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ASSESSMENT OF INDIVIDUAL PSYCHOPHYSIOLOGICAL CHARACTERISTICS OF VEHICLE DRIVERS

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Abstract. To ensure safe transitions between automated and manual driving in automated vehicles, it is necessary to monitor the driver's state. Existing research in this area primarily assesses the driver's current state without predicting their potential behavior in complex driving situations, which could negatively impact the safety of automated vehicles when switching between driving modes. To address this shortcoming, this article proposes a method for assessing relatively stable individual driver psychophysiological characteristics that could serve as predictors of their ability to mobilize internal reserves when making decisions in complex driving situations. The method allows one to determine the numerical values of indicators of such individual psychophysiological characteristics as reaction time, ability to take emergency actions, vigilance, concentration and distribution of attention, perception of speed and distance, as well as risk propensity during manual driving.

Keywords: automated vehicle, road safety, driver, information technology, multimodal interface, control transfer, psychophysiological qualities, driving mode, human factor.

Conflict of interests. The authors declare that there is no conflict of interests.

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ОЦЕНКА ИНДИВИДУАЛЬНЫХ ПСИХОФИЗИОЛОГИЧЕСКИХ ХАРАКТЕРИСТИК ВОДИТЕЛЕЙ ТРАНСПОРТНЫХ СРЕДСТВ

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Аннотация. Для обеспечения безопасности при переходе между автоматизированным и ручным вождением в автоматизированных транспортных средствах необходимо контролировать состояние водителя. Существующие исследования в этой области в основном направлены на оценку текущего состояния водителя без прогнозирования его возможного поведения в сложных дорожных ситуациях, что может негативно сказаться на безопасности эксплуатации автоматизированных транспортных средств при смене режима вождения. С целью устранения этого недостатка в статье предлагается метод оценки относительно стабильных индивидуальных психофизиологических характеристик водителя, которые могли бы служить в качестве предикторов его способности мобилизовать внутренние резервы при принятии решений в сложных дорожных ситуациях. Метод позволяет определить численные значения показателей таких индивидуальных психофизиологических характеристик, как время реакции, способность к экстренным действиям, бдительность, концентрация и распределение внимания, восприятие скорости и расстояния, а также склонность к риску во время ручного вождения.

Ключевые слова: автоматизированное транспортное средство, дорожная безопасность, водитель, информационные технологии, мультимодальный интерфейс, передача управления, психофизиологические качества, режим вождения, человеческий фактор.

Конфликт интересов. Авторы заявляют об отсутствии конфликта интересов.

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Introduction

In a level 3 automated vehicle, the driver can transfer the control of the vehicle to the automated driving system (ADS) and be involved in other things such as reading, eating, sleeping or anything else, but in emergency situations the driver should take over vehicle control [1]. In these cases, the driver can lack situation awareness and not be ready to perform safely the driving task. To address this problem, the driver's readiness to take-over control from an ADS must be carefully evaluated. For this purpose, the driver's psychophysiological and behavioral data are analyzed and combined with the data on the current driving situation. In this regard, it is essential to recognize potentially dangerous driver states, such as distraction, fatigue, drowsiness, and other undesirable states that affect takeover performance negatively [2–6].

The control mode can be switched from automated driving (AD) to manual driving (MD) immediately and completely after the take-over request is confirmed by the driver or gradually with increasing authority, depending on the driver state and the driving situation [7, 8]. The immediate control transfer from automation to driver can be performed if the driver's readiness for MD is high enough for the required driving task. If the driver's readiness for MD does not meet the required level it is necessary to help the driver to increase his/her control capability to required level. For this purpose, the approach based on the concept of driver-automation shared control during take-over process is used since it allows to allocate the execution of the driving task between automation and driver in accordance with the current driver state and driving situation until the driver's state reaches the desired level and takeover is complete [9–12]. Such an approach may help the driver to take back control of a vehicle in a safe and smooth manner if the time budget allows to do it. But in critical situations when urgent take-over is required due to ADS failure the shared control during authority transition can be risky. In such critical situations when the driver's readiness for MD does not meet the required high level and is close to the minimum allowable value, other solutions are needed.

In addition, it should be noted that the existing research on this topic mainly focuses on characterizing the current state of the driver without prediction of his/her future behavior that can be affected by the intrinsic variability of human nature [13]. To overcome this shortcoming of existing research, we propose a method of assessing the driver's relatively stable individual psychophysiological characteristics (IPC) such as motor reaction, ability to act urgently, concentration and distribution of attention, and so on, that can be used as predictors of his/her ability to mobilize the required internal resources for decision making in critical situations during the transition from AD to MD.

A method of assessing the driver's individual psychophysiological characteristics

The method allows determining the numerical values of indicators of such IPC as reaction time, ability to act urgently, vigilance, concentration and distribution of attention, perception of speed and distance, and risk propensity during periods of MD. The method is based on detecting the unintentional deviation from the driving lane, unsafe distance from the vehicle ahead, potential collision with a pedestrian in front of the vehicle, and speed limit signs along the road, which can be performed by using a collision avoidance system, for example Mobileye 8 Connect[1]. To ensure the reliability of the IPC assessment, the necessary data must be recorded only in cases when the weather conditions are favorable for driving.

An algorithm for estimation of the driver's reaction time and indicator of ability to act urgently is depicted in Fig. 1, where D is the current distance from the vehicle ahead; D_1 is a predefined safety threshold value; t_R is the driver's reaction time to warning alert; t_S is the time of restoring the safe situation; T is the predefined test time; n is the number of potentially dangerous situations detected during time T.

[1] *Driven by Safety. An AI-powered Fleet Safety Solution*. Available: https://ims.mobileye.com/fleets/uk/products/mobileye-8-connect/.

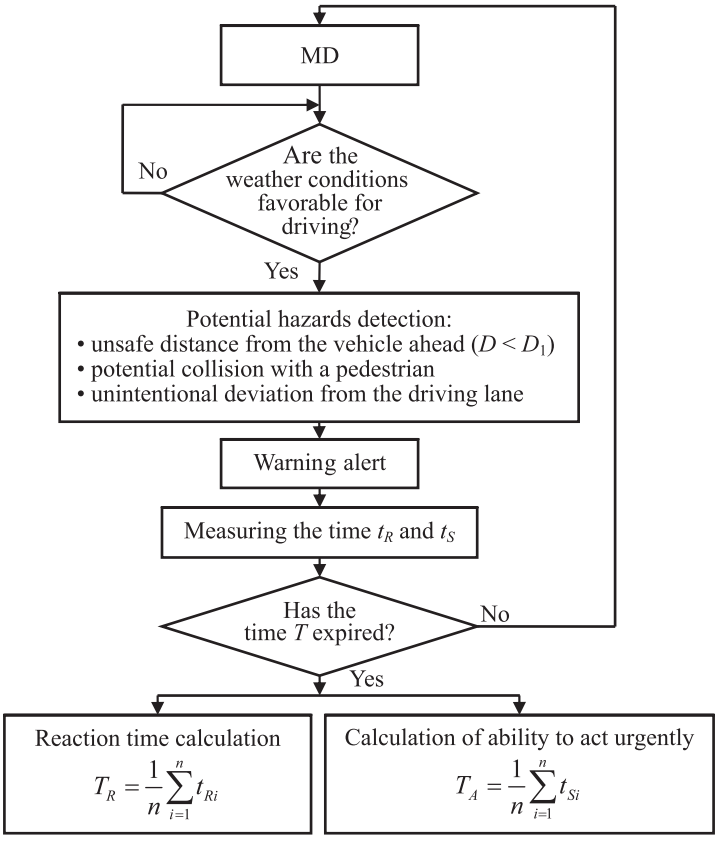

Fig. 1. An algorithm for estimation of driver's reaction time and indicator of ability to act urgently

During periods when the vehicle is in MD mode under favorable weather conditions, the collision avoidance system detects potentially dangerous situations: unsafe distance from the vehicle ahead (when the current distance D is below a pre-defined safety threshold value D_1); potential collision with a pedestrian; unintentional deviation from the driving lane. A pre-defined safety threshold value D_1 is the distance, that corresponds to three seconds time to collision with the vehicle ahead, taking into account the relative traveling speed[1]. When the collision avoidance system detects any of these situations, an alert is issued and the time t_R of the driver's reaction to a warning alert (the time between the onset of an alert and the beginning of braking in the first two situations, and the activation of the turn signals or beginning of decreasing deviation in the third situation) and the time t_S of restoring the safe situation (the time between the appearance and disappearance of the warning alert) are measured. After the predefined test time T has elapsed, the indicator T_R of the driver's reaction time and the indicator T_A of the driver's ability to act urgently (the indicator T_A shows how quickly the driver copes with a critical situation) are calculated:

$$T_R = \frac{1}{n}\sum_{i=1}^{n} t_{Ri}; \tag{1}$$

$$T_A = \frac{1}{n}\sum_{i=1}^{n} t_{Si}. \tag{2}$$

An algorithm for estimation of driver's vigilance indicator is depicted in Fig. 2, where D, D_1, t_R, T – the same as in Fig. 1; $D_2 \approx (1{,}2–1{,}5)D_1$ is a predefined value; N is the overall number of all detected situations; n_V is the number of detected potentially dangerous situations

During periods when the vehicle is in MD mode under favorable weather conditions, the collision avoidance system detects potentially dangerous situations: unsafe distance from the vehicle ahead (when $D < D_1$); potential collision with a pedestrian; unintentional deviation from the driving lane; exceeding the speed limit; and also such situations as: "$D < D_2$" situations (Fig. 3); pedestrians in the path of a vehicle; speed limit signs; lane change maneuvers.

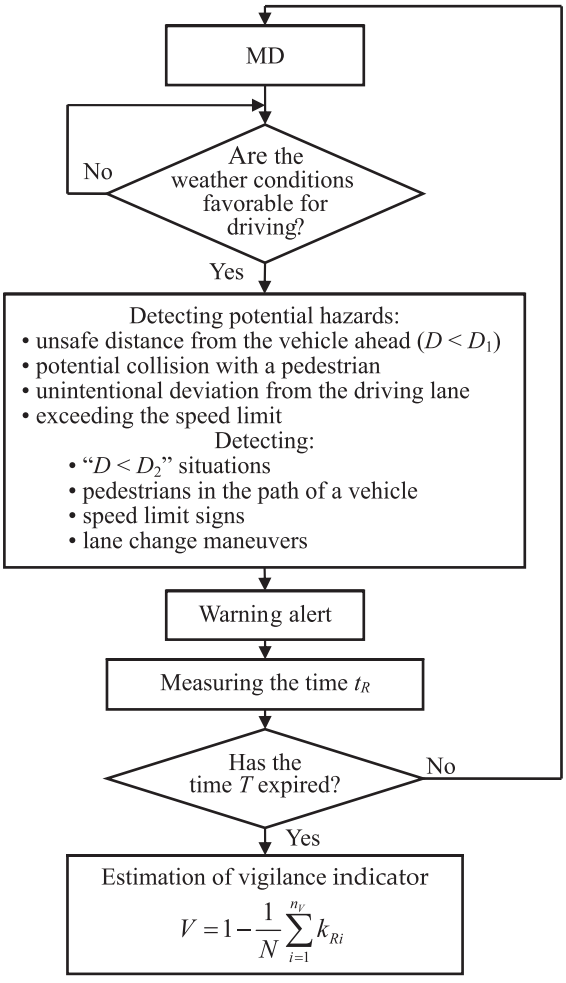

Fig. 2. An algorithm for estimation of driver's vigilance indicator

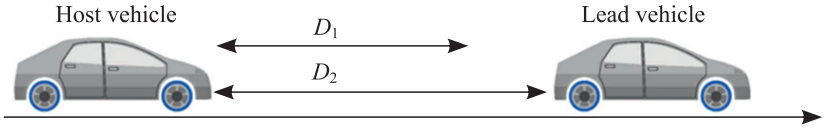

Fig. 3. An illustration of a leading vehicle and a host vehicle separated by a distance $D_2 \approx (1{,}2–1{,}5)D_1$

We introduced the notion of distance D_2 in order to consider the driver's behaviour in situation close to the potentially dangerous situation when $D < D_1$.

When the collision avoidance system detects any of potentially dangerous situations, an alert is issued and the time t_R of the driver's reaction to warning alert is measured. After the predefined test time T has elapsed, the indicator V of the driver's vigilance level is estimated

$$V = 1 - \frac{1}{N}\sum_{i=1}^{n_V} k_{Ri}, \tag{3}$$

where $k_R = \frac{e^{2t_R} - 1}{e^{2t_R} + 1}$ is a coefficient that takes values from 0 to 1; N is the overall number of all detected situations.

We introduce the coefficient $k_R = f(t_R)$ to take into account the driver's response to alerts from a collision avoidance system. Such a dependence can be described, for example, by a bipolar sigmoid (hyperbolic tangent) function $y = \frac{e^{2x} - 1}{e^{2x} + 1}$ and makes it possible to obtain values of k_R in the range from 0 to 1 (Fig. 4).

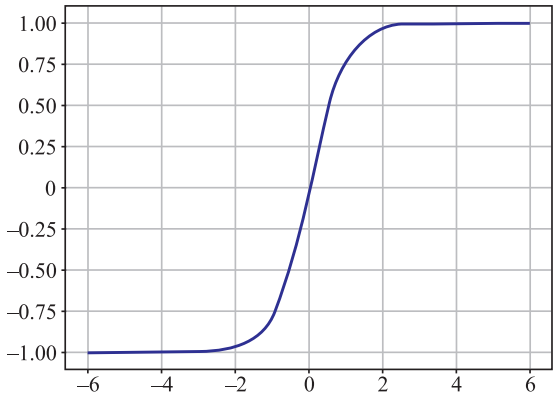

Fig. 4. An illustration of the hyperbolic tangent function

An algorithm for estimation of driver's concentration of attention indicator is depicted in Fig. 5, where N_C and n_C are the overall number of all detected situations and the number of detected potentially dangerous situations, respectively.

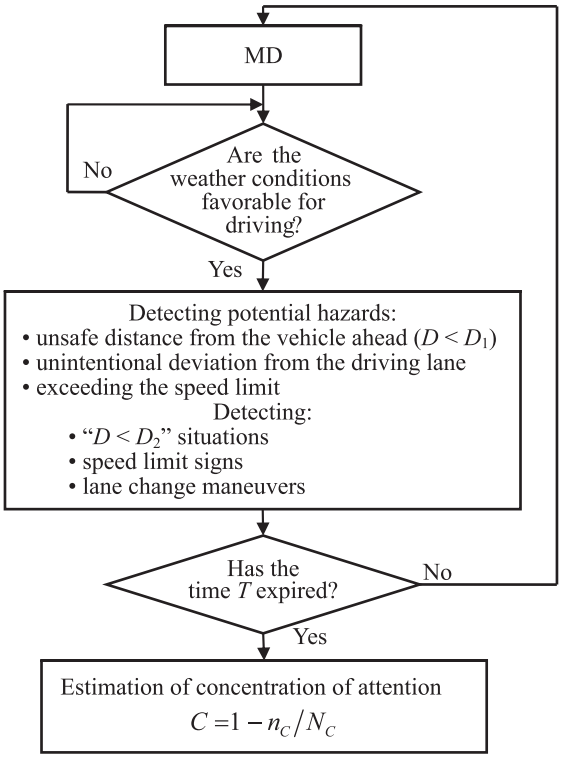

Fig. 5. An algorithm for estimation of driver's concentration of attention

During periods when the vehicle is in MD mode under favorable weather conditions, the collision avoidance system detects potentially dangerous situations: unsafe distance from the vehicle ahead (when $D < D_1$); unintentional deviation from the driving lane; exceeding the speed limit; also such situations as "$D < D_2$" ($D_2 \approx (1{,}2–1{,}5)D_1$); speed limit signs; lane change maneuvers. After the predefined test time T has elapsed, the indicator C of the driver's concentration level is estimated

$$C = 1 - n_C / N_C . \quad (4)$$

The indicator C shows the driver's ability to monitor the driving scene carefully, avoiding potentially dangerous situations.

An algorithm for estimation of driver's ability to distribute attention is depicted in Fig. 6, where M is the number of detected lane change maneuvers; m is the number of detected potentially dangerous situations that occur during lane change maneuvers.

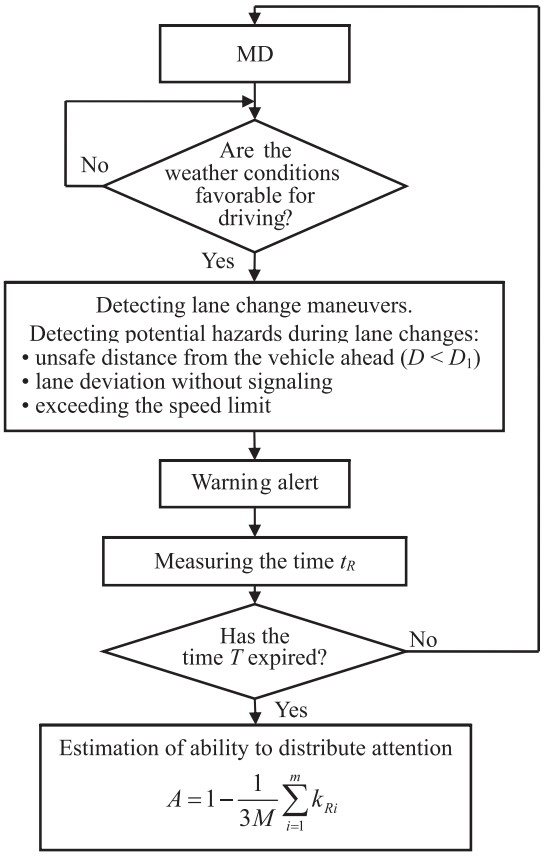

Fig. 6. An algorithm for estimation of driver's ability to distribute attention

During periods when the vehicle is in MD mode under favorable weather conditions, the collision avoidance system detects lane change maneuvers and potentially dangerous situations that occur during these maneuvers: unsafe distance from the vehicle ahead (when $D < D_1$); lane deviation without signaling; exceeding the speed limit. When the collision avoidance system detects any of these potentially dangerous situations, an alert is issued and the time t_R of the driver's reaction to warning alert is measured. After the predefined test time T has elapsed, the indicator A of the driver's ability to distribute attention is calculated

$$A = 1 - \frac{1}{3M}\sum_{i=1}^{m} k_{Ri}\,. \tag{5}$$

The indicator A shows the driver's ability to monitor the driving scene during lane change maneuvers, avoiding potentially dangerous situations.

An algorithm for estimation of driver's speed and distance perception ability is depicted in Fig. 7, where k and l are the number of "$D_1 < D < D_2$" and "$D < D_2$" situations, respectively.

During periods when the vehicle is in MD mode under favorable weather conditions, the collision avoidance system detects "$D_1 < D < D_2$" and "$D < D_2$" situations and their durations tP_1 and tP_2, respectively.

After the predefined test time T has elapsed, the indicator P of the driver's speed and distance perception ability is estimated

$$P = \frac{\sum_{i=1}^{k} t_{P1i}}{\sum_{j=1}^{l} t_{P2j}}. \tag{6}$$

The indicator P shows the driver's speed and distance perception ability based on his/her behavioral data in situations when "$D_1 < D < D_2$".

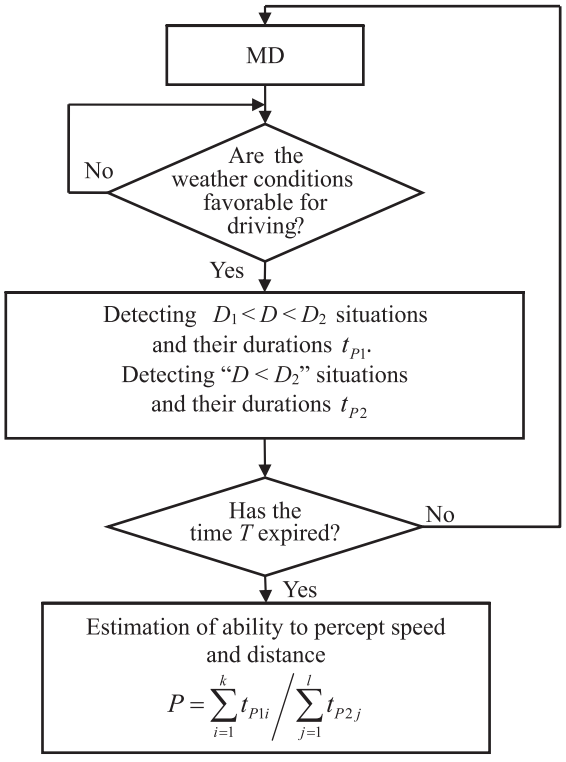

Fig. 7. An algorithm for estimation of driver's speed and distance perception ability

An algorithm for estimation of driver's risk propensity indicator is depicted in Fig. 8.

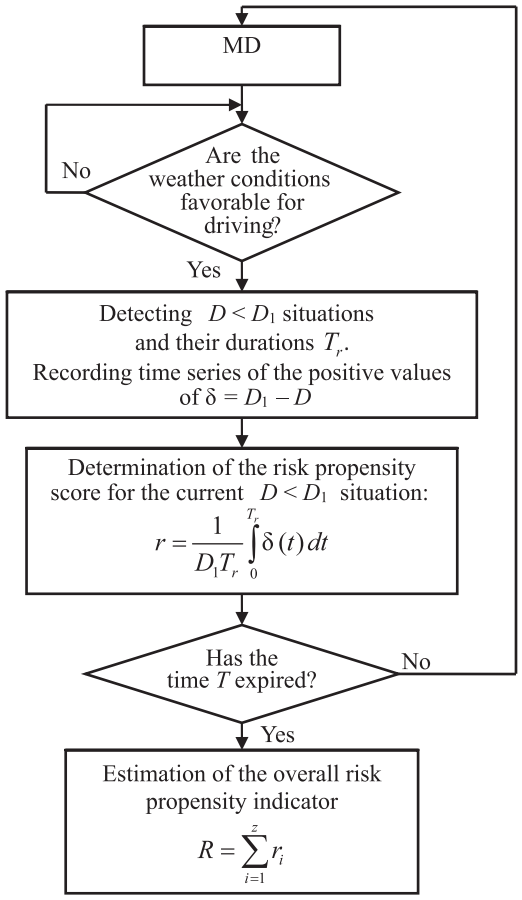

Fig. 8. An algorithm for estimation of driver's risk propensity indicator: z is the number of "$D < D_1$" situations

During periods when the vehicle is in MD mode under favorable weather conditions, the collision avoidance system detects potentially dangerous "$D < D_1$" situations, then their durations T_r and time series of the positive values of $\delta = D_1 - D$ are recorded. For each "$D < D_1$" situation, the risk propensity score r is calculated as follows: $r = \frac{1}{D_1 T_r} \int_0^{T_r} \delta(t)\, dt$. The risk propensity score r shows how far the current potentially dangerous "$D < D_1$" situation has progressed. After the predefined test time T has elapsed, the indicator R of the driver's overall risk propensity indicator is calculated:

$$R = \sum_{i=1}^{z} r_i. \tag{7}$$

The values of all these particular indicators should be recorded in the driver's database (that can be created in the cloud) and then combined for each single period of time (e. g. day) into a holistic measure that can be used as additional factor for decision making when transferring vehicle control from AD to MD is required. To represent the driver's IPC through a single measure the simple aggregation method such as the arithmetic mean can be used. In this case an overall index of driver's IPC is calculated by summing up values of all particular IPC indicators and dividing the total by the number of included particular IPC indicators.

Conclusion

In this paper, we propose a method for determining the numerical values of indicators of such individual psychophysiological characteristics as reaction time, ability to act urgently, vigilance, concentration and distribution of attention, perception of speed and distance, and risk propensity during periods of manual driving. Such individual psychophysiological characteristics of the driver are important for traffic safety, especially in critical situations, and must be taken into account as an additional risk factor during take-over process. The method is based on detecting the unintentional deviation from the driving lane, unsafe distance from the vehicle ahead, potential collision with a pedestrian in front of the vehicle, and speed limit signs along the road, which can be performed by using a collision avoidance system.

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Authors' contribution

Dubovsky V. developed algorithms, prepared the manuscript of the article.
Savchenko V. carried out the task setting for the study, performed analysis of results.

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