Expression Method of Human Locomotion Records for Path Planning and Control of Human-symbiotic Robot System based on Spacial Existence Probability Model of Humans

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Abstract

In this paper, a novel describing method of human locomotion trajectory record was proposed, and methods of its application to the path planning and control of human-symbiotic mobile robots were indicated. The novel describing method, named as Existence Record Probability Map (abbreviated ERPM hereafter), was generated through the following three steps: 1) measuring human locomotion path using pressure distribution sensor floor, 2) applying a probability potential model of human body to the measured path, and 3) integrating such probability potential maps for some time period. From an ERPM, a) an existence probability value, b) ridge lines of the potential, and c) Q-value at a point on a ridge line, were elicited. As a usage of these information, methods of a) finding a position where a collision probability of a mobile robot and a human is high, b) finding major trajectories of human locomotion, and c) evaluation of path width to avoid collision with a human, were indicated.

1 Introduction

A number of researches have been conducted on mobile robot system, and path planning to avoid collision has become one of the major areas. In the case of factory, space, and nuclear plant application, path planning to avoid collision with an object is emphasized. On the other hand, development of humanoids and welfare robots are quite active, and in the near future, a human-robot symbiosis environment, where robots assist humans in ordinary houses, may become feasible. In this case, not only collision prevention but also more sophisticated control like keeping some distance with humans which is regarded as being comfortable for the humans, will become essential. To realize such human-robot symbiosis environment, the following two techniques are important:

- Technique to measure the positions of humans and robots simultaneously by the sensory equipments
- Technique to control the position and action of robots based on the measured human position

As for the first technique, there seems to be two approaches: One is to install sensory equipments in the environment, and the other is to install them in the robots and humans such as wearable position transmitter and so on. The authors think the former one more feasible because sensory equipments in the environment do not restrict the ordinary movement of humans and robots. Intelligent Room of MIT [1], the Aware Home of Georgia Tech [2], Neural Network House of University of Colorado [3] are the examples sensory environment system to measure the positions of humans and robots. In the Intelligent Room, human position is measured by vision sensor, and floor type sensor is used for personal identification in the Aware Home. The Neural Network House is equipped with sensors to monitor motion, temperature, light and sound. However, these intelligent environments are developed mainly for informative support to humans, namely they are not intended to create human-robot symbiosis environments for the purpose of mechanical support to humans. In the near future, not only informative support but also mechanical support such as fetching things out of the reach of a human, will become important. To realize this mechanical support, it is essential to develop the techniques to measure and accumulate the locomotion of humans correctly, and to process the information to the shape suitable for path and motion planning. From this viewpoint, this paper firstly proposes the method to create a potential map named ERPM, which describes the major path of human locomotion as a potential, and secondly proposes methods to utilize the characteristic values elicited from ERPM for path planning of human symbiosis mobile robots. In chapter 2, methods to measure the locomotion record of humans are explained. In chapter 3, the ERPM, a novel expression of human locomotion trajectory records and the characteristic values which can be elicited from it are discussed. In chapter 4, methods of applying the ERPM and the characteristic values made from actual human locomotion data to the path planning and control of human symbiosis mobile robots are shown. Chapter 5 is the conclusion.

2 Measurement of human locomotion by the sensor floor

Before explaining a novel expression method for human locomotion records, this section describes measurement method of human movement by sensor floor which can measure the pressure distribution as a bitmap image.

2.1 Outline of the sensor floor

To measure pressure distribution, sensor floor[4] shown Figure 1 was used for detecting human locomotion trajectory. This sensor floor covers 2m×2m area with 256×256=65,536 pressure measurement points. The sensor floor consists of 16 floor sensor units. Figure 2 shows the details of floor sensor unit. As showed in Figure 2(right), each floor sensor unit is composed of upper sheet and bottom pattern. When pressure is applied on the upper sheet, it deforms and touches the bottom pattern to make the short-circuit. This short-circuit is detected by the controller. The distribution of switch ON and switch OFF information are converted to a bitmap image and is put on the serial bus line as the output. Table 1 shows the specification of the sensor floor.

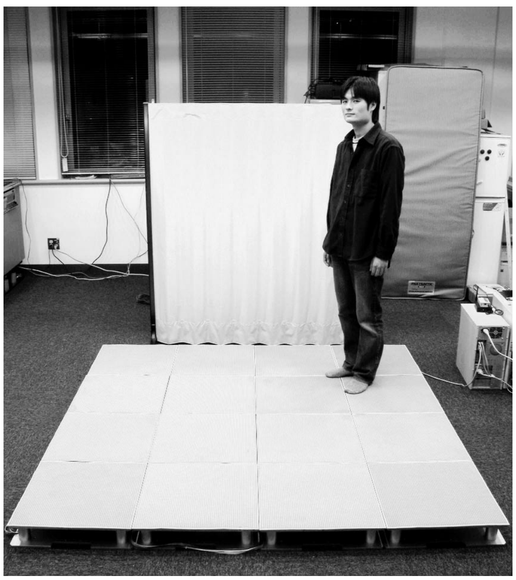

Figure 1: *Pressure Sensor Distributed Floor to Obtain Footprints of Humans*

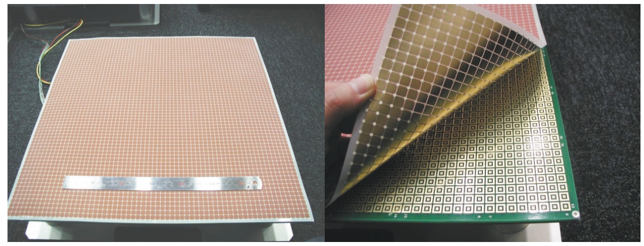

Figure 2: *Floor Sensor Unit*

Table 1: *Sensor Floor Specification*

Sensing Area	2000 × 2000 mm
Sensor Pitch	7 mm
Output Data	ON-OFF(1bit)
Transition Pressure	25 kPa
Sampling Frequency	Approx. 16 Hz
Data Transfer Rate	115200 bps
Data Type	Compressed Character

2.2 Data obtained from the sensor floor

Figure 3 is the typical data obtained from the sensor floor. The figure displays the data of human walking on bare foot. While human is walking on the sensor floor, immediately after the human foot touches the sensor floor, small blob image comes out. Then the size of blobs becomes larger and reaches to its maximum when all foot backside touches the floor, and becomes smaller as his foot separates from the upper sheet. This dynamic transition is captured as a series of bitmap images.

3 Novel expression method of human locomotion record (ERPM) and its characteristic values

This section describes the calculation algorithm to obtain ERPM, and the characteristic values elicited from the ERPM. Figure 4 shows the flow of data processing. There are five processing steps in the flow. The ERPM is obtained through the first three steps, and the characteristic values are elicited in the latter two steps.

1. Interpolation of human footprints by B-spline curve.

2. Expansion of B-spline curve width.

3. Accumulating potential maps.

4. Extraction of ridge lines from ERPM.

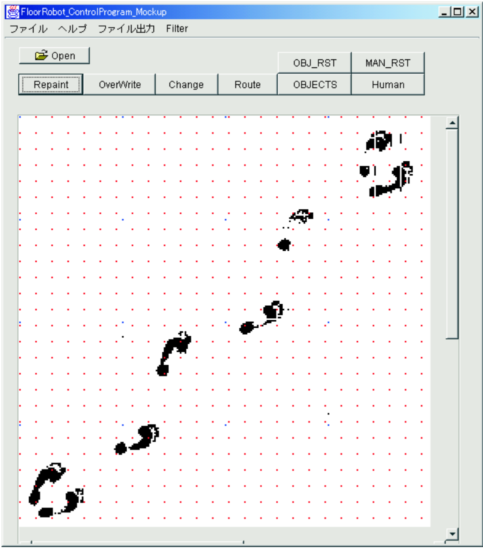

Figure 3: *Pressure Data Obtained when Walking on Bare Foot*

5. Calculation of Q-value at each points on a ridge line of ERPM.

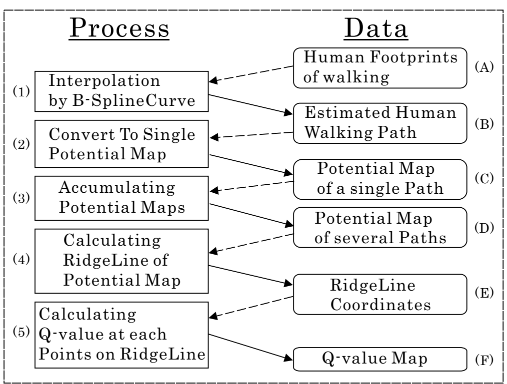

Figure 4: *Data Processing Flow*

3.1 Interpolation of human footprints by B-spline curve

As described before, discrete footprint image can be obtained from the sensor floor. An image of one foot doesn't always become a single blob. In case when one footprint consist of two blobs, one is an image of tiptoe and the other is an image of heel. In these cases human foot position is estimated by calculating the gravity center of two or more blobs. By repeating this step, touch down points of each foot are obtained and a B-spline curve that interpolate those points is calculated. This B-spline curve is defined as human walking path. More research should be done to determine which is the best among various interpolation methods, but in this paper we use B-spline curve for convenience.

3.2 Expansion of B-spline curve width

In the previous step, we got the estimated human walking path. In this step, we need to express human body width. There may be two kinds of human body width. One is the breadth of shoulders that occupies the space consistently. The other is the region where hands and feet pass by beyond the breadth of shoulders while walking. The latter region should be treated by a probability method. To realize this, probability model shown Figure 5(A) should be arranged along the B-spline curve. Figure 5(A) shows that the probability becomes lower in the outside of the cylinder. The parameters of this conic cylinder model need to be determined by experimental method. In this paper, we used cone and cylinder like Figure 5(B),(C) for simplicity, and obtained qualitatively proper results.

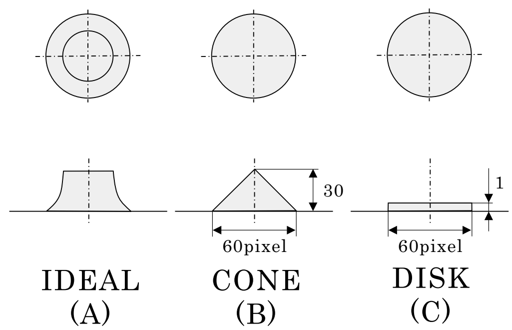

Figure 5: *Models Used to Expand B-spline Line*

3.3 Accumulating Potential Maps

When a human walks in a room, even if start and end point are fixed, the routes he takes varies according to the subject and to the cases. However a typical route emerges after many trips. To express such situation, human walking data that have same start area and same goal area are processed by step(1),(2), and ERPM is made by accumulating the output.

3.4 Extraction of ridge lines from ERPM

There can be found some ridge lines in ERPM, and they can be reagarded as typical human locomotion routes because because these ridge lines connect the peaks of ERPM. Usually there shows middle size ridge lines in addition to the typical route. Sorting the extracted ridge lines by its height makes it possible to detect a typical route.

3.5 Calculation of Q-value at each points on a ridge line

Even on the same typical ridge line, the potential value is not constant. For example, 1) If there is narrow area in the path where only one person can pass the area at the same time, all people must walk on that point. Therefore the potential of the point becomes high and the shape of potential map becomes sharp. In the opposite case, 2) If the width of the road is enough for several people passing through at the same time, people can select their route freely, and the potential becomes low and dull. To treat this numerically, a virtual cross section perpendicular to the typical route is assumed. The shape of this cross section is generally a hill shape. Firstly h is defined as the height of the hill, and w as the width of hill at the half height. Secondly a value $Q = h/w$ is adopted, and Q is called as "Q-value". 1)This Q-value becomes big when the ERPM is sharp at the point, and 2) becomes small when the potential is dull. This value can be used for indicating concentration degree of human walking to the typical route.

4 Experiments and Discussion

4.1 Experiments

Figure 6 shows the setup of experiments. 1m×1m Goal and Start areas are prepared at the downleft and upright corners of 2m square floor. Two chairs are used as obstacles that restrict human walking path. In the case of experimental setup 1, subjects are supposed to walk between the two chairs. In the case of experimental setup 2, subjects are supposed to walk around the two chairs. Figure 7 is the footprints image obtained in the experimental setup 1.
In the Figure 8, "◯"marks denote the gravity center of footprints image, and the line is the B-spline curve that interpolates these points. 100 cones shown in Figure 5(B) are arranged on the B-spline curve in Figure 8, and by calculating enveloping surface of cones the potential of single path shown Figure 9 is obtained. Figure 10 displays the potential of single path made by arranging disks shown Figure 5(C) instead of cones. Comparing Figure 10 with Figure 9, Figure 9 potential seems to reflect the human locomotion in the sense that probability of existence becomes lower, getting apart from the curve. Figure 11 shows the potential calculated by accumulating cone shape potentials shown in Figure 5(B) instead of calculating enveloping surface. However this calculation seems to be inadequate for single path potential because the potential values at the center and the ends on the same route are different.

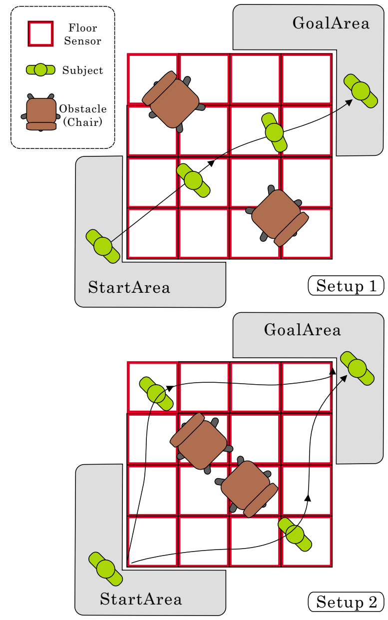

Figure 6: *Experimental Setup*

Under the experimental setup 1 of Figure 6, subjects were asked to walk from start area to goal area freely for 120 times. These 120 footprints images are interpolated by B-spline curve and transformed to single path potential maps by arranging cones on the curve. Figure 12 shows the accumulated potential map(ERPM) of 120 single path potential maps. At the center area the potential values are high, because the walking path is restricted by the two chairs. Start area and goal area have certain width, and there are many choices of routes for subjects. Therefore the potential spread broad. Similarly, experiment under setup 2 of Figure 6 was carried out for 120 times. Figure 13 shows the potential map(ERPM). In this experiment setup, there are obstacles at the center of floor, and two routes are available for subjects, right and left routes. These two routes are clearly shown in the potential map.

Figure 14, Figure 15 is the ridge lines extracted from Figure 12, Figure 13 potential maps respectively. In Figure 14, there are main ridge line running from downleft to upright, and some extra ridge lines around start area and goal area. This result means that some subjects didn't walk through the main typical route, but took other routes. For example, a subject seems to have entered the floor from left floor edge and exited from right floor edge. In the experimental setup 2 of Figure 15, some extra

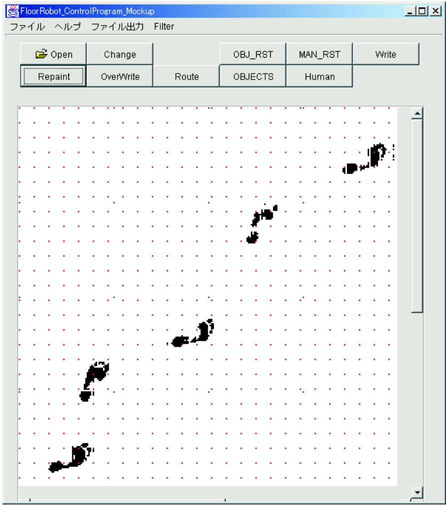

Figure 7: *An Example of Pressure Data Obtained in Experimental Setup 1*

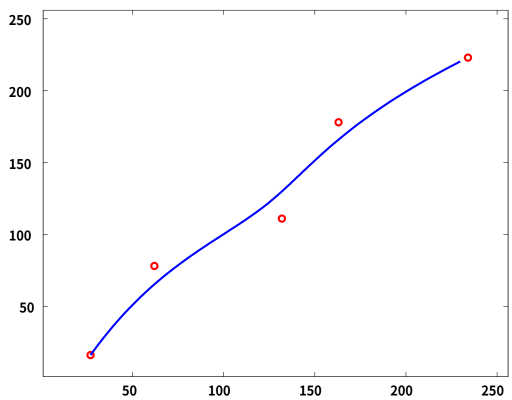

Figure 8: *Interpolation of Footprints by B-spline Curve*

routes can be seen near the floor edges in addition to the main routes. Among many ridge lines of Figure 14, one ridge line was selected as a shortest course from downleft start area to upright goal area. Figure 16 shows the extracted ridge line. Figure 17 is the graph of Q-value change along the selected ridge line. Left edge of graph corresponds to the donwleft corner of Figure 17 map, and right edge to the upright corner. Q-value is quite high at the center of floor and relatively low at the corner.

4.2 Discussion

Adoption of temporal weight. In the experiments of this paper, each single path potential are accumulated with the same weight. However if the passage of time from data sampling moment to the present is considered in the way that weight parameters are changed depending on the passage of time,

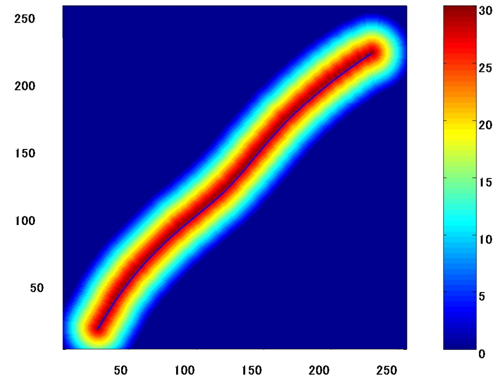

Figure 9: *Expansion of Walking Path by Enveloping Cone-shaped Potentials*

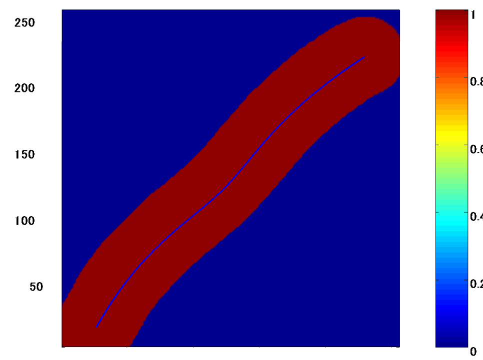

Figure 10: *Expansion of Walking Path by Enveloping Disk-shaped Potentials*

dynamic potential map can be obtained. In such a dynamic potential map, typical route and Q-values will be changing continuously. That is to say, if the reciprocal number of the passage of time is used for weight parameter, past walking data is treated lightly and latest walking data is emphasized.

Application for robot path planning. In a human symbiotic robot system, robot and human live together. In such a system, path planning for robot movement is significant in the following two points 1) Robot must fit into human daily life, 2) Robot shouldn't disturb human life. In the former case, when mobile robot fits into human life, robot can moves on the typical route of human walking route. In this case robot should be controlled as moving along the ridge line of ERPM. In the latter case, robot is thought not to disturb human life. If robot moves along the ridge line, robot may collide with human, and such situation is thought to be inadequate. In such case, robot should check the Q-value at each

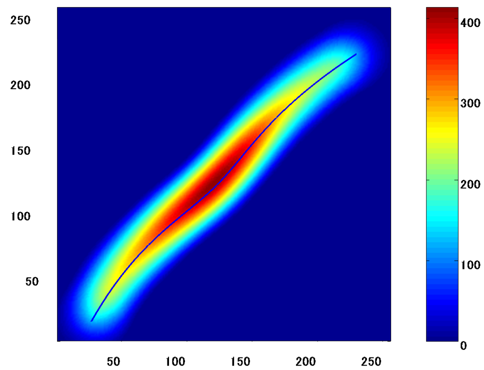

Figure 11: *Expansion of Walking Path by Accumulating Cone-shaped Potentials*

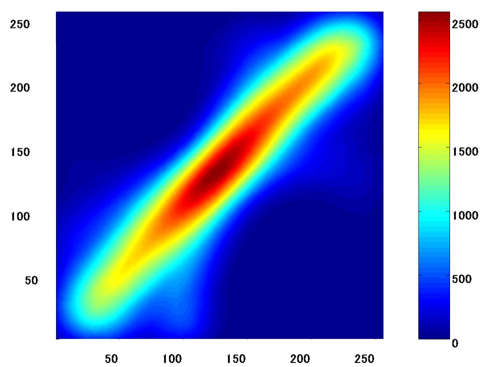

Figure 12: *Potential Map made by Accumulating Several Paths (Experimental Setup 1)*

points of the ridge line. Low Q-value indicates that the route along the ridge line have extra space for robot, and the robot can go through this extra space. Conversely high Q-value means the route don't have so much extra space and people can't walk away from the ridge line. A robot may come across people at such point because people must walk tightly along the ridge line, so the robot must confirm the vacancy on the route before going into such point and pass there as quick as possible.

5 Conclusion

In this paper, a novel expression method of human locomotion records was proposed, and basis for its application to the path planning and control of human symbiosis mobile robots was shown. In order to get an expression, the following two procedures are necessary: 1) measuring the human locomotion path by using pressure distribution sensor floor, and 2) producing 2D human existence probability map by applying the human existence probability model to the path and by making integration of them for some

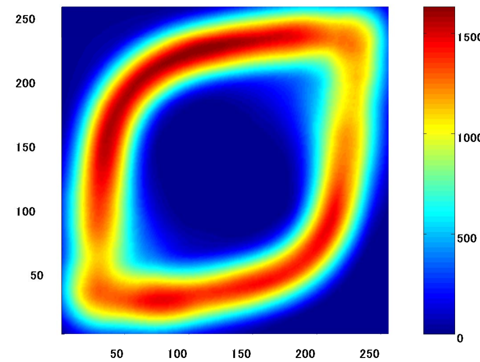

Figure 13: *Potential Map made by Accumulating Several Paths (Experimental Setup 2)*

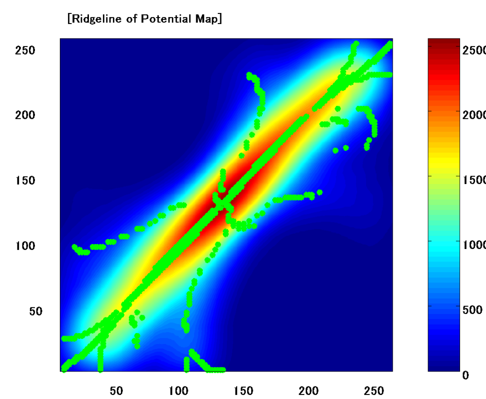

Figure 14: *Ridge Lines Extracted from the Potential Map (Experimental Setup 1)*

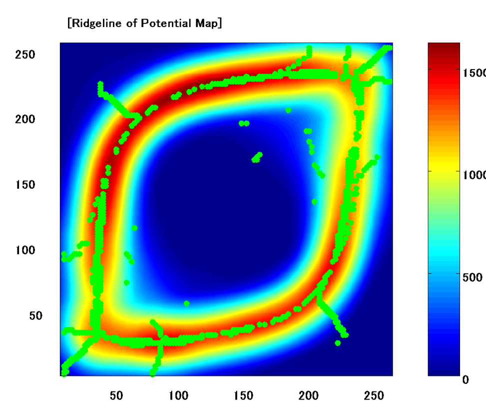

Figure 15: *Ridge Lines Extracted from the Potential Map (Experimental Setup 2)*

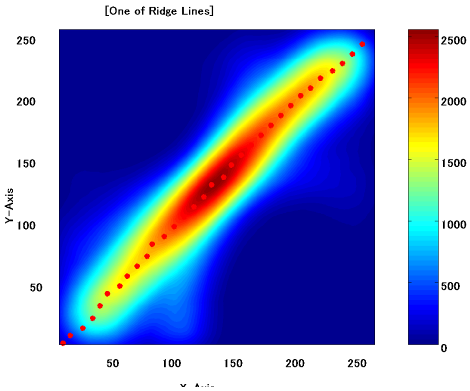

Figure 16: *One Ridge Line of Potential Map (Experiment 1)*

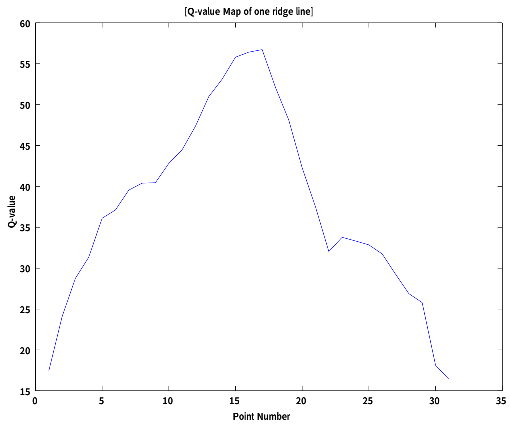

Figure 17: *Q-value Transition One Ridge Line(Experiment 1)*

time period. This map is the probability expression of human locomotion records, and the authors named it as Existence Record Probability Map (ERPM). In the experiments, 2m×2m pressure distribution sensor floor was used to measure the footprints generated during the human locomotion. Two types of path settings were experimented by setting two obstacles on the floor. 120 trips in each setting were recorded and ERPMs were calculated respectively. From these ERPMs, ridge lines were extracted, and Q-values were calculated. In this paper, characteristic values extracted from ERPM and its application method to the path planning and control of human symbiosis robots were discussed. This application method is summarized as follows: a) Direct usage of ERPM value: probability of a human at a certain point is calculated by dividing the ERPM by total number of trips. Therefore when a mobile robot goes into such point that ERPM value is high, special care should be taken to avoid collision with a human. b) Usage of ridge line of ERPM: the ridge lines of ERPM show the typical locomotion path of humans. Therefore, when one wants to control the mobile robot to follow the same path as humans travel, this ridge line can be used as a path for the mobile robot. c) Usage of Q-value on the ridge line: the Q-value which is obtained from the cross section figure perpendicular to the ridge line, shows the allowance for the mobile robot path to the typical human locomotion path. Therefore in case the mobile robot should be programmed to take the same path as humans take and also to minimize the disturbance to the humans, this Q-value plays a important role. If Q-value is low, the mobile robot can take a little apart path from the typical human locomotion path. When the Q-value is high, the path is narrow and it is impossible to take a path apart from the typical human path. In this case, the mobile robot is reqeuested to proceed after confirming that no one is on the typical path and to pass that area as quick as possible. Introducing the temporal weight onto the ERPM will emphasize the newly recorded paths, and this time-considered ERPM will be useful to describe the changing environments.

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References

[1] Nicholas Hanssens, Ajay Kulkarni, Rattapoom Tuchinda, and Tyler Horton “Building Agent-Based Intelligent Workspaces” *The International Workshop on Agents for Business Automation. Las Vegas, NV, 2002*

[2] Kidd, Cory D., Robert J. Orr, Gregory D. Abowd, Christopher G. Atkeson, Irfan A. Essa, Blair MacIntyre, Elizabeth Mynatt, Thad E. Starner and Wendy Newstetter. “The Aware Home: A Living Laboratory for Ubiquitous Computing Research” *the Second International Workshop on Cooperative Buildings, October 1999.*

[3] Mozer, M. C. “The neural network house: An environment that adapts to its inhabitants.” *the American Association for Artificial Intelligence Spring Symposium on Intelligent Environments, pp.110-114, Menlo Park, CA: AAAI Press. 1998.*

[4] H.Morishita, Rui Fukui and Tomomasa Sato “High Resolution Pressure Sensor Distributed Floor for Future Human-Robot Symbiosis Environments”, *IEEE/RSJ IROS 2002 Proceedings, pp.1246-1251, EPFL, Lausanne, Switzerland, September 2002.*