Task Planning for Service Robots with Limited Feedback

Chung-Woon Park, Jungwoo Lee, and Jong-Tae Lim[†]

Abstract—In this paper, we propose a novel limited feedback scheme for task planning with service robots. Instead of sending the full service robot state information for the task planning, the proposed scheme send the best-M indices of service robots with a indicator. With the indicator, the proposed scheme significantly reduces the communication overhead for task planning as well as mitigates the system performance degradation in terms of the utility. In addition, we analyze the system performance of the proposed scheme and compare the proposed scheme with the other schemes.

Keywords—Task Planning, Service Robots, Limited Feedback, Scheduling.

I. INTRODUCTION

AN industrial robots for working in factory environment were broadly studied and lead enormous development in the 20th century [1]. But the research subjects are moving to service robotics with the busy life style of humans in the 21st century. Humans have great concern in healthy life and do not want to get 3D jobs (difficult, dangerous and dirty) as well as repeated simple jobs. For these reasons, service robots(SRs) which do these jobs instead of humans are the main focus of research nowadays.

As SRs perform their jobs in the same environment as humans, SRs should have essential abilities humans have. They should recognize faces, gestures, characters, objects, speech and atmosphere. They should find their way to reach the goal without collisions and destructions, and accomplish the task at hand successfully. They should grab and deliver some objects. They should communicate with humans based on emotion. These all research subjects are included in service robotics area.

One of the key points of the future SRs is the concept of network computing. By connecting existing standalone robots to the communications network, some of their computations are performed on remote, distributing their loads over the network. This distribution is expected to raise customers' satisfaction because it can increase the number of services available, which would not be possible with standalone robots. Moreover, their prices could also be lowered than ever because they do not need to have expensive computing devices anymore expensive computations are now done on remote servers [2].

On the other hand, in order to allocate SRs for the task planning, a task planner requires robot state information (RSI). Since RSI uses a full feedback protocol at each time, it requires a significant communication overhead. Moreover, the communication overhead increase as the number of SRs increases. Thus, in this paper, we propose a novel limited feedback scheme for the task planning with the service robots. Instead of sending the full service robot state information for the task planning, the proposed scheme send the best-M indices of service robots with the indicator. The indicator divides the best-M SRs indices into two group based on the threshold. Then, the task planning is performed based on the limited information instead the full RSI. We analyze the system performance of the proposed scheme in terms of the utility and the communication overhead. Then, we compare the proposed scheme with the other schemes. Simulation results show that the proposed scheme mitigates the system performance degradation in terms of the utility as well as significantly reduces the communication overhead for task planning.

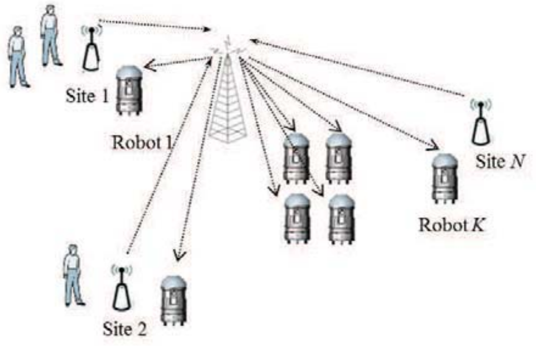

Fig. 1. System architecture with K service robots and N sites

II. SYSTEM MODEL

We consider a system with K SRs and N sites. We assume that there is a task planner in the central area of the system communicating with multiple sites over independent channels as shown in Fig. 1. K SRs are allocated to N sites by the task planner. In each site there is a mobile station which sends RSI to the task planner and SRs are allocated to the site based on the RSI information. We assume that there is always works to do in each site. Each K SRs perform the service in the site based on the unit of time slot t as shown Fig. 2. Note that $S_i(t)$ is the allocated site index for SR i at time t.

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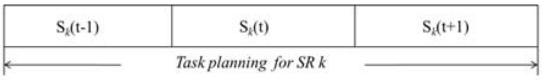

Fig. 2. Time slots for task planning

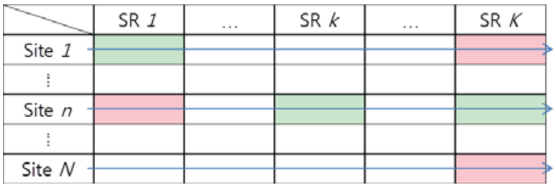

Fig. 3. Bit map for SR allocation of the proposed scheme

III. Proposed Scheme

The proposed feedback scheme consists of two stages. In the first stage, in each site the mobile station sends RSI to the task planner with the limited feedback. Then, in the second stage, the task planner allocates the service robots to the site based on the feedback information. To facilitate SR allocation to the each site, each site estimates RSI of all SRs and sends an feedback information to the task planner. We assume that allocation is fast when compared to RSI coherence time, i.e., temporal feedback delay is neglected.

In the proposed feedback method, the M best SRs are selected out of the total of K available SRs at the site with the indicator (threshold) r_{th}. The indicator divides the M best SRs into two groups. The RSI of SRs in the first group are greater than r_{th} and the RSI of SRs in the second group less than r_{th}. The index which indicates the selected combination of the SRs is signaled back to the task planner. There are $\left(\begin{array}{c}K\\M\end{array}\right)\times\sum_{M_1=0}^{M}\left(\begin{array}{c}M\\M_1\end{array}\right)=\frac{K!}{M!(K-M)!}\cdot 2^M$ different possible feedback words in the proposed feedback scheme. Thus, the feedback method requires $M+\log_2\lceil\frac{K!}{M!(K-M)!}\rceil$ bits per site.

The task planner then allocates SRs to sites based on the received feedback information as shown Fig. 3. In the SR allocation, if two more sites send the feedback message including the same SR, then SR is allocated based on the indicator. If the SR does belong to the first group (green) of the M-best SRs more than two, the SR is randomly allocated to the site which send the SR as the first group. However, if the SR belongs to the first group of the certain site and belongs to the second group (red) of the other sites, the SR is allocated to the site which SR is belong to the first group. If the SR does not belong to any feedback message of the sites, it is randomly allocated to the site.

IV. Performance Analysis

In this section, we analyze the performance of the proposed scheme in terms of the utility in the site and the average communication overhead for the task planning. We assume that the utility function in the site is a logarithm function of RSI. A utility function measures an investor's relative preference for different levels of total wealth [6]. Thus, the average utility in the site is described as

$$U=\int_0^\infty \log(r)f_r(r)dr \tag{1}$$

Note that $f_r(r)$ is pdf of RSI. Then, the task planner allocates SR k to the site i following:

(a) The case is that the robot k does not belong to any feedback message.

$$\left(\frac{{}_{K-1}C_M}{{}_KC_M}\right)^N\frac{1}{N}\int_0^\infty \log(r)f_{r_i}(r)dr \tag{2}$$

(b) The case is that robot k only belongs the feedback message of the site i.

$$\left(\frac{{}_{K-1}C_M}{{}_KC_M}\right)^{N-1}\left(\frac{{}_KC_{M-1}}{{}_KC_M}\right)\int_0^\infty \log(r)f_{r_i}(r)dr \tag{3}$$

(c) The case is that the robot k belongs more than two sites and RSI of the robot k is below the indicator (threshold) in that feedback message.

$$\sum_{i=1}^{K}\left(\frac{{}_{K-1}C_M}{{}_KC_M}\right)^{N-i}\left(\frac{{}_{K-1}C_{M-1}}{{}_KC_M}\right)^i\frac{1}{i}\int_0^{r_{th}} \log(r)f_{r_i}(r)dr \tag{4}$$

Note that i sites send the limited feedback containing SR k.

(d) The case is that the robot k belongs more than two sites and only RSI of the robot k is above the indicator (threshold) in the site i.

$$\sum_{i=1}^{K}\left(\frac{{}_{K-1}C_M}{{}_KC_M}\right)^{N-i}\left(\frac{{}_{K-1}C_{M-1}}{{}_KC_M}\right)^i\int_{r_{th}}^\infty \log(r)f_{r_i}(r)dr \tag{5}$$

(e) The case is that the robot k belongs more than two sites and RSI of the robot k is above the indicator (threshold) in more than two sites.

$$\sum_{i=1}^{K}\left(\frac{{}_{K-1}C_M}{{}_KC_M}\right)^{N-i}\left(\frac{{}_{K-1}C_{M-1}}{{}_KC_M}\right)^i\sum_{j=1}^{i}\frac{1}{j}$$

$$\cdot\int_{r_{th}}^\infty \log(r)f_{r_i}(r)dr \tag{6}$$

Then, the average utility in the site for SR k is described as $U_k=(1)+(2)+(3)+(4)+(5)$ where $U=\sum_{k=1}^{K}U_k$.

V. Simulation Results

In this section, we simulate the proposed scheme and compare the performance of the proposed scheme with the other schemes. In our simulation, we assume that RSI is exponentially distributed. In the simulation, we set $N=5$ and change K from 5 to 30.

First, we simulate the average utility in the site of the proposed scheme and the other schemes. Figure 4 shows that the resulting average utility as the number of SRs increases. As shown in 4, the average utility of the proposed scheme increases as the number of SRs increases. In addition, the proposed scheme achieves higher average utility than the

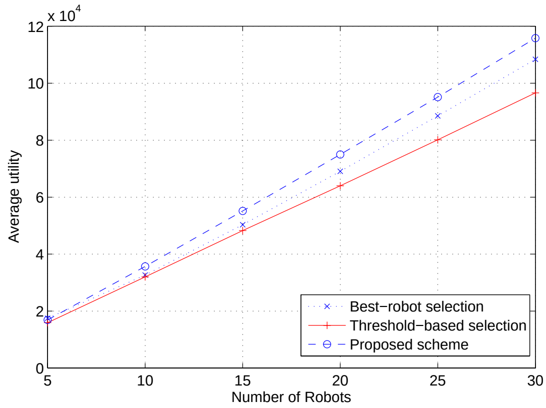

Fig. 4. Average utility of the proposed scheme and the other schemes

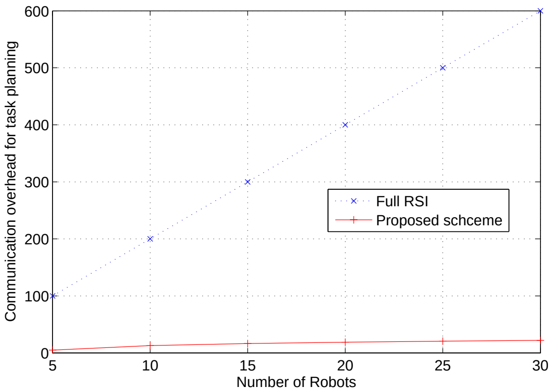

Fig. 5. Average communication overhead for task planning of the proposed scheme and the full RSI scheme

existing other schemes based on the limited feedback. This is because the proposed scheme mitigate the degradation of the system performance including the indicator (threshold) r_{th}. Without the indicator with r_{th}, SR is randomly chosen, it sacrifice the system performance. Thus, with the indicator the proposed scheme improves the system performance. Figure 5 show the average communication overhead for task planning of the proposed scheme and the full RSI scheme. In the full RSI scheme, the number of communication overhead is obtained from a product K, M, and the bit for RSI. As expected, the number of communication overhead linearly increases in both schemes. However, the slope of the full RSI scheme is very steep while the slope of the proposed scheme is gentle. Thus, the proposed scheme significantly reduces the communication overhead compared to the full RSI scheme.

VI. CONCLUSION

In this paper, we propose the novel feedback scheme for task planning with the limited feedback. The proposed scheme significantly reduce the communication overhead for the task planning. The proposed scheme exploits the limited feedback which contains the best-M SRs each site for task planning. The task planner then allocates SRs to each site based on the feedback information. Simulation results show that the proposed scheme slightly increases the average utility compared to the other scheme with limited feedback.

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