The 2010 IEEE/RSJ International Conference on
Intelligent Robots and Systems
October 18-22, 2010, Taipei, Taiwan

Dual Structure of Mobiligence –Implicit Control and Explicit Control–

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Abstract— **In this paper, we propose an idea which can solve the complexity of the overlapping situation observed in control system of living things. We introduce an another element between controlled object and control law. This newly introduced element is named as Implicit Control Law and decided by interaction of the controlled object , the control law and the field. Furthermore, the Implicit Control Law does not only solve the indivisibility problem but also produces a start point for understanding of realtime environmental adaptation function of living thing with tiny brain. That is, the Implicit Control Law is a core principle of Mobiligence.**

I. INTRODUCITION

Living thing can move adaptively even if put it in an unknown environment. We call this ability as Mobiligence[1]. Furthermore, many living things, for example ant or bee, often construct very big and complicated nests[2].

If we observe these behavior, it seems that complicated program for constructing the nests or producing adaptive movements are implemented in there brain system. However, we know that their brains are too tiny to memorize such a huge program. Then, where is the ability for this highly sophisticated action of living things which hold only limited calculation resources hidden?

Till now, to solve the secret we often put them to our laboratory and analyze the brain, but we have not understood the mechanism of the ability. Intuitively, we must have overlooked something important. But we have not known the missing thing until now.

On the other hand, because Mobiligence is an upper function of motion ability, to understand the mechanism of Mobiligence we have to know the mechanism of the control system embedded in the living thing. See Fig.1.

Norbert Wiener proposed Cybernetics[3]. And in Cybernetics, he treated both living things and artificial machine uniformly via signal flow. This concept is one of the origin of modern control engineering. Owing to this development, we have been able to treat the living thing as a simple control system. This has been a big contribution to the problem which we want to solve.

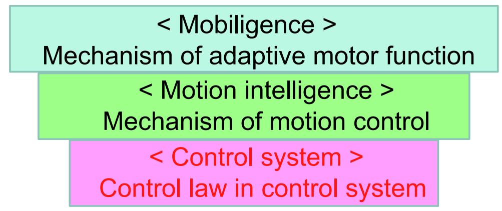

Fig. 1. Mobiligence is on Control System

However, we also notice that we can not interpret the living thing as a control system as mentioned before.

For example, we can see that the following properties belong to the system of living thing.

- P1 **Indivisible system:** Border of plant, control law and field are not clear.
- P2 **Non-stationary system:** Border of plant, control law and field are not fixed.
- P3 **Sel-freference system:** Biological system can produce reference trajectory by itself.
- P4 **Self-energy-generating system:** Biological system has energy source inside the body.

These are the properties that are not seen in most artificial control system. As we mention later, the most essential property in the above four is Indivisibility(Indivisibility system). In other words, once we could treat this property well, then we can expect that the other properties can be treated properly too. Here, we define the problem, which find a method for treating the indivisibility well, as Problem of Indivisibility.

Generally, in the field of control engineering, we often assume that a controlled object and a control law are exactly separated and a reference trajectory is given from outside of the control system. Therefore, it is hard to analyze the system which has the above properties via control engineering approach. We are thinking that this is a reason why the traditional control engineering approach has not been successed to solve the understanding-problem of biological control.

From the above discussion, we came to know that the problem which have to be solved firstly is the Indivisibility Problem (that is to say Overlapping Problem).

Therefore, in this paper, we propose an idea which can solve the problem. To overcome the complexity of the overlapping situation, we introduce an another element between

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controlled object and control law. This newly introduced element is named as Implicit Control Law and decided by interaction of the controlled object , the control law and the field. Furthermore, the Implicit Control Law does not only solve the indivisibility problem but also produces a start point for understanding of realtime environmental adaptation function of living thing with tiny brain. That is, the Implicit Control Law is a core principle of Mobiligence.

Here, to distinguish the ordinary control law from Implicit Control Law, we call the ordinary control law as Explicit Control Law. And, we would like to claim the following two points. (a) Implicit Control Law plays an important role for emergence of Mobiligence. (b) To understand the mechanism of Mobiligence, we have to understand both Explicit Control Law and Implicit Control Law.

In other words, what we have been missing in the past research must be Implicit Control Law . Or, the living things construct their Explicit Control Law to utilize Implicit Control Law effectively. These two are the hypotheses what we want to say in this paper. See Fig.2.

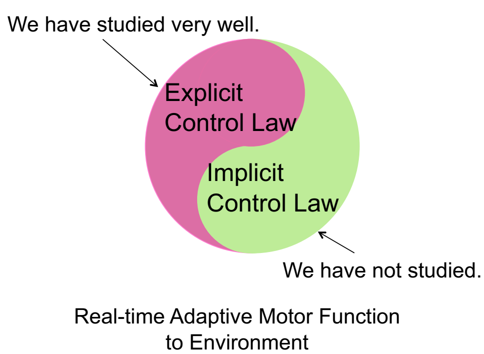


Fig. 2. Explicit and Implicit Control Law

The construction of this paper is the following. In Chapter II, we consider a biological control system and introduce the Indivisibility Problem. In Chapter III, we define the Problem of Embedding to clarify the Indivisibility Problem. Then, for an answer to the problem, we propose a concept of Implicit Control Law. In Chapter IV, we show that the Implicit Control Law holds a key for solving the secret of realtime adaptability. And we lead a conclusion that the Implicit Control Law can be a candidate of a common principle of Mobiligence.

II. Biological Control System

In this chapter, we consider a biological system as a control system and define the Indivisibility Problem. This is the motivation for introducing a implicit control law later.

A. Observation of Biological Control System

It is well known that all ants construct their nests. For example, Fig.3 shows an anthill built by magnetic termites. This is about 6m height and the inside structure of the anthill is very complicated and sophisticated one[4].

It will be sure that a control system is embedded to some kind of living things making an organized behavior.

Fig. 3. Anthill of Magnetic termites

Therefore, we try to treat a living thing as a control system and try to express a block diagram of the system. Then, we soon notice that we can not express such a clear block diagram as shown in Fig.4. The question is "Which part is a controlled object and which part is a control law?" For

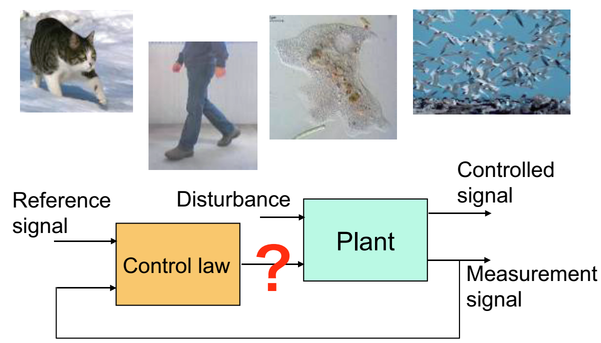


Fig. 4. Control System and Living Things

example, in case of human or cat, muscles and bones system seems to be considered as a controlled object and cerebral nerve system seems to be a control law. However, it is known that many local feedbacks are embedded in muscles or nerve systems and these seems to be both controlled object and control law. Furthermore, it will be clear that the creatures such as an amoeba , a slime mold and a sea cucumber cannot distinguish controlled object from a control law definitely.

B. Problem of Indivisibility

From the previous subsection, it is difficult to express a living thing as an ordinary control system. On the other hand, remember that the living things have evolved since ancient age without distinguishing these parts. We merely have treated these parts separately for our convenience. Therefore, if we express a living thing as a control system, it is suitable to express the system as the block diagram as shown in Fig.5 instead of Fig.4 .

Where we define the terminologies in the figure as the following.

- D1 E(Environment) : Space where all of the individuals (a living thing or a group of living things) belong is defined as Environment.
- D2 S(Control System) : The individual inside the space which is considered is defined as Control System .

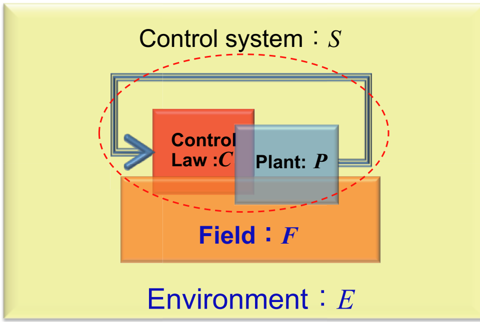


Fig. 5. Control System of Living Things (2)

D3 F(Field) : A subset of environment which affects the behavior of the control system is defined as Field .

D4 P(Plant) : An element which belongs to the control system considered as a controlled object is defined as Plant.

D5 C(Control Law) : An element to be able to consider to work effectively to control the Plant along a purpose is defined as Control Law.

It is noticed that the border between P and C is not fixed, that is this is a time-varying elements. Other words, Fig.5 can be said as a picture of a snap shot. And, because E exists every time, we omit E and only F is drawn from now.

Here, considering the above discussion, we define the following problem.

Def.1:Problem of Indivisibility: When the border between control law and plant does not seem to be necessarily clear, in a certain control system, we call this with Indivisible Problem. □

III. Implicit Control Law

In this chapter, we define a problem of embedding to attack the problem of indivisibility, and propose a concept of Implicit Control Law as a solution for the problem.

A. How to treat the overlapping

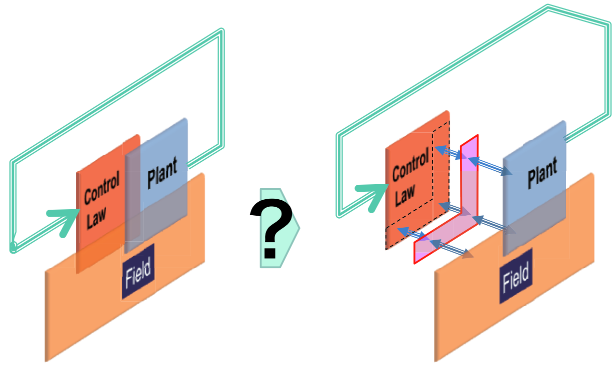
In control system of biological system, there are various pattern of Problem of Indivisibility. In this section, we consider a method for treating these patterns uniformly. The point of this is how to treat the overlapping.

After some considerations, we came to think that the following idea must be an effective method for solving the overlapping problem. The idea is to introduce an another element which is sandwiched between the Plant and the Control Law instead of overlapping. That is, as a solution to the Problem of Indivisibility, we propose the block diagram shown in right hand side of Fig.6 instead of the block diagram shown in left hand side of Fig.6.

B. Problem of Embedding and Implicit Control Law

From the above discussions, we formulate the following problem.

Def.2:Problem of Embedding: Problem of embedding can be defined as the problem which makes clear the possibility



(a) Overlapping? (b) Something exists?

Fig. 6. Overlapping or something exists?

that a kind of control law appears by interacting with plant and field. See the right hand side of Fig.6. And, "to answer the following questions" is defined as "to solve the problem". (i) Clarify whether such an element is embedded in the control system or not. (ii) If there is a possibility, then show us the element clearly. □

Furthermore , if some kind of control law can be found, then let's define the following partial implicit control laws.

Def.3:Explicit Control and Implicit Control: When a kind of element which appears by interaction between Plant$P$ and control law can be recognized as an another control law, then call this element as Implicit Control LawC_I. The remainder element We call an element which remained after substract Implicit control law from control law as Explicit Control LawC_X. See Fig.7. Therefore, Control Law consists of Explicit Control Law and Implicit Control Law as shown in the next equation.

$$C = C_X \bigoplus C_I. \tag{1}$$

Where, $A \bigoplus B$ implies composition of A and B without common set. □

Furthermore, we divide the Implicit Control Law as the following.

Def.4:Decomposition of Implicit Control: Implicit Control Law consists with the three parts as shown in the next equation. See Fig.7.

$$C_I = C_F \bigoplus C_P \bigoplus C_{FP}. \tag{2}$$

Here,

C_F Field dependent Sub-Implicit Control Law,

C_P Plant dependent Sub-Implicit Control Law,

C_{FP} Plant and Field dependent Sub-Implicit Control Law.

□

When we observe decerebrate cat[6] and a slime mold, an amoeba, their behavior seemed to be able to be realized (even if or an effect becomes small) without Explicit Control Law. In addition, if we see various results concerned with passive dynamic walking[7][8] [9]which can be regarded as a system without Explicit Control law, we can say the existence of Implicit Control Law.

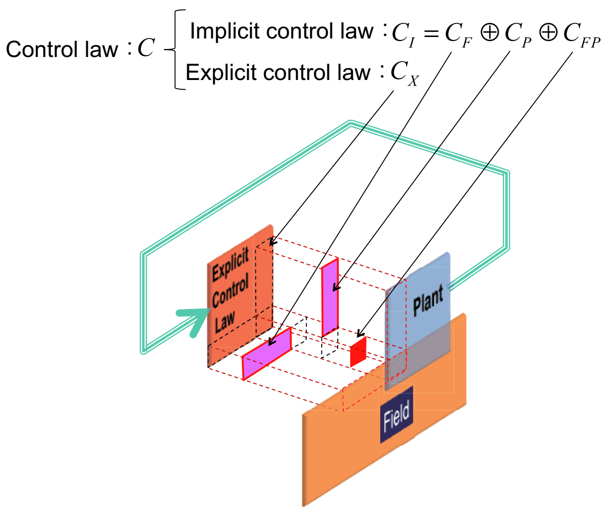


Fig. 7. Structure of implicit control law

C. Special Solution of Implicit Control Law

From the above discussion, to consider the biological control, we gradually focus a target and we found that we should locate the Implicit Control Law as the first step. Therefore, we discuss the Implicit Control Law in this section.

We have not yet found the general formulation of Implicit Control Law, we can show you the Implicit Control Law in a special cases. That is to say, we can show you some special solutions. At this stage, we expect that, by showing some special solutions, we may show the existence of general solution including the special solutions. See Fig.8.

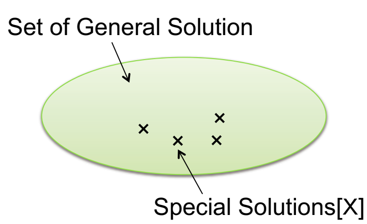


Fig. 8. General and Special solutions

One method for finding a special solution is to find and arrange a special situation in such a situation feedback loop and Explicit Control Law disappear. The conditions for the motion is the following.

Def.5:Condition of Motion: We call the motions which satisfy the following conditions as Open loop and decoupling motion.

1) The motion has a meaning.
2) The motion is stable. That is, the motion can be realized with no external input. □

In this section, considering a motion which satisfies the above conditions, we show an example of Implicit Control Law[5].

Consider an attitude control problem of manipulator in the gravity field shown in the left hand side of Fig.9. The first joint is fixed on the ground. In this case, the Field is the gravity field. Here, for simplicity, suppose that the all joints are rotary type and the all axis of the joint are perpendicular to the paper. Each joint has no friction torque and can be supplied input torque.

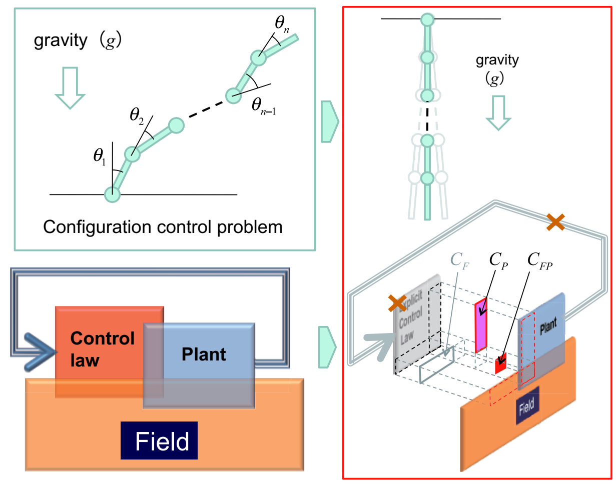


Fig. 9. From closed loop system to open loop system

Among the set of attitude control problems, we can find the next special problem which satisfy the above Condition of Motion. The problem is this. As shown in the right hand side of Fig.9, let us consider the problem of the attitude control problem: Let the manipulator straight to the downward.

Actually, this is a realistic attitude problem and we can easily check that this motion satisfies the above Condition of Motion. In the following, we confirm this i intuition and show the Implicit Control Law in this case. That is to say, we solve the Problem of Embedding.

At first, the dynamical equation of the manipulator can be obtained as

$$J(\theta)\ddot{\theta} + c(\theta,\dot{\theta}) + B\dot{\theta} + h(\theta,g) = u. \quad (3)$$

Where, $\theta = [\theta_1, \theta_2, \cdots, \theta_n]^T$ is a joint angle vector and set $\theta = 0$ when the manipulator straight downward. The u is n dimensional input torque vector, the $J(\theta)$ is a inertia matrix, the $c(\theta,\dot{\theta})$ is a centrifugal and Corioli's torque, the $B\dot{\theta}$ is the viscosity friction torque term. The $B = diag\,[B_1, B_2, \cdots, B_n]$ is the coefficient of viscosity friction of each joint. THe $h(\theta,g)$ is the acceleration of gravity, and $h(\theta,0) = h(0,g) = h(0,0) = 0$.

Here, we have the following result.

Result 1: In case of the attitude control problem of manipulator, the sub-implicit control laws C_P and C_{FP} can be obtained as the following.

$$C_P \quad : \quad u_P = -B\dot{\theta} \quad (4)$$
$$C_{FP} \quad : \quad u_{FP} = -h(\theta,g) \quad (5)$$

See Fig.10. □

Proof) In Eq.(3)(manipulator), if we set a target attitude as $\theta_d = [0,0,\cdots,0]^T = 0$, then we have $lim_{t\to\infty}\theta(t) = \theta_d$ with

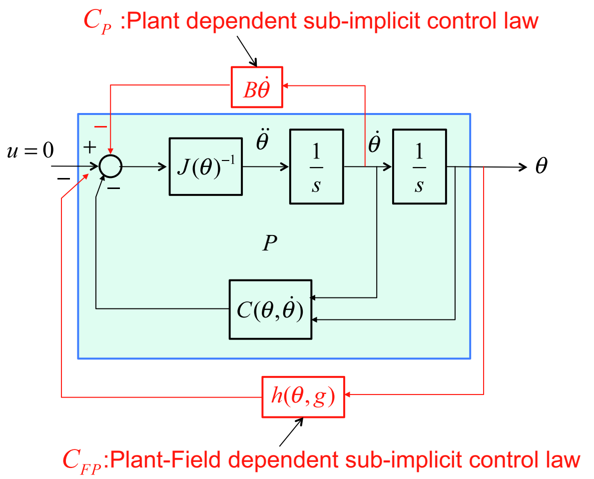


Fig. 10. Two implicit control law in manipulator configuration control problem

$u=0$. From the proof of this fact (for example see[10]), we can see that the term u_P produces the asymptotic stability of the state, and the term u_{FP} control the attitude of the manipulator to the target attitude. And in this case, because $u=0$, then we have no Explicit Control Law. So, we have no C_F. Furthermore, the term $u_P=-B\dot{\theta}$ is not field dependent term, but is plant dependent term. And the term $u_{FP}=-h(\theta,g)$ is field dependent term. Concretely, by change of the acceleration of gravity, this term also changes. Also, this term change by the change of the physical parameters of the manipulator. That is to say, the term u_{FP} is the field and plant dependent term.

From these discussion and the definition of C_P and C_{FP}, Eq.(4) can be regarded as the Plant dependent Sub-Implicit Control Law and Eq.(5) can be regarded as the Field and Plant dependent Sub-Implicit Control Law.

Here, we have to notice that these implicit control laws work on the specified target. That is to say, if the task changes, then the suitable implicit control law also should change. □

In the previous example, we show the two of three Sub-Implicit Control Laws (C_P and C_{FP}). We have not introduce the third one: C_F. It is assumed that this Sub-Implicit Control Law C_F is born between Explicit Control Law C_X and Field F. Therefore, to have C_F in the individual, the individual system has to have a kind of high level Explicit Control Law.

That is, we can say that such a system must have a high level adaptive motor function. In addition, the interaction between Field and Explicit Control Law may not be done by dynamical effect but be done by information effect. We have not yet been carrying out precise discussion on this point. But we are thinking that this topics must be related with the idea of Emergence of Constraints proposed by Yano[11].

IV. Implicit Control Law and Realtime Environmental Adaptation Function

A above, we introduced the Implicit Control Law as one solution for the Problem of Indivisible in the creature control system. Moreover, this Implicit Control Law can be understood as an important key for the expression of the real-time environment adaptation function that a creature had.

In this chapter, we investigate C_{FP}, which seem to have the strongest relationship to the environment adaptive function, from an adaptive functional point of view. The result shown in the previous section was restricted very simple one (special solution: see Fig.8). But, the result implies the possibility of existence of general solution of Implicit Control law.

As see the following, the C_{FP} is the most important for appearance of realtime adaptive motor function of biological systems. Till now, we expressed that the Sub-Implicit Control Law C_{FP} is appeared by interaction between plant and field. Actually, in case of the attitude problem of manipulator, the Sub-Implicit Control Law C_{FP} appears when the manipulator is in the gravity field, and disappears when the gravity field is removed (that is $g=0$.).

Thus, the following "summary" is obtained. See Fig.11.

- The Sub-Implicit Control Law C_{FP} is the implicit control law which is appeared by the interaction of field F and plant P. And, this is induced by the feedback structure constructed between plant and field. We call this feedback structure "Implicit Feedback structure".
- The Sub-Implicit Control Law C_{FP} disappear with disappearing the interaction of field F and plant P.
- The SUb-Implicit Control Law C_{FP} changes in realtime according to realtime variation of the field F.

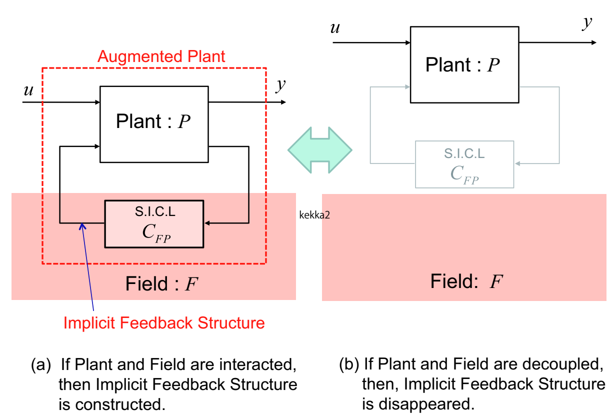


Fig. 11. Appearance and disappearance of C_{FP}

Integrating the above considerations, we can have the following our understanding of the realtime adaptive motor function of living things.

The field surrounding the living things changes in various factors. The change will occur by the change of the field itself. The field seen from the living thing changes by the movment of the living thing. To cope with these changes, living things seem to embed a kind of adaptive function so as to maintain the internal state or itself optimal. If they do not do so, their life become danger.

Then, we can naturally derive an assumption that the element which can have such an adaptive function may be the Explicit Control Law C_X. Because the Implicit Control Law is constrained by the Field or the Plant, the element is not suited for the element.

From these discussion we have the conclusion of this paper.

Conclusion: Realtime Environmental Adaptation Function: We understand the realtime environmental adaptation function of the living thing as the following.

R1 [Existence] The realtime environmental adaptation function of the living thing come from the Sub-Implicit Control Law C_{FP}.

R2 [Function] The function of the realtime adaptation of the living thing is a function which adjusts the Explicit Control Law C_X so as to utilize the characteristics of Implicit Control Law C_{FP} efficiency. See Fig.12.

R3 [Understanding] To understand the realtime adaptive ability of the living things, we have to know both Explicit Control Law C_X and Implicit Control Law C_I simultaneously. Especially, because the Implicit Control Law never exists outside the Field, if you take the living thing out of the field and put it in your laboratory, you never understand the realtime adaptive ability. Of course, in this case, you can understand the ability of the Explicit Control Law C_X. But this does not mean that you can understand the whole ability which we want to know. See Fig.2. □

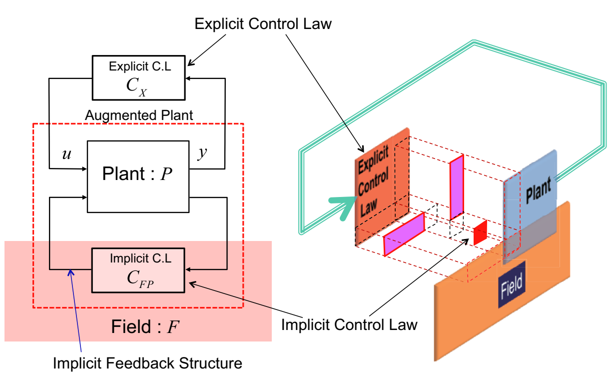


Fig. 12. Explicit Control Law and Implicit Control Law

V. Conclusion

In this paper, we proposed a concept of Implicit Control Law. And we led that both understanding of the Explicit Control Law and the Implicit Control Law are necessary to understand the realtime environmental adaptation function of the living things (Mobiligence). From this point of view, we can say that the traditional researches concerned with this topics have been concentrated to only the research of the Explicit Control Law.

From now on, introducing the Implicit Control Law, we have to carry out re-thinking of the realtime environmental adaptive function.

If we see some moving things, we often wonder why they can behave in such a complicated manner with very simple control law. This feeling can be obtained from not only living things but also artificial things. Especially, we strongly feel the feeling when we see the behavior of insects who has only tiny brain. The typical example is the anthill introduce in ChapterII-A. At this stage, we are convinced that this anthill have never built by only Explicit Control Law of the ants. The Implicit Control Law must be constructed by interaction with the Field.

Finally, we can say that, at this stage, we understand the problem of Mobiligence. This means that we understand the location of the problem of Mobiligence and clarified the essence of the problem. That is to say, what we have to do from now is to focus our consciousness to the Implicit Control Law.

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