Screening of mild cognitive impairment in elderly via Doppler radar gait measurement

Kenshi Saho1a), Kazuki Uemura1, and Michito Matsumoto2

1 Faculty of Engineering, Toyama Prefectural University
5180 Kurokawa, Imizu, Toyama 939-0398, Japan
2 Department of Social Welfare, Toyama College of Welfare Science
579 Sanga, Imizu, Toyama 939-0341, Japan
a) saho@pu-toyama.ac.jp

Abstract: This letter presents a screening technique for elderly adults with mild cognitive impairment towards the early detection of dementia based on daily gait measurement using a Doppler radar. The gait parameters corresponding to walking speed, gait cycle, and leg velocities were remotely extracted using a simple Doppler radar system for elderly participants aged 65 years and above. The screening capabilities of the participants with mild cognitive impairment were investigated by using the extracted gait parameters. The results verified that our Doppler radar technique achieved mild cognitive impairment screening with approximately 94% sensitivity and 69% specificity.

Keywords: mild cognitive impairment, dementia, Doppler radar, elderly people, gait analysis

Classification: Sensing

References

[1] J. Verghese, M. Robbins, R. Holtzer, M. Zimmerman, C. Wang, X. Xue, and R. B. Lipton, “Gait dysfunction in mild cognitive impairment syndromes,” J. Am. Geriatr. Soc., vol. 56, no. 7, pp. 1244–1251, Jul. 2008. DOI:10.1111/j.1532-5415.2008.01758.x
[2] J. W. Kim, D. Y. Lee, E. H. Seo, B. K. Sohn, Y. M. Choe, S. G. Kim, S. Y. Park, I. H. Choo, J. C. Youn, J. H. Jhoo, K. W. Kim, and J. I. Woo, “Improvement of Screening Accuracy of Mini-Mental State Examination for Mild Cognitive Impairment and Non-Alzheimer Disease Dementia by Supplementation of Verbal Fluency Performance,” Psychiatry Investig., vol. 11, no. 1, pp. 44–51, Jan. 2014. DOI:10.4306/pi.2014.11.1.44
[3] T. Buracchio, H. H Dodge, D. Howieson, D. Wasserman, and J. Kaye, “The Trajectory of Gait Speed Preceding Mild Cognitive Impairment,” Arch. Neurol., vol. 67, no. 8, pp. 980–986, Aug. 2010. DOI:10.1001/archneur.2010.159
[4] M. Lussier, M. Lavoie, S. Giroux, C. Consel, M. Guay, J. Macoir, C. Hudon, D. Lorrain, L. Talbot, F. Langlois, H. Pigot, and N. Bier, “Early detection of mild cognitive impairment with in-home monitoring sensor technologies using functional measures: A systematic review,” IEEE J. Biomed. Health Inform., vol. 23, no. 2, pp. 838–847, Mar. 2019. DOI:10.1109/JBHI.2018.2834317

©IEICE 2019
DOI: 10.1587/comex.2019XBL0136
Received October 4, 2019
Accepted October 23, 2019
Publicized November 8, 2019
1 Introduction

Mild cognitive impairment (MCI) is known as the pre-dementia stage, i.e., the transitional state between cognitive decline due to normal aging and serious decline due to dementia [1, 2, 3]. Daily screening of MCI strongly aids in early detection of dementia. Question/interview-based MCI screening tests have been widely used and validated [2, 3]. For example, Ref. [2] proposed a simple screening test for the MCI by combining two well-used cognitive tests: mini-mental state examination (MMSE) and verbal fluency test (VFT). However, conventional MCI screening tests require a questioner/grader, which makes daily use difficult.

To solve this problem, gait sensing techniques based on relationships between walking ability and cognitive function [1, 3] are applicable for the MCI screening. Because a traditional walk test timed by stopwatch [3] is unsuitable for daily monitoring, some recent studies have used infrared motion sensors to automatically measure gait speed and its association with MCI [4]. However, this technique can measure only gait speed, and detailed gait information such as leg velocities are not obtained. Accelerometry-based detailed gait measurement techniques have been proposed, and the effectiveness for the MCI screening is shown in [5]; however, these are unsuitable for daily use because the study participants must wear accelerometers.

Doppler radar technique is a promising candidate for avoiding the above problems because it can measure various gait parameters remotely without constraints of participants and this letter presents a MCI screening via gait sensing using a Doppler radar. Our previous study [6] revealed that the cognitive impairment can be identified via micro-Doppler radar gait measurement. Although this previous study assumed the detection of relatively serious cognitive impairment, we hypothesize that our technique can also be applicable for the screening of the milder decline observed in MCI. We ver-
ify the screening capability of elderly participants with MCI using the gait parameters measured with our Doppler radar system.

2 Experimental protocol

The study participants were 178 elderly adults aged 65 years and above. They performed the MMSE/VFT-based MCI screening test [2] and we classified the participants using this test score into the MCI group (18 people: 9 men and 9 women, mean age 78.4 ± 6.82 years, mean height 154.8 ± 10.2 cm, mean mass 57.1 ± 9.39 kg, mean muscle mass 17.4 ± 4.18 kg) and the healthy group (160 people: 62 men and 98 women, mean age 73.4 ± 4.89 years, mean height 157.3 ± 8.70 cm, mean mass 55.1 ± 9.29 kg, mean muscle mass 17.0 ± 4.02 kg).

The participants then performed an unconstrained walk test using the Doppler radar measurement described in the next section. They also performed the conventional 5-m walk test timed by a stopwatch [3] and the gait speed $v_{5m}$ was measured as a result of the conventional method. We investigated the effective gait parameters acquired with the Doppler radar for the screening of the participants in the MCI group.

The experimental protocol was approved by the local ethics committee (Toyama Prefectural University, approval number H29-1).

3 Doppler radar gait measurement

A Doppler radar measurement system similar to that in [6] was used for this study. Fig. 1 shows the gait measurement situation and the representative spectrogram obtained from the received signal. A single Doppler radar was installed in front of the participant at a height of 0.86 m. The radar transmitted a sinusoidal wave at a frequency of 24 GHz and an effective isotropic radiated power of 40 mW to the participant. The sampling frequency of the received signal was set to 600 Hz. The participants walked toward the radar along a 10-m straight walkway at a self-selected comfortable pace.

For a received signal processing to acquire the gait parameters, the similar procedure indicated in Ref. [6] was conducted to extract the time-velocity distribution, and its feature envelopes are shown in Fig. 1. The length of the data extracted from each participant was one walking cycle and our used data correspond to walk of approximately 2 m. The Hamming window function with a length of 213 ms was empirically used for the short time Fourier transform of the received signals. Mean, upper, and lower envelopes were extracted as $V_m(t)$, $V_u(t)$, and $V_l(t)$, which correspond to body motion, forward motion of the legs, and motion of the legs in contact with the floor, respectively, as indicated in Fig. 1. (these physical interpretations of the envelopes have been validated by [7] using motion capture data). The following gait parameters were extracted using these envelopes. Although the single Doppler radar measures radial velocity and the measured velocities of the arms and legs depend on the distance between the participant and radar, we confirmed that this effect was negligible in the estimation of the following
parameters in our radar setup because of the sufficiently far distance from the participants.

- The gait cycle $t_{\text{walk}}$ was estimated based on interpolated maximum peaks as indicated in the spectrogram of Fig. 1.
- Mean body velocity $v_{\text{m,mean}}$ was extracted as $E[V_m(t)]$, where $E[\cdot]$ denotes the mean with respect to time.
- $v_{u,\text{mean}}$ was extracted as $E[V_u(t)]$. This corresponds to the mean velocity of forward motions of the legs.
- $v_{l,\text{mean}}$ was extracted as $E[V_l(t)]$. This corresponds to the mean velocity of the motions of legs in contact with the floor.
- Degree of variation of body velocity $v_{\text{m,std}}$ was extracted as $\text{STD}[V_m(t)]$, where $\text{STD}[\cdot]$ denotes the standard deviation with respect to time.
- $v_{u,\text{std}}$ was extracted as $\text{STD}[V_u(t)]$. This corresponds to degree of variation of the forward motions of the legs.
- $v_{l,\text{std}}$ was extracted as $\text{STD}[V_l(t)]$. This corresponds to degree of variation of the motions of legs in contact with the floor.

![Fundamental information of our radar measurement: Experimental site (left) and an example of spectrogram for one walking cycle (right).](image)

Fig. 1. Fundamental information of our radar measurement: Experimental site (left) and an example of spectrogram for one walking cycle (right).

4 Screening of MCI and its accuracy evaluation

We constructed a logistic regression model [8] for the MCI screening by combining the gait parameters extracted using the Doppler radar, which is expressed as:

$$
\ln \frac{p_{\text{mci}}}{1 - p_{\text{mci}}} = \beta_0 + \beta_1 x_{\text{gait},1} + \beta_2 x_{\text{gait},2} + \cdots, \tag{1}
$$

where $p_{\text{mci}}$ is a probability that the participant is in the MCI group, $\beta_i$ is $i$-th coefficient of the model, and $x_{\text{gait},i}$ is $i$-th predictor. We selected the predictors that achieved the lowest Akaike information criterion (AIC) for the model [8] from all combinations of the gait parameters explained in the previous section.
The screening of the participants with the MCI is conducted with a cut-off value $p_{\text{cut}}$ of $p_{\text{mci}}$; i.e., the participants with $p_{\text{mci}} > p_{\text{cut}}$ are judged to person with the MCI. To determine $p_{\text{cut}}$ and an evaluation of the screening accuracy, receiver operating characteristic (ROC) curve and precision-recall (PR) curve analyses [9] were performed for the constructed model. The area under the ROC Curve (AUC) was also calculated to evaluate the screening capability. The ROC and PR curves and their AUCs were calculated and compared with those of the results of the conventional walk test of $v_{5\text{m}}$.

5 Results and discussion

We first show the results for the gait parameter extraction and model construction for $p_{\text{mci}}$. The parameters of the model of Eq. (1) constructed by the logistic regression and the minimum AIC criterion were: $(x_{\text{gait},1}, x_{\text{gait},2}, x_{\text{gait},3}, x_{\text{gait},4}) = (t_{\text{walk}}, v_{\text{m,mean}}, v_{\text{l,mean}}, v_{\text{l,std}})$ and $(\beta_0, \beta_1, \beta_2, \beta_3, \beta_4) = (16.2, -7.38, -20.2, 17.7, 29.0)$. All parameters were significant ($p$-values in $t$-tests [8] were smaller than 0.05). Fig. 2 shows the examples of plots for the gait parameters selected in the constructed model. This figure indicates that although the clear boundary to completely classify the two groups were not confirmed, the participants in the MCI group in the feature space composed of the variables in the model can be screened because of significantly large differences between the two groups.

![Fig. 2. Plots of gait parameters selected for the logistic regression model for all participants.](image)

We evaluated the screening capability for the constructed model. Fig. 3 depicts the ROC and PR curves with $p_{\text{mci}}$ and $v_{5\text{m}}$, and their AUCs of the ROC curves were estimated as 0.869 and 0.692, respectively. Their AUCs of the PR curves were estimated as 0.645 and 0.312. These results for both curves verify that the screening capability of the constructed model is clearly larger than that of the conventional 5-m walk test. For $p_{\text{cut}} = 0.742$, the screening using $p_{\text{mci}}$ achieved 94.4 % sensitivity with 68.8 % specificity as indicated in the ROC curve. This study used imbalanced data between the two groups, the results of the PR curve are relatively high [9] and this curve also indicates that there was a better MCI screening accuracy using the Doppler radar parameters than the 5-m walk test. Thus, these results verified the accurate screening capability of the extracted gait parameters.
Finally, we discuss the results above. The reason for MCI screening capability using the extracted gait parameters is that the gait dysfunction due to cognitive decline was detectable even though the decline is mild. In our previous study [6], the participants with larger cognitive declines in various cognitive domains were classified with the radar gait parameters. Although the MCI corresponds to a milder cognitive decline compared to our previous study, Ref. [1] reported that the MCI is also associated with gait speed and stride length. The stride length is closely related to not only gait speed, but also leg velocities corresponding to $V_l(t)$. In addition, gait speed was closely related to the parameters of the mean envelope, as shown in Fig. 1, corresponding to body motion. Thus, the MCI screening was achieved using the gait parameters. However, the parameters extracted from $V_u(t)$ were not selected for the logistic regression model despite our previous findings [6] of the efficacy of these parameters in leg forward motion for the evaluation of various cognitive functions. The mechanism of our results including the reason for the ineffectiveness of $V_u(t)$ could be investigated using a larger dataset in future studies.

6 Conclusion

In this study, we verified the screening capability for participants with MCI using the gait parameters obtained with the Doppler radar. This study can lead to the development of a daily unconstrained MCI detection system that contributes to the prevention and early detection of dementia.

Acknowledgments

This work was supported in part by the Ministry of Internal Affairs and Communications of Japan and JSPS KAKENHI (Grant no. 16K16093).