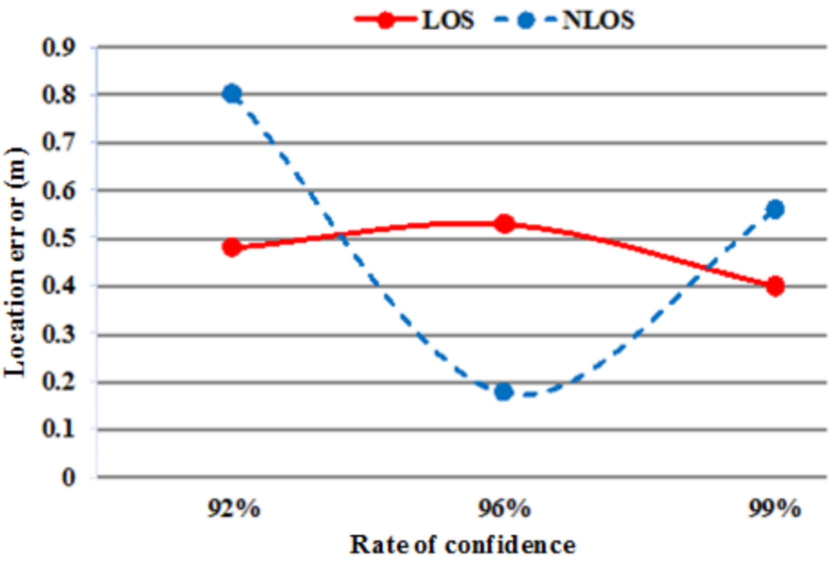

Figure 5 Evolution of the error in NLOS and LOS of the modified multilateration according to the rate of confidence.

For the case of our experimental tests, we work outdoors, to verify the applicability of the new technique. This technique is dedicated to systems of radio-location in real time, with applications in supplying medical help for car accidents on the road, and victims of natural disasters for which there is a need to be located quickly in order to direct the necessary help to them. In terms of error, we see that according to Fig. 5, in LOS (red solid line) or in NLOS (blue dashedline) this error is less than 1 m, independent of the rate of confidence.

VI. CONCLUSION

We have studied the performance of a geometrical method of localization based on a process of compensation between the powers of the signals received, in order to reduce the number of unknowns and to improve the precision of localization. The guiding principle consisted of using a ratio of the powers received, referenced to a pair of simultaneous base stations in order to locate a mobile node within a zone of detection. The technology used was Wi-Fi and included scenarios involving both LOS and NLOS. We compared the results obtained with the hyperbolic technique and traditional multilateration. Simulations showed that this technique provided considerable improvement in the precision of the localization, compared to the conventional methods based on the RSS, under conditions of propagation in line of sight and in situations involving obstacles.

The performance of the method was validated when i) the power of effective emission is unknown, ii) the index of propagation of the medium varies overthe course of time, iii) there is an uncertainty in the parameters used in the models of propagation, such as the heights of the antennas and variations in the transmission powers.Thus, the technique of compensation between the powers of the received signals particularly makes the technique of localization more robust in the case of the multilateration. A further question is to determine if this technique can improve other techniques of radiolocation. This will be the focus of our future research.

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