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DE-A1-102009 014 766
DE-A1-102009 018 403
US-A1- 2006 071 625
US-A1- 2008 065 257
US-B1- 6 212 443
S.-S. YOON et al.: "Dynamic Anti-Windup for Robot Systems with Friction", ICCAS2005: International Conference on Control, Automation and Systems, 5 June 2005 (2005-06-05), Korea Retrieved from the Internet: URL:https://pdfs.semanticscholar.org/05b4/ 4626caefcb218165267baec1d8bb774c0cf0.pdf

Description

The invention relates to an industrial robot. Industrial robots are working machines that can be equipped for the automatic handling and/or machining of objects with tools and are programmable in several axes of motion, for example, in terms of orientation, position and workflow. Industrial robots typically include a robotic arm with a plurality of links arranged in series, articulated through joints with respect to axes, and programmable controllers (control devices) which control the motion sequences of the industrial robot during operation.

During operation of the industrial robot or during manual movement of the same, it is desirable that the robot does not collide with any object.

The DE 10 2009 018 403 A1 discloses a method and apparatus for controlling a manipulator. For the control upper limits of restoring forces or a limitation of a maximum target motor current in a current loop are provided.

The US 2008/0065257 A1 discloses adjusting the coefficients of a PI controller. The publication "Dynamic Anti-Windup for Robot Systems with Friction" by S.-S. Yoon, Y. Yamada, J.-K. Park and T.-W. Yoon in ICCAS2005: International Conference on Control, Automation and Systems, 2005, Korea describes a control algorithm in which the integral component of a controller is limited to control robot systems, taking into account frictional forces as part of a dynamic anti-windup control

The object of the invention is to provide an industrial robot such that the negative effects of a collision of the robot arm with an object are at least mitigated.

The object of the invention is achieved by an industrial robot according to claim 1.

The industrial robot according to the invention is therefore set up to be operated with force control, at least in a partial operating mode. For this purpose, the control device is provided in the control device of the industrial robot according to the invention. This is designed as digital control. The force control is preferably carried out as running on the control device computer program in the operation of the industrial robot according to the invention.

The control device comprises at least one integral component (I component), which according to the invention is limited based on the criterion. Due to the limitation of the invention, integration of a so-called anti-wind-up effect is realized and thus the transient response of the control device when, then only slightly deteriorated, but at the same time limits the maximum applied torque of the members of the robot arm moving drives. This makes it possible to reduce or even prevent potential damage to the robot arm when it inadvertently collides with an object.

According to the invention, the control device is arranged to dynamically limit the integral portion, on the basis of an uncertainty stored in the control device, the dynamic properties of the robot arm modelling dynamic model of the industrial robot.

According to the embodiment of the industrial robot according to the invention a dynamic model of the robot arm is stored in the control device, which models the dynamic properties of the same. The dynamic properties of the robot arm are associated with a friction, in particular a friction of the gear of the electric drives. However, the dynamic properties of the robot arm may also relate to torques of the robot arm due to gravitational forces and inertia. According to this embodiment of the industrial robot according to the invention, the control device may be designed to calculate the desired torques in such a way based on the dynamic model and due to the angular positions of the members of the robot arm relative to each other. Thus, the accuracy of the torques associated with the target force of the electric drives to be applied by the electric drives of the electric drives can be better calculated or regulated.

The control device of the industrial robot according to the invention is set up to dynamically limit the integral component due to an uncertainty of the dynamic model. The robotic arm cannot be modelled accurately by the dynamic model, creating uncertainty. This uncertainty is used according to this embodiment as the criterion for limiting the integral component, whereby it is achieved that due to the dynamic model, a variably calculated torque is at least partially compensated once again.

The uncertainty may preferably be modelled as an error function stored in the control device. This may preferably be associated with an uncertainty of the modelled friction of the dynamic model.

The uncertainty of the modelled friction can be assigned to a current angular position of the individual members of the robot arm relative to one another, to a current rotational speed of the electric motors associated with the electrical drives and/or to a current state and efficiency of transmissions associated with the electrical drives. The friction of the transmission or the transmissions depending on their power flow or their power flows can differ fairly much, that is if the transmission in question is operated backwards or forwards.

The control device might have a force regulator, whose input signal is the desired force to be applied by the robot arm, an inverse Jacobian matrix connected downstream of the force regulator, whose output signal is assigned to forces and/or torques to be applied by the robot arm in the joint space of the robot arm, and a regulator downstream of the inverse Jacobian matrix, which has the integral part, which is especially dynamically limited on the basis of the criterion. Here, the Jacobian matrix results from the relationship between the velocities in the joint space and the velocities in the Cartesian space at the so-called Tool Center Point (TCP).

According to one embodiment of the industrial robot according to the invention its control device is designed such that it specifies the desired torques as electrical desired currents for the electric drives.

According to a preferred variant of the industrial robot according to the invention, the latter has a force torque sensor coupled to the fastening device, which is set up to detect force acting on the fastening device due to manual movement of the robot arm, which is the basis for the desired force. By means of this variant, it is possible to manually move the industrial robot supported by its drives.

Depending on the embodiment of the industrial robot according to the invention it is operated at least in a partial operating mode by means of a force control.

If the robot arm of the industrial robot according to the invention collides with an object, the contact force can result from the kinetic energy, the environmental stiffness plus the drive torque of the electric drives which is predetermined by the control device.

If the drive torque predetermined by the force control is limited, in particular by means of an anti-windup method, then the contact force and/or speed can be limited according to the time instant of a (usually unforeseeable) collision. It is the damage which could arise after the impact, e.g. one millisecond later (= time of a control stroke) could arise (i.e., particularly in time after the reduction of, especially, large parts of the kinetic energy of the robotic arm, caused by the abrupt slowing down of the movement of the robotic arm, possibly to a standstill).

In particular, the integral part of the force control can be dynamically limited to the torque, which results from the uncertainty of the dynamic model. The uncertainty can be set up as an error function (also called a disturbance variable function). The error function may preferably correspond predominantly to the approximate model deviation of the transmission friction torque, especially depending on the speed and condition and efficiency of power flow direction (transmission driving backwards or forwards). With this control concept according to the invention, the industrial robot according to the invention together with the collided object are better protected against damage.

One embodiment of the invention is illustrated by way of example in the accompanying schematic figures. Thereby:

fig. 1 shows an industrial robot with a control device and a robot arm and

fig. 2 shows a structural diagram of a force control device of the industrial robot.

Fig. 1 shows a perspective view of an industrial robot 1 with a robot arm 2.

In the case of the present embodiment, the robot arm 2 comprises a plurality of links arranged one after the other and connected by means of joints. Regarding the links it is more specifically a stationary or movable frame 3 and a carousel 4 rotatably mounted relative to the frame 3 about a vertical axis A1. Further links of the robot arm 2 are according to the present embodiment a rocker 5, a boom 6 and a preferably multi-axis robot hand 7 with a flange 8 designed as a fastening device. The rocker 5 is at the lower end e.g. pivotally mounted about a preferably horizontal axis A2 on a swing bearing head not shown on the carousel 4. At the upper end of the rocker 5, again the arm 6 is pivotally mounted about a likewise preferably horizontal axis A3. It carries the robot hand 7 with its preferably three axes A4, A5, A6.

To move the industrial robot 1 or its robot arm 2 automatically, it comprises in a generally known manner electric drives 26 connected to a control device 9. Only a few of the electric motors 10 of these drives 26 are shown in fig. 1.

In the case of the present exemplary embodiment, the industrial robot 1 is operated with force control, at least in a partial operating mode. A force control device 21 intended for this partial mode of operation is deposited in the control device 9, the structural image of which is shown in fig. 2.

The force-controlled partial operating mode may be controlled by the control device 9 e.g. during an automatic movement of the robot arm 2.

In the case of the present exemplary embodiment, it is provided in particular that the force-controlled partial operating mode in the context of a manual or hand-guided movement of the robot arm 2 e.g. is carried out as part of a programming of the industrial robot 1. For this case, e.g. a handle 11 might be attached to the flange 8 of the robot arm 2, by means of which the robot arm 2 can be moved manually or hand controlled. A force torque sensor 12 connected to the control device 9 can also be arranged in or on the flange 8 or in or on the handle 11, which senses a force acting on the flange 8, in particular on a so-called Tool Center Point of the robot arm 2 or of the handle 11 and/or a torque acting on the robot arm 2 or its flange 8 due to the manual movement.

If the robot arm 2 is to be moved manually, then the force determined by the force torque sensor 12 is multiplied by the factor "-1". The resulting signal is an input signal of the force control device 21 and is especially supplied to a force regulator 22 of the force control device 21, which e.g. is designed as a PI controller.

The output signal of the force controller 22 corresponds in the case of the present embodiment, a 6-dimensional vector comprising force and torque components with which the robot arm 2 automatically controlled by the control device 9 is to be moved, so that the handle 11 and its Tool Center Point moves according to the manually applied force.

The output signal of the force controller 22 is fed to a block 23 of the force control device 21, which on the basis of the output of the force controller 22 and the current angular positions φ of the members of the robot arm 2 relative to each other transforms a transformation of the force and torque components in the so-called joint space principally know in the art, For this purpose, the so-called inverse Jacobian matrix is used. The actual angular positions φ of the links of the robot arm 2 are determined e.g. by means of suitable, e.g. on the robot arm 2 arranged, angle measuring devices, such as resolvers, and form further input signals of the force control device 21.

The output signal of the block 23 is the input signal of a further regulator 24 of the force control device 21, which has an integrating behaviour and is designed, for example, as a PI (Proportional Integral) controller. The output signal of the controller 24 is assigned to the torques which the individual electric drives 26 of the robot arm 2 or their electric motors 10 are to apply.

In order to at least partially compensate for example, the gravity of the robot arm 2 and/or the friction of the joints, gears, etc., the force control device 21 in the case of the present embodiment, comprises a dynamic model 25, which models the dynamic behaviour of the robot arm 2. This is used to, based on the actual angular positions φ of the links of the robot arm 2 relative to each other, calculate their first derivatives in time $d\varphi /dt$ and their second derivatives on time $d^2\varphi /dt^2$ compensating torques, which the electric drives 26 of the robot arm 2 and their electric motors 10 are to apply, for example, in order to at least partially compensate for the friction or the effects of gravity. The calculated compensating torques are added to the torques calculated by means of the controller 24, whereby target torques are calculated, which are to be applied by the electric drives 26 of the robot arm 2 and their motors 10. The desired torques are e.g. converted into corresponding desired electrical currents for the electric drives 26 and the motors 10, so that, for example, the electric drives 26 can be controlled accordingly in a manner known to those skilled in the art, the output signals of the force control device 21.

In practice, the dynamic model 25 has uncertainties or can only be created and/or implemented with limited accuracy. To at least reduce an expected damage to the robot arm 2 and/or the object in the event of a collision of the structure of the robot arm 2 with an object, it is provided in the case of the present embodiment to limit the output signal of the controller 24. In the case of the present exemplary embodiment, this is achieved by limiting the integrating component (I component) of the controller 24 (anti-wind-up).

In the case of the present embodiment, the I component of the controller 24 is dynamically limited and/or individually limited for each electric drive 12. It is provided that the I component is limited due to the uncertainty or incorrectness of the dynamic model 25. Preferably, a not exactly modelled friction of the robot arm 2, i.e. frictions of the joints, possibly used transmission, etc. considered. Also, a current angular position of the individual members of the robot arm 2 relative to each other and/or the current speed of the individual electric motors 10 and/or the current state and efficiency, depending on the power flow direction (backwards or forwards driving transmissions), are considered.

In the case of the present embodiment, the said uncertainty is set up as an error function 27 or disturbance function. This can be assigned predominantly to the approximate model deviation of the individual transmission torque of the electric drives 26, in particular depending on the current rotational speed of the electric motors 10 in question and/or whether the transmission in question is operated backwards or forwards.

More specifically, the error function 27 might be determined empirically by examining the robot arm 2 in question for different axis positions and movements of the individual members of the robot arm 2 or determining or at least estimating the friction. The error function may also have been determined based on statistical methods, for example by examining a plurality of robot arms 2 of the same type or category.

The force-controlled partial operation mode can also be performed during the automatic operation of the industrial robot 1 as described above, i.e. the I component of the regulator 24 may be limited as described. In automatic mode, however, no force due to manual movement of the robot arm 2 is measured, which is used as an input to the force controller 22 and the force control device 21, respectively. In the automatic mode in question, the force regulator 22 or the force control device 21 can be given a desired force. This desired force may have a predetermined directional component, which in particular corresponds to a direction in which the Tool Center Point is to exert the predetermined force.

PATENTKRAV

1. Industrirobot omfattende

- en robotarm (2) med en flerhed af lemmer (4-7), som er anbragt bag hinanden og kan bevæges i forhold til akser (A1-A6), elektriske drev (26) til bevægelse af lemmerne (4- 8), og en fastgørelsesanordning (8) for fastgørelse af en endeeffektor, og

- en styringsanordning (9) forbundet til de elektriske drev (26), hvilken styringsanordning (9) er konfigureret til at styre ved elektrisk regulering af de elektriske drev (26) for en bevægelse af lemmerne (4-7), i det mindste i en delvis driftstilstand ved hjælp af en reguleringsanordning (21), hvor reguleringsanordningen (21), på grund af en nominel kraft der skal påføres af robotarmen (2), bestemmer nominelle drejningsmomenter, der skal påføres af drevene (26), og omfatter mindst en integreret komponent, **kendetegnet ved**, at reguleringsanordningen (21) er konfigureret til at begrænse integralkomponenten på basis af en usikkerhed af en dynamisk model (25) af industrirobotten (1) gemt i styringsanordningen (9) som modellerer robotarmens (2) dynamiske egenskaber.

2. Industrirobot ifølge krav 1, hvor kriteriet er forbundet til en friktion af robotarmen (2), især en friktion af gear af de elektriske drev (26).

3. Industrirobot ifølge krav 2, hvis styringsanordning (9) er konfigureret til at modellere den aktuelle friktion af gearet, især under hensyntagen til det aktuelle power flow i det pågældende gear og/eller en hastighed af den elektriske motor (10) forbundet til det pågældende gear af det pågældende elektriske drev (26).

4. Industrirobot ifølge ethvert af kravene 1 til 3, hvor den dynamiske model (25) af robotarmen (2) modellerer de dynamiske egenskaber af robotarmen (2) som en friktion og/eller drejningsmomenter, der udøves af tyngdekraft på lemmerne af robotarmen (2).

5. Industrirobot ifølge ethvert af kravene 1 til 4, hvor reguleringsanordningen (21) er konfigureret til at beregne de nominelle kræfter på basis af den dynamiske model (25) og på basis af vinkelpositionerne af lemmerne af robotarmen (2) i forhold til hinanden.

6. Industrirobot ifølge ethvert af kravene 1 til 5, hvor usikkerheden er modelleret som en fejlfunktion (27) gemt i styringsanordningen (9), der er forbundet især til en usikkerhed af den modellerede friktion af den dynamiske model (25).

7. Industrirobot ifølge krav 6, hvor usikkerheden af den modellerede friktion en aktuel vinkelposition af de individuelle lemmer af robotarmen (2) i forhold til hinanden og/eller en aktuel hastighed af de elektriske motorer (10) forbundet til de elektriske drev (26) og/eller en aktuel tilstand og effektivitet af gearene forbundet til de elektriske drev (26) tages i betragtning.

8. Industrirobot ifølge ethvert af kravene 1 til 7, hvor reguleringsanordningen (21) omfatter en strømstyring (22), hvis indgangssignal er den nominelle kraft, der skal anvendes af robotarmen (2), en omvendt Jacobian matrix (23) nedstrøms for strømstyringen (22), hvis udgangssignal er tildelt kræfter og/eller drejningsmomenter, der skal anvendes af robotarmen (2) i robotarmens (2) fællesområde og en styringsanordning (24) nedstrøms for den inverse Jacobian matrix (23), hvilken styringsanordning omfatter den integrerede komponent, som er begrænset dynamisk på basis af kriteriet.

9. Industrirobot ifølge ethvert af kravene 1 til 8, hvis reguleringsanordningen (21) er udformet til at specificere de nominelle drejningsmomenter som elektriske nominelle strømme for det elektriske drev (26).

10. Industrirobot ifølge ethvert af kravene 1 til 9, omfattende en kraftmomentsensor (12) koblet til fastgørelsesanordningen (8), som er konfigureret til at bestemme en kraft, der virker på fastgørelsesanordningen (8) på basis af en manuel bevægelse af robotarmen (2), hvilken kraft er basis for den nominelle kraft.

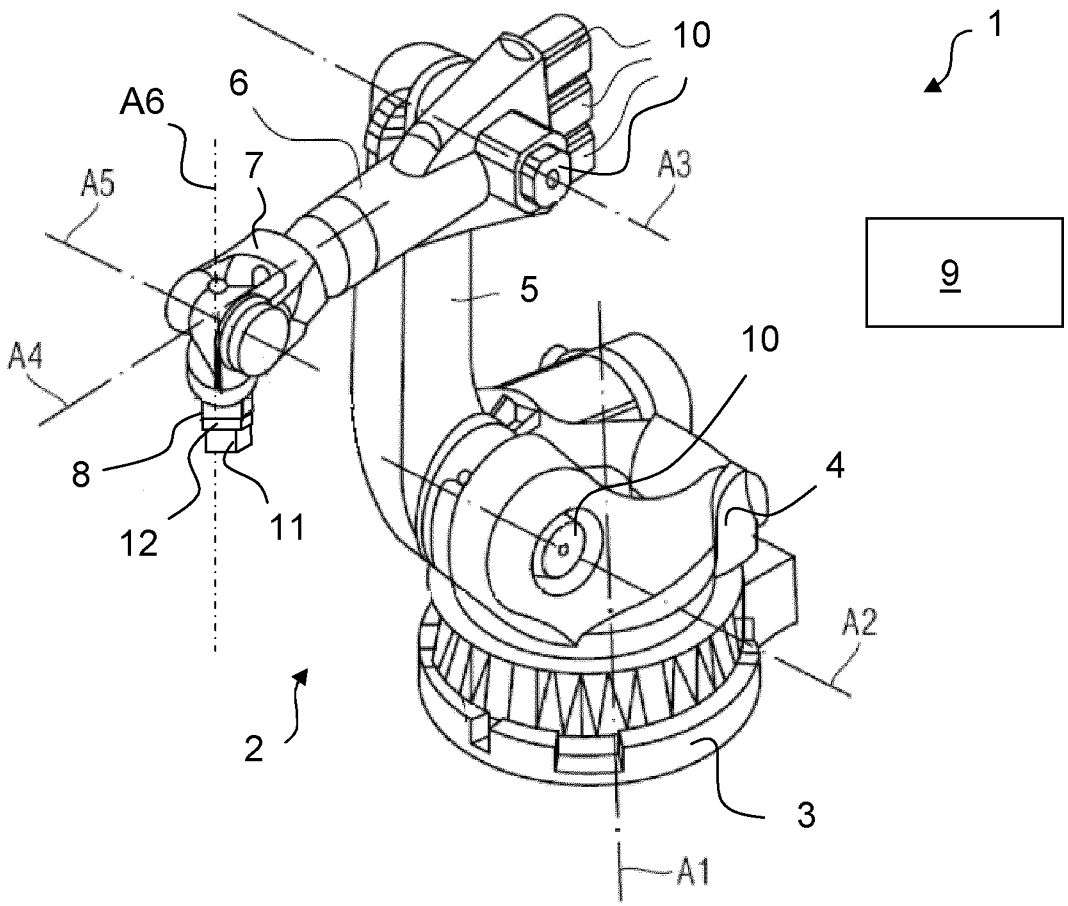

FIG. 1

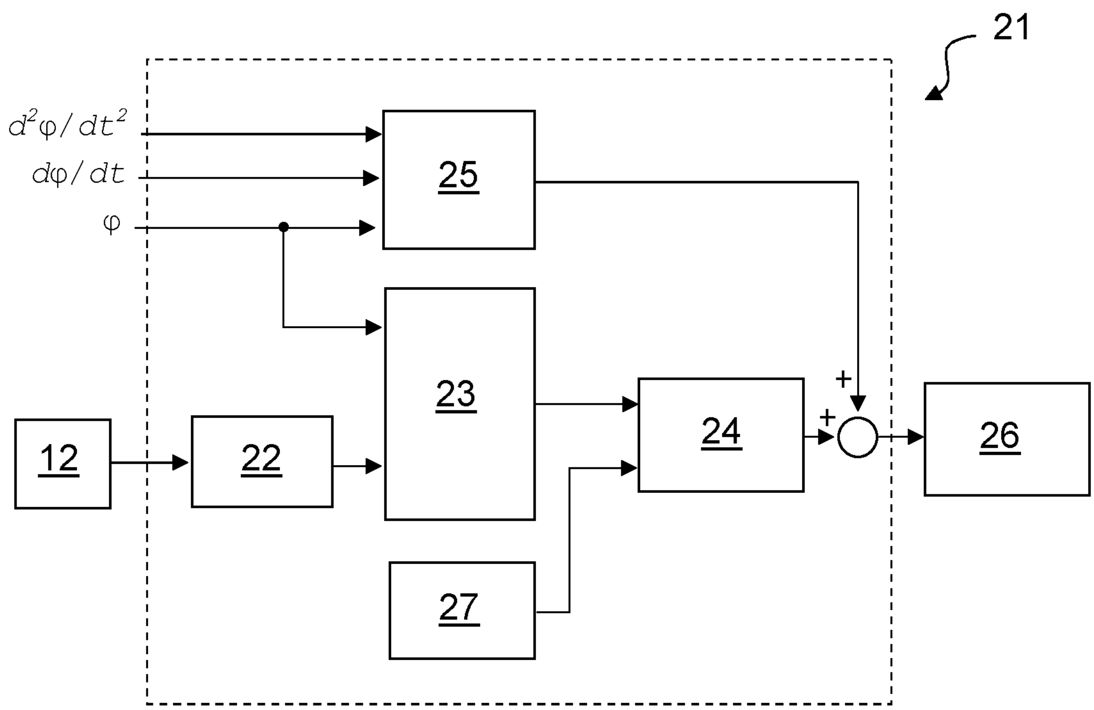

FIG. 2