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Local Navigation System Using Prospective and Retrospective Landmark Sequences

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Abstract– We propose a dedicated local navigation system inspired by the sequence learning mechanism of the entorhinal-hippocampal loop circuit. The proposed system uses prospective and retrospective landmark sequences for dedicated human-like navigation. The retrospective landmark sequence enables the system to store and recall partially overlapped multiple routes and accomplishes the judgment of the correct direction at a crossing without any other trials. The proposed system is designed based on a standard digital manner, and the phase-coded data register unit included in the system handles both prospective and retrospective landmark sequences. In this paper, the behavior of the proposed system is described and the importance of the retrospective landmark sequences in practical local navigation is discussed using simulation results.

1. Introduction

Today's rapid progress in information technology gives us a plenty of fruitful products. Navigation systems using GPS information lead us to our destination by giving only start and end points to the systems on high-resolution digital map data. Lack of such GPS information, however, suspends the systems, and we lose our ways. A flexible local navigation technology without GPS information is expected as the way to make up for the weakness of the above high-performance navigation systems.

We can reach our destination using our experiences even if environment changes slightly. Recently, place cells have been found in the hippocampus and the entorhinal cortex, and theta phase-coding of place sequences has also been unveiled [1, 2]. Igarashi et al. have proposed a network model of the entorhinal cortex layer II (ECII) with entorhinal-hippocampal loop circuitry as a computational model of the sequence learning in the brain [3]. Loop connections between stellate cells in ECII are selectively potentiated by afferent signals to ECII, and consequently stellate cells connected by potentiated loop connections fire successively in each theta cycle. In our previous work, we developed a local navigation system inspired by the sequence learning mechanism of ECII with entorhinal-hippocampal loop circuitry and confirmed the validity of the navigation system in experiments using an autonomous mobile robot [4]. However, the system handled only one sequence at a time for storing and recalling.

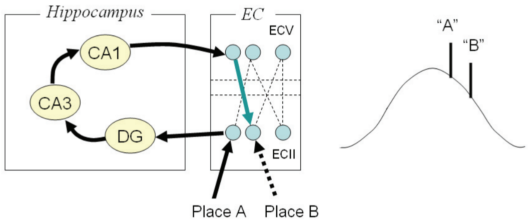
An effective key for solving this problem is the use of retrospective sequences. Frank et al. suggested that the retrospective coding is important for animals to make a decision on which way to go [5]. Yoshida and Hayashi have proposed a computational model of the retrospective sequence learning in the hippocampus; neurons that learn a sequence of signals can be produced in the hippocampal CA1 using propagation of neuronal activity in the hippocampal CA3 [6].

We propose here a dedicated local route memory system using prospective and retrospective sequences for human-like local navigation. The information on retrospective sequences enables the system to store and recall multiple routes without any other trials. We will describe the mechanism of the proposed system and discuss the validity using simulation results.

2. Sequence learning mechanism in the entorhinal-hippocampal loop circuit

We focus on the sequence learning mechanism in the entorhinal-hippocampal loop circuit in this chapter. Igarashi et al. have proposed the ECII network model with entorhinal-hippocampal loop connections [3]. In their model, a pair of afferent pulse trains to ECII whose frequencies were properly different was selected by virtue of loop connections, and loop connections were selectively potentiated by the pair of the afferent signals. The phase coding by the signal transmission delay through the loop connections produces the order of places.

Here, let's assume that a route is coordinated by a sequence of places, A, B, C, D, and E. The signal of each place is represented by the frequency depending on the distance between the observer and the place; a higher frequency corresponds to a shorter distance. A higher frequency signal makes the membrane potential of the place cell exceed the spike threshold in a shorter period of time. If the places, A, B, and C, exist in the observable range, these signals are fed into the ECII. The place cell A fire a spike first by the signal of the place A, and the spike is transmitted from the place cell A in ECII to the other place cells in ECII through the entorhinal-hippocampal loop circuit, as shown in Fig.1 (a). If the arrival of the transmitted spike and firing of the place cell B by the afferent signal of the place B take place simultaneously, the loop connection between the place cells, A and B, is enhanced through a STDP learning rule. This means that a relationship between the place A and the place B is established. Then, the spike is transmitted from the place cell B to the other cells, and the loop connection between the place cells, B and C, is enhanced by the coincidence of the transmitted spike and the firing of the place cell C. As a result, the order of places is embedded in the loop connection weights between the place cells and spikes of the place cells are organized within a theta cycle (Fig. 1(b)). The phase precession of the phase coded spikes occurs when the animal moves.



(a) (b)

Figure 1: Sequence learning mechanism in the entorhinal-hippocampal system: (a) Spike is transmitted from the place cell A in ECII to the other place cells through the entorhinal-hippocampal loop connections. The loop connection between the place cells, A and B, is enhanced when the arrival of the transmitted spike to the place cell B coincides with the firing of the place cell B by the afferent signal. As a result, a route, i.e. a sequence of landmarks, is stored as a chain of loop connections. (b) Established relationship between places is represented by the phase coded spikes within a cycle of the theta wave.

3. Local navigation system using prospective and retrospective sequences inspired by the sequence learning in the hippocampus and the entorhinal cortex

We propose a practical local navigation system inspired by the sequence learning in the hippocampus and the entorhinal cortex. The system uses prospective and retrospective sequences for navigation. Especially, the retrospective sequence is necessary for judgment of head direction at a crossing.

The proposed system consists of a phase-coded data register unit, a retrospective flag generator unit, and a local route memory unit. The phase-coded data register unit is inspired by the phase cording mechanism in the hippocampal-entorhinal cortex system and handles both prospective and retrospective sequences. The retrospective flag generator unit put a flag up to select a correct direction at a crossing when routes with common partial sequence are detected in route learning. In the local route memory, the sequence learning mechanism of the entorhinal-hippocampal system is implemented using a fully-connected-type network and sequences of landmarks are embedded in the connection matrix.

3.1 Phase-coded data register

The phase-coded data register consists of main register and sub registers. Each register consists of five registers in this case as shown in Fig.2. The number of the registers represents the number of the landmarks and is customized for each application. Detected landmark is stored in a register of the main register. An intensity of the landmark is represented by frequency as described in Sec. 2. The landmark with the highest frequency is stored in the left-end register and the lowest frequency is stored in the right-end register. Data of each register of the main register is transferred to the corresponding register of the next sub register at the observer's movement. The data of each sub register is transferred in the same manner. As the result, landmark data are arranged as shown in Fig.2. The retrospective landmark sequence comes up in the left-end row and the prospective sequence comes up in the main register. The retrospective sequence is used to distinguish the routes having a partial overlapped sequence. A landmark observed continuously is indicated in registers arranged in a diagonal line therefore the landmark can be accepted as a reliable one. The reliable landmark is fed into the local route memory.

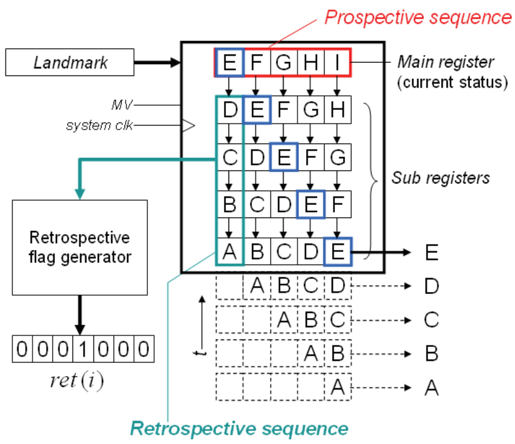


Figure 2: Phase-coded data register. The register handles both prospective and retrospective landmark sequences.

3.2 Retrospective flag generator

The retrospective flag generator generates a flag $ret(i)$ when the overlapped routes are stored in route learning. The flag of the retrospective landmark sequence is assigned as follows:

$$ret(i) = \begin{cases} 1 & \text{for the activated line} \\ 0 & \text{others} \end{cases} \tag{1}$$

where $ret(i)$ is *i-th* bit of the flag. The flag is used to switch the node in route recalling as described in Sec. 3.3.

3.3 Local route memory that can store multiple routes

The introducing of the retrospective landmark sequence enables store and recall of multiple routes. In the local route memory, the sequence learning mechanism of the entorhino-hippocampal system is implemented using a fully-connected-type network and sequences of landmarks are embedded in the connection matrix as shown in Fig.3.

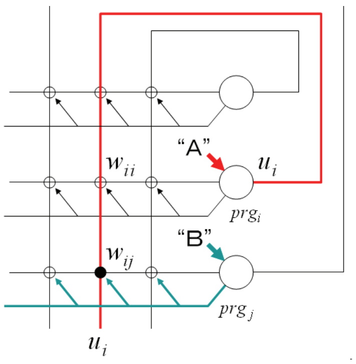


Figure 3: Local route memory. The sequence learning mechanism of the entorhinal-hippocampal system is implemented using a fully-connected-type network.

The connection weight is assigned as follows.

$$w_{ij} = \begin{cases} 1 & \text{when } u_i \text{ and } prg_j \text{ are activated} \\ 0 & \text{others} \end{cases} \quad (2)$$

where u_i, prg_j, and w_{ij} are output of *i-th* soma, program signal of *j-th* soma, and weight of connection (*i, j*), respectively. The connection switch is controlled by the connection weight w_{ij} in the old model. In this paper, by introducing the retrospective sequence, the connection switch is controlled by sw_{ij} defined as shown in Table I.

Table I: Functions for sw_{ij}

$ret(i)$	r_{ij}	sw_{ij}
1	1	w_{ij}
1	0	0
0	1	0
0	0	w_{ij}

4. Simulations and Discussions

4.1 Simulation results of the phase-coded data register

To confirm the validity of the phase-coded data register, we design the unit by using VHDL and investigate the behavior by using logic simulator ModelSim. Simulation results are shown in Fig.4. Five place signals are used. Each landmark signal changes the cycle T (f = 1/T) from 100ns (10MHz) to 20ns (50MHz) according to the distance between the observer and the landmark. Here five phase zones are set within the observable range and the frequency is changed when the observer crosses the phase zone as shown in Fig.4. The main cycle corresponding to the theta cycle is 1us in this case. The spikes of the landmarks are organized within the cycle. The simulation results show the system is executed well. As shown in Fig. 4, the phase coding and phase precession are observed. In the hardware system, it is easy to adapt the system to the applications because user can set the timing freely.

4.2 Local route memory that can store multiple routes

In order to investigate the usage of the proposed navigation system, storing and recalling behavior using routes as shown in Fig.5 is discussed.

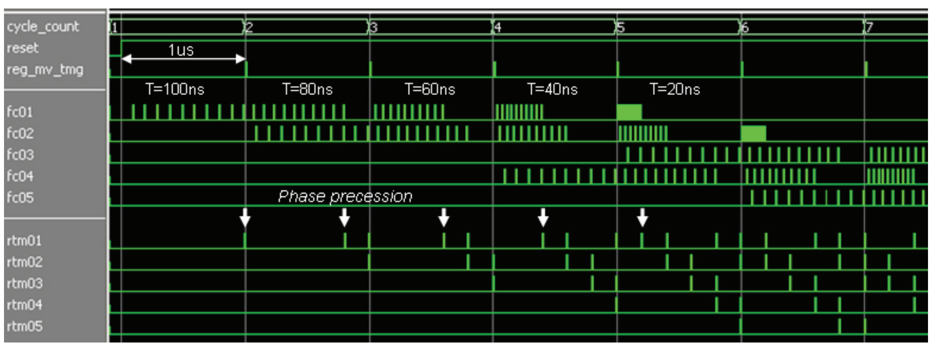


Figure 4: Simulation results of the phase-coded data register. The unit is designed by using VHDL and the behavior is investigated by the logic simulator ModelSim. The phase coding and the phase precession are observed.

We assume that the two routes (Route1: “A”→ “B”→ “C”→ “D”→ “E”, Route2: “a”→ “B”→ “C”→ “D”→ “e”), which have a partially overlapped sequence (“B”→”C”→”D”). At first, route 1 is stored by feeding the landmarks into the local route memory from “A” to “E” as shown in Fig.5 (a). After that, route 2 is stored. Here landmarks from “a” to “D” are stored in the ordinary manner. When the connection will be established, two connections are occurred in the same activated line u_i as shown in Fig.5 (b). In recalling mode, the connection pattern brings suspension of landmark recalling. In order to avoid the suspension, the retrospective landmark sequence is functioned. Because the retrospective landmark sequence is memorized in learning mode, the connection is switched by the retrospective flag as shown in Fig.5 (c). This algorithm is extensible for multiplex routes lager than two by changing the flag code longer.

5 Conclusions

The local navigation mechanism inspired by functions in the hippocampus and the entorhinal cortex was proposed. The proposed system uses prospective and retrospective landmark sequences for dedicated local navigation. The prospective information is used for tracing the stored route and the retrospective information enables for judgment of a head direction at a crossing without any other trials. Furthermore, the introduction of the retrospective sequence allows the present navigation system to store and recall multiple routes in the local route memory. Although, in this paper, we showed the case for two routes which have a common partial sequence, the system can be extended for more than two routes by arranging the flag form. In our future work, we will confirm the validity of the proposed system by applying other maize problems and investigate the performance for real world task by implementing the system to an autonomous mobile robot.

Acknowledgments

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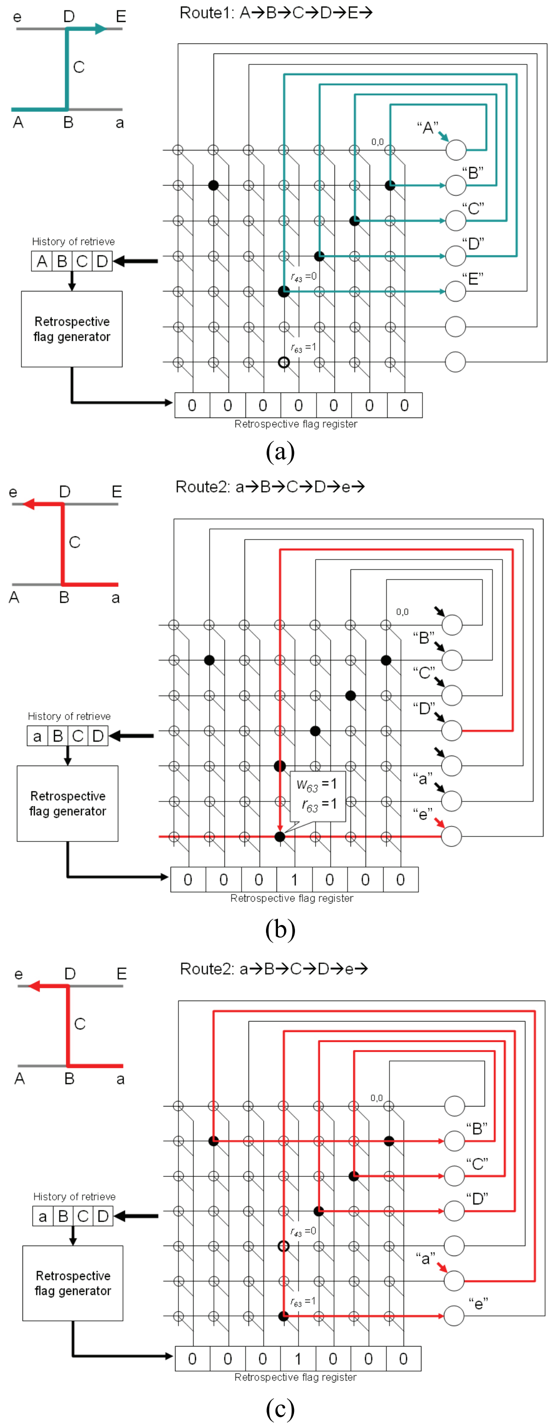

Figure 5: Proposed local route memory can treat multiple routes by using the retrospective sequence. (a) Normal storing. (b) Multiple routes are detected. (c) Judgment using the retrospective sequence.

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