Optimal Fault Tolerant Gait Sequence of the Hexapod Robot with Overlapping Reachable Areas and Crab Walking

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Abstract—This paper extends the authors' previous results on fault tolerant locomotion of the hexapod robot on even terrain by relaxing nonoverlap of redefined reachable cells of legs and considering crab walking. It is shown that in fault tolerant locomotion two adjacent legs of the hexapod robot can have overlapping reachable cells with each other and consequently the stride length of the gaits is increased. Also, the optimal fault tolerant periodic gaits for hexapod robots to have the maximum stride length in one cycle in crab walking on even terrain are derived with distinct reachable cells. The derived sequence for crab walking has different orders of leg swing according to the relative values of the crab angle and some design parameters of the robot.

I. INTRODUCTION

Fault detection and tolerance is one of most necessary functions for robots to perform tasks robustly and intelligently, especially in remote or hazardous environments. Robots need the ability to effectively detect and tolerate internal failures in order to continue performing their tasks without the need for immediate human, or outer intervention [1]. From their inherently multilegged characteristics, walking robots have more fault tolerant capability than conventional wheeled mobile robots. For instance, a failure in one leg of the hexapod robot may not cause catastrophic failure nor instability in the locomotion. So gait control algorithms in the literature [2]–[6] to choose the best sequence for lifting and placing the legs of a walking robot with the assumption of no fault event may be adapted to tolerate the occurrence of some kinds of faults.

Manuscript received February 10, 1997; revised November 1, 1997 and August 1, 1998.

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Publisher Item Identifier S 1083-4427/99$10.00 © 1999 IEEE
Fig. 4. The optimal fault tolerant gait sequence of straight-line motion with nonnegative fault stability margin in a locomotion cycle: (a) initial state, (b) lift leg 3 and leg 4, (c) place leg 3 and leg 4, (d) move body, (e) lift leg 2 and leg 5, and (f) place leg 2 and leg 5.

perfectly even terrain. The sequence in [7] tolerates a fault in one leg which prevents the leg from maintaining support state until the end of the locomotion so that it does not fall down even if such a fault occurs. It is optimal in the sense that the hexapod has the maximum stride length in one cycle. For developing fault tolerant locomotion, fault stability margin was defined to represent potential stability which a gait can have in case a sudden fault event occurs to one leg, and a geometric condition was postulated to guarantee the feasibility of the derived optimal sequence.

In this paper we extend the previous results in two parts: 1) the fault tolerant gait sequence in straight-line motion with the overlapping redefined reachable cells of legs; 2) the optimal fault tolerant gait sequence of the hexapod for crab walking on perfectly even terrain. First, the constraints of redefined reachable cells of legs are relaxed by allowing overlap of adjacent cells. In [7], distinct rectangular regions developed in [2] and [4] were used as redefined reachable cells of legs preventing a priori overlap of adjacent reachable cells. But, in this paper, it is shown that overlapping reachable cells cause no interference problems in the optimal fault tolerant gait sequence for straight-line motion proposed in [7] and, on the contrary, improve the performance of the robot movement with respect to the stride length of the gaits. Secondly, based on the sequence derived in straight-line
motion in [7], the optimal fault tolerant periodic gait sequence of the hexapod robot for crab walking over even terrain is derived. We prove that the corresponding order of leg swing is not fixed but is variant depending on the crab angle and kinematics of the hexapod robot. It should be noted that in crab walking the hexapod robot has the same redefined reachable cells of rectangular shape and initial foothold positions as in straight-line motion.

This paper is organized as follows. In Section II we give the modeling of the hexapod robot and assumptions on its kinematics and dynamics, and review the previous work of fault tolerant locomotion of the hexapod robot. Section III presents the fault tolerant locomotion with overlapping reachable cells. In Section IV we propose the optimal fault tolerant locomotion for crab walking. Section V concludes this paper.

II. PRELIMINARIES

A. Problem Statement

Fig. 1 is the simplified two-dimensional model of the hexapod robot with a reachable area of each leg. From the kinematic configuration of the multilegged robot system, each leg has a reachable area in the form of a sector of an annulus [2], where adjacent areas overlap each other's region. Thus for avoiding interference problems redefined reachable cells are assigned for all the legs as in Fig. 2. Fig. 2(a) shows three parameters which specify the reachable region: maximum angle $\psi$, minimum radius $r_{min}$, and maximum radius $r_{max}$. Fig. 2(b) is the layout of a rectangular redefined reachable cell made within an annulus where $P$ and $Q$ denote length and width of the cell. As shown in the figure, it is supposed that the annulus has a geometric property such that the following relations are held:

$$\frac{1}{2} P < r_{min} \tan \psi,$$
$$r_{max}^2 = (r_{min} + Q)^2 + (\frac{1}{2} P)^2.$$  

Fig. 3 shows all the redefined reachable cells with specific foothold positions and the scale of the robot body. $C$ is the center of gravity and the origin of the machine coordinate system. $W$ is the distance between the reachable cell and the robot body and $U$ is the width of the body. If $W < 0$, it means that the hexapod has a kinematic structure such that some portion of the redefined reachable cell is located below the robot body. The following assumptions on kinematics and dynamics of the hexapod are made for the simplicity of analysis:

1) The hexapod has a symmetric structure and the body is rectangular.
2) The contact between a foot and the ground is a point.
3) There is no slipping between a foot and the ground.
4) All the mass of the legs is lumped into the body, and the center of gravity is assumed to be at the centroid of the body.
5) The initial foothold positions should be at the specified locations before the locomotion starts.
6) Unless specified otherwise, the speed of the hexapod body when it moves and the average speed of each leg during transfer phase are constant.

In [7], we have developed the detection scheme for a kind of faults which prevent a leg from maintaining support state. Those accidents include a failure in the kinematic part of a leg and a failure of communication between the controller and a leg effector in transfer state so that the leg cannot change its state to support state until recovered. Our work in this paper also deals with a fault tolerance problem for such faults. Here again, we adopt the following fault occurrence situations from [7]

1) only one fault event occurs during a whole locomotion;
2) the fault is not recovered during the locomotion.

B. Review of Previous Work

By definition in [7], fault stability margin $S_f$ of a gait is the minimum of stability margins of gaits generated by changing alternately the state of one supporting leg of the gait to transfer state and maintaining the other legs' states. $S_f$ means the degree of potential stability to which the hexapod is guaranteed its stability in case one of the supporting legs becomes transfer state abruptly by fault occurrence. Therefore, for tolerating fault occurrence in the locomotion with situations 1) and 2) prescribed in the previous subsection, the hexapod should maintain fault stability margin nonnegative throughout the locomotion.

The hexapod can have at most quadruped gaits for fault tolerant capability, since $S_f$ becomes negative in any tripod gait. Fig. 4 is the sequence of optimal quadruped gaits guaranteeing nonnegative fault stability margin derived in [7], with Fig. 4(a) as the initial foothold positions. It is noted in the sequence that the center of gravity does not move while the robot lifts or places legs and it moves onto a specific point before the robot transfers from a gait with all the legs in support to a quadruped gait as in Fig. 4(d) and (g). The point is the intersection of two diagonals of the support pattern made by the
quadruped gait. We designate such a point as a critical point. For guaranteeing execution of the above sequence without any problem of the kinematic limit, the hexapod should satisfy the following geometric condition as was proved in Theorem 3 in [7]:

$$Q \geq \frac{1}{3}(U + 2W).$$  

III. FAULT TOLERANT LOCOMOTION WITH OVERLAPPING REACHABLE AREAS

In this section, we show that in the optimal fault tolerant locomotion of the hexapod robot, overlap of redefined reachable cells could be allowed without any problem of gait control and even improve the performance of the locomotion. As was mentioned before, the redefined reachable cells are prescribed to escape the obstruction between adjacent legs in gait control at the cost of losing the use of some region of reachable areas. On the other hand, in the optimal fault tolerant gait sequence in Fig. 4, there is no overlap between any pair of foothold positions during one cycle. Therefore some overlapping of reachable cells could be allowable.

In Fig. 5(a), the rectangle with length $P$ is the redefined reachable cell of a leg used in the gaits in Fig. 4. An extended redefined reachable cell could be made by extending the length to $P + 2L$ where...
Fig. 8. (Continued). The optimal fault tolerant gait sequence of crab walking when $\alpha \geq \beta$ and $\alpha \leq \theta \leq (\pi/2)$: (g) move body, (h) lift leg 1 and leg 6, and (i) place leg 1 and leg 6.

$L$ is less than $\frac{1}{2}P$ and the front-end foothold position (or the rear-end foothold position) of the cell is in the reachable range. As indicated in the figure, the extended redefined reachable cell has unreachable areas in the upper right and left corners. Nevertheless, the hexapod robot can have the same gait sequence as in Fig. 4, since none of six legs place their feet on these regions during the sequence. In fact, every foothold position of six legs in the sequence is one of the three specified positions. Thus the overlapping reachable cells at the initial foothold positions become as in Fig. 5(b) where dotted lines indicate the boundaries of the old redefined reachable cells and $P' = P + 2L$ is the length of the extended reachable cell. With the new reachable cells, the optimal fault tolerant locomotion has the same order of gaits as in Fig. 4, but each leg places on the new front-end foothold position situated in front of the old position by distance $L$.

Now we derive the geometric constraint that the hexapod should satisfy for the locomotion with the new redefined reachable cells. It is necessary for the success of the sequence in Fig. 4 that all the feet of legs in support state at any gait could remain on the ground in the movement of the robot body. Thus we should check only the movement of the body at the gait in Fig. 4(d) with the new redefined reachable cell. Fig. 6 shows the support pattern of the gait that the hexapod has after swing of leg 3 and leg 4. The center of gravity of the robot body should move from the initial position $A$ to the critical point $B$.

**Theorem 1:** For the center of gravity to move onto position $B$ in Fig. 6 without violating the kinematic limit, the following geometric condition should be satisfied:

$$Q \geq \frac{P + 2L}{3P - 2L} (U + 2W).$$  \hspace{1cm} (2)

**Proof:** Let us denote the distance between $A$ and $B$ in $Y$-axis as $m$. From the trigonometric theorem on triangle we can get the following proportionality equation:

$$m: \frac{1}{2}P + L = m + \frac{1}{2} (Q + U + 2W); \frac{5}{2}P + L.$$

Then, $m$ is obtained as

$$m = \frac{P + 2L}{8P} (Q + U + 2W).$$  \hspace{1cm} (3)

$m$ should not be greater than the kinematic limit in the direction of $Y$-axis, or

$$\frac{Q}{2} \geq m.$$  \hspace{1cm} (4)

Therefore, from (3) and (4),

$$Q \geq \frac{P + 2L}{3P - 2L} (U + 2W).$$
Fig. 9. The optimal fault tolerant gait sequence of crab walking when $\alpha \geq \beta$ and $\alpha_1 < \theta < \alpha$: (a) initial state, (b) lift leg 3 and leg 4, (c) place leg 3 and leg 4, (d) move body, (e) lift leg 2 and leg 5, and (f) place leg 2 and leg 5.

This is an interesting result, compared with (1) derived from the sequence with the distinct reachable cells. As we know easily, (2) is more restrictive for $Q$ than (1). So if $Q$ is sufficiently long enough to satisfy (2), then the hexapod could have the sequence with the extended cells. In other words, the fault tolerant locomotion of the hexapod in the straight-line motion could be given the improved efficiency by reducing the wasted reachability of all the legs. As a comparison in a quantitative way, let us check the stride length of the center of gravity in one cycle in two cases. The stride length with distinct reachable cells is $P$ while that with the extended reachable cells is $P' = \frac{1}{2} P + L$. Thus the extension of reachable cells results in the increase of the stride length by $L$ and consequently increase of the average translation speed of the robot. If $L = 0$, (2) becomes identical to (1).

IV. FAULT TOLERANT LOCOMOTION FOR CRAB WALK

A. Definitions

The results derived for straight-line motion can be further extended to establish the optimal fault tolerant locomotion for crab walking over even terrain. Crab walk is defined as a walking motion with the direction of locomotion different from the longitudinal axis of the
robot body [3]. We assume that the fault occurrence situations 1) and 2) in Section II are equally applied to the locomotion in crab walking. Also, it is supposed that the hexapod in crab walking has the same initial foothold positions as in straight-line motion [Fig. 4(a)]. We first study the optimal fault tolerant sequence in crab walking with distinct reachable cells. The case of using overlapping reachable cells is very similar to that with distinct cells and will be discussed in the remark. Before developing theories, we employ the following definitions for discussing derived gait sequences in a precise manner.

Definition 1: The crab angle, denoted by $\alpha$, is defined as the angle between the longitudinal axis of the robot body and the direction of crab walking. It is sufficient to determine the range of the crab angle as $0 \leq \alpha \leq (\pi/2)$.

Definition 2: $\alpha_1$ is defined as the angle which is made by the two lines from the initial foothold position of leg 6 to those of leg 1 and leg 4 (or leg 5) as shown in Fig. 7(a).

Definition 3: $\beta$ is defined as the angle between the off-diagonal and the base of the reachable cell as shown in Fig. 7(a).

By definition, it is clear $\beta = \tan^{-1}(Q/P)$ and $\alpha = \tan^{-1}(Q + U + 2W/2P)$.

Definition 4: $\alpha_1$ is defined as the angle made by $\alpha$ in the reachable cell as shown in Fig. 7(b).

Let us express $\alpha_1$ with kinematic parameters. In Fig. 7(b),

\[
\begin{align*}
x &= \frac{1}{2} P - \frac{1}{2} \frac{Q}{\tan \alpha} \\
y &= \frac{1}{2} Q - x \tan \alpha = Q - \frac{1}{2} P \tan \alpha.
\end{align*}
\]

Therefore, $\alpha_1$ is derived as

\[
\alpha_1 = \tan^{-1}\left(\frac{y}{\frac{1}{2} P}\right) = \tan^{-1}\left(\frac{3Q - (U + 2W)}{2P}\right).
\]

The optimal fault tolerant locomotion of the hexapod in crab walking has different orders of lifting and placing of legs according to relative values of $\theta, \alpha$, and $\beta$ with each other. We investigate separately the case of $\alpha \geq \beta$ and that of $\alpha < \beta$. The reason for the separate investigation of these two cases will be apparent as we proceed.

B. The Case of $\alpha \geq \beta$

Fig. 7(a) shows the feature of the hexapod with $\alpha \geq \beta$. From the definition of fault stability margin, the hexapod should always have quadruped gaits for the optimal fault tolerant locomotion. This premise also applies to the case of crab walking. We now postulate the following theorem.
Fig. 10. The optimal fault tolerant gait sequence of crab walking when \( \alpha \geq \beta \) and \( 0 \leq \theta \leq \alpha_1 \): (a) initial state, (b) lift leg 3 and leg 4, (c) place leg 3 and leg 4, (d) move body, (e) lift leg 2 and leg 5, and (f) place leg 2 and leg 5.

**Theorem 2:** Let the initial foothold of each leg be the middle foothold position as in Fig. 8(a) and assume that the hexapod satisfies kinematic condition (1) for straight-line motion. Then the sequence of optimal quadruped gait locomotion in crab walking, guaranteeing the maximum stride length in one cycle and nonnegative fault stability margin according to the crab angle \( \theta \), is as follows:

\[
\begin{align*}
\alpha &\leq \theta \leq \frac{\pi}{2} & \text{the sequence in Fig. 8,} \\
\alpha_1 &< \theta < \alpha & \text{the sequence in Fig. 9,} \\
0 &\leq \theta \leq \alpha_1 & \text{the sequence in Fig. 10. (5)}
\end{align*}
\]

**Proof:** First, it should be noted that among the possible combinations of two legs which can be lifted maintaining nonnegative fault stability margin at the initial position the choices of pairs (leg 1, leg 6) and (leg 3, leg 4) yield the same result by symmetry of the hexapod’s structure. Hence, throughout this paper, let us conventionally choose (leg 3, leg 4) when we are faced to do one of the two pairs. Also note that in Figs. 8–10 the redefined reachable cells are drawn fixed at the initial position for the convenience of illustration. In fact, the real locations of all the six reachable cells should be moved as the position of the center of gravity changes. The proof is made in a manner similar to that of Theorem 2 in [7].

i) **Case I,** \( \alpha \leq \theta \leq \frac{\pi}{2} \): At the initial position, all the possible combinations of two legs which can be lifted maintaining nonnegative fault stability margin are (leg 3, leg 4) and (leg 2, leg 5). Fig. 11
Fig. 10. (Continued). The optimal fault tolerant gait sequence of crab walking when $\alpha \geq \beta$ and $0 \leq \theta \leq \alpha_1$: (g) move body, (h) lift leg 1 and leg 6, and (i) place leg 1 and leg 6.

shows the front-end foothold positions and the critical points when (leg 3, leg 4) and (leg 2, leg 5) are chosen as the initially lifted pair, respectively. As is shown in the figure, for optimality of the sequence, the next foothold positions of two lifted pairs should be onto the boundaries of the reachable cells, resulting in the maximum stroke length of each leg. In case (leg 2, leg 5) is selected, the center of gravity should move onto $C_1$ after placing the pair and (leg 3, leg 4) will be lifted as the unique next pair. In case (leg 3, leg 4) is selected, the critical point becomes $C_2$ and (leg 2, leg 5) will be lifted as the unique next pair. In both cases, $C_3$ is reduced to the next critical point after swing of the two pairs (leg 2, leg 5) and (leg 3, leg 4), regardless of the order. But the choice of (leg 2, leg 5) as the initially lifted pair is superior to that of (leg 3, leg 4) since the trace of the center of gravity of the former case, $OC_1 + C_1C_2$, is shorter than that of the latter, $OC_3 + C_2C_3$. Therefore, (leg 2, leg 5) is chosen as the initially lifted pair and the consequent sequence is as in Fig. 8.

ii) Case II, $\alpha_1 < \theta < \alpha$: We take (leg 3, leg 4) as a candidate for the initially lifted pair. The qualification of the pair (leg 2, leg 5) as the other candidate will be investigated later. If $\theta$ is identical to $\alpha$, the critical point becomes $E_1$ as in Fig. 12(a) and the displacement of the center of gravity along $Y$-axis is $\frac{1}{2}Q$. On the other hand, if $\theta$ is in the range $\alpha_1 < \theta < \alpha$, the critical point would be on the segment $E_1E_2$ and the necessary displacement along $Y$-axis is out of the kinematic limit. Therefore, the farthest foothold points onto which the lifted legs can place are on the segment between the foothold positions of the case $\theta = \alpha$, denoted by $AB$ in the figure.

Fig. 11. Critical points for initially lifted pairs when $\alpha \geq \beta$ and $0 \leq \theta \leq (\pi/2)$.

For example, the foothold position of leg 3 is $F$ in Fig. 12(b). Now we investigate whether (leg 2, leg 5) could be chosen as the initially lifted pair. Fig. 13 shows the front-end foothold positions and the critical points in case $\alpha_1 < \theta < \alpha$. As the figure shows, if (leg 2, leg 5) is chosen as the initially lifted pair, the critical point $C_2$ is located beyond the kinematic limit. So the initially lifted pair should be (leg 3, leg 4) and the trace of the center of gravity becomes $OC_1 + C_1C_2$. It should be noted that $\alpha_1 \geq 0$ since the hexapod satisfies condition (1) by assumption.
Fig. 12. (a) Kinematic limit when $\alpha \geq \beta$ and $\alpha_1 < \theta < \alpha$ and (b) foothold position on $AB$. Any foothold position on the shaded area is out of the kinematic limit.

Fig. 13. Critical points for initially lifted pairs when $\alpha \geq \beta$ and $\alpha_1 < \theta < \alpha$.

iii) Case III, $0 \leq \theta \leq \alpha_1$ : The proof of this case is similar to Case II. Fig. 14 shows the front-end foothold positions and the critical points of the initially lifted pairs (leg 3, leg 4) and (leg 2, leg 5) when $0 \leq \theta \leq \alpha_1$. As in Fig. 13, only (leg 3, leg 4) can be selected as the initially lifted pair, as the resultant critical point $C_1$ is within the kinematic limit.

In Figs. 8–10, the foothold position of each leg and the critical point of the robot body are determined by the kinematic limit and stability margin. This strategy of gait generation is similar to that in [8], where foot and body adjustment is determined according to a stability analysis for the hexapod to have wave gait for walking on a rough planar terrain.

C. The Case of $\alpha < \beta$

The case of $\alpha < \beta$ comes from the situation where the width of the redefined reachable cell is exceptionally long or $W < 0$, meaning that some portion of the redefined reachable cell is located below the robot body. In this paper we assume the latter case, i.e., $W < 0$.

Theorem 3: Let the initial foothold of each leg be the middle foothold position as in Fig. 8(a). Then the sequence of optimal quadruped gait locomotion in crab walking, guaranteeing the maximum stride length in one cycle and nonnegative fault stability margin according to the crab angle $\theta$, is as follows:

1) $\alpha \leq \theta \leq (\pi/2)$: the sequence is the same as that of Fig. 8 except that the front-end position of each leg is on the boundary of the reachable cell.
2) $0 \leq \theta < \alpha$: the sequence is the same as that of Fig. 10.

Proof:

i) Case I, $\alpha \leq \theta \leq (\pi/2)$: Fig. 15 shows the front-end foothold positions and the critical points when (leg 3, leg 4) and (leg 2, leg 5) are chosen as the initially lifted pair, respectively. In the figure, $\theta$ is set to be $\beta$ specifically. As shown in the figure, (leg 2, leg 5) is the only pair that can be the initially lifted legs. Hence the order of the resultant sequence is identical to that of Fig. 8. But, unlike Case II in Theorem 2, all the lifted legs can put their feet on the boundary of the redefined reachable cells regardless of the value of $\theta$ because the critical point $C_1$ is always within the kinematic limit as is clear in the figure.

ii) Case II, $0 \leq \theta < \alpha$ : The reason of selecting (leg 3, leg 4) as the initially lifted pair is illustrated in Fig. 16. The proof is similar to that of Case III in Theorem 2.

It is noted that we have not mentioned any necessary geometric condition in deriving Theorems 2 and 3. This comes from the fact that in all the proposed sequences the choice of the initially lifted pair is sufficient to satisfy the kinematic constraint enough for the center of gravity to move to the next critical point.
Fig. 16. Critical points for initially lifted pairs when $\alpha < \beta$ and $0 \leq \theta < \alpha$.

Remark: To use overlapping reachable cells in deriving the optimal fault tolerant locomotion in crab walking needs some precaution, since in extending the redefined reachable cells some unreachable areas are included in the cell. To explain more precisely, let us remind the shape of the overlapping reachable cell in Fig. 5(a), where unreachable regions are located in the upper right and left corners of the extended cell. Following the proposed sequences for crab walking, there might be cases where some lifted legs cannot place their feet on the front-end positions that are on the unreachable regions. For example, in the case of $\alpha < \beta$ and $\theta = \beta$, the front-end foothold position of leg 2 when it is initially lifted is the apex of the reachable cell in the upper right corner as shown in Fig. 15. But, if the hexapod has the overlapping reachable cells, the point is reduced to be in the unreachable region. Hence in using the overlapping reachable cells it is necessary to check if or not such a problem of kinematic limit occurs during the locomotion. If the hexapod has the problem inherently, the foothold positions should be changed to some feasible locations within the kinematic limit and consequently the proposed sequence should be adapted with changed foothold positions.

V. Conclusion

In this paper, we have shown that when the hexapod robot has the fault tolerant gait sequence in straight-line motion, each leg can have the overlapping redefined reachable cells of legs, improving the performance of the sequence with respect to the stride length. With overlapping reachable cells, the gait sequence for the locomotion in straight-line motion could be executed with the increased stride length of the center of gravity in one cycle, without causing any violation of the kinematic limit. In addition, we have presented that, as in straight-line motion, the optimal fault tolerant gait sequence of the hexapod for crab walking can be generated on perfectly even terrain.

Retinally Reconstructed Images: Digital Images Having a Resolution Match with the Human Eye

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Abstract—Current digital image/video storage, transmission and display technologies use uniformly sampled images. On the other hand, the human retina has a nonuniform sampling density that decreases dramatically as the solid angle from the visual fixation axis increases. Therefore, there is sampling mismatch between the uniformly sampled digital images and the retina. This paper introduces retinally reconstructed images (RRI’s), a novel representation of digital images, that enables a resolution match with the human retina. To create an RRI, the size of the input image, the viewing distance and the fixation point should be known. In the RRI coding phase, we compute the “retinal codes,” which consist of the retinal sampling locations onto which the input image projects, together with the retinal outputs at these locations. In the decoding phase, we use the backprojection of the retinal codes onto the input image grid as B-Spline control coefficients, in order to construct a three-dimensional (3-D) B-spline surface with nonuniform resolution properties. An RRI is then created by mapping the B-spline surface onto a uniform grid, using triangulation. Transmitting or storing the “retinal codes” instead of the full resolution images enables up to two orders of magnitude data compression, depending on the resolution of the input image, the size of the input image and the viewing distance. The data reduction capability of retinal codes and RRI is promising for digital video storage and transmission applications. However, the computational burden can be substantial in the decoding phase.

Index Terms—Compression, fovea, image coding, reconstruction.

I. Introduction

The properties of the human visual system have enabled technologies for many applications. The 50 Hz temporal resolution

REFERENCES


