(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 760 513 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
06.01.2021 Bulletin 2021/01

(21) Application number: **18920691.5**

(22) Date of filing: **13.08.2018**

(51) Int Cl.:
B61L 27/00 *(2006.01)*

(86) International application number:
PCT/CN2018/100192

(87) International publication number:
WO 2019/227674 (05.12.2019 Gazette 2019/49)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **31.05.2018 CN 201810551198**

(71) Applicant: **CRSC Research & Design Institute Group Co., Ltd.**
Beijing 100070 (CN)

(72) Inventors:
- **LIU, Ling**
  Beijing 100070 (CN)
- **WEI, Wei**
  Beijing 100070 (CN)
- **ZHANG, Bo**
  Beijing 100070 (CN)
- **ZHANG, Youbing**
  Beijing 100070 (CN)

(74) Representative: **Huang, Liwei**
Cäcilienstraße 12
40597 Düsseldorf (DE)

(54) MULTI-TRAIN COOPERATIVE CONTROLLING METHOD AND SYSTEM USING VIRTUAL COUPLING

(57) Disclosed is a multi-train cooperative controlling method and system using virtual coupling; the method comprises: obtaining acceleration of a train adjacent to a controlled train, a speed difference value between the train adjacent to the controlled train and the controlled train, and a redundancy distance between the train adjacent to the controlled train and the controlled train; determining acceleration of the controlled train according to the acceleration of the train adjacent to the controlled train, the speed difference value between the train adjacent to the controlled train and the controlled train, and the redundancy distance between the train adjacent to the controlled train and the controlled train; and adjusting a speed of the controlled train according to the determined acceleration of the controlled train. The mode of making each train closely follow an immediately preceding train implements stable cooperative operation of a train group, and achieves purposes of safety and high efficiency.

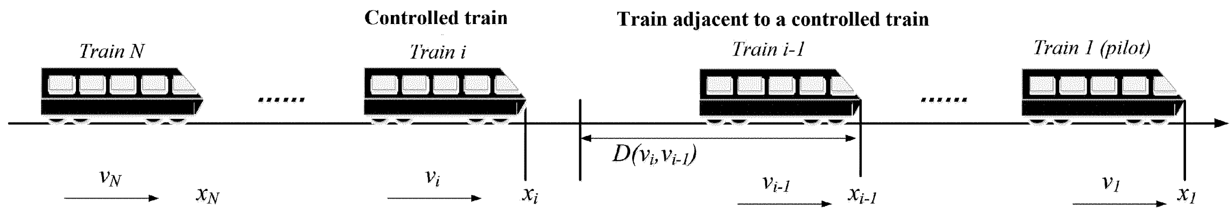

FIG.1

Printed by Jouve, 75001 PARIS (FR)

Description

[0001] The present application claims priority of Chinese Patent Application No. 201810551198.0 filed on May 31, 2018, the disclosure of which is incorporated herein by reference in its entirety as part of the present application.

TECHNICAL FIELD

[0002] The present disclosure relates to a field of rail transit technology, and more particularly, to a multi-train cooperative controlling method and system using virtual coupling.

BACKGROUND

[0003] In rail transit, tracking control is usually carried out by blocking, that is, it is a technical method of sectioning by using a signal or a certificate to ensure trains to operate in such a way that a certain distance must be maintained between a preceding train and a tracking train (a block-based system). In this mode, a front controlled train is tracked according to a block section, which has a relatively large tracking interval, and relatively low control efficiency as affected by more control hierarchies; in addition, the two trains are managed as independent individuals, respectively occupying a train number and a planned line, and thus, transportation capacity of a single train cannot be flexibly adjusted. Although existing lines adopt a train reconnection mode, yet as affected by physical connection of a device such as a coupler, connection and disassembly efficiency thereof is not high, so online dynamic control cannot be implemented, and as affected by a length of a platform, physical reconnection of only two trains can be implemented.

[0004] Patent Application No. CN201710686257.0 discloses a virtual coupling small-group train control method; in the method, point-to-point communication is implemented between controlled trains based on a vehicle-mounted device, to further constitute a virtual coupling small-group. Since coupling is implemented in a virtual mode, higher requirements are put forward for multi-train cooperative control in the trains; a tracking strategy of a controlled train to an immediately preceding train in the above-described patent is that: the main train follows operating states, i.e., accelerating, cruising and decelerating of the immediately preceding train; a control model is for closed-loop feedback control based on acceleration, with distance deviation and speed deviation as input; and meanwhile, a relative safety distance is calculated in real time according to a current speed as a safety restrictive condition of the control model. However, such a tracking strategy is very simple; during actual operation of virtual coupling trains, the trains will experience rapid acceleration, rapid deceleration and other phenomena that cause the train to shake, making passengers seriously uncomfortable. Such a phenomenon is especially serious in multi-train situations, for example, 3-train grouping, 8-train grouping, and 16-train grouping.

SUMMARY

[0005] With respect to the technical problem in the prior art that stable cooperation cannot be achieved in multi-train virtual coupling situations, the present disclosure proposes a multi-train cooperative controlling method using virtual coupling.

[0006] There is provided a multi-train cooperative controlling method using virtual coupling, the method including:

Firstly, obtaining acceleration of a train adjacent to a controlled train, a speed difference value between the train adjacent to the controlled train and the controlled train, and a redundancy distance between the train adjacent to the controlled train and the controlled train;
Secondly, determining acceleration of the controlled train according to the acceleration of the train adjacent to the controlled train, the speed difference value between the train adjacent to the controlled train and the controlled train, and the redundancy distance between the train adjacent to the controlled train and the controlled train; and
Finally, adjusting a speed of the controlled train according to the determined acceleration of the controlled train.

[0007] There is provided a multi-train cooperative controlling system using virtual coupling, the system including:

[0008] An information obtaining unit, configured to obtain acceleration of a train adjacent to a controlled train and the controlled train, a speed difference value between the train adjacent to the controlled train and the controlled train, and a redundancy distance between the train adjacent to the controlled train and the controlled train;

[0009] An acceleration calculating unit, configured to determine acceleration of the controlled train according to the acceleration of the train adjacent to the controlled train, the speed difference value between the train adjacent to the controlled train and the controlled train, and the redundancy distance between the train adjacent to the controlled train and the controlled train;

[0010] A speed adjusting unit, configured to adjust a speed of the controlled train according to the determined acceleration of the controlled train;

[0011] A communicating unit, configured to perform communication between front controlled trains and communication between the trains and a control center; and

[0012] The control center, configured to monitor an operating state of a train group in real time.

[0013] Through the technical solution of the present disclosure, efficient and safe operation of the virtual coupling multi-train group is achieved. Other features and advantages of the present disclosure will be further explained in the following description, and partly become self-evident therefrom, or be understood through implementation of the present disclosure. The objectives and other advantages of the present disclosure will be achieved through the structure specifically pointed out in the description, claims, and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014]

FIG. 1 shows a schematic diagram of a positional relationship of cooperative control according to an embodiment of the present disclosure;

FIG. 2 shows a schematic diagram of switching operating states according to the embodiment of the present disclosure;

FIG. 3 shows a schematic diagram of a positional relationship between two trains with a negative redundancy distance according to the embodiment of the present disclosure; and

FIG. 4 shows a structural diagram of a cooperative controlling system according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0015] In order to further set forth the technical means adopted for achieving a predetermined object of the present disclosure and effects thereof, specific implementations, structures, features and effects of the application according to the present disclosure will be described in details in conjunction with accompanying drawings and preferred embodiments as follows. In the following description, different phrases "one embodiment" and "an embodiment" do not necessarily refer to the same embodiment. In addition, specific features, structures, or characteristics in one or more embodiments may be combined in any suitable form.

[0016] In the embodiments of the present disclosure, multiple trains are no longer physically connected by a device such as a coupler, but implement multi-train virtual coupling by means of wireless communication such as train-to-train communication. In a virtual coupling system, since the respective trains are not physically connected by a device such as a coupler, but are connected in a wireless manner, a distance between the trains or relative positions thereof will change during operation of the trains. For example, FIG. 1 exemplarily shows a diagram of a positional relationship between multiple trains under cooperative control in the virtual coupling system. In the present disclosure, virtual coupling multi-train cooperation are controlled, and according to a front-rear relationship of multi-train positions, the consecutive multiple trains are regarded as a virtual coupling train group; when controlling a certain train in the train group, the train may be regarded as a controlled train, and according to a state of the controlled train and an operating state of an adjacent train thereof, control acceleration of the controlled train is determined, so as to adjust a speed of the controlled train.

[0017] As shown in FIG. 1, the multiple trains include train 1...train i-1, train i...train N, where, train 1 may be taken as a pilot train. The embodiment of the present disclosure are exemplarily described with two trains, i.e., train i and train i-1, which are in a front-rear adjacent relationship among the multiple trains as an example.

[0018] Train i, as a controlled train, has a certain distance from train i-1, which is an immediately preceding train adjacent thereto. In the diagram, x_i and x_{i-1} respectively represent positions where heads of train i and train i-1 are located; v_i and v_{i-1} respectively represent current driving speeds of train i and train i-1; $D(v_i, v_{i-1})$ is an ideal distance that needs to be maintained between the two trains when the driving speed of train i is v_i, and the driving speed of train i-1 is v_{i-1}; and the ideal distance is affected by a speed of the controlled train. During operation of the trains, the distance $D(v_i, v_{i-1})$ between train i and train i-1 is a relatively ideal distance; and when the two trains maintain the ideal distance for operation, efficient operation of the trains can be ensured, without safety issues such as collision.

[0019] Where, the above-described ideal distance $D(v_i, v_{i-1})$ is also related to a safety distance d_0, a train length L, a common braking distance $Sc_i(v_i)$ of train i, and an urgent braking distance $Su_{i-1}(v_{i-1})$ of train i-1. The common braking distance $Sc_i(v_i)$ of train i depends on the current speed v_i of train i, and may be obtained by querying actual train parameters; and the urgent braking distance $Su_{i-1}(v_{i-1})$ of train i-1 depends on the current speed v_{i-1} of train i-1, and may be obtained by querying actual train parameters.

[0020] The above-described ideal distance $D(v_i, v_{i-1})$ is specifically expressed by a formula below:

$$D(v_i, v_{i-1}) = d_0 + L + Sc_i(v_i) - Su_{i-1}(v_{i-1}) \qquad (1)$$

[0021] In the above-described Formula (1), d_0 is the safety distance reserved between the head of the controlled train and a tail of the immediately preceding train when the two trains stop after the controlled train adopts common braking, in a case where the immediately preceding train adopts urgent braking. The safety distance d_0 is affected by brake reaction time of a driver, signal processing and transmission delay in a train device, and a speed of the controlled train; specifically, the safety distance d_0=(brake reaction time+signal processing and transmission delay)×controlled train speeds×safety factor, where, the safety factor is between 1 and 2.

[0022] The operation process of the multi-train system based on virtual coupling according to the embodiment of the present disclosure is divided into different operating states based on a distance relationship and a speed relationship between the controlled train and the immediately preceding train; and by control means such as train speed accelerating or decelerating, the train may switch between different operating states, to finally achieve a balanced operating state where the controlled train and the immediately preceding train have consistent speeds and a stable distance. For example, a table below shows 9 operating states.

Distance relationship	Speed relationship	Operating states	Accelerating/decelerating trend analysis
$x_i<x_{i-1}-D(v_i, v_{i-1})$	$v_i>v_{i-1}$	1	Controlled train decelerates, entering operating state 5.
	$v_i=v_{i-1}$	2	Controlled train firstly accelerates, entering operating state 1; then decelerates, entering operating state 5.
	$v_i<v_{i-1}$	3	Controlled train firstly accelerates, entering operating state 2; further accelerates, entering operating state 1; and then decelerates, entering operating state 5.
$x_i=x_{i-1}D(v_{i-1}\ v_{i-1})$	$v_i>v_{i-1}$	4	Controlled train operates at a constant speed, to enter operating state 7.
	$v_i=v_{i-1}$	5	Controlled train maintains a current operating state. If it accelerates, it will enter operating state 7; and if it decelerates, it will enter operating state 3.
	$v_i<v_{i-1}$	6	Controlled train operates at a constant speed, to enter operating state 3.
$x_i>x_{i-1}-D(v_i, v_{i-1})$	$v_i>v_{i-1}$	7	Controlled train firstly decelerates, entering operating state 8; further decelerates, entering operating state 9; and finally accelerates, entering operating state 5.
	$v_i=v_{i-1}$	8	Controlled train firstly decelerates, entering operating state 9; then accelerates, entering operating state 5.
	$v_i<v_{i-1}$	9	Controlled train accelerates, entering operating state 5.

[0023] As shown in the above table, based on a relationship between an actual distance and the ideal distance $D(v_i, v_{i-1})$, as well as the speed relationship between the controlled train (train i) and the immediately preceding train (train i-1), the operating states of the train are set to 9 types. During actual operation, a speed of the controlled train may be controlled, for example, the speed may be increased or decreased through acceleration, so that the controlled train enters from one operating state into another operating state; and it should be well known to those skilled in the art that, acceleration is a positive number when increasing the speed; while deceleration is a negative number when decreasing the speed. Wherein, in operating state 5, the distance between the controlled train and the immediately preceding train is the ideal distance $D(v_i, v_{i-1})$, and operating speeds of the two are also the same, that is, the two enter a stable operating state. If all the trains in the train group (except the pilot train) are near the stable operating state 5, the entire train group may achieve efficient and safe operation.

[0024] During operation of the trains, due to some objective reasons, it is necessary to adjust the speed and the separation distance between trains, so that the controlled train further switches between the above-described operating states and changes between a stable operating state and an unstable operating state. For example, FIG. 2 shows a schematic flow chart that the controlled train switches between different operating states.

[0025] As shown in FIG. 2, in operating state 6, the distance between train *i* (the controlled train) and train *i*-1 (the immediately preceding train) is the ideal distance $D(v_i, v_{i-1})$, while at this time, the speed v_i of train *i* is less than the speed v_{i-1} of train *i*-1; and such a speed relationship changes the distance relationship between the front train and the rear train from x_i=x_{i-1}-$D(v_i, v_{i-1})$ to x_i<x_{i-1}-D(v_i, v_{i-1}). At this time, train *i* enters operating state 3; in operating state 3, train *i* accelerates, and after accelerating to v_i=v_{i-1}, it enters operating state 2. In operating state 2, train *i* continues accelerating and enters operating state 1. In operating state 1, v_i>v_{i-1}, at this time, train *i* begins to decelerate, and finally makes x_i=x_{i-1}-$D(v_i, v_{i-1})$, v_i=v_{i-1}, entering stable operating state 5. At this time, the front train and the rear train maintain the ideal distance $D(v_i, v_{i-1})$, and have consistent speeds, that is, the two trains are in a stable, efficient and safe operating state.

[0026] As shown in FIG. 2, in operating state 4, the safety distance between train i (the controlled train) and train *i*-1 (the immediately preceding train) is the ideal distance $D(v_i, v_{i-1})$, while at this time, the speed v_i of train *i* is greater than the speed v_{i-1} of train *i*-1; and such a speed relationship changes the distance relationship between the two trains from x_i=x_{i-1}-$D(v_i, v_{i-1})$ to x_i>x_{i-1}-$D(v_i, v_{i-1})$. At this time, train *i* enters operating state 7; in operating state 7, train *i* decelerates, and after decelerating to v_i=v_{i-1}, the train enters operating state 8. In operating state 8, train *i* continues decelerating and enters operating state 9. In operating state 9, v_i<v_{i-1}, at this time, train *i* begins to accelerate, and finally makes x_i=x_{i-1}-$D(v_i, v_{i-1})$, v_i=v_{i-1}, entering stable operating state 5. At this time, the front train and the rear train maintain the ideal distance $D(v_i, v_{i-1})$, and have consistent relative speeds, that is, the two trains are in a stable, efficient and safe operating state.

[0027] In the stable operating state, the front train and the rear train have consistent relative speeds and maintain a certain ideal distance, for example, the trains are in a stopped operating state or a high-speed stable operating state.

[0028] However, due to some objective reasons such as train departure, stop at a station, or line speed limit, etc., a train in a stable operating state needs to break the above-described stable operating state. Therefore, train *i* (the controlled train) will enter from the stable operating state into other unstable operating state. Exemplarily, when train *i* is in stable operating state 5, a front train is about to arrive at the station, at this time, train *i*-1 decelerates, and the speed v_{i-1} thereof decreases, causing the speed v_i of train *i* to be greater than the speed v_{i-1} of the immediately preceding train, at this time, train *i* enters from operating state 5 into operating state 4, and further enters into operating state 7; when the train leaves the station, the speed v_{i-1} of train *i*-1 increases, causing the speed v_i of train *i* to be less than the speed v_{i-1} of train *i*-1, at this time, the train enters from operating state 5 into operating state 6, and further enters into operating state 3. Exemplarily, when the train is operating at a high speed, and the track line is in a good condition, train *i* may increase the speed, at this time, the train enters from operating state 5 into operating state 3; and if the line condition is poor, train *i* needs to pass through at a reduced speed, and at this time, the train enters from operating state 5 into operating state 7.

[0029] After train *i* enters into operating state 3 or operating state 7 as described above, as shown in the above table and FIG. 2, it may continue to change the operating state by control means of acceleration and deceleration and reach a stable operating state.

[0030] Among the 9 operating states as listed above, a control force (a combined force of a driving force, a braking force, resistance, etc.) reasonably exerted on the controlled train may accelerate or decelerate the latter, so that the controlled train may switch between different operating states, and finally switch to stable operating state 5, that is, when all trains in the train group are operating at a high speed, it is guaranteed that the respective trains track one after another at a same high speed with a suitable safety distance, or all trains in the train group stop.

[0031] In order to judge the various operating states of the trains for cooperative control, to further achieve safe operation of the trains, during operation of the trains, the immediately preceding train may send information such as position information, speed information, and acceleration information thereof to the controlled train in real time. Optionally, the controlled train may also actively detect information such as position, speed and acceleration of the immediately preceding train in real time through a detecting apparatus, or obtain information such as position, speed and acceleration of the immediately preceding train through a train control system.

[0032] After the train is in one operating state, train *i* may switch between different operating states by control means of speed increasing or decreasing through certain acceleration. During acceleration and deceleration, train *i* dynamically adjusts its own acceleration a_i based on a redundancy distance Δx_i and a relative speed $\hat{v}_i$ between the controlled train and the immediately preceding train.

[0033] In the embodiment of the present disclosure, an acceleration difference value Δa_i of the front controlled train is calculated by using a formula below:

$$\Delta a_i = \dot{v}_i - \dot{v}_{i-1} = a_i - \overline{a}_{i-1} = \begin{cases} \max(\hat{v}_i^2/(2\Delta x_i), a_{break\_c} - \overline{a}_{i-1}) & \hat{v}_i > 0, \Delta x_i < 0 \\ \min(\hat{v}_i^2/(2\Delta x_i), a_{acc\_\max} - \overline{a}_{i-1}) & \hat{v}_i < 0, \Delta x_i > 0 \\ \min(-\Delta x_i \times a_{acc\_\max}/x_m, a_{acc\_\max} - \overline{a}_{i-1}) & \hat{v}_i \le 0, \Delta x_i < 0 \\ \max(\Delta x_i \times a_{break\_c}/x_m, a_{break\_c} - \overline{a}_{i-1}) & \hat{v}_i \ge 0, \Delta x_i > 0 \\ 0 & \hat{v}_i = 0, \Delta x_i = 0 \end{cases} \quad (2)$$

[0034] Where:

i=2,3,...,N;

max() means to take a maximum value between two or more;

$\hat{v}_i$ (i>1, the controlled train) is the speed of train i relative to train i-1, $\hat{v}_i = v_i - v_{i-1}$;

Δxi (i>1, the controlled train) is a distance difference between train i and a position $D(v_i, v_{i-1})$ after train i-1, and is an allowable redundancy distance between train i and train i-1, where, $\Delta x_i = x_i(x_{i-1} - D(v_i, v_{i-1}))$; the trains maintain the ideal distance $D(v_i, v_{i-1})$ during operation, but in practice, there may be the redundancy distance Δxi that deviates from the ideal distance $D(v_i, v_{i-1})$, in other words, Δx_i is the distance between the position of train i and the position $D(v_i, v_{i-1})$ after train i-1; for example, FIG. 3 shows a schematic diagram that the distance between the controlled train and the immediately preceding train is greater than the ideal distance $D(v_i, v_{i-1})$, that is, the redundancy distance at this time is a negative number; and from the diagram, it can be seen that, the actual distance $(x_{i-1}-x_i)$ between the front train and the rear train is $D(v_i, v_{i-1})-\Delta x_i$;

x_i is a position of the head of train i; v_i is the speed of train i; a_i (i>0, a non-pilot train) is the control acceleration of train i; $\overline{a}_{i-1}$ (i>0, a non-pilot train) is the actual acceleration of train i-1;

a_{acc_max} is maximum driving acceleration of the train; and it should be well known to those skilled in the art that, the driving acceleration is a positive number during driving;

a_{break_c} is common braking acceleration of the train; and it should be well known to those skilled in the art that, the braking acceleration is a negative number during braking;

x_m is distance deviation when a train control force reaches the maximum, and has a value between 90 m and 120 m.

[0035] With respect to the pilot train among the trains, head position, train speed, and actual train acceleration are respectively x_1, v_1 and $\overline{a}_1$;

[0036] In the embodiment of the present disclosure, with respect to multi-train cooperative control, information such as current head position, speed, and acceleration of the immediately preceding train is considered, so that the controlled train efficiently and safely follows the immediately preceding train.

[0037] After the acceleration difference between the controlled trains is obtained by using the above-described Formula (2), train i adjusts the acceleration of train i according to the acceleration of train i-1, to further change the operating state of the train; and the control acceleration of train i is as shown in Formula (3). Through acceleration and deceleration adjustments according to the embodiment of the present disclosure, multiple trains using virtual coupling implement cooperative control, which greatly improves stability, comfort, and safety of train operation.

$$a_i = \Delta a_i + \overline{a}_{i-1} \qquad (3)$$

[0038] Corresponding to the above-described method, an embodiment of the present disclosure further provides a multi-train cooperative controlling system using virtual coupling. As shown in FIG. 4, a control center implements data transmission with respective trains through a train communicating unit; and data transmission between the respective trains may be implemented through the train communicating unit. The cooperative controlling system includes an information obtaining unit, an acceleration calculating unit, and a speed adjusting unit, wherein, the information obtaining unit is configured to obtain acceleration of an immediately preceding train, a speed difference value between the immediately preceding train and a controlled train, and a redundancy distance between the immediately preceding train and the controlled train; the acceleration calculating unit is configured to determine control acceleration of the controlled train according to the acceleration of the immediately preceding train, the speed difference value between the immediately preceding train and the controlled train, and the redundancy distance between the immediately preceding train and the controlled train; and the speed adjusting unit is configured to adjust a speed of the controlled train according to the determined control acceleration of the controlled train. The cooperative controlling system further includes a communicating unit; and the communicating unit is configured to implement data transmission between trains and between the trains and the control center.

[0039] The embodiment of the present disclosure is exemplarily described by taking the rear train as a controlled train that follows the front train, but it is not limited to the mode in which the rear train follows the immediately preceding train. On the contrary, it is also applicable to the present disclosure that the front train is taken as a controlled train that makes adjustment according to an operating state of the rear train.

[0040] In the embodiments of the present disclosure, multiple adjacent trains operating on a same line in a same direction are organized as a whole, and the trains are no longer independent individuals but have an internal association relationship established, thereby breaking the concept of block section, and improving train control efficiency; the acceleration of the rear train is determined according to the acceleration parameter of the front train, the parameter of the speed difference value between the front train and the rear train, and the parameter of the redundancy distance between the front train and the rear train, thereby making the virtual coupling trains safer and more reliable, and further reducing a tracking distance between two adjacent trains among multiple trains; there is no physical connection between the trains, and flexibility thereof is greatly improved.

[0041] In summary, it is easy for those skilled in the art to understand that, the above-described respective advantageous modes may be freely combined and superimposed on the premise of no conflict.

[0042] The above is only preferred embodiments of the present disclosure and is not any formal limitations to the present disclosure; any simple changes, equivalent variations, and modifications made to the above embodiments based on the technical essence of the present disclosure are still within the scope of the technical solutions of the present disclosure.

Claims

1. A multi-train cooperative controlling method using virtual coupling, comprising:

firstly, obtaining acceleration of a train adjacent to a controlled train, a speed difference value between the train adjacent to the controlled train and the controlled train, and a redundancy distance between the train adjacent to the controlled train and the controlled train;
secondly, determining acceleration of the controlled train according to the acceleration of the train adjacent to the controlled train, the speed difference value between the train adjacent to the controlled train and the controlled train, and the redundancy distance between the train adjacent to the controlled train and the controlled train; and
finally, adjusting a speed of the controlled train according to the determined acceleration of the controlled train.

2. The multi-train cooperative controlling method using virtual coupling according to claim 1, wherein,
an acceleration difference value between the train adjacent to the controlled train and the controlled train is determined according to the speed difference value between the train adjacent to the controlled train and the controlled train, and the redundancy distance between the train adjacent to the controlled train and the controlled train; and
the acceleration of the controlled train is determined according to the acceleration difference value and the acceleration of the train adjacent to the controlled train.

3. The multi-train cooperative controlling method using virtual coupling according to claim 2, wherein,
the acceleration difference value Δa_i between the train adjacent to the controlled train and the controlled train is specifically determined as:

$$\Delta a_i = \begin{cases} \max(\hat{v}_i^2/(2\Delta x_i), a_{break\_c} - \overline{a}_{i-1}) & \hat{v}_i > 0, \Delta x_i < 0 \\ \min(\hat{v}_i^2/(2\Delta x_i), a_{acc\_\max} - \overline{a}_{i-1}) & \hat{v}_i < 0, \Delta x_i > 0 \\ \min(-\Delta x_i \times a_{acc\_\max}/x_m, a_{acc\_\max} - \overline{a}_{i-1}) & \hat{v}_i \le 0, \Delta x_i < 0 \\ \max(\Delta x_i \times a_{break\_c}/x_m, a_{break\_c} - \overline{a}_{i-1}) & \hat{v}_i \ge 0, \Delta x_i > 0 \\ 0 & \hat{v}_i = 0, \Delta x_i = 0 \end{cases}$$

where,

i=2,3,...,N;
max() means to take a maximum value between two or more;
$\hat{v}_i$ is a difference value between the speed v_i of the controlled train and the speed v_{i-1} of the train adjacent to the controlled train, $\hat{v} = v_i - v_{i-1}$;
Δx_i is a redundancy distance between the controlled train and the train adjacent to the controlled train;
a_{acc_max} is maximum driving acceleration of the train;
a_{break_c} is common braking acceleration of the train;
$\overline{a}_{i-1}$ is actual acceleration of the train adjacent to the controlled train;
x_m is distance deviation when a train control force reaches the maximum;

the control acceleration α_i of the controlled train is specifically determined as:

$$a_i = \Delta a_i + \bar{a}_{i-1}.$$

4. The multi-train cooperative controlling method using virtual coupling according to any one of claims 1 to 3, wherein, a distance between the controlled train and the train adjacent to the controlled train, and an ideal distance between the controlled train and the train adjacent to the controlled train are obtained; and
the redundancy distance between the train adjacent to the controlled train and the controlled train is determined according to the distance between the train adjacent to the controlled train and the controlled train, and the ideal distance between the train adjacent to the controlled train and the controlled train.

5. The multi-train cooperative controlling method using virtual coupling according to claim 4, wherein,
the ideal distance between the train adjacent to the controlled train and the controlled train is determined according to the safety distance between the train adjacent to the controlled train and the controlled train, the common braking distance of the controlled train, and the urgent braking distance of the train adjacent to the controlled train.

6. The multi-train cooperative controlling method using virtual coupling according to claim 5, wherein,
the common braking distance of the controlled train is obtained by querying actual train parameters.

7. The multi-train cooperative controlling method using virtual coupling according to any one of claims 5 to 6, wherein, the urgent braking distance of the train adjacent to the controlled train is obtained by querying actual train parameters.

8. The multi-train cooperative controlling method using virtual coupling according to any one of claims 5 to 6, wherein, the safety distance is determined according to brake reaction time, signal processing and transmission delay, and speeds of the train adjacent to the controlled train and the controlled train.

9. The multi-train cooperative controlling method using virtual coupling according to claim 8, wherein,
safety distance=(brake reaction time+signal processing and transmission delay)×controlled train speed×safety factor.

10. A multi-train cooperative controlling system using virtual coupling, comprising:

an information obtaining unit, configured to obtain acceleration of a train adjacent to a controlled train and the controlled train, a speed difference value between the train adjacent to the controlled train and the controlled train, and a redundancy distance between the train adjacent to the controlled train and the controlled train;
an acceleration calculating unit, configured to determine acceleration of the controlled train according to the acceleration of the train adjacent to the controlled train, the speed difference value between the train adjacent to the controlled train and the controlled train, and the redundancy distance between the train adjacent to the controlled train and the controlled train;
a speed adjusting unit, configured to adjust a speed of the controlled train according to the determined acceleration of the controlled train;
a communicating unit, configured to perform communication between front controlled trains and communication between the trains and a control center; and
the control center, configured to monitor an operating state of a train group in real time.

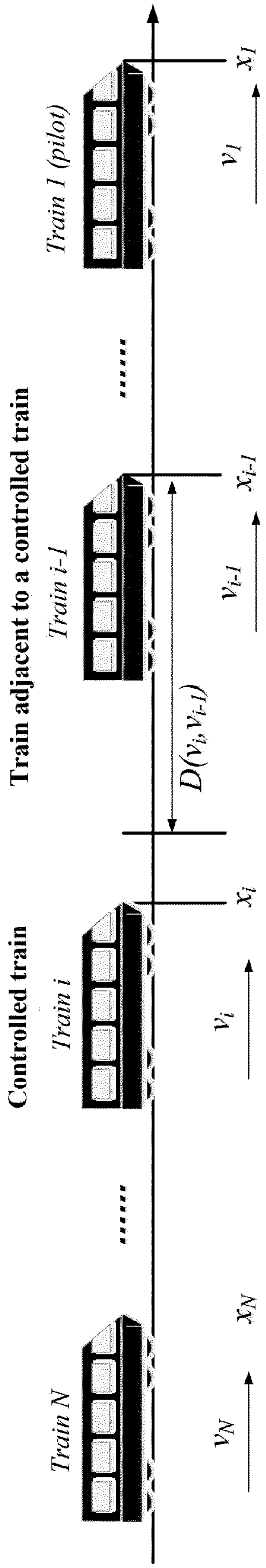
Train 1 (pilot)
v_1
x_1
Train adjacent to a controlled train
Train i-1
v_{i-1}
x_{i-1}
$D(v_i, v_{i-1})$
Controlled train
Train i
v_i
x_i
Train N
v_N
x_N

FIG.1

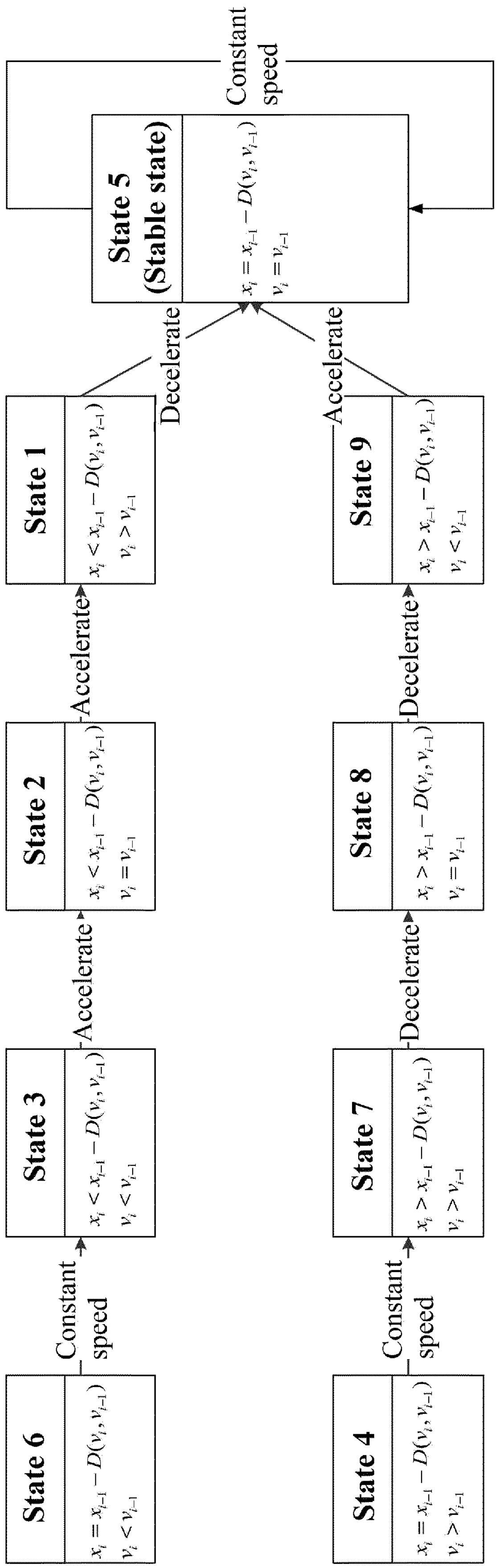
Constant speed
State 5 (Stable state)
$x_i = x_{i-1} - D(v_i, v_{i-1})$
$v_i = v_{i-1}$
Decelerate
Accelerate
State 1
$x_i < x_{i-1} - D(v_i, v_{i-1})$
$v_i > v_{i-1}$
State 9
$x_i > x_{i-1} - D(v_i, v_{i-1})$
$v_i < v_{i-1}$
Accelerate
Decelerate
State 2
$x_i < x_{i-1} - D(v_i, v_{i-1})$
$v_i = v_{i-1}$
State 8
$x_i > x_{i-1} - D(v_i, v_{i-1})$
$v_i = v_{i-1}$
Accelerate
Decelerate
State 3
$x_i < x_{i-1} - D(v_i, v_{i-1})$
$v_i < v_{i-1}$
State 7
$x_i > x_{i-1} - D(v_i, v_{i-1})$
$v_i > v_{i-1}$
Constant speed
Constant speed
State 6
$x_i = x_{i-1} - D(v_i, v_{i-1})$
$v_i < v_{i-1}$
State 4
$x_i = x_{i-1} - D(v_i, v_{i-1})$
$v_i > v_{i-1}$

FIG. 2

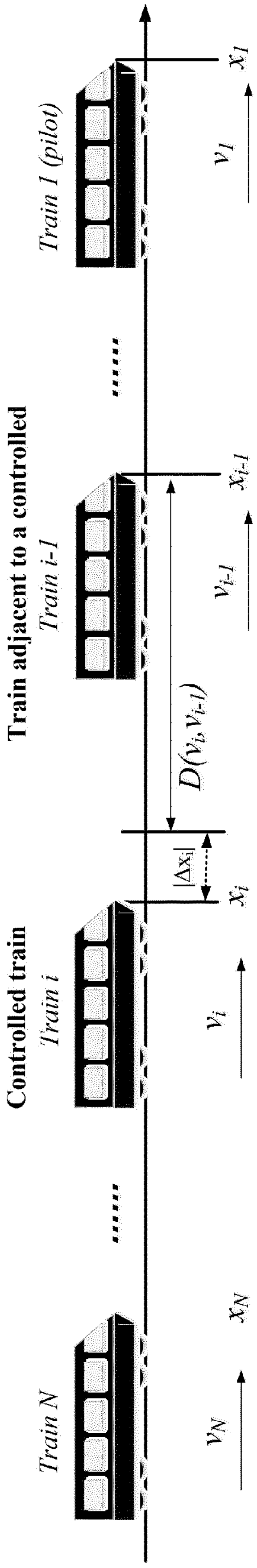
Train 1 (pilot)
Train adjacent to a controlled
Train i-1
Controlled train
Train i
Train N
x_1
x_{i-1}
x_i
x_N
v_1
v_{i-1}
v_i
v_N
$D(v_i, v_{i-1})$
$|\Delta x_i|$

FIG. 3

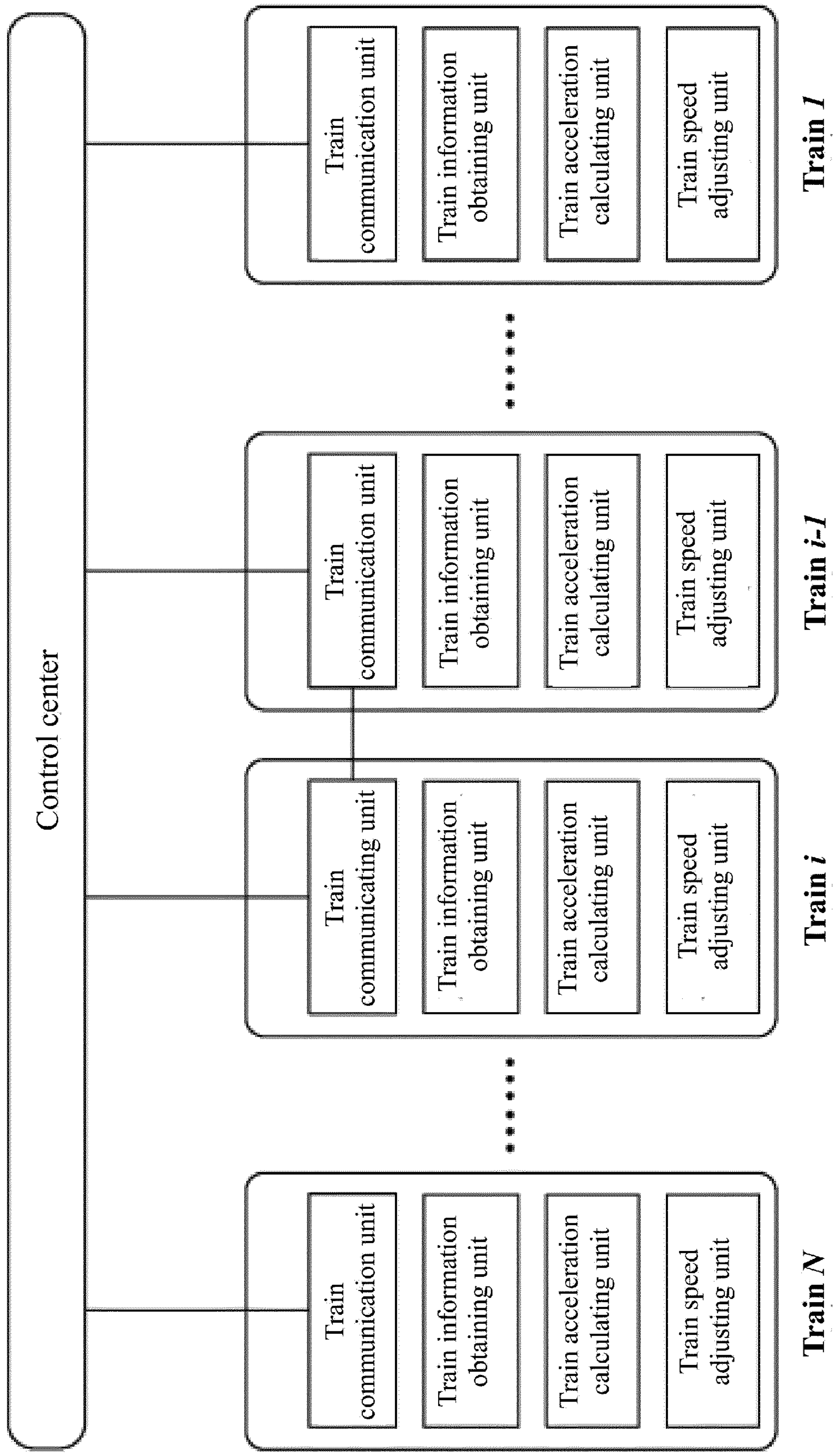
Control center
Train communication unit
Train information obtaining unit
Train acceleration calculating unit
Train speed adjusting unit
Train 1
Train i-1
Train communicating unit
Train i
Train N

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2018/100192

A. CLASSIFICATION OF SUBJECT MATTER

B61L 27/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B61L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNPAT, CNKI, WPI, EPODOC: 轨道, 多, 列车, 加速度, 速度, 距离, 协同, 通信, 控制, railway, train, multiple, rail, accelerate, speed, velocity, distance, cooperate, coordinate, communicate, control

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 107685749 A (SIGNAL & COMMUNICATION RESEARCH INSTITUTE OF CARS ET AL.) 13 February 2018 (2018-02-13) description, paragraphs 12-67, and figures 1-4	1-10
A	CN 106672027 A (GUANGZHOU METRO GROUP CO., LTD. ET AL.) 17 May 2017 (2017-05-17) entire document	1-10
A	CN 105329264 A (BEIJING TRAFFIC CONTROL TECHNOLOGY CO., LTD.) 17 February 2016 (2016-02-17) entire document	1-10
A	JP 2011168217 A (MITSUBISHI HEAVY INDUSTRIES LTD.) 01 September 2011 (2011-09-01) entire document	1-10
A	US 2017355388 A1 (WESTINGHOUSE AIR BRAKE TECH. CORPORATION) 14 December 2017 (2017-12-14) entire document	1-10
A	US 3934125 A (GEN SIGNAL CORP.) 20 January 1976 (1976-01-20) entire document	1-10

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 January 2019	**27 February 2019**

Name and mailing address of the ISA/CN	Authorized officer
State Intellectual Property Office of the P. R. China **No. 6, Xitucheng Road, Jimenqiao Haidian District, Beijing 100088** **China**	
Facsimile No. **(86-10)62019451**	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2018/100192

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
CN 107685749 A	13 February 2018	None	
CN 106672027 A	17 May 2017	None	
CN 105329264 A	17 February 2016	None	
JP 2011168217 A	01 September 2011	None	
US 2017355388 A1	14 December 2017	CA 2949808 A1	08 December 2017
		MX 2016010702 A	07 December 2017
US 3934125 A	20 January 1976	ZA 7405670 A	24 September 1975
		FR 2246905 A1	02 May 1975
		IT 1022484 B	20 March 1978
		CA 1024243 A	10 January 1978
		AU 7380674 A	01 April 1976
		NL 7412450 A	02 April 1975
		GB 1490533 A	02 November 1977
		JP S557042 B2	21 February 1980
		JP S5076704 A	23 June 1975
		AU 497458 B2	14 December 1978

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- CN 201810551198 **[0001]**
- CN 201710686257 **[0004]**