CONTROL FUSION IN BULLDOZER

—— AN APPLICATION OF THE NEURAL NETWORK ——

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ABSTRACT

The construction work and the machine action are very complicated. This is the main reason why the automation at construction site is very difficult and not realized yet. Focusing on the complicated and cooperative action of construction machinery, which needs combination of several actuators, some are repeated and some needs great skill. And all of them needs recognition of the environments as a result of work. Here, the necessity of cooperation between automatic control and human control are found.

The fusion will be realized through recognizing the intention which takes real shape in the manipulation and producing optimized control signal according to the prior knowledge. The coupled control sysytem is proposed to realize this system in the blade control of bulldozer, as a tipical case of the construction machinery. This system is consist of two element. One is to produce optimized control signal for each job, and the other is to recognize intention of the operator from his manipulation and to select the optimized signal for the job.

In order to realize the key unit of recognition, the neural network is selected. In application of the neural network, the problem of confusion in the trangent period between typical pattern was treated through application of the variogram. And the neural network with competetitive learning system could recognize leveling operation from the manipulation signal and the piching signal.

Keywords: coupled system, neural network, minimum variance estimator, bulldozer

1 Introduction

A robot of the playback type was first developed in the U.S. in 1962 and was brought to Japan five years later. The "hand" known as the "manipulator" which was unlike the human hand or robot's hand in the SF world, was substituted for the human hand in factories. Thereafter, these manipulators underwent rapid improvement and widely spread together with NC machine tools within 10 years for the automation and robotization of entire factories.

When we look at the construction industry, rationalization is now being demanded in order to cope with the advancing age of the labor force and the low level of labor productivity in the construction industry which is currently characterized by economic and technological exchanges at the international level. Much effort is being made to solve the problems. However, no great improvement has been achieved in the industry when compared to the automation in factories. To cope with these problems, rationalization that makes great use of mechanized construction work is urgently needed, and the robotization of the construction machinery is the core of the rationalization.

For this purpose, several construction robots have been individually developed and much publicized but most of these were not directly related to the rationalization of construction work. Therefore, for restarting the robotization in construction, the authors have studied the themes of automation in the area of construction machinery and reviewed one direction or objective of the construction robots.

This report presents a concept of control system for the construction robot and an application of the automation concepts to the bulldozer. The concept of control system was introduced from analyzing the flow of automation by comparing it to the automation in factories. And in the application of the automation concepts to the bulldozer, the neural network is known to be effective in the coupled system.

2 Requested Items for Construction Robots

2.1 Characteristics of Construction Work and the Measures for Robotization

The construction work may be roughly classified into jobs by general purpose machines offering functions made from complicated and diversified composite operations, and jobs by special purpose machines that repeat simple, univocal operations. Also, for some part of the jobs by special purpose machines and the jobs by general purpose machines, it has been pointed out that the purpose and effects of the jobs can be planned and evaluated on the basis of the coordinates.

For construction machines similar to those used in factories, it is of course necessary to carry out the present automation by considering the control of the machines on the basis of methods derived from conventional control methods. For instance, in the case of the diaphragm wall rigs, the work can be univocally determined by the coordinates from the ground surface to the location where the machine is set, and the work can be carried out by using the coordinates as the target and any deviation from it as the assessed value. For other machines similar to the above, control is possible upon the basis of mainly the information obtained from the internal sensors in the main body of the machine.

However, the general purpose construction machines that represent the majority of construction machines have other aspects greatly differing from the equipment in factories. The key issue is the following two items.

a) The mechanism is not divided into simple element

b) The position or the state of machine can not be determined by the univocal coordinate.

In the machine tools such as lathes, the work used to be fixed in manual work but with mechanization, the work is rotated and the tool fixed and simplified instead with the automation of machine tools realized through this conversion. On the other hand, ordinary construction machines such as hydraulic excavators for example, can be considered as an enlarged tool for workers. In other words, the operation and mechanism of hydraulic excavators itself magnifies the complex actions of workers (Fig.1). For instance, an excavating operation is determined not by the locus of the bucket but by the kind of action performed upon the earth or by the characteristics of the mutual relationships and the lapse of time between the actions of each element. Because of this, the element of work can be explained only when the relation with the external situation is known and cannot be determined by univocal coordinates.

Also, the main objects of construction work are earth and concrete materials, and the work can advance mainly by moving these materials through stacking and cutting. In this sense, the construction work can be said to have the nature of molding work. In this kind of machine and work, the construction machine corresponds to the tool tip of the manufacturing machine, and the earth corresponds to the processing work(Fig.2).

Thus the position and the state of the construction machine is the key to estimate and program the work. And the identification of the state is to be synchronized with the work programing.

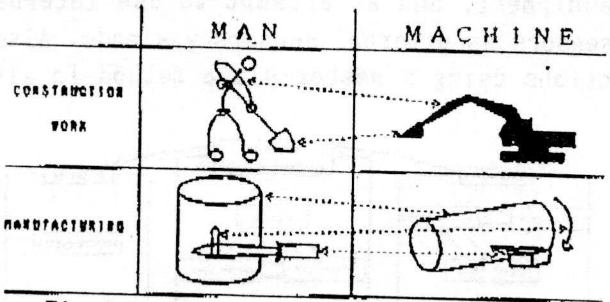


Fig.1 Factory and Construction Work

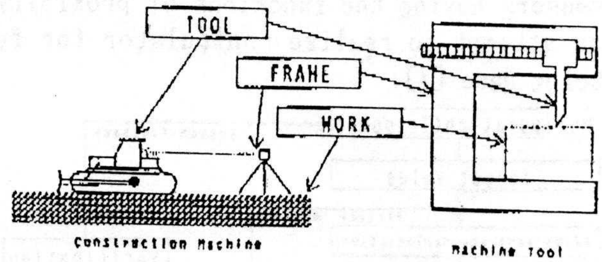


Fig.2 Machine Tools and Construction Machines

In this way, the construction work is formed by the stacking of very intelligent and sensor-dependent operations. And in case of finishing the floor, even sizes of several tens of meters or the 1 centimeter order are required to have dimensional accuracies of less than 1 mm on the surface. Thus, the mutual supplement of absolute coordinates and incremental coordinates instead of the absolute coordinates or a control separated from coordinates is now requested. Therefore, the conventional control method which evaluates the behavior plan and its effect on the basis of position coordinates may not be able to provide sufficient accuracy and information for work planning. Thus, the mutual supplement of absolute coordinates and incremental coordinates instead of the absolute coordinates or a control separated from coordinates will be requested.

In promoting the automation of construction work having the characteristics stated above, there is one more problem that the system shall be formed where workers and robots coexist and cooperate instead of estranging the workers as in factories. A system of cooperation between independent robots and workers can be finally considered, and this will be initiated by the realization of a cooperation phase where operators manipulate the robots while always guiding them.

2.2 Changes in the Control of Construction Robots

For construction machines having the characteristics as stated above, the following explains how robotization has been carried out for general purpose construction machines having properties peculiar to the construction work. The explanation will mainly concern a typical hydraulic excavator and bulldozer.

2.2.1 Progress of Robotization in the Hydraulic Shovel

In the automatic mechanism of a hydraulic excavator, the following has been attempted for particular operations extracted from several work patterns [9]:

a) To realize operation by the coordinated operation of plural actuators by means of one button or one lever.

b) To perform indication or positioning for key points in work.

These are controlled only by internal sensors, and the control is of the closed loop type for one part of the operation but is of the open loop type for the construction machine as a whole. A feedback channel for returning the system output in the form of manipulation is held by the operator(Fig. 3).

A trial of change from the automation for only the playback portion stated above to the automation for different coordinates even for the same operation has just started. One of the authors has attended automation as the continuity of patterns which do not fix the coordinates [6]. In this case, the operation of a hydraulic excavator was divided into several elements, and the work was considered as their network(Fig. 4).

No fixed coordinates were designated for the elements, certain algorithms were assumed for determining the position of working equipment, and an attempt to use internal sensors having the functions of proximity sensors as external sensors was made. Also, an attempt to realize manipulator for functions using a master-slave method is also being made [7].

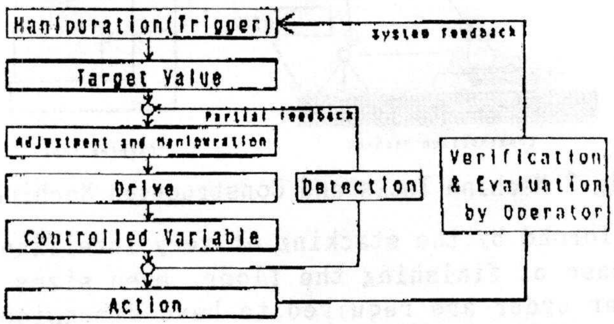


Fig.3 Partial Feedback and System Feedback

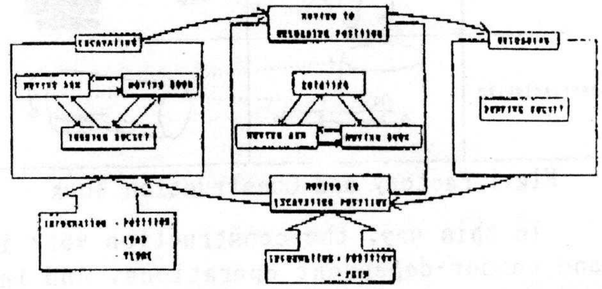


Fig.4 Operation of excavater as a Network of Action Units

2.2.2 Progress of Robotization in the Automation of Bulldozer

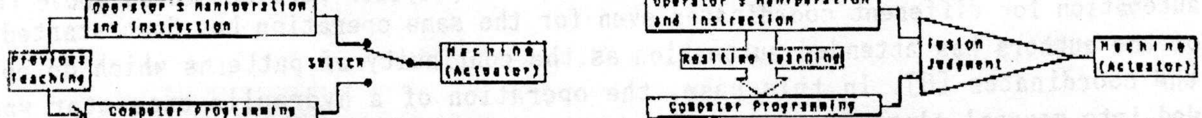
In the automation of bulldozers, a first attempt was made to develop a device to maintain the blade at a certain height. This was for forming a reference plane by rotating a laser beam at a constant height and maintaining the blade height in alignment with the reference plane. This device was mainly introduced for farm land consolidation for leveling huge areas of land and has realized a level of finish that is independent of the skill of the operator. However, although this method can form flat surfaces, it cannot create land in accordance with a design.

In order to eliminate these shortcomings, the Public Works Research Institute and Komatsu Ltd. jointly studied and developed a control system performing three-dimensional measurement in 1987. As the position measuring functions, two 'lighthouses' with rotating laser beams are installed, the angle of line-of-sight is calculated from the timing of receiving laser beam by sensors attached to the bulldozer, and the position calculated by trigonometry from the angle and the distance between the laser lighthouses. In addition, the sensors attached to the front and rear of the bulldozer can measure the slant, height and direction of the bulldozer. Based on the data from these sensors, landscaping can be now performed automatically in accordance with a design, even though the change in height may be limited.

If the ground surface has not already been roughly prepared to an average height, these control mechanisms often cause problems such as difficult forward movement due to pushing of an excessive volume of earth by the blade or difficulty in sensing the position of the bulldozer in accordance with the design. Therefore, what is needed is to design a mechanism that is easily able to perform work by receiving assistance given by an operator for those aspects of bulldozer operation requiring high skill.

2.3 Fusion of manipulation and Automatic Control

Conventionally, "how to move faithfully as instructed" was the main objective of a control mechanism. However, this kind of negative, passive control filter basically relies upon the correctness of the instructions and performs only ON-OFF switching for direct instructions(Fig. 5).



(a) Conventional Control System (b) Ideal Control System (Fusion)

Fig.5 Two types of Control System

The complementary relationship that has been sought between man and machine, has been realized to a certain extent when the robot relies upon an operator for the portion requiring the intelligent sensing and the operator relies upon the robot's judgment for the mechanical portion. In this form of cooperation, the robot determines the intention of the operator from the manipulations, reacts as instructed if the instructions contain the optimum manipulations contents, and outputs the optimum operations instead of those manipulations if the instructed manipulations are not appropriate. Moreover, since the purpose of operation is not given by numerals such as coordinates, the operations are assessed by successive manipulation inputs from the operator.

3 Proposal of Positive Control

3.1 Concept

In the basics of conventional automated machines, the tasks are executed automatically on the basis of program as long as no errors are created [11]. In recent years, several new control methods have been proposed as a manifestation of the trend (Fig.6). These include supervisory control in which tasks are subdivided and prepared as a menu, and their selection performed by the operator; and advanced telecontrol in which computers offer assistance work in error processing (and an operator offers assistance if the robot is considered as the leading part).

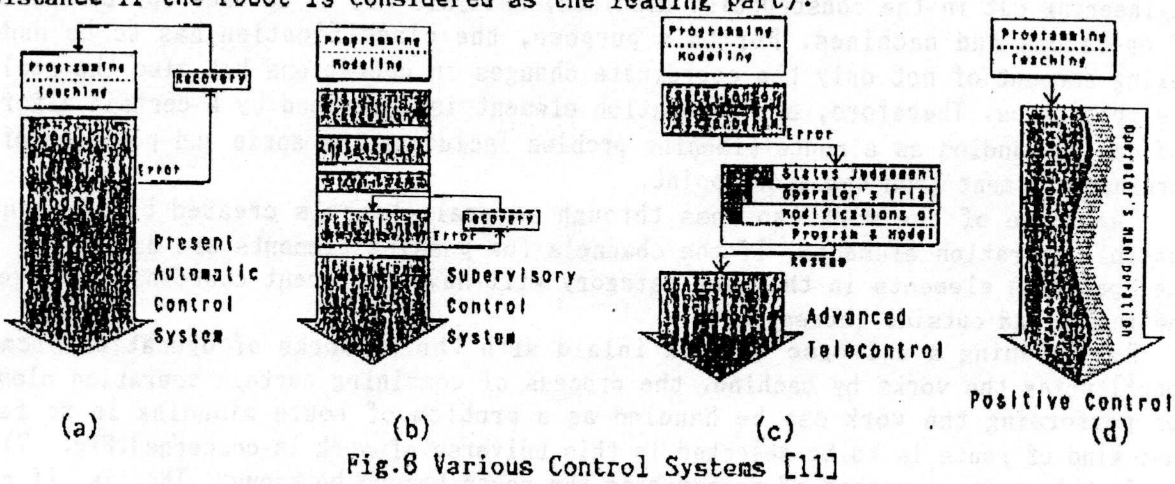


Fig.6 Various Control Systems [11]

Fundamental to robot operation planning is the recognition of the difference between the final target and the present situation. In case of construction machine, there are many kinds of operation elements constituting the work, and the ways of combinations of the operation elements vary widely. In factory work, materials are able to stand alone in most cases and there is no such a concept of "stability of working face" in the performance of cutting work. However in construction work, each job has to be performed little by little and in sequence, instead of cutting a whole portion at a time. Therefore, here are several methods for decreasing this difference, and the method to be used will be determined depending on the size of the difference and the the forecast and recognition of the influence by the planned operation.

Measurement of the present situation is one of characteristics of work by general purpose construction machines. First, an absolute measurement is needed in recognition of the present situation corresponding to the target shape. Secondly, a relative measurement is needed in recognition of the stability in the process of changing from the present situation to the target shape, of the situation occurred by the previous operation, and of the influence upon the next operation.

For the first recognition, it is necessary to have an absolute reference point for measurement, and the measurements from this reference point must have the predetermined accuracy. For the second recognition, there are three problems, though most jobs have to be performed in accordance with the operation plan based on this recognition.

a) The influence of work (such as the instability of cutting surface) can be hardly predicted.

b) The progress in the middle of work is important.

c) The non-contact recognition of quality (such as loosed earth and ground) is vitally important.

Therefore, it is intended to rely upon operators for feedback by relative recognition which directly restricts the individual operation, to make decisions automatically for the operation range, to reduce the combinations of construction machine operations into flexible pattern combinations, and to realize those which can operate by means of optimum operation outputs.

3.2 Work Planning and Route Planning Problem

All work can be divided into several operation elements as stated above. And the individual operation elements are classified by purpose and movement independently from the position on the coordinate system. This is caused, as already pointed out, because the construction machine itself is a magnification of the actions of laborers and tools. Only the elemental actions of laborers were considered in the industrial engineering but in the construction machines, analysis has to be made for combinations of operators and machines. For this purpose, the classification has to be made by taking account of not only the coordinate changes in operations but also the goals of the operations. Therefore, each operation element is described by a certain algorithm and can be handled as a route planning problem including the angle and position of the working equipment from the start point.

The route of the work can pass through several channels created by adjacent or possible operation elements. If the channels for passing elements are different, then the operation elements in the same category will have different coordinate changes at the inside and outside thereafter.

By presuming a universe of work inlaid with the networks of operation elements constituting the works by machine, the process of combining certain operation elements for performing the work can be handled as a problem of route planning in so far as what kind of route is to be selected in this universe of work is concerned(Fig. 7).

In this case, a method of prescribing the route has to be known. That is, if rough routes can be prescribed by the operator's manipulation, then there will be a high possibility of realizing the optimum route by using a very simple algorithm. Also, if there are well-arranged algorithms and sufficient external sensors, then there may be the possibility of realizing route planning independently of operators.

3.3 Components

This control mechanism comprises two control units for recognizing the operator's manipulations and for creating the optimum output as well as sensors for real time control information. Works by bulldozer can be roughly divided into ground leveling, excavation and dozing(pushing earth by dozer blade), with each blade operated by an individual algorithm. Thus, it is being attempted to realize operation based on multiple algorithms, and real time control by continuous input through the judgment of work target on the basis of the machine condition and manipulation input and by making a selection from several optimum operation outputs.

In this kind of control mechanism, not only the level of an operator but also even his habit are learned by the control mechanism, so that this kind of information has to be recorded in a certain form in a portable memory unit so that when an operator mounts on a machine, this has to be transmitted to a control device as in the case of engine key, and the learned information has to be always updated.

The operation elements to be selected on the basis of changes with time in the operator's manipulation and on the information from the required minimum outside sensors are first selected, and the optimum output (route) is sent out in accordance with the respective algorithm in order to drive the actuators. Then, when the next manipulation is performed after the machine has started moving in response to the previous manipulation, the properness of the output can be determined and the knowledge base update by learning(Fig. 8).

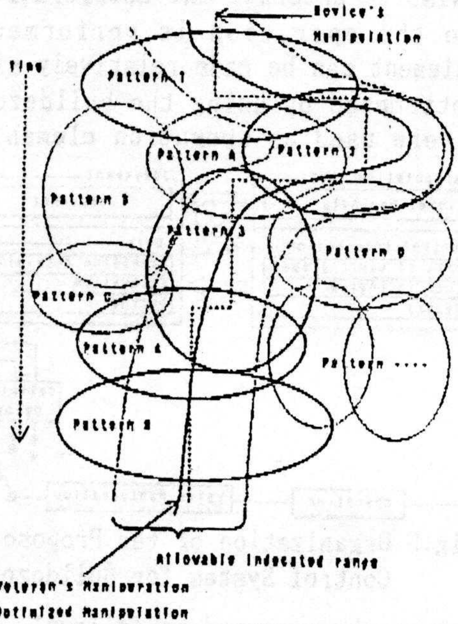


Fig.7 Image of positive control

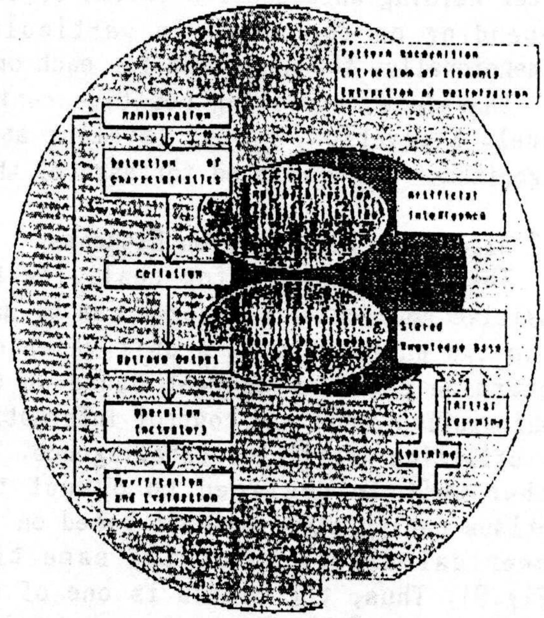


Fig.8 Components of positive control

4 Application to Construction Machines

4.1 Operation Elements of Construction Machines

In excavation work using a hydraulic excavator, no excavation is possible by merely pushing the bucket hard because the motion of scraping up is also required. Also, when the volume of loosened earth reaches a certain volume, the operations of scooping up and scraping up are both necessary at the same time. Therefore, control based on the purpose of lever manipulation is required to determine whether the claw is inserted at the optimum angle for the degree of stress applied to the bucket and the increase in the volume of loosened earth in front of the bucket, so as to cancel the pushing operation and give priority to the scraping operation, or to automatically give a scooping-up operation simultaneously with scraping. Together with the above, sequential control such as the mechanism for horizontal extrusion or maintaining the bucket angle can be utilized. Also, for loading scooped earth by a hydraulic excavator in particular, earth is unloaded at the same place several times, so that it is effective to automatically store its position in the memory and to move quickly to that position. However, in this kind of machine, the motion is made three-dimensionally so that the operation element algorithm becomes complex.

In an example of ground leveling work by bulldozer, an unskilled operator is unable to move the blade in alignment with the pitching of the machine body so that the phenomenon of more waving occurs if the operator tries harder to make the machine level. To cope with this, it may be possible to judge whether the manipulation is for leveling work from the oscillation of the machine body and the up and down patterns of the blade, to cancel the blade operation which does not match the pitching of the machine body, and to move the blade up and down at the optimum timing. In this case, the blade operation is generally made with a time delay from the pitching of machine body, so that a manipulation signal has to be sent in advance in the positive control. Therefore, if there is no following blade operation which is expected to occur according to the previous manipulation, it is necessary to judge if this is a change in work and if necessary, to cancel the signal previously sent out. In addition, under the concept of the positive control, it may become possible to raise the blade for escape after holding an excessive volume of earth and also to automate the acceleration work depending on the load. In particular, since the operation is performed two-dimensionally, the algorithm for each operation element can be made relatively simpler.

Therefore, realizing positive control was attempted by using the bulldozer as a model. Excavation, ground leveling and dozing were used as operation elements, and algorithms were attempted for each of them.

4.2 Algorithms of Operation Elements

The configuration for realizing the positive control of bulldozer can be made from two units. One is a unit which can determine the work content based on the manipulation input and control information by utilizing artificial intelligence. The other unit is designed to output the optimum manipulated variable based on the numerical algorithm at the same time (Fig.9). Thus, the system is one of the coupled system[13]. The basic concept in this case can be arranged as follows:

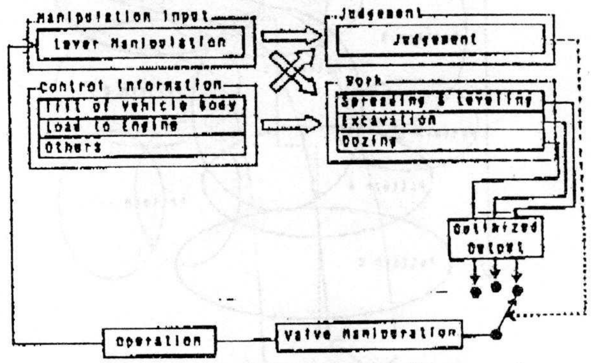


Fig.9 Organization of the Proposed Control System for Bulldozer

4.2.1 Excavation

In the excavation work, the branching judgment is made at the start and end of the work. That is, at the time of start, the blade is lowered to the required excavation depth and is advanced and then excavation performed horizontally at the level where the blade raising operation is made. However, the main body enters into the excavated portion and then the blade is affected so that a required operation is performed. Then, before holding a limit volume of earth, manipulation for stopping the excavating work and for shifting to the work of dozing is performed. In an actual machine, the limit is determined from the situation for slip between the crawler and the ground surface or the load to engine. This limitation can be negrected, because the operator can easily recognize it and perform some manipulation.

4.2.2 Dozing

In the work of dozing, the blade moves as if it traces the ground surface. Therefore, in the case of an actual machine, the ground surface is verified by visual observation and is then traced during operation. For automating the machine however, the ground surface is very difficult to recognize and the burden on the external sensors have to be reduced as much as possible. Thus, the blade supporting force will be maintained to a level which is able to withstand the downward force created by the rolling of the weight of the blade and the earth borne. Thus the dosing as a transportation of earth is very similar to the leveling.

4.2.3 Leveling

If the ground surface has a large swell, the work of excavation and dozing is indispensable for smoothing the surface. In ordinary ground leveling, the surface is leveled by moving the blade up and down in response to the pitching of the machine body. That is, the wavelength of swell is close to the length of the machine body in ordinary ground leveling work.

If the wavelength is less than the length of machine body, then the ground leveling can be performed by holding the blade at a position referenced to the center point of the machine body. If the wavelength exceeds the length of machine body, the blade should not be delayed when the machine goes across a peak or dip. And here exist the most difficulty in operation.

4.3 Selection of Operation Elements

With respect to the recognition of various manipulations, if the manipulations are considered to be not optimum by the major premise, then it becomes difficult to recognize the purpose of manipulation from a certain algorithm partly because the operator's habits are incorporated into the manipulation itself. Therefore, to respond to the change in manipulation due to improved skill, it becomes necessary to change the algorithm for recognizing the manipulation.

As stated above, in the sense of changing the algorithm itself which is difficult to be systematized, the use of artificial intelligence can be considered. In particular, the bulldozer has less kinds of work elements so that the element number of outputs is smaller when compared to the element number of inputs thereby making the introduction of AI seems to be effective. In this case, another algorithm is also required for determining whether the results of optimum output have been appropriate or not, but the same unit for this determination may be utilized depending upon whether the determination after a certain time delay is the same as before or not.

In the work of ground leveling by bulldozer, the determination can be made on the basis of the up and down motion of the blade relative to the up and down movement of the machine body, or on the basis of the average height of the blade and the average height of the ground. Since the height of the ground cannot be measured without an external reference point and the recognition of the change due to work cannot be easily performed, it is more realistic to adopt a determination method based upon the slant of the machine body and the blade operation.

In case of the operation of the construction machinery, the operation will be decided on the basis of intelligent recognition of its environment. The algorithm is very complicated, and difficult to be translated to computer.

The authors are interested in the manipulation which involve the intention of the operator. And also, it is intresting that the intention is a result of intelligent decision based on the aim of work and present situation. Thus the recognition of the intention expressed in lever manipulation is the key in the proposed system.

5 Construct the control system

In the application of the positive control to bulldozer, the clasification of operation is the problem. The system will be divided into two components. One is the unit to produce optimum output based on machine status, the other is the unit to select optimimum output. The problem in the former unit has been introduced in many opportunity, and also our institute has been studying this problem. The problem in the latter unit needs the application of AI in order to eliminate the analisys of confused, evasive and equivocal algorithm.

In this kind of recognition, the problem is whether the decision is logical. As a general, the algorithm of this decision cannot be devided from environment recognition which needs high level inteligence, though the algorithm itself is simple. Therefore, the application of AI system in the recognition of the intention will be effective to utilize the intelligence of operator. And the authors aimed at the neural net as a self

-tuning intelligence without definit algorithm of the pattern recognition. There is som eproblem in the application of neural-net to the recognition of the intention of the operator from his manipulating pattern.

5.1 Identification of the Output of the Neural Network

One of the most important problem is that the data set of certain period shifts as time goes, because the data set is some seriese of operating patern in the last period. This causes the conventional pattern matching method by the neural net will confuse between the tipical patterns.

First the neural network with competitive learning method is assembled. After learning several patterns, the network get capability to identify them. This network is confused and can not identify in the transient period from one pattern to the other (Fig. 10).

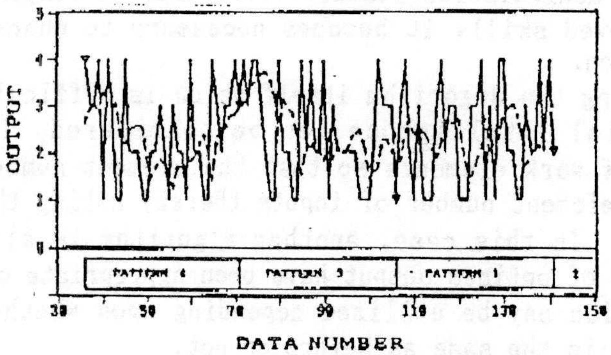


Fig.10 Application of Valiogram to the Neural Network

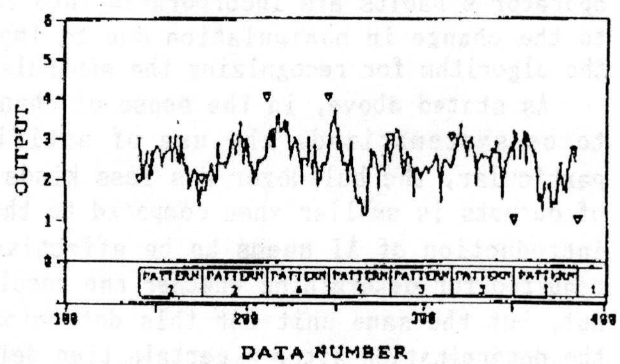


Fig.11 Application of Valiogram to the Neural Network

If the network obtained the enough ability, the tendency of the output will mean the identification. In order to treat this kind of dispersed data eliminating noise, the authors interested in the minimum variance unbased estimators for a class of nonhomogeneous random fields from noisy observation data. Mathematical analisys of this estimation model is explained in full detail in the literature number 14.

In application of this method to identification of the output of the neural network, the method of presumption in order is expected to be effective. This is why the estimation shall be done depending on the past data, because the data is obtained one after another and the data set is nonhomogeneous[15]. Application of this method to the typical pattern recognition can identify the transient from tipical point(shown in the figures by ∇) to the other as shown in Fig.10 and 11.

5.2 Application to the identification of operation

In order to confirm that the neural network with the minimum variance estimator can identify the intention of operator by his manipuration, the autors tried to determin the actual manipuration by the neural network.

At first, the manipurationdata and the machine status(pitching, brade position) is obtained under the following condition. The pitching was sensed by the vertical gyroscope. The manipuration of the operator was senced by setting the potential meter to the brade control lever. The brade position was senced by setting the potential meter to the brade lift cylinder.

a) prepare the undulation on th ground, with wavelength of 2, 3 and 4 times of the crawler length

b) perform the leveling work, recording the pitching, lever manipulation and stroke of the brade lift cylinder

c) the operation was done by veteran and novice

By this experiment, the operation data was obtained as shown in Fig. 12. After regularizing them, the neural network learned to identify the pattern of work for 30 times. After the learning, the output of clusters could not show the distinction, as it was expected.

After application of the the minimum variance estimator, the output level is relatively high in the leveling work period(Fig. 13). In this figure, the VARIOGRAM is the correction term at the minimum variance estimator. In reference 14 and 15, the VARIOGRAM is one of correlation function because the minimum variance estimator treats data whose domain is two dimension. Thus the application of neural network is effective to determin the intention of operator through his manipuration.

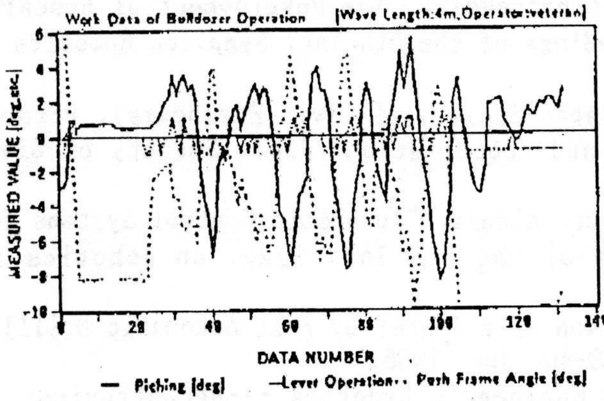


Fig.12 Work Data of Bulldozer

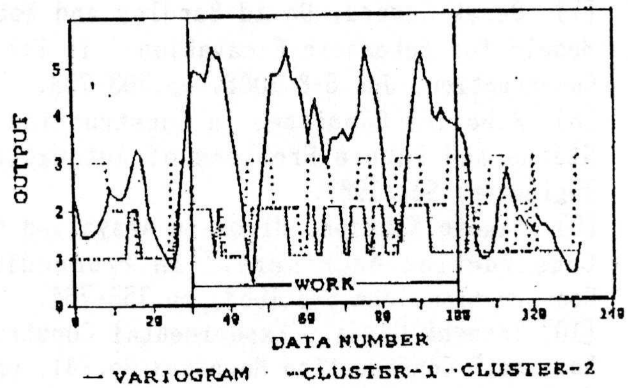


Fig.13 Valiogram in Application of the Neural Network

6 Conclusion

It is difficult to perform unmanned operation since the work is carried out in coexistence with man. The numerical control is difficult in prescribing and using coordinates. And the operation being human-like with complex algorithms and the progress of work is important. As a cooperative method between man and machine overcoming these obstacles in the automation of general purpose construction machines, a positive control which is able to harmonize man's instructions with machine's instructions has been proposed instead of the conventional method which switches between computer and operator manipulation.

In order to realize the positive control system, the coupled system is proposed to the bulldozer control. In the coupled system, the unit of selecting the optimum output based on the intention of the operator is vital. Here, the application of neural network to this unit was tried. And the competitive learning method was tried in this application as an unsupervised learning method. In this application, the neural network could identify the leveling work of the bulldozer.

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