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Dependence of mobile robot task scheduling on fitness functions

***Abstract**. The results of simulation studies designed to assess two of the fitness functions ($Or1$ and $Or2$) for the GRASP algorithm used in the elastic scheduling task model (ESTM) have been presented in the paper. The obtained results indicate that the GRASP algorithm with the fitness function $Or2$ was better at choosing new settings for T_{sel} to exploit the hardware resources of a mobile robot. Furthermore, it has been found that for $Or2$ new settings for T_{sel} are closer to T_{nom} than T_{max} (task cycle execution is reduced which enables a quicker response of a mobile robot to events).*

Streszczenie.** W artykule przedstawiono wyniki badań symulacyjnych umożliwiających ocenę dwóch opracowanych funkcji celu ($Or1$ i $Or2$) dla algorytmu GRASP zastosowanego w elastycznym modelu szeregowania zadań. Otrzymane wyniki badań wskazują, że dla funkcji celu $Or2$ nowe nastawy T_{sel} lepiej dopasowały wykorzystanie zasobów sprzętowych robota mobilnego do założonej wartości. Ponadto dla Or2 stwierdzono bliższy dobór wartości T_{sel} do T_{nom} niż T_{max} (cykl wykonywania zadań skraca się, przez co robot mobilny może szybciej reagować na zdarzenia).**Wpływ funkcji celu na szeregowanie zadań w robocie mobilnym.

Keywords: scheduling tasks, elastic task model scheduling, heuristic algorithms.
Słowa kluczowe: szeregowanie zadań, elastyczny model szeregowania zadań, algorytmy heurystyczne.

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Introduction

In this paper related tasks of modelling techniques, planning and control of mobile robots (in particular wheeled ones) are considered [1]. Endeavours have also been made to schedule tasks conditionally in the robot [2]. In the latter case, the Knowledge of Volumes framework for robot task Planning has been developed [3]. In contrast, causal knowledge has already been used in the planning task, in the form of sematics maps [4]. The mobile robot may also use scheduling, which approach is shown in [5].

Task scheduling is used in many fields and concerns the order of operations or activities of equipment (e.g., machinery, operating systems) [6]. Task scheduling can also be applied for allocation of resources in computer systems and networks, in production management and services (for example in coordinating treatment of patients in hospitals). Depending on its specific application, task scheduling needs to adapt the task scheduling model (TSM) to the object.

In the mobile robot the TSM can be used to meet the time constraints of task analysis. In its simplest form, the TSM may include periodic tasks. This form is known as the static scheduling task model (SSTM) [5], in which tasks are described by the following timing parameters [5]:

(1) $<C, T, D>$

where: C – maximum execution time of the task, T – the period of the task occurrence, D – the relative deadline time limit within which the processor must finish the task.

The characterized parameters are illustrated in Figure 1 for the task Z_1 performed in time C_{Z_1} and repeated with a period T_{Z_1}; D_{Z_1} is relative deadline which means that the task must be completed within the specified time.

Elastic scheduling task model

The mobile robot described by the SSTM has a major disadvantage, namely, the inability to carry out aperiodic tasks or periodic ones with changing timing parameters. As is shown in Figure 1, the aperiodic task Z_3 is performed as an additional one to the tasks Z_1 and Z_2, which are realized periodically. Assuming that the executed periodic tasks Z_1 and Z_2 take full advantage of the mobile robot hardware resources U determined as [7]:

$$U = \sum_{i=1}^{n} \frac{C_i}{T_i}, \quad (2)$$

where: i – task index, n – number of tasks in a mobile robot, the execution request for aperiodic task Z_3 leads to lack of adherence regime of time required to complete periodic tasks.

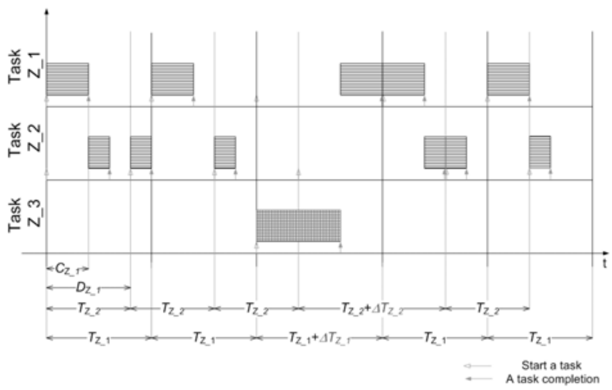

Fig.1. Example of realization of periodic tasks Z_1 and Z_2 and aperiodic task Z_3

In the mobile robot, the execution of such tasks can be achieved through expansion of hardware resources. Such a solution, however, is costly and can lead to inefficient use of resources and greater consumption of electricity. Another solution may be referred to as the elastic scheduling task model (ESTM), the idea of which is to modify the period of occurrence of tasks. In the literature, there are few publications related to ESTM [8, 9, 10]. One of the new proposals of ESTM is presented in [11]. In this model it is possible to:

- decide which tasks should modify the settings of periods T,
- modify the settings of periods T in a manner which is not necessarily executed in a proportionate way,
- determine, at the design phase of a mobile robot, the parameters of resource use during operation, providing the opportunity to reduce energy consumption.

The proposed ESTM [11,12] is described by the following parameters

(3) $<C, T_{nom}, D, T_{min}, T_{max}, wvt, U_{su}>$

where: T_{nom}, T_{min}, T_{max} – sequence for nominal, minimum and maximum occurrence of a task, wvt – weighting of the validity of a task, U_{su} – assumed value of the node resource use. Parameters C and D have the same meaning as in the model (1).

The proposed ESTM ensures, without increasing the resources of a mobile robot, the execution of periodic tasks or aperiodic tasks with changing timing parameters. This is possible because, for the tasks of the least importance for the stability of the robot, the incidence of such task periods is increased. The decision over the necessity of the tasks performed by the mobile robot, using the ESTM, is taken on the basis of the properties of the task assigned to each wvt factor. The decision over the selection of new task T_{sel} occurrence periods is made on the basis of pre-defined intervals for each task T_{min} and T_{max}. When tuning T_{sel}, the condition over the exploiting of the mobile robot resources is taken into account. The decision over whether the chosen values for tasks T_{sel} satisfy the condition is dependent on the current resource calculation formula *U* (2). If the value of $U > U_{su}$, another selection T_{sel} period is sought. The complexity of the selection process T_{sel} periods is assigned to the class of NP hard problems [11, 12, 13], which are addressed, among other solutions, by heuristic algorithms. The GRASP algorithm, shown in Fig. 2, is a heuristic algorithm whose characteristics make it possible to use in ESTM [11]. The GRASP algorithm, after entering ESTM parameters, starts by creating an nw_i vertex of a graph by calculating for each task, and performs the selection of a new set of options for the T_{sel} period. The assumed value of the number of the set selection T_{sel} period for the i-th task (lz_i) is created for each task 2^{lz_i} graph vertex. For the first three vertices, the value T_{min}, T_{nom} and T_{max} are assigned sequentially. For the remaining vertices of the graph, the selection of new settings T_{sel} is made by using the formula:

$$T_{wyb_{i,\alpha+3}} = T_{min_i} + \alpha \cdot kp_i , \tag{4}$$

where:

$$\alpha = 1,\ldots,2^{lz_i} - 3; \quad \text{for} \quad lz_i \ge 2,$$

$$kp_i = \frac{T_{max_i} - T_{min_i}}{2^{lz_i} - 2}.$$

In the next stage of the GRASP algorithm (Fig. 2), the value of $g(x)$ is calculated for each graph vertex nw_i on the basis of the fitness function (Or). The Or calculation is required to seek the path in the resulting graph. For the sought route the smallest value of the function Or is considered, which at the same time meets the U_{SU}. When calculating function the i-th period of occurrence of *T* task is assumed for Or. For other tasks T_{max} values are taken, because these values are most likely to meet the condition of resource U_{su}. The choice of the best path follows after choosing the top of the nw_i, for which the resulting value of $g(x)$ is the lowest and also true for the condition $U \le U_{su}$. Sequentially in the algorithm it is checked whether among the tracks there is a path which would include all the task periods of T_{sel}. If there is no such path, the best path is chosen for the creation of successive vertices of a graph containing the path for the next task. If it is found that the path for all tasks includes T_{sel} the GRASP algorithm ends since a resolution has been created.

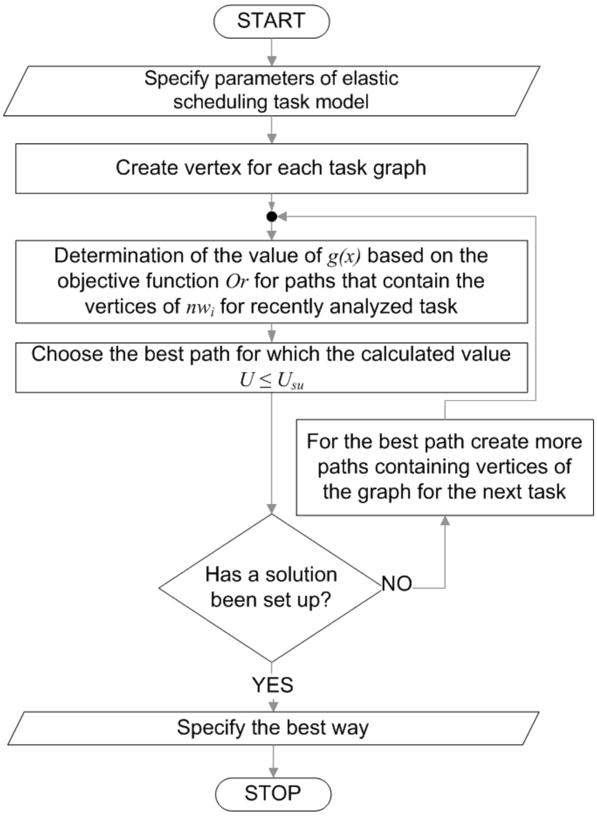

Fig.2. Flowchart of the GRASP algorithm used in ESTM

In the case of the ESTM fitness function the aim is an evaluation tuning T_{sel} , the formula of which is specified in [10]

$$Or1 = \begin{cases} \sum_{i=1}^{n} \left(\frac{\left(T_{nom_i} - T_{wyb_i}\right)^2}{\sum_{j=1}^{n}\left(T_{nom_j} - T_{wyb_j}\right)^2} \cdot \frac{wvt_i}{\sum_{k=1}^{n} wvt_k} \right) & ,when \quad \sum_{j=1}^{n}\left(T_{nom_j} - T_{wyb_j}\right)^2 > 0 \\ 0 & ,when \quad \sum_{j=1}^{n}\left(T_{nom_j} - T_{wyb_j}\right)^2 = 0 \end{cases}, \tag{5}$$

where: j, k – task index.

Imperfection of the fitness function $Or1$ (5) results mainly from not fully taking into account the assumed value of resource U_{su} of the mobile robot. The GRASP algorithm with the fitness function should reject solutions that do not meet the condition $U \le U_{su}$, but also choose T_{sel} values for all defined tasks in a mobile robot to achieve the result $U = U_{su}$. Imperfections in the fitness function $Or1$ were the basis for the development of a new fitness function $Or2$, defined by the formula:

(6)
$$Or2=\begin{cases}\sum_{i=1}^{n}\left(\frac{\left|T_{wyb_i}-T_{nom_i}\right|}{T_{\max_i}-T_{\min_i}}\cdot\frac{wvt_i}{\sum_{j=1}^{n}wvt_j}\right) & ,when\quad T_{\max_i}-T_{\min_i}\neq 0\\ \sum_{i=1}^{n}\left(\frac{\left|T_{wyb_i}-T_{nom_i}\right|}{T_{nom_i}}\cdot\frac{wvt_i}{\sum_{j=1}^{n}wvt_j}\right) & ,when\quad T_{\max_i}-T_{\min_i}=0\end{cases}.$$

The simulation study

The aim of this study was to compare the simulation fitness function to $Or1$ and $Or2$, both of which are used in the GRASP algorithm, for the selection of the ESTM T_{sel} for different values of the parameter wvt. At the beginning tests were performed for the exemplary mobile robot, in which the three functions are implemented with the parameters shown in Table 1.

Table 1. Sample values for the three tasks

Task number	C [ms]	T_{min} [ms]	T_{nom} [ms]	T_{max} [ms]	lz_i
Z_1	1	5	40	80	10
Z_2	45	100	150	300	10
Z_3	20	5	30	60	10

The study assumes full use of the mobile robot resources (U_{su} = 1), which will be matched by a new set T_{sel} by the ESTM. For the adopted values of the time task parameters (Table 1), the value for the use of mobile robot resources while working with nominal values T_{nom} is U = 0.99. Simulation studies of the fitness function $Or1$ and $Or2$ involved a situation in which one of the tasks (e.g., task Z_1) would be performed two to four times more likely (T_{nomZ_1} = 20 ms and T_{nomZ_1} = 10 ms). Such a situation may occur when the mobile robot has to increase the frequency of reading the distance to obstacles in its path of movement. Then, without modifying the set of periods, it is impossible to perform tasks on a mobile robot as the T_{nomZ_1} = 20 ms, U = 1.02, and for T_{nomZ_1} = 10 ms, U = 1.07.

This scenario corresponds to a situation in which one of the periodic tasks changes its timing parameters. This leads to the inability to carry out the tasks with the given mobile robot hardware resources. Wvt parameters were chosen in such a way that if the settings for the task periods T_{sel} Z_1 (wvt with the highest value) are modified in the smallest degree, the GRASP algorithm changes the frequency for performing this task. The greatest opportunity for modification was assigned to task Z_3 (wvt with the lowest value). Table 2 shows the results of tuning T_{sel} for two cases: T_{nomZ_1} = 20 ms and T_{nomZ_1} = 10 ms.

Table 2. Determined values of T_{sel} based on two $Or1$ and $Or2$ fitness functions for 3 tasks, when T_{nomZ_1} = 20 [ms] and T_{nomZ_1} = 10 [ms]

Task number	T_{nomZ_1} = 20 [ms]		T_{nomZ_1} = 10 [ms]	
	T_{sel} [ms] with $Or1$	T_{sel} [ms] with $Or2$	T_{sel} [ms] with $Or1$	T_{sel} [ms] with $Or2$
Z_1	20	20	10	10
Z_2	150	150	150	150
Z_3	60	30,78	60	33,36
U	0.68	0.99	0.73	0.99

Based on the results shown in Table 2, the GRASP algorithm was found for the fitness function $Or1$ and $Or2$ assigned to T_{sel} T_{nom} values for task Z_1. The assignment of the average value of wvt to task Z_2 resulted in T_{sel} for this task being equal to T_{nom}. Differences in choice of setting for T_{sel} appeared, however, for Z_3 task. The fitness function $Or1$ in this case for T_{sel} assigned the value T_{max}, thus causing the smallest gain of U and extending the period of occurrence of task Z_3 to the value of T_{max}. An $Or2$ of double and fourfold decrease in T_{nomZ_1} forced a change in the choice of T_{sel} for task Z_3 near to the nominal value, so that the U-value calculated by the formula (2) was close to the value of U_{su}.

Further simulation studies were carried out for three tasks (Table 1), replacing the value of wvt between tasks Z_2 and Z_3. The results of the selection T_{sel} as the value for the fitness function $Or1$ and $Or2$ are shown in Table 3. Wvt assigned values resulted in fitness functions $Or1$ and $Or2$ for tasks Z_1 and Z_3 choosing T_{sel} with the values T_{nom} of these tasks (Table 3). Differences in the selection of settings T_{sel} result, as in the previous study, from the assumed value of wvt. The fitness function $Or1$ for the task Z_2 selected value T_{sel} = T_{max}, and the function $Or2$ drew T_{sel} closer to nominal values, so that the U-value was as close as possible to U_{su} values. Both examples (see Table 2 and 3) confirmed better accounting of U_{su} by the fitness function $Or2$ during tuning T_{sel} in the mobile robot using ESTM.

Table 3. Other determined values of T_{sel} based on two $Or1$ and $Or2$ fitness functions for 3 tasks, when T_{nomZ_1} = 20 [ms] and T_{nomZ_1} = 10 [ms]

Task number	T_{nomZ_1} = 20 [ms]		T_{nomZ_1} = 10 [ms]	
	T_{sel} [ms] with $Or1$	T_{sel} [ms] with $Or2$	T_{sel} [ms] with $Or1$	T_{sel} [ms] with $Or2$
Z_1	20	20	10	10
Z_2	300	164,97	300	202,74
Z_3	30	30	30	30
U	0,86	0,99	0,92	0,99

Given the fact that the mobile robot can perform more tasks, further simulation tests were carried out for 5, 10, 15, 25, 50, 75, 100, 150, and 250 tasks under the assumption that for each task lz_i value = 10. For each test the number of tasks is repeated 1000 times for various time parameters. In order to automate the process of simulation research, especially for a large number of tasks, the choice of timing parameters was carried out on the basis of a method developed for calculating the values of some parameters of the ESTM [6]. To set the maximum number of tasks each task execution time C was selected using a random number generator with uniform distribution in the range from 1 to 10. For the accepted values of the parameters: U_{nom}, U_{min} and U_{max} were calculated for all tasks of T_{nom}, T_{min} and T_{max}. The i-th values of the task periods were calculated with the formulas:

$$T_{nom_i}=\frac{C_i}{U_{nom}-\left(\frac{(n-i)}{n}U_{nom}+\sum_{j=1}^{i-1}\frac{C_j}{T_j}\right)}$$

(7)
$$T_{\min_i} = \frac{C_i}{U_{\max} - \left(\frac{(n-i)}{n} U_{\max} + \sum_{j=1}^{i-1} \frac{C_j}{T_j} \right)}$$
$$T_{\max_i} = \frac{C_i}{U_{\min} - \left(\frac{(n-i)}{n} U_{\min} + \sum_{j=1}^{i-1} \frac{C_j}{T_j} \right)}$$

The equations in (7) are obtained through converting formula (2). During a further simulation study the highest value of *wvt* was attributed only to task Z_1. Other tasks were assigned the lowest wvt value during the tuning T_{sel} in the ESTM. This method of assigning wvt was intended to provide a situation in which there was reported an aperiodic task Z_1 which was critical to the stability of the mobile robot.

The first series of tests comparing the simulation function $Or1$ and $Or2$ for different numbers of tasks performed in a mobile robot were carried out for three settings scenarios (sc) U_{nom}, U_{min}, U_{max}, and U_{su} (Table 4).

Table 4. Scenarios of simulation studies

	$sc1$	$sc2$	$sc3$
U_{min}	0.7	0.8	0.9
U_{nom}	1.1		
U_{max}	1.2		
U_{zal}	1		

Differentiation of U_{min} (Table 4) illustrates the possibility of adjusting the tuning ranges T_{sel} in EMSzZ. The lower the value U_{min}, the greater will be the value of T_{max} calculated by the formula (7) (greater possibility of tuning T_{sel}). On the other hand, accepting equal values for U_{nom} and U_{max} (greater than U_{su}) for the three scenarios (sc) allow you to check how fitness functions $Or1$ and $Or2$ affect the selection of T_{sel} *periods by* the GRASP algorithm to suit the assumed value of U. This assessment was based on the calculated rate of

(8)
$$u = \frac{U_{zal} - U_{avg}}{U_{avg}} \cdot 100\%,$$

where: U_{avg} – the average U (formula 2) from all simulation repetitions.

The value U_{avg} cannot accept a value greater than U_{su}, because the assumptions of the GRASP algorithm for such solutions are rejected (Fig. 2). U_{avg} cannot be zero, because this would mean that the mobile robot has performed no task. Smaller values *of* u mean that the value of T_{sel} *chosen* by the EMSzZ make a better fit of U to U_{su}. Figure 3 shows the calculated u values of the three scenarios for different numbers of tasks n using the fitness function $Or1$ and $Or2$ in the selection T_{sel} by the GRASP algorithm. For all three scenarios (sc) function $Or1$ chooses feature T_{sel} with respect to setting U to U_{su} with worse results than $Or2$. The calculated values of u, however, did not exceed 4.5%. The differences between the values in the scenarios $sc1$, $sc2$ and $sc3$, for the fitness function $Or1$, result from the fact that the smaller the value of U_{min} there more opportunities there are for selection of T_{sel}. The calculated values of the fitness function $Or2$ for all three scenarios do not exceed the value of 0.04%. Based on the results shown in Figure 3, one can also note that for the fitness function $Or2$ different values U_{min} had no significant effect on u.

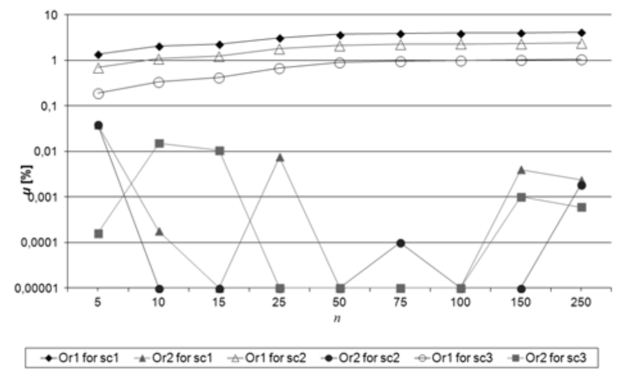

Fig. 3. Influence of the number of tasks n on u for the fitness function $Or1$ or $Or2$ of three scenarios

Another series of simulations have been performed for the fitness functions $Or1$, $Or2$ and for different numbers of tasks n in a mobile robot with different values of U_{su} depending on the number of tasks for U_{nom} = 0.9, U_{min} = 0.6 and U_{max} = 1. The accepted value U_{su} for the number of tasks n was calculated by the formula:

(9)
$$U_{su} = n \cdot \left(2^{1/n} - 1\right).$$

Equation (9) is used for the RM method with fixed priority assignment when it is necessary to ensure that the n tasks are executed before the expiry of time limit for the tasks, while meeting the real-time conditions [11]. Figure 4 shows the u values for different numbers of n for fitness function $Or1$ and $Or2$.

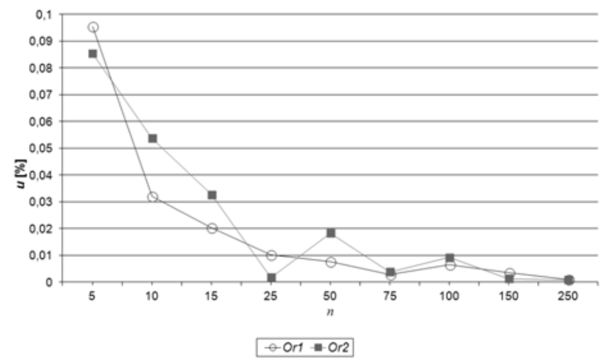

Fig. 4. Influence of the number of tasks n on u for the fitness function $Or1$ or $Or2$

On the basis of Figure 4, it can be concluded that the values $Or1$ and $Or2$ decrease while the number of tasks n increases if U_{su} is calculated in accordance with the formula (9). Decreasing values of the functions $Or1$ and $Or2$ during the selection period T_{sel} means that the GRASP algorithm is better at matching U to U_{su} calculated from the formula (9) with an increase in the number of tasks n.

Summary

The use of the ESTM in mobile robots is especially important in the case when aperiodic tasks or periodic tasks with changing timing parameters are executed. In addition, the ESTM provides the ability to ensure the exploitation of task resources at a level not exceeding U_{su} cycles through the selection of tasks. For scheduling in the ESTM, heuristic algorithms such as GRASP algorithm can be used [6]. For each of the heuristic algorithms, a definition of the fitness function that assesses the value of T_{sel} is required in order that this algorithm can be realized properly. Both functions

$Or1$ and $Or2$ provide the possibility to select T_{sel} in the ESTM. The newly proposed function $Or2$ feature makes the selected value of T_{sel} in ESTMZ a better fit of U to U_{su}. In this study the GRASP algorithm with function $Or2$, in contrast to $Or1$, chose a new set of T_{sel} closer T_{nom} than T_{max}. This method of selecting new settings for T_{sel} shortens the cycle of tasks, which enables the mobile robot to respond more quickly to events.

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