A RELIABILITY TEST METHOD FOR AGRICULTURAL PADDY FIELD INTELLIGENT ROBOT
/
一种农业水田智能机器人可靠性测试的方法

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ABSTRACT
With the development of artificial intelligence technology, in order to alleviate the labour intensity of agricultural paddy field production and improve production efficiency, the development of robot used in paddy field production has been a hot research in the field of agricultural production. Different from the industrial environment, the agricultural production environment is complex, and there are many interference factors to the intelligent robot. Therefore, ensuring the reliability of the robot in the operation has become an important index in the production process. The model checking technique can evaluate the reliability of the system when designing the system. In this paper, timed automata is used to model the agricultural paddy field intelligent robot, and the environmental influence factor model is introduced, so as to evaluate the reliability of the system qualitatively and quantitatively in the design of the agricultural paddy field robot. Finally, the control prediction of the system safety is carried out, and to provide a definite basis for the actual engineering design.

摘要
随着人工智能技术的发展，为了缓解农业水田生产作业的劳动强度，提升生产效率，用于水田生产的机器人的研制一直是农业生产领域的热点研究。与工业环境不同，农业生产环境复杂，对智能机器人的干扰因素较多，因此，保证作业中机器人的可靠性成为生产过程中的重要指标。模型检测技术可以在系统设计时对系统的可靠性做评估，本文采用时间自动机对农业水田智能机器人进行建模，引入环境影响因素模型，从而在农业水田机器人的设计时对系统的可靠性进行定性与定量的评价。最后对系统安全进行控制预测，并且为实际工程中设计提供确定的依据。

INTRODUCTION
With the development of artificial intelligence technology, intelligent agricultural machinery design has become a hot issue of the new generation of agricultural machinery research.

In China, as a big agricultural country, “smart agriculture” has always been the most sought after goal of people. At the same time, it is also an advanced stage of agricultural development, which includes the integration of Internet of things, cloud computing, automatic control and other technologies. Finally, the intelligent perception of agricultural production environment, intelligent early warning, intelligent analysis is realized, which provides accurate planting, visual management, intelligent decision making and so on for agricultural production. Intelligent agricultural machinery and equipment (currently called "intelligent agricultural machinery" by agricultural machinery management departments in some provinces and cities) is not only an important part of intelligent agriculture, but also an important material means for the development of Intelligent Agriculture. Although most of the current agricultural machinery has information-based operation, its efficiency is still low, cannot liberate human and material resources, waste of human resources and other problems, the design of agricultural machinery integrated with artificial intelligence control is gradually making agricultural machinery more capable of executing instructions automatically, such as *Zhang et al. (2021)* designed based on STM32F7 agricultural machinery automatic navigation operation controller. The controller uses STM32F7 as the main control chip, which is composed of wireless data transmission module, wheel angle sensor, filter circuit and so on. It can realize the path tracking control of agricultural machinery and the control of operation parts according to the control instructions, and complete the combination of automatic navigation and automatic operation.

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Paddy field production has high labour intensity and low production efficiency, so there is a great demand for the development of intelligent robot for paddy field production. At present, there are many applications in the development of intelligent robot for paddy field operation, such as *Zhang et al. (2013)* developed a mechanical weeding robot - a small stampede weeding robot. The use of the robot not only does not cause pollution to the environment, but also because of its small size can meet the requirements of those engaged in agricultural production at this stage. DSP is the main control chip of the robot, and motion control module, data communication module and image acquisition module are designed around the robot. This method is not only flexible and convenient to develop, but also greatly enhances the modifiability and portability, which can realize real-time image acquisition, processing and recognition, so as to achieve the purpose of weeding in paddy field.

Yang et al. (2021) designed and built a robot mobile platform with electric drive, which mainly includes walking chassis and control system. The walking chassis is composed of main frame, electric drive system, walking assembly, steering assembly and lifting mechanism. The control system uses STM32F407IGT6 as the main controller, and realizes remote driving control of robot platform by using speed measuring encoder, angle sensor, AT9S remote controller and R9D wireless module etc. *Zhang et al. (2013)* designed the conventional path planning method of rectangular field for automatic rice transplanter, and then extended it to trapezoidal field, and further designed the path planning method of rectangular field according to the mechanical characteristics and agronomic requirements of cultivated land tractor. This method can not only obtain the optimal path, improve the efficiency of paddy field operation, but also reduce the production cost, which makes the automatic agricultural robot practical, and can control the automatic operation of rice transplanter in any quadrilateral field. *Zhu et al. (2018)* established the single leg finite element model and soil finite element model of foot robot through ABAQUS to explore the influence of typical gait (rectangle, modified cycloid, ellipse, zero impact) and its parameters on unit energy consumption of foot robot in paddy soil environment. Based on C8051F340 single chip microcomputer, *Qi et al. (2013)* and others designed a control system of weeding robot platform suitable for paddy field operation environment. The system is mainly composed of vehicle control module, PC translation and transmission module, and remote control module. It realized two functions of automatic navigation control and manual remote control.

In the design of many paddy field robots, the general robot test method mainly uses the means of field test, the main test indicators include reliability, robustness and other performance indicators. When the robot is in an unstable environment or under certain business pressure, the robot is required to run for a period of time without the influence of the outside world, so as to determine whether the robot can run well. Therefore, it is necessary to observe the running state and resource index of the robot to carry out reliability test; robustness test is the key to judge whether the system can continue to operate normally when the robot is in abnormal or dangerous situation; the test is to test the function of each module and the fault tolerance of the system. The accuracy test requires that the robot can make a more accurate judgment in route planning, image recognition, obstacle avoidance and tracking, and then issue instructions to ensure that the system can run accurately; feasibility test is required to judge whether the robot meets the purpose of project development, whether it is suitable for most people, whether its price is moderate, and whether the allocation of resources is appropriate. For example, *Zheng. (2020)* proposed a method to test the imaging performance of ground mobile robot visual system. It includes resolution, colour difference, distortion and other basic imaging performance, frame frequency, delay, bit rate, video defects and other video quality performance detection methods. It provides a test basis for the inspection of visual imaging performance of ground mobile robot, and provides a theoretical basis for the formulation of inspection method standard of visual system imaging performance of ground mobile robot. The field test of robot paddy field, due to the complex actual working conditions, is greatly affected by environmental factors, and the specific working environment cannot test all the working scenes, resulting in incomplete test. After the test, the system is officially put into use. If the reliability cannot be fully evaluated, the production will be lost.

This paper presents a reliability testing method of paddy field intelligent robot based on timed automata, which can be used to evaluate its reliability in the design process of paddy field intelligent robot, so as to meet the design requirements and ensure the correctness of the system in the model design, so as to reduce the problems in the field test. The model checking technique based on timed automata is a mathematical based method. Therefore, the evaluation process is mainly based on theoretical testing, which has the characteristics of accurate testing and high efficiency. It can be used as an effective means to ensure the rationality of design.

ANALYSIS OF WORKING ENVIRONMENT OF PADDY FIELD

The paddy field environment is different from the industrial environment. In the industrial environment, robots are less affected by uncertain factors. In the paddy field environment, for example, to overcome the problem that the silt block below the water surface may hinder the robot movement, because the obstacle detection module installed on the robot cannot detect the potential obstacles under the water surface. In the long run, it will inevitably cause problems to the operation of the robot, and even lead to idling phenomenon. In the paddy field, weeds are also a common problem, because when the robot is running, weeds are likely to be rolled into the wheels. If this problem occurs, the wheels will be restricted, and eventually the motor will be damaged. For a robot, when it moves in water, the first thing is to prevent water ingress, because the robot is an electronic device after all. When the robot moves in the water, it will inevitably cause water spray. Once the robot enters the water, it will cause the robot to burn to a great extent. In addition, when the robot encounters silt and weeds, it will inevitably lead to the shaking of the paddy field intelligent robot, which will interfere with the signal returned by the intelligent robot, resulting in the signal not being sent back in time and weakening the signal. As shown in Figure 1, the paddy field simulation environment of intelligent robot is as follows:

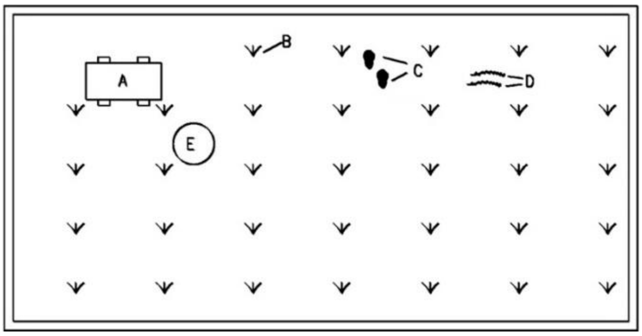

Fig. 1 - Paddy Field Simulation Environment of Intelligent Robot

A - stands for paddy field intelligent robot;
B - stands for crops;
C - stands for silt block;
D - stands for water grass;
E - stands for the sunken part of the paddy field.

The area around Figure 1, where the double solid lines are drawn, is the field ridge of paddy field.

It can be seen from the above figure that if the paddy field intelligent robot wants to realize its basic functions, the first thing it should do is to recognize the crops and not damage the seedlings in the process of movement. If one wants to make the intelligent robot walk according to the predetermined route and not damage the crops, the robot needs to have the functions of image recognition, tracking and obstacle avoidance. When the car moves forward, it will encounter C (silt block). If it wants to cross the silt block, it will need to increase the power, which will make the intelligent robot vibrate, and if the power is too large, the damage to the motor cannot be underestimated.

When the robot is lucky enough to cross the C (silt block), it will encounter D (water grass) when it continues to move forward. Once the water grass is involved in the wheel of the robot, it is bound to have an impact on the movement of the robot. The control centre outputs signals, but the rotation of the motor is not enough to drive the wheel to get rid of the control of the water grass, so there will be machine jam or idling, but no matter what kind of phenomenon, we don't want to see. When the robot is lucky to get rid of the control of D (water grass), it will go to the edge of the paddy field, that is the field ridge. At this time, the intelligent robot needs to have the function of judging whether the road ahead can be carried out. Obstacle avoidance is the basic requirement to realize this function. When completing obstacle avoidance (bypassing the ridge), the robot needs to plan its next route, that is, turn left or right. When the car is lucky enough to bypass the ridge, it will encounter E (the sunken part of the paddy field). Once it enters the sunken area, there will be three problems. Firstly, the rise of the water level is a problem, because the robot is always in the safe water level range when it does not enter the sunken part, but when the robot falls into E (the sunken part of the paddy field), its water level is bound to rise; secondly, when the robot is trapped in E (the sunken part of the paddy field), the vision of the robot will be affected, which makes the signal sent back by the robot unstably; thirdly, if the robot wants to run out of E (the sunken part of the paddy field), it needs to increase the power of the motor, which will cause the robot to shake and have the influence to the signal return.

MATERIALS AND METHODS

Design framework of paddy field intelligent robot

Paddy Field Intelligent Robot generally completes the agricultural production operation in the paddy field. In order to make it work normally, the general design structure of the intelligent robot in the paddy field is shown in Figure 2. It is mainly composed of central control module, camera module, motor drive module, power module, sensor module, display module and wireless module. The central control module mainly processes the images and data uploaded by camera module and sensor module, and turns the processing results into instructions to drive the motor. The camera module is to obtain the external environment in real time, to detect the path visually, and uploads the collected information back to the central control module. The motor driving module is used to drive the motor, which mainly receives the information from the central control module to realize the basic movement of the robot, such as turn left, turn right, straight travel and so on. The power module is used to supply power to the central control module and motor drive module. The sensor module is mainly used to achieve the basic obstacle avoidance or tracking function, which can be used with the camera to improve its stability, reliability and other performance. The display module is used to display the image or video information captured by the camera in real time. The wireless module uploads the information to the computer, which is convenient for the user to monitor the working state of the robot in real time, and the user can judge whether the robot has problems through the uploaded information, which is convenient for timely maintenance.

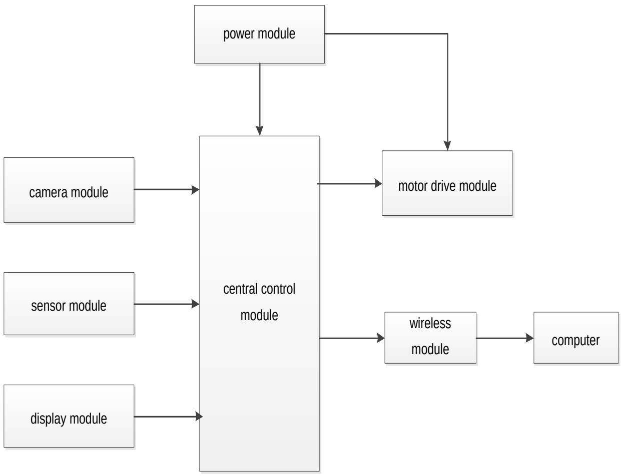

Fig. 2 - Framework of Paddy Field Intelligent Robot

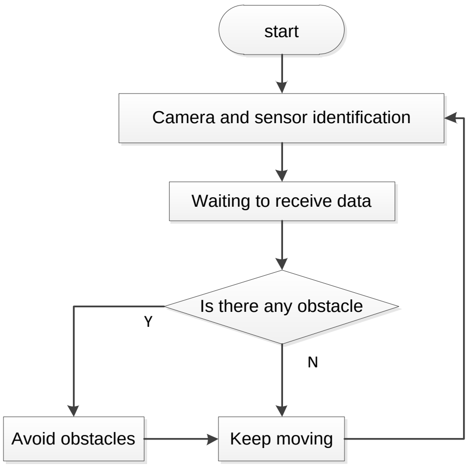

Fig. 3 - Flow Chart of The Paddy Field Intelligent Robot

Figure 3 shows the flow chart of the paddy field intelligent robot system: when the paddy field intelligent robot starts to work, its central control module will wait for the data from the camera module and the sensor module.

Once the data is sent back to the central control module, the central control module will process the signal. For the image or video sent back by the camera, the central control module will carry on the image recognition, and carries on the vision plan to its path, and can effectively avoid the obstacle to a certain extent. For the sensor module, the central control module calculates the distance according to the data sent back, so as to avoid obstacles. The use of camera module and sensor module at the same time will increase the robustness of paddy field intelligent robot to a certain extent. However, after the data returned by the system is processed, if the central control module finds that there is an obstacle in front of it, the control module will send a command to the motor drive module to avoid the obstacle, and the motor drive module will control the wheel of the intelligent robot to wake up the function of turning left or right, so that the intelligent robot can be used normally and efficiently.

The design framework of the paddy field intelligent robot can be widely used in various fields of paddy field, as long as a little change on this basis can achieve a variety of effects, such as the use of weeding in farmland. We all know that there are two traditional weeding methods: the first method is to employ a lot of human resources, and use a lot of weeding tools (hoes, sickles, etc.) to achieve the purpose of weeding by hand. This practice is obviously a waste of human and material resources, employers will also bear a large amount of employment costs, and the efficiency of weeding is low. And the second method is to rely on spraying pesticides to achieve the purpose of weeding. Although this method liberates human and material resources to a certain extent, its disadvantages are still very obvious, that is, a large number of pesticide spraying will cause damage to the environment, and in the long run will cause soil hardening, which is not conducive to the growth of plants. However, if we can add a rotating blade on the basis of the paddy field intelligent robot, and use our camera module to recognize and process the images, we can achieve the effect of weeding specific weeds. Compared with the traditional manual weeding operation mode, the farmland weeding robot can well liberate human and material resources, and greatly improve the agricultural production efficiency, and greatly reduce the harm to the environment. As we all know, the traditional agricultural planting method mainly relies on employing a lot of manpower to carry out manual transplanting. This transplanting method has very high requirements for technical personnel. It not only requires that the transplanter's transplanting force is appropriate enough; if the force is too large, it will damage the root of the seedling, but if the force is too small, it may lead to the impossibility for the seedling to be really inserted into the soil, and finally cause the seedling to be damaged-death. For the traditional transplanting method, people will plan the farmland before transplanting in order to get enough sunshine in the process of seedling growth, but only by visual observation, it is inevitable that there will be errors. But if on the basis of the paddy intelligent robot described in this paper, we add a mechanical arm, use its mechanical arm to carry out rice transplanting, and use the camera of the robot to carry out path recognition and paddy field planning, which not only liberates human and material resources, speeds up the production efficiency, but also ensures the survival rate of seedlings to a great extent. It can be seen that the applicability of the paddy field intelligent robot is very considerable.

Introduction of timed automata and model checking technique

Model checking is a technology of testing and analysing design based on mathematical method. It was first proposed by Clarke and Emerson, Quelle and Sifakis, It is a formal verification method. It analyses system attributes by exploring all reachable states (state space) of system model *(Einollah Pira., 2021)*.The model detection is mainly based on explicit state search or implicit fixed point calculation to verify the modal or propositional properties of concurrent systems in finite state. The model checking method can be executed automatically to determine the correctness, validity and reliability of the system model, and the model checking method can put forward the counterexample path when the system does not meet our proposed properties. Model checking consists of three parts: one is the canonical temporal logic propositional language; the second is the method of coding state machine; the third is the verification method of intelligently searching the state space to determine whether the specification is true or false. Model checking has attracted the attention of academia and industry since it came into being, and its application fields are very wide, for example, it can be used in the analysis and verification of computer hardware, communication protocol, control system, security authentication protocol. A new technique to reduce the explosion state in model checking is proposed in the paper written by *Aung et al. (2021).* This technique, called divide and conquer, is used for the final model checking. As the name suggests, the technology is dedicated to the final attribute. This technique divides the original final model checking problem into several smaller model checking problems, and solves each smaller model checking problem.

Feng et al. (2021) proposed a class of graphical and numerical techniques using model simulation to check the overall fit of the marginal additional hazard model to the current state data of multivariable, the test method is based on the maximum value of the random process, which is based on the cumulative sum of time and covariant residuals. *Baouya et al. (2021)* introduces a novel deployment decision method based on prism probabilistic model checker, which uses software components and physical platform to generate a group of candidate deployment. Starting from system modelling language (SysML), the process includes the mechanism of extracting hardware and software functions and executing a set of candidate deployment. Each candidate should satisfy the reliability attributes written in probabilistic tree logic. Thus, model detection is still a hot issue.

Timed automata is proposed by Alur and Dill. They point out that if A has two clocks, the problem of universality cannot be determined. However, when A has a single clock, their problem states are still unresolved. *Sproston et al. (2021)* closed the gap between infinite word timed automata by proving the uncertainty of the universality of a clock. For timed automata overrun words, this paper proves that a clock universality problem is decidable and has non-primitive recursive complexity. This reveals the surprising divergence between finite words and infinite words in timed automata theory. If ϵ transition or nonsingular postposition condition is allowed, then a clock universality problem cannot be determined in finite words and infinite words. Timed automata is a set of theory for modelling and verifying real-time systems. A timed automaton A is a tuple $<N, l_0, E, I>$ where

- N is a finite set of locations (or nodes),
- $l_0 \in N$ is the initial location,

• $E \subseteq N \times B(C) \times \Sigma \times 2 C \times N$ is the set of edges and

• $I : N \longrightarrow B(C)$ assigns invariants to locations

We restrict location invariants to constraints that are downwards closed, in the form: $x \le n$ or $x < n$ where n is a natural number. *(David Al. et al., 2015)*. A lot of validation tools (such as Uppaal) we know are based on time automata theory. It is easy to guess from the name that timed automata is a finite automata with clock set. When a finite number of clocks are set together, a clock set is formed, and each clock is a variable with a value greater than 0. When the timed automata satisfies certain clock constraints, certain transitions can occur between its states. If the state of timed automata is attached with the property of "position invariance", this property is also equivalent to a clock constraint, so as to ensure that the state will not stay in place. This kind of automata is also called “Timed Safety Automata". Timed automata not only has several real valued variables, but also is an abstract model of time series system. Only when the clock satisfies the clock constraint (guard), its state can jump.

DESIGN AND MODELING OF PADDY FIELD INTELLIGENT ROBOT

Paddy field environment and paddy field operation robot constitute the paddy field production system. On this premise, this paper introduces the paddy field environment model, abstracts the complex environmental factors of paddy field into event input state machine, and then tests and simulates the model. The modelling and analysis process consists of the following steps:

Modelling: the paddy field environment and robot system are described by timed automata tools to make them into discrete and continuous environmental conditions. For example, in the design of paddy field robot, the normal operation of the robot will not be affected when passing through the silt area within a certain length. If the silt area does not exceed the safe range that the robot can bear, it is considered that the robot will be in normal driving state, otherwise it will be considered as abnormal state, and necessary treatment should be carried out;

Model qualitative detection: verify the nature of the model through the given condition, check whether the design model has deadlock and other problems, so as to ensure the correctness of the system design;

Instantiation model: by introducing specific design requirement, the model is instantiated to provide basis for quantitative evaluation of design;

Quantitative analysis of the model: quantitative analysis of the working state of the model through the simulation method, giving the reference of the change of the working state of the model.

System modelling

The description of paddy field environment is introduced into the modelling of paddy field intelligent robot, so the system modelling is divided into two parts: paddy field environment modelling and robot system.

Paddy field environment modelling: the influence of paddy field environment on intelligent robot is composed of many factors, such as weeds, silt, etc. Formal modelling tools such as timed automata are based on discrete event modelling, so continuous events should be discretized first. In the model of paddy field influencing factors, the abnormal continuous events will be quantized and discretized. For example, driving in the mud for a certain time does not affect the robot's moving. When the driving distance reaches a certain range, the output power will be increased to ensure the robot's continuous operation.

Here, the timed automata model as shown in Figure 4 (a) is established. In the model, it is advisable to set that when a certain kind of event is encountered, it will not affect the operation of the system within a certain period of time [I, J]. When such event exceeds the reliability design requirements of the system, the system will produce emergency measures such as error reporting. The event was initiated by E_ S_ Start state to E_ S_ T state and indicates the range of events that the system can process automatically. After exceeding the range, it is judged whether there is still such event influence. In some cases, taking the equal probability model as an example, such events can continue to occur or not. Therefore, there are two branches of event processing. In the model, E_ S_ D() and E_ S_ Er() are used for recording the frequency of the above two situations.

Robot system modelling: intelligent robot system consists of sensor elements which can perceive environmental factors, peripheral equipment of actual operation and core control module. Therefore, these components are modelled respectively.

In general, the core processor of the robot system has a fixed clock cycle. When the system is running, the core control chip is used as the minimum unit of the system running cycle. For this, the model as shown in Figure 4 (b) is established, where M_ S_ start state is the start state of each clock cycle. In each clock cycle, the MS signal is used as the clock cycle signal, and the model uses M_ S_ D () function to record the running time.

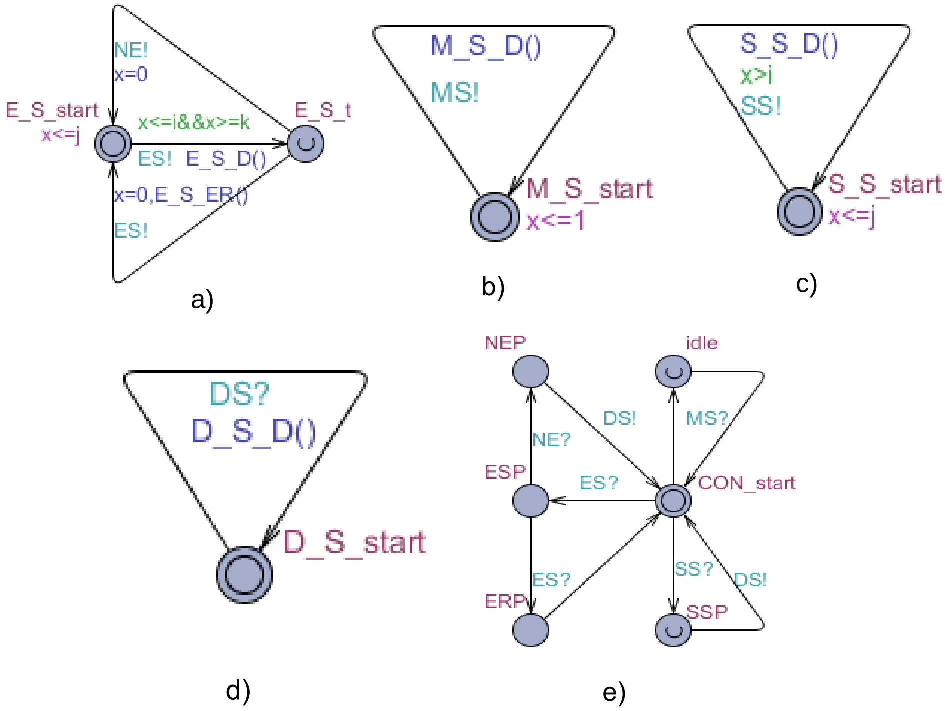

Fig. 4 - Timed Automata Model of Paddy Field Robot System

The sensor in the system is used to collect data at a fixed time interval, and its model is shown in Figure 4 (c), where S_ S_ Start is the initial state of data acquisition, and it is specified to complete data acquisition in time interval [I, J], and send synchronous signal SS, in which the S_ S_ D () function be used for recording the amount of data collected.

The execution device in the system is used to receive signals and perform corresponding work, and its model is shown in Figure 4 (d), where D_ S_ Start is the initial state of the device. After receiving the signal DS, the device performs the corresponding operation. The model uses D_ S_ D () to record the operation of the equipment.

The core control module in the system is used to process corresponding data and send control information. Its model is shown in Figure 4 (E), where CON_ Start is the initial state of the control module. If there is no data input, the system will enter idle state.

If there is a sensor transmitting data, it will be disposed, and then it will enter SSP state. After that, it will send DS information to the device. If there is an abnormal state in the external environment, it will enter ESP state. If there is no impact on the system operation within the scope of reliability design, it will enter ESP state. If the system cannot automatically handle, it will enter ERP state, which is used to alarm or for manual intervention processing.

Case analysis

The model of paddy field intelligent robot system is established by timed automata, which can be used to check the correctness and evaluate the reliability of the model. This paper uses UPPAAL timed automata tool to verify.

Example description

This section takes the paddy field weeding robot as an example to illustrate the process of model verification and analysis. In order to explain the problem conveniently, only verify the visual recognition process. Paddy field weeding robot uses machine vision module to identify weeds. The vision module uses OpenMV camera to collect data, and the recognition time is 12ms. The core microcontroller uses STM32, and the speed is about 13.2MHz. For external events, the passing of silt is regarded as an external abnormal event, and it takes about 3.5 seconds for the design to pass 5cm silt.

The model variables are initialized according to the above data, as shown in Table 1. The running speed of the core is very fast compared with the acquisition speed and the initialization unit 1 is 0.01ms in the M_S model, so the running rate controlled by the core should be about 104 times in this time interval. According to this standard, the parameters i and j in S_S model are about i = 15, j = 18. In E_ S model i and j are initialized as i = 460 and j = 500, where k is set 480, which means that the interval between 460 and 480 is the interval where the abnormal event occurs but does not affect the operation of the system. If the abnormal event continues to occur after that, the system cannot automatically handle it.

After the model is instantiated, the effect displayed by the timed automata tool UPPAAL simulator is shown in Figure 5.

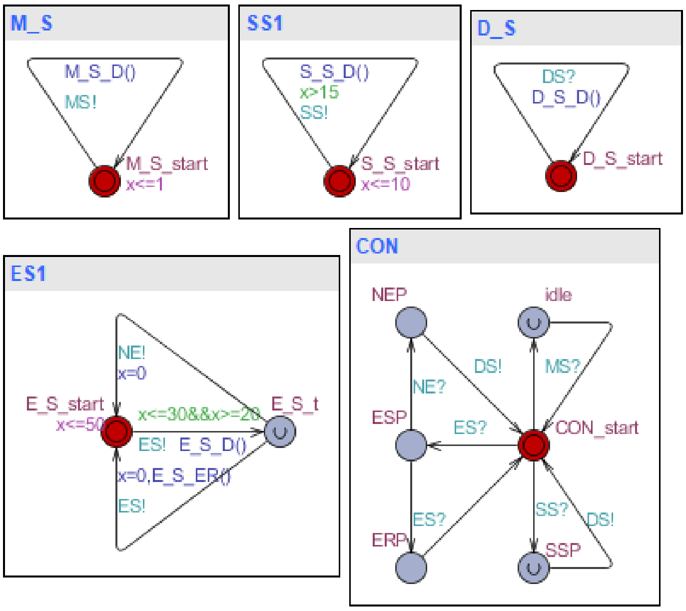

Fig. 5 - Example Model of Paddy Field Intelligent Robot System

Verification of model properties

The properties of system design model can be used to test the correctness of system design and provide theoretical evidence for the guarantee of system reliability. In this example, we can verify whether the execution logic of the system is correct and reliable through reachability. It can be verified by inputting the corresponding BNF expression in the model verifier of the timed automata tool UPPAAL. Such as, whether the sensor signal can be correctly processed, E < > CON.SSP imply D_ S.D_ S_ Start, Table 1 lists the expressions of model correctness verification, and the results verified by the verifier.

For other properties in the system, UPPAAL can be used to verify the relevant characteristics according to the engineering needs.

Table 1

Examples of Paddy Field Intelligent Robot Model Verification

EXPRESSION	EXPLANATION	RESULT
E<> CON.SSP imply D_S.D_S_start	Verification of the correctness of the signal sent by the sensor which is processed by the controller	Satisfied
E<> CON.ESP imply ES1.E_S_t	Whether the controller can handle verification when an exception occurs	Satisfied
E<> CON.NEP||CON.ERP imply ES1.E_S_start	The processor can handle verification normally in two cases of abnormal events	Satisfied
E<>D_S.D_S_start imply ES1.E_S_t ||SS1.S_S_start	The execution device performs verification caused by signals collected by sensors or abnormal events	Satisfied
E<> CON.idle imply M_S.M_S_start	Controller standby state verification	Satisfied

Simulation analysis

The nature of the model can qualitatively verify the model, but it cannot give quantitative data simulation. The dynamic simulation of the model can be carried out by using the simulator, and the quantitative evaluation of the model can be given by analysing the relevant simulation data. This example model uses the simulator to carry on the simulation operation, and can carry on the quantitative research to the related indexes, such as the utilization rate of the microcontroller and other indexes, which can be used to optimize the system design. The experiment simulates the microprocessor running about 2500 cycles.

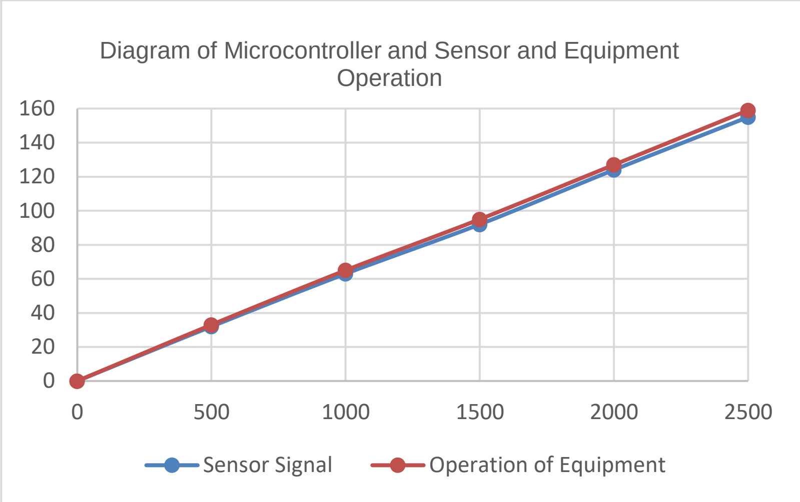

Fig. 6 - Simulation Diagram of Running Relationship between Microcontroller, Sensor and Equipment

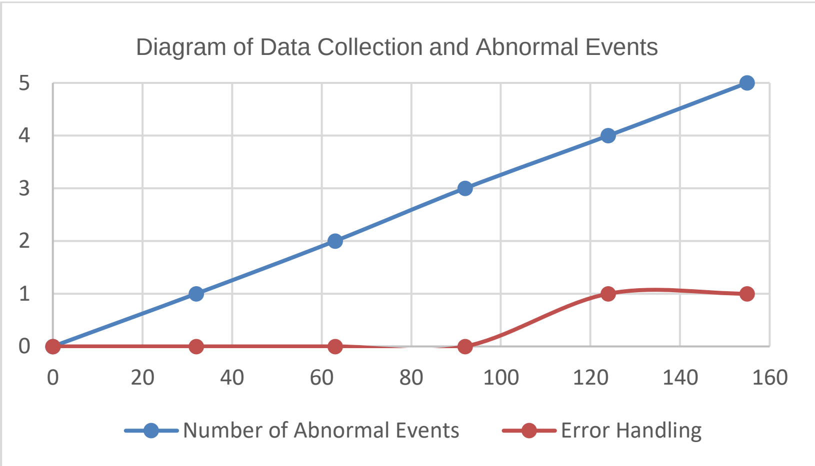

Fig. 7 - Simulation Diagram of Corresponding Relationship between Microcontroller Running Time and Abnormal Events

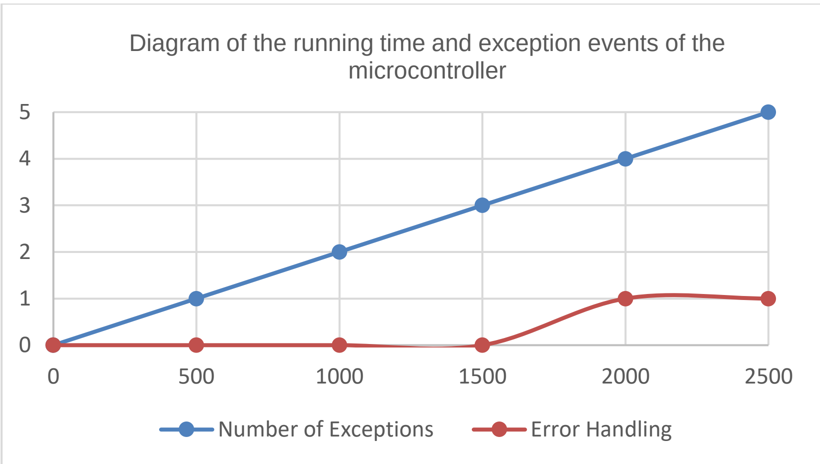

Fig. 8 - Simulation Diagram of Corresponding Relationship between Collected Data and Abnormal Events

Figure 6 shows the simulation results of the running relationship between the microcontroller, sensor and equipment. Corresponding to the microcontroller, the sensor takes a long time to collect data. From the data in the figure, it can be seen that the microcontroller has a lot of standby time. Therefore, the microcontroller can run more modules to make full use of its processing capacity.

Figure 7 shows the simulation data results corresponding to the running time of the microcontroller and the abnormal events, in which the abnormal events appear in a periodic manner to complete the test of whether the system can stably handle the abnormal events. As shown in Figure 6, when the abnormal events accumulate to a certain length of time, the system fails to handle the situation and enters into the error handling phase.

Figure 8 shows the simulation results of the corresponding relationship between the collected data and the abnormal events. In the relationship of Figure 8, it can be seen that the occurrence of abnormal events is similar to that in Figure 7. Since the collection data is approximately linear with the operation time of the microcontroller, the situation shown in Figure 8 is similar to figure 7, and the correctness of the system operation state is verified. It can be seen that the system abnormal error is a small probability event compared with the system operation cycle. It can be used to calculate whether the system meets the reliability requirements of the design requirements.

CONCLUSIONS

Aiming at the analysis of paddy field intelligent robot system and its running environment, this paper puts forward a model checking method based on timed automata for the design of paddy field intelligent robot system. Using this method, the correctness of the system design can be verified by formal method, and the designed model can be simulated and analysed by relevant model checking tools, so as to provide basis for system design optimization and ensure the reliability of system design.

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