AGENT-BASED APPROACH FOR INTELLIGENT AUTOMATED LANDFILL OPERATION SYSTEM

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Abstract: Workers and operators in sanitary landfill sites face the health risk due to the constant exposure to the toxic solid, liquid, and gaseous by-products of the waste materials. One solution to this problem is automation technology that can increase productivity and quality as well as safety. But, developing an automated system for landfill operations is usually a complex task due to the dynamic aspect of the environment and the uncertainty in task planning. Cooperation is another fundamental concern that is fundamental for a collection of automated equipment to achieve more than the sum of what each can achieve individually. To reduce the above complexity to some extent, a new approach is required for developing an automated landfill system. This paper describes an agent-based cooperative system for an automated landfill system that is to perform landfill compaction operations effectively, and to provide a means of cooperation between landfill equipment. Three kinds of landfill agents are defined and a methodology for simple task allocation among them is suggested. The critical factors for task allocation are identified, and then, based on these factors, a cost model for calculating the execution cost of each piece of equipment is established. For effective cooperation, all agents in the proposed system should have autonomy and interact with each other in a partially centralized and partially decentralized way.

Keywords: Automation system, Landfill operation, Multi-Agent, Task allocation

1. INTRODUCTION

In recent years, the need for improvement in safety, productivity, and quality has motivated several research investigations in the area of automation and robotics in construction in spite of the difficulties in designing and implementing automation technologies. One area of research on construction automation and robotics is hazardous waste handling in sanitary landfill sites. Basically, the sanitary landfill project disposes of solid wastes in a manner that minimizes environmental pollution. After the landfill project is completed the land can be used for recreational-open space, agricultural land, or limited types of institutional land. The major concern with the hazardous waste handling is the potential long-term health risk faced by workers from constant exposure to the toxic solid, liquid, and gaseous by-products of the waste materials in a landfill site [1]. There are several hazardous waste handling operation tasks in the landfill site such as excavating, grading, compacting, and hauling. Automation is applicable to the above tasks that are hazardous to human health, physically dangerous, repetitive, continuous, and tedious.

Developing an automated system for landfill operations is a complex task. There are many factors contributing to this complexity. These factors fall into two main categories: 1) the dynamic factors such as landfill site conditions, unexpected weather conditions, machine breakdowns, accidents involving machinery or workers, and uncertainty associated with initial planning for waste compaction tasks; and 2) the number of equipment involved in landfill operations with different functions. In addition, cooperation is fundamental for a collection of automated equipment to achieve more than the sum of what each can achieve individually. To reduce the above complexity to some extent, a new approach is required for designing and implementing an automated landfill system. Recently, there has been an emerging trend to enhance automation system intelligence. Intelligent automation systems, based on the understanding of the environment, can emulate human thought processes in the analysis, reasoning, judgment, and final performance of complex tasks in a given problem domain [2]. This paper describes a conceptual framework for developing an intelligent automated landfill operation system.

This paper is organized as follows: In the following section, we describe the agent architecture for an automated landfill operation system. Subsequently, we discuss the task allocation methodology for a simple landfill operation. Finally, we explain our future research for development of an intelligent automated landfill system.

2. SYSTEM ARCHITECTURE

The agent-based system for automated landfill operation developed by the authors consists of a landfill environmental database, an operational knowledge base, and three sorts of landfill agents: 1) system agent, 2) landfill equipment agent, and 3) truck agent (See Figure 1). The agents of this system can be envisioned as independent sub-systems that can work either in cooperation with other agents or in isolation. The agents negotiate with each other by passing messages to achieve goals for cooperative work.

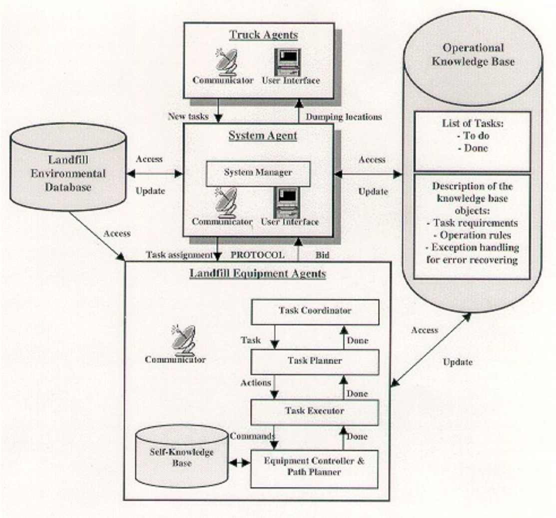

Figure 1. System Architecture

2.1 Landfill Environmental Database

The landfill environmental database (LED) has information about 1) the partitions, called *cells*, of a landfill site, 2) the position of all cells, 3) the target volume (capacity) of the cells, 4) the current landfill volume of the cell under waste handling operation, 5) gas and leachate systems, 6) the total space consumption of a landfill site, and 7) the exact locations and types of compacted waste materials which would benefit the landfill excavation operation or recycling programs. Whenever the waste handling task is done by the landfill equipment agent, this database is updated.

2.2 Operational Knowledge Base

The operational knowledge base (OKB) contains the list of tasks, which should be done and have been done. It also contains the description of the knowledge base objects such as task requirements, operation rules and operation exception handling rules for error recovering.

2.3 System Agent

The system agent (SA) is responsible for identifying and distributing the waste-handling tasks that have been confided to it, updating the landfill environmental database, and monitoring the execution of tasks. It must allocate the tasks to landfill equipment agents, while trying to satisfy the constraints as well as global optimality criteria. The SA must also keep track of the result of task execution. It can be considered a software expert for the landfill operation system. The involved elements can be briefly explained as follows:

- System manager
  The system manager has three roles: 1) predicting waste volume generation and cover material volume, 2) identifying tasks for the solid waste compaction and cover material placement, and 3) advertising tasks and assigning them to landfill equipment agents.
- User interface (Man-Machine Interface)
  The user interface provides the system operator with tools for the input of commands in order to recover system errors, and for data visualization. When the automation system is down or makes errors, the user can check landfill equipment status through the user interface.

Communicator
The communicator is responsible for sending and receiving real-time data and messages, and for transporting commands and bids between the agents for the effective landfill operations.

2.4 Landfill Equipment Agent

The landfill equipment agent (LEA) represents the means of excavating, spreading, compacting, and hauling the solid wastes and cover materials, such as crawler dozer, crawler loader, rubber-tired dozer, rubber-tired loader, landfill compactor, scraper, and dragline. Every LEA is capable of accepting and assigning tasks, which means it can act as a bidder or a provider of tasks. LEAs will consist of a number of elements with different functions. The evolved elements can be briefly explained as follows:

Self-knowledge base
The knowledge database has global position data and information on ownership/operation cost, productivity, and its own failure rate of itself. It also has self-knowledge that might be divided into two parts: 1) operational-specific knowledge for self-diagnostics and error recovering; and 2) machine-specific knowledge such as location, speed, power, weight, physical dimension, capacity, available turn-radius, production rate etc.

- Communicator
  The communicator is identical to that of the SA.
- Task coordinator
  The task coordinator is responsible for calculating an execution cost, submitting a bid for a task assignment, and making a contract. If the task announced is so simple that one LEA can finish it without the consideration of cooperative work, the task coordinator makes a bid for task assignment. By contrast, if the task consists of various subtasks and/or has a lot of work volume that cannot be performed by one

LEA, the task coordinator finds a group of LEAs, which all together are able to perform the given task, and then makes a bid for task assignment. To perform this type of task, several LEAs have to cooperate, because each LEA can only play a part to execute a specific task. The main problem to be solved here is to find a consistent group of LEAs, called a well-matched team. This means that the team is guaranteed to succeed in executing the given task as long as there are not exceptional events.

- Task planner
  The task planner is responsible for creating a local task. This means that it decomposes the given task into simple actions, which can be executed by the individual LEA without interacting with other LEAs. If the assigned task does not comply with the agent's plan or other internal constraints, then the given task may be rejected. When there are exceptional events such as break down of the LEA, errors in task execution, etc., the task planner may propose its task to another agent or rearrange its plan.
- Task executor and Equipment controller
  The primitive actions derived in the task planner are executed in the task executor. By executing simple actions, A LEA does not have to interact with other LEAs. Precomputation with sensor data, which are dynamic environment data of a landfill site, is done in the task executor for the path planning. Simple control commands are sent from the task executor to the equipment controller where the actions are actually executed.
- Path planner
  The path planner is in charge of finding the optimal trajectory according to the requested movement. It uses GPS data that provide the location of landfill equipment, finds the link or the node of the landfill site network graph where the landfill equipment belongs, and then checks any conflict on that node or link.

2.5 Truck Agent

The truck agent (TA) represents the means of transporting the solid waste materials to the work area. They receive orders of the forms "Transport solid waste materials to the work area and dump it at the specific location." They inform the SA of the type and volume of the solid waste materials. Usually, the specific dump location is selected by the SA. It consists of two elements: a communicator and a user interface. The communicator is identical to those of other agents. The user interface allows the truck operator to input data on solid waste materials and to get the specific dump location in the landfill site. The volume of solid waste materials, which are the critical resource, may change over time and play a major role in decision making for the task allocation process.

2.6 Relationship among Landfill Agents

All agents in the proposed system have autonomy and interact with each other in a partially centralized and a partially decentralized way. The TAs trigger the start of this system. After TAs dump solid waste materials in the landfill site, the SA assigns the task for waste material compaction to other LEAs. Then, LEAs perform the given task in a cooperative manner.

In order to achieve a coherent global behavior of the system and in order to coordinate the local activity, two kinds of relationship between landfill agents are used in the system: a horizontal relationship and a vertical relationship. Horizontal relationship means interaction among a group of LEAs. LEAs can share information on solid waste and cover material compaction operations, and their availability. This sharing is not performed hierarchically; rather it is associated with the aspects of conflict and cooperation. Each agent is responsible for its own movements and actions it should take on the basis of interaction with other agents. The coordination protocol describes these kinds of execution patterns. Vertical relationship represents interaction among TAs, a SA, and LEAs. This relation is hierarchical; the SA is obliged to give its best to allocate the task for solid waste material compaction given by TAs, and LEAs are requested to perform the assigned task by the SA and they are obliged to provide the SA with a report of what they have done.

We can say that the proposed system is a hybrid relational system; rather than a system that has purely vertical or horizontal relationship.

3. TASK ALLOCATION

In this section, task allocation factors and a task allocation methodology for a simple task, which can be accomplish by one LEA, are described. Even though a simple task can be executed by one LEA, the task allocation algorithm provides a means of cooperation between LEAs.

3.1 Factors Used for Task Allocation

There are several factors used for task allocation. When an agent generates a new task, all the possible bidders for executing the newly generated task will respond to it by submitting a cost that is calculated by using several factors as follows:

- Ownership cost
  Ownership cost includes the cost of depreciation, interest, taxes, insurance, and storage, which accrue whether or not the equipment is used. These are generally considered as fixed costs.
- Operating cost

Operating cost includes the cost for fuel, lubricants, filters, grease, overhead and, when applicable, tire replacement and repairs, ripper tips and cutting edges, and so forth. The operator's wage is not considered because we suppose that LEAs move and perform tasks automatically.

- Performance characteristics
  The ability of equipment to perform many functions that must be carried out at a sanitary landfill should be considered with respect to the needs and condition of each site. The performance values based on the types of LEAs on a landfill site and the job description are shown in Table 1.

Table 1. Performance Values of Landfill Equipment (Modified from Weiss 1974)

Equipment	Solid Waste		Cover Material			
	Spreading	Compacting	Excavating	Spreading	Compacting	Hauling
Crawler Dozer	1	0.75	1	1	0.75	0
Crawler Loader	0.75	0.75	1	0.75	0.75	0
Rubber-tired Dozer	1	0.75	0.5	0.75	0.75	0
Rubber-tired Loader	0.75	0.75	0.5	0.75	0.75	0
Landfill Compactor	1	1	0.25	0.75	1	0
Scraper	0	0	0.75	1	0	1
Dragline	0	0	1	0.5	0	0

* 1- Excellent, 0.75- Good, 0.5- Fair, 0.25- Poor, and 0- Not Applicable

- Productivity
  The productivity value of landfill equipment is supplied by the manufactures. It can also be obtained from previous experience and historical data.
- Failure rate
  The failure rate means the possibility that a LEA will break down within a certain period of time.
- Moving cost
  Moving cost means the travel cost of moving the LEA between two distant places to perform a task in the landfill site. If two LEAs which have the same ownership, operating, and performance costs are available for a task announced by an agent, the agent will choose the LEA that has the lowest moving cost, because it can execute the announced task sooner than the LEA that has the higher moving cost.

All the LEAs calculate the execution cost for submitting a bid based on the above factors.

3.2 Cost Model For Task Execution

The equation below expresses the total cost for task execution calculated by each LEA, after receiving a task announcement from the SA.

$$TC_i = W_1 \frac{OC_i}{MOC_{all}} + W_2 \frac{OPC_i}{MOPC_i} + W_3(1 - PV_i)$$
$$+ W_4 \cdot PR_i + W_5 \cdot FR_i + W_6 \frac{D_i}{MD_i}$$

Where, TC_i is the total cost of LEA i; W_1,W_2,W_3,W_4, W_5 and W_6 are weight factors; OC_i is the ownership cost of LEA i; MOC_{all} is the maximum ownership cost among all LEAs in the landfill site; OPC_i is the operating cost of LEA i; $MOPC_i$ is the maximum operating cost among all LEAs in the landfill site; PV_i is the performance value of LEA i; PR_i is the production rate of LEA i; FR_i is the failure rate of LEA i; D_i is the distance between the location of landfill equipment agent and the location of work; and MD_i is the maximum distance between two points in a cell.

3.3 Simple Task Allocation Methodology

The agents negotiate with each other by message passing to achieve goals for cooperative work. Mutual agreement is achieved through communication. The principle modules for task allocation and execution are depicted in Figure 2. They consist of four categories: 1) waste transport module, 2) task allocation module, 3) bidding module, and 4) task execution module. The message flow among these modules is described below:

(1) TAs: TAs transport solid waste materials and send information about the types and volume of waste materials to the SA. If the whole system is not activated yet, this step will launch and initialize the system.
(2) SA: the SA receives information from the TAs, partitions the landfill site, and notifies the TAs of the dump location in a specific cell. If a TA cannot dump solid waste materials on the given location, the SA selects and assigns a new dump location.
(3) TAs: the TAs unload solid waste materials and notify the SA of what has been done. If it cannot dump solid waste materials due to machine break down, obstacles, unexpected site condition, or other reasons, the TA in trouble asks the SA for a new dump location.
(4) SA: after the TAs unload waste materials, the SA broadcast tasks to LEAs, which will submit a bid for the task assignment contract.
(5) LEAs: after receiving a task announcement from the SA, LEAs calculate the execution cost and submit it to the SA.
(6) SA: the SA selects the LEA that submits the lowest execution cost, and assigns tasks to that LEA.
(7) LEAs: LEAs can either accept the task allocated or reject it. After accepting and finishing the given tasks, LEAs will inform the SA that the

given task is done, and announce its availability to other agents in the landfill site.

(8) SA: the SA updates the space consumption of the landfill site and stores information on the location and types of compacted waste materials.

3.4 Extended Task Execution Module

The Contract Net concept [4] is adapted for the simple negotiation model. However, it assumes that agents dedicate themselves to a given task until it is completely executed; thus, when agents break down, deadlock occurs. Also, the Contract Net does not provide any means to handle interactions among agents' plans. Suppose even though some agents are available, there is no available task in the task list, thus the SA cannot provide any task to them. In this case, for the cooperative work, agents can submit a bid to other LEAs, which are performing some task. LEAs assist each other by sharing the computational load for the execution of tasks. The modified task execution module is presented as shown in Figure 3 and is explained as follows:

After the LEA accepts the task, the task execution module checks whether the LEA has broken down or not. If it were broken down, the LEA will announce its task to other LEAs (Task allocation module-Type A). When it is not a peak time in the landfill site, the task execution module finds an agent to work with the LEA performing the task using Task allocation module-Type B. There is a difference between Task allocation module Type A and Type B. In the case of Type A, a LEA passes its task to another agent and it is not involved in the task execution. By contrast, Type B achieves cooperative work by assigning a portion of its task to another agent. If the SA and other LEAs call for bids at the same time, the SA has priority; thus, available LEAs submit a bid to the SA.

4. SUMMARY AND FUTURE RESEARCH

The agent-based approach for an automated landfill operation system can provide some benefits in terms of reducing the complexity mentioned in Section 1 and increasing flexibility of the system. This paper describes an agent-based cooperative system for an automated landfill system that is to perform landfill compaction operations effectively, and to provide a means of cooperation between LEAs. Three kinds of landfill agents are defined and a methodology for simple task allocation among them is suggested in this paper. The critical factors for task allocation are identified, and then, based on these factors, a cost model for calculating the execution cost of each piece of equipment is established. For effective cooperation, all agents in the proposed system have autonomy and interact with each other in a partially centralized and partially decentralized way.

In the proposed system, an agent is a physical or virtual entity that can exchange messages. As for human beings, communication is the basis for interaction. If the agent does not have communication ability, it is merely an isolated individual. With communication, agents can cooperate, coordinate their actions, carry out tasks jointly and become truly social beings [5].

To interact and cooperate effectively, the landfill agents require three functional components: 1) a common language, 2) a common understanding of the knowledge exchanged, and 3) the ability to exchange whatever is included in 1) and 2). An agent exchanges messages within structured plans with other agents, which are supposed to perform particular tasks. These plans should be defined by a communication language, which will be developed for the automated landfill operation system.

The development of a complex task allocation methodology is on going. The authors will focus on finding a complete group of LEAs with the minimum execution cost to succeed in executing complex tasks.

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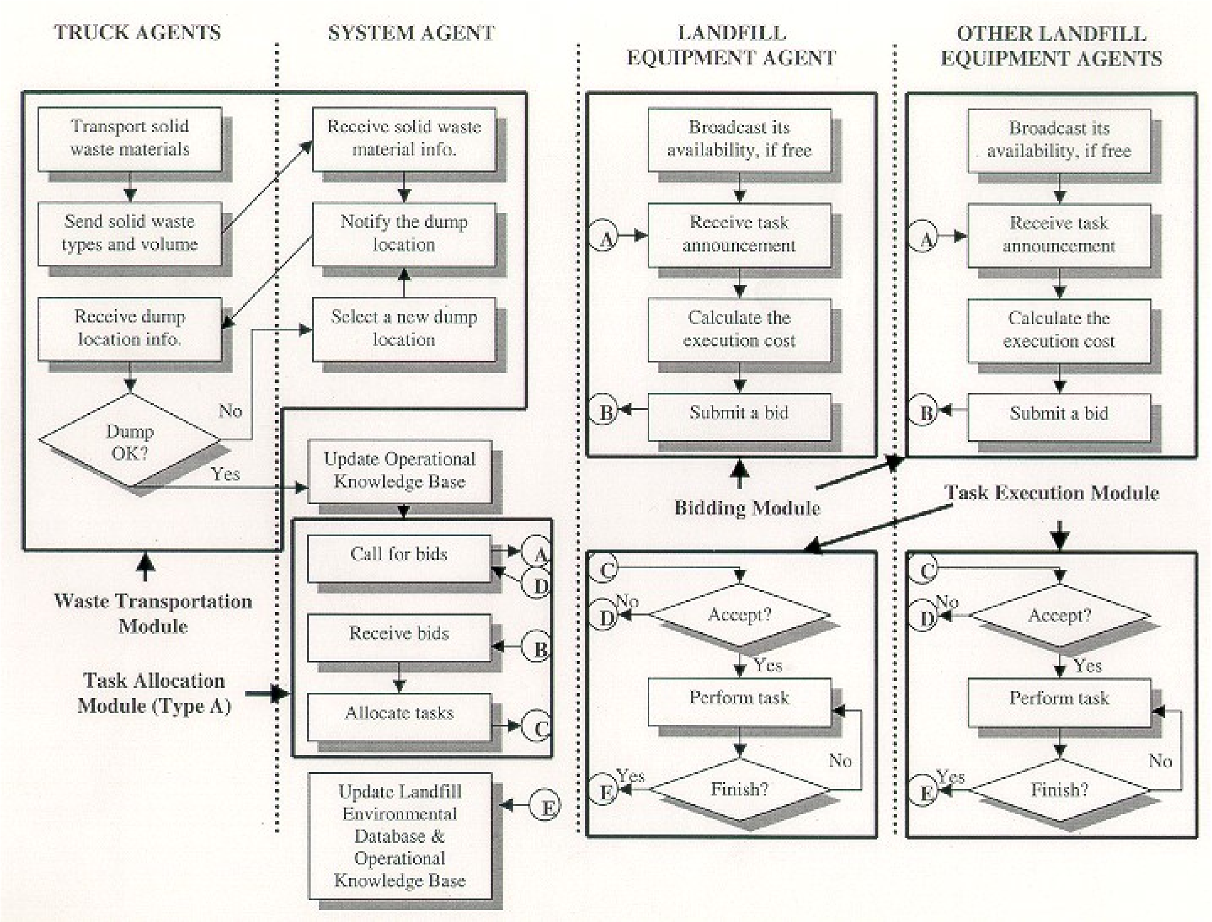

Figure 2. Message Flow Among Principle Modules

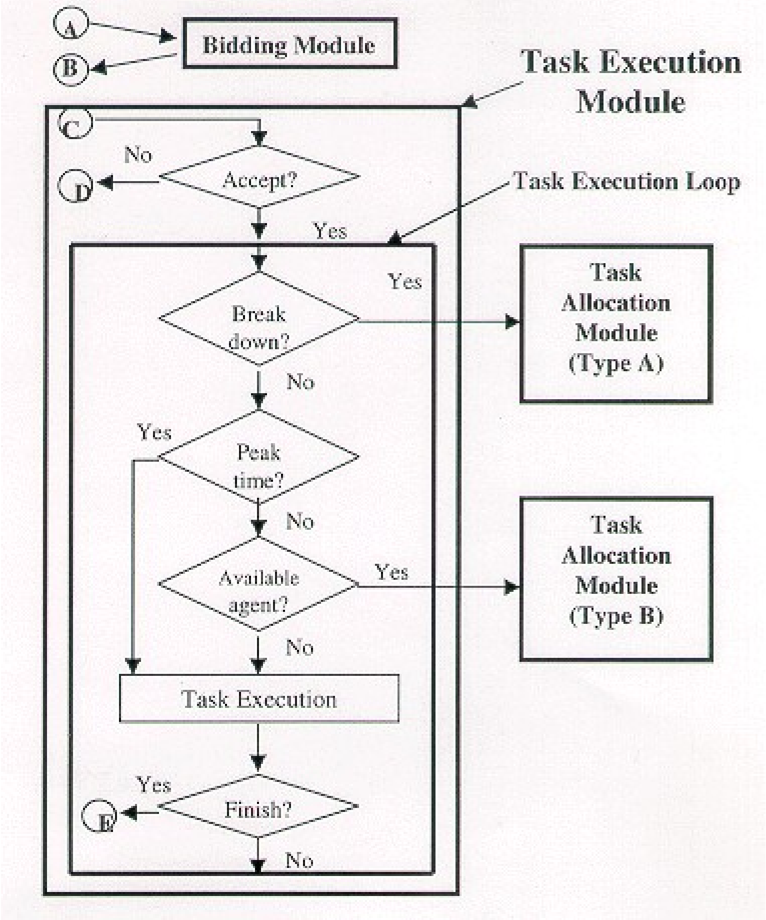

Figure 3. Modified Task Execution Module