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Hybrid Assembly: A Strategy for Advancing the Role of "Advanced" Assembly Technology

Paul S. Wu, H. Y. Tam, and P.K. Venuvinod
Department of Manufacturing Engineering
City University of Hong Kong

Abstract

In response to the market pressure of product variety of small batch size and quick delivery, intelligent flexible systems have been developed and used by many companies in various countries to stay competitive [1]. Heavy investments, both in equipment and personnel are necessary in order to realize one of these advanced manufacturing strategies. Only large and well-established companies are positioned to benefit from them.

The dedicated manual assembly line is the common assembly practice adopted by small companies in Hong Kong which manufacture light products such as toys and small appliances. To stay competitive, less capital intensive assembly strategies that allow simultaneous assembly of different products in the same assembly line need to be developed.

This paper addresses the need by presenting a hybrid assembly strategy. This strategy is suitable for adoption by small companies used to practice manual assembly. It involves a combination of manual and robot assisted assemblies. It converts an existing manual assembly line from a single-product production to a multiple-product production. It deals with two major problems arose due to the introduction of robot into a manual assembly line: 1) identification and retrieval of workpieces from a continuous flow line and 2) the cooperative interface between human and machine during the assembly. A case study is used to illustrated this hybrid assembly strategy.

Introduction

There has been great progress in the development of *advanced* assembly technologies in the last twenty odd years. The term *advanced assembly* today conjures up images dominated by the use of sophisticated robots equipped with ever more sophisticated end-effectors, vision systems, a wide variety of sensors, flexible conveying systems, automated guided vehicles, automatic storage and retrieval systems, emerging artificial intelligence techniques such as artificial neural nets and fuzzy logic, etc. Indeed, there have been several successful systems based on these advanced assembly technologies — for example, Sony's recent ?????? system [1]. Some countries, such as Japan, have even thrived through their adoption. Consequently, the initial euphoria generated by these *advanced* technologies was such that one expected their widespread application all around the world by the turn of the century.

However, a dispassionate assessment (i.e. one untainted by unbridled technological enthusiasm) of the current global scene suggests that the adoption of these advanced technologies is nowhere near the expectation of technological enthusiasts. Economic and social factors, as always, seem to have taken precedence over *dreams* based merely on technological feasibility.

Today, assembly operations are steadily being transferred from industrially mature countries to developing countries in pursuit of lower production costs. However, these less developed countries, unlike the industrially mature countries, are unable to support advanced assembly technologies owing to the challenges posed by inadequate capital availability, and the abundance of cheap but unskilled labor. The result has been that the cause of advanced assembly technologies, when placed in the global perspective, has actually suffered. How can this trend be reversed? How can advanced and automated assembly technologies coexist with traditional manual assembly which , correctly, dominates the developing world? In particular, how can one take advantage of the emerging high capabilities of advanced assembly technologies in enhancing the efficiency of the current ethos of assembly dominated by human operators as a result of socio-economic imperatives? A review of recent assembly literature suggests that these important questions have received relatively little attention owing to the dominance of technological euphoria. This paper addresses some technological aspects concerning these questions. The technological strategy proposed in this paper is inspired by the experiences of Hong Kong which, over the years, has gained international reputation as a large and cost-effective assembly house. The proposal is based on the authors' involvement with Hong Kong industry and the ongoing research work being carried out in the substantial flexible assembly facility available in the Department of Manufacturing Engineering at the City University of Hong Kong.

In most developing countries, including China and Hong Kong, assembly of light products such as toys and electric appliances continues to be based on dedicated manual assembly lines. The work flow on these lines is continuous with the workers carrying out their assembly tasks seated alongside a conveyor line moving at constant speed. Usually, the line is configured to assemble multiple instances of the same product — hence the term "dedicated". Each line consists of a serially organized set of assembly stations. At each station, the worker repeatedly performs the same cycle of operations consisting of retrieving parts from the feeder trays, handling and inserting the parts, and returning the assembled part to the conveyor. When dissimilar products need to be assembled, the required number of single-product assembly lines are setup to satisfy the demand. This dedicated production strategy works well when the batch size is relatively large and skilled manpower is abundantly available.

In 19??, there were about 2000 toy factories in Hong Kong [2]. The majority of these (98%) were small companies employing less than 200 manual workers. Almost all these companies had long been successfully adopting dedicated manual assembly for many years. However, in recent years, owing to rapidly rising costs of space and labor within Hong Kong, most of these companies have had to move their assembly operations to mainland China and other South East Asian regions where labor and space costs are substantially lower than in Hong Kong. However, these companies soon realized that the skill level of workers in these regions was not on par with what the companies were used to in Hong Kong.

The first response to the problem of low worker skill levels was to redesign products and the assembly processes so that the worker skill level requirement could be minimized. Quite naturally, initially, this meant that "low-tech" assembly technologies had to be adopted. However, this low-tech approach has its limitations in terms of the achievable productivity and quality particularly in the context of ever increasing global demand (which Hong Kong companies mainly serve) for higher product quality (therefore, greater product precision), product sophistication (therefore, greater product complexity) and, at the same time, greater product variety.

The requirement for minimizing manual skill level is very important in view of the high worker turnover rate associated with rapid economic expansion in the regions. One of the strategies used by Hong Kong's manufacturing entrepreneurs was to adopt more scientific approaches towards Design for Assembly [3, 4] and to segment the entire assembly operation into a large number of sequential small steps such that each assembly step involves only simple actions. Indeed, this fine subdivision of assembly facilitates (i) line balancing; (ii) the identification of common assembly cycles among different product lines, and (iii) the possibility of local automation . However, the penalty is that the number of assembling workers increases substantially.

There have been many technological responses to the global demand for of large product variety coupled with short delivery times. In particular, many flexible robotized assembly strategies [5] suitable for different product contexts have been reported. The result has been a general and seemingly compulsive pursuit of *full* automation of flexible assembly. However, there is much published literature (which is too extensive to be cited here) which suggests that this pursuit of full automation has de-emphasized the role of human operators in flexible assembly and that this de-emphasis has been a costly mistake. The reasons for the failure of full flexible automation in practice are many. The inappropriateness of and incompatibility between the structures and cultures that exist in many organizations are some of the reasons for this failure [6]. Insufficient understanding of the human factor is another important reason [7]. As a result, the concept of human integrated production systems is gaining ground [8]. The intention here is to allow the human operator to be a significant participant in the future computer integrated manufacturing (CIM) systems. However, all these fine developments and achievements are still *pies in the sky* for most small companies in many developing industries including those in Hong Kong.

In the following we propose a hybrid assembly strategy which introduces advanced assembly automation technologies into conventional manual assembly lines in a controlled manner. It is assumed that the workers are relatively unskilled. Hence, robot station(s) are introduced in a manner that would not disturb the conventional working environment as perceived by human operators. Rather than expecting the human operators to adjust to the trauma of advanced technology introduction, the robot station is designed to fit into existing conventional lines. This has required a new way of looking at the relative capabilities of robot and human work stations. In particular, the robot station is viewed as the one endowed with superior intelligence. This is contrary to the prevalent view in full flexible automation of assembly. Fortunately, current robot technology seems to be sufficiently advanced to take on the challenge. However, it appears that many technical principles concerning robot station design need to be reviewed. We will identify the more important principles that need to be revised and propose solutions. The feasiblity of many of the proposed solutions has already been tested at the authors' laboratories.

A Hybrid Assembly Strategy

The proposed hybrid assembly strategy aims to redress the problems of small companies currently engaged in assembling a set of similar products on dedicated manual assembly lines. In particular, unlike with traditional manual assembly based on single-product conveyor lines, the strategy aims to facilitate simultaneous assembly of more than one product model on the same manual assembly line. This means that the strategy should require very few alterations to the existing manual assembly line(s) during the introduction of new products. Further, the ratio of manual stations to robot stations in the hybrid system should remain large. The proposed strategy is such that, in most cases, there is only one robot station that is used to perform the necessary functions while allowing multiple decisions and variations in assembly tasks.

When multiple single-product manual assembly lines are combined into one, a variety of parts will flow through each assembly line. In such a situation it is necessary to ensure that the general nature of all manual assembly tasks remains essentially similar to that on traditional dedicated assembly lines. Work should continue to be planned such the processing cycles undertaken by each worker are largely similar for all the parts to be assembled. Operators should not need to change tooling or fixtures in order to process different workpieces. The y should be able to handle all parts to be assembled and the associated assembly processes at essentially the same skill level. These constraints are necessary is to avoid the possible reduction in work efficiency and the increase in defects that invariably occur when unskilled workers are required to carry out non-repetitive processing cycles.

In contrast to the above, note that the work cycle of a robot station (assuming that it is sufficiently *advanced*) can vary with different workpieces. Here, the robot can be viewed as an intelligent human line operator possessed with the quick decision capability required for identifying the arriving workpiece, processing it according to the specified assembly plan, and returning it to the appropriate down-stream line. It is assumed that the robot station is equipped with the parts and processing equipment necessary for servicing the required variety of workpieces. As the variety of the product-mix is increased, the function of the robot may switch from assembly to that of dispatching the incoming parts from the upstream flow line to the corresponding manual down-stream assembly line as shown in Figure 1.

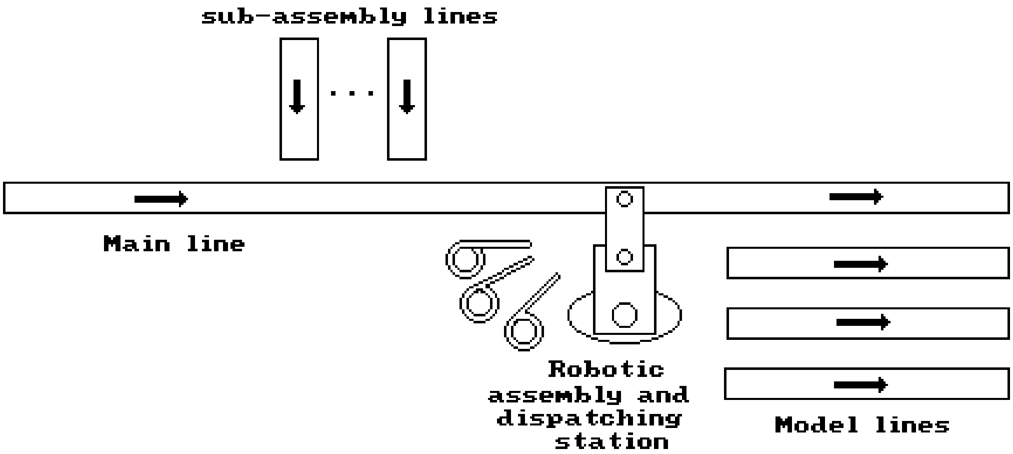

Figure 1 A robot station in a manual assembly line

Introducing a Robot Station in a Manual Assembly Line

Contemporary practice in manual assembly of light products employs continuous flow line strategy for workpiece transfer. Workers simply pick the arriving workpiece, which was previously placed randomly on the transfer line by the upstream workers, perform the required assembly task and, subsequently, return the assembled part back to the line. In contrast, robotized assembly systems often use intermittent or asynchronous transfer systems. Such systems usually present the workpiece to the robots in a precise location and orientation either at regular time intervals or at a time interval dictated by the requirement of each robot station. Assembly processing takes place while the workpiece remains in the work-carrier.

The premise underlying the proposed hybrid assembly strategy is that the existing manual assembly practice should be retained as far as possible. Thus, the approach to be adopted for integrating the manual and robot assembly stations requires the robot station to adapt to the existing setup for manual assembly. Two issues arise in such an adaptation. They concern (i) the retrieval of the workpiece from the flow line by the robot, and (ii) the design of the robot station controller to enable proper interfacing with the rest of the assembly line and proper sequencing of work within the robot station.

Retrieval of Workpiece from the Flow Line

In order to ensure the minimum possible disturbance to the manual assembly line, workpieces are retrieved from the flow line directly just like what a worker does when a workpiece arrives at a manual station. The retrieval process consists of the robot reaching out to the workpiece and grasping it. It may commence any time after the workpiece motion has been established. Based on the predicted motion, a robot trajectory is planned, which when followed, allows the robot end-effector to reach out to the moving workpiece [9]. In the case of retrieving moving objects where the motion of an object keeps on changing, the robot trajectory is modified upon every update of the object motion prediction [10].

Retrieving moving objects is uncommon in shop-floor applications of robots. Apart from high positioning accuracy which crucial for a robot to successfully retrieve a moving object, the ability of the robot end-effector to grasp at the right time is equally important. The proposed setup for robotic retrieval of workpiece from a flow line is shown in figure 2.

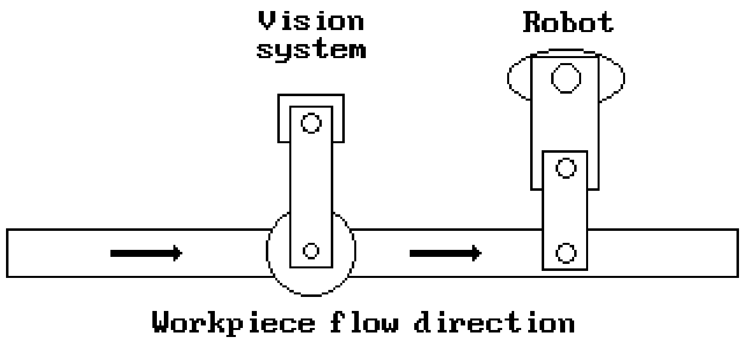

Figure 2 Moving object retrieval

There are two basic causes that make the grasping of a moving object at the right time difficult [11]: (i) errors in estimating the object arrival time, and (ii) non-systemic delay in communication and grasping actuation. These problems are, in principle, solvable by the strategies reported in [11]. The arrival time could be estimated on the basis of the object position measured from a vision system and the conveyor motion derived from the associated encoder signal. Further improvement is achievable by utilizing an LED (light emitting diode)signal that detects the workpiece approach. The second cause may be alleviated by planning robot motion such that, instead requiring the robot to stop at the expected location of object interception, the robot may be allowed to continue to move at the same velocity as the object after the interception. Grasping can then be initiated after the stable object tracking by the robot has been established. Thus, the effect of small time delays could be rendered insignificant.

During the assembly of mixed product models production, the identity of an arriving workpiece would not be known by the robot beforehand. In such situation, a vision system could be used to identify the product type as discussed in [12]. When the workpiece passes underneath a fixed CCD camera, an image is captured and processed. Output from the vision system includes information concerning the type of the workpiece, its position and orientation, and grasping location. This information allows the robot to determine how the workpiece should be processed. In this operation, the conveyor belt is assumed to run at a constant speed.

Workstation Control

In most intelligent flexible assembly strategies, human operators are expected to “fit into” the otherwise automation system. In contrast, in the proposed hybrid assembly strategy, the robot station is required to fit into the otherwise manual system. This represents a total reversal of the conventional stratgey in hybrid assembly. Since the majority operations are performed by essentially unskilled workers in the hybrid system, the robot must coordinate with human workers to ensure that all workpieces in the flow line are processed as planned.

Since the incorporation of an robotic station in an existing manual system represents a substantial investment, it is essential to ensure that the robot does not idle during production. On the other hand, the robotic station should not be overloaded to the extent that it slows down the normal manual assembly process. *(Is this correct?)*

A station controller is usually assigned to coordinate the operations of the robot and accessory automation equipment within a robot workstation. The controller is responsible for the synchronizing tasks required within the station as well as while interacting and cooperating with other human workers in the assembly line. In particular, it needs to work with the immediately up-stream and down-stream human operators. The line supervisor can be expected to be able to easily modify the operations at the robot station when the production schedule is changed or the product mix is altered. In this context, there are basically three operational modes to be considered: (i) retrieving the workpiece from the up-stream flow line and returning it to the appropriate down-stream flow line; (ii) retrieving the workpiece from the up-stream flow line, processing it, and returning it to the appropriate down-stream flow line; and (iii) letting the workpiece to directly pass through to the down stream flow line.

Coordinating with the up-stream human operator: In the extreme, a workpiece may be expected to be served along its route by each of the workstations in the flow line. As a mix of workpieces sequentially arrive from the up-stream station in an irregular fashion, the station controller directs the robot to temporarily place some of the workpieces in buffers (the number of buffers required depends on the number of different types of workpieces produced by the up-stream station) with a view to regulating the arrival times. This is achieved by sensing each arrival with the help of a CCD camera and then tracking the *time-to-arrive*. If the time-to-arrive of the nearest workpiece is smaller than the time it will take to finish the present sequence, the robot retrieves the incoming workpiece and transefers it to the appropriate buffer before continuing with its noemal sequence.

Coordinating with the down-stream human operator: When the down-stream worker is overloaded or interrupted for some reasons, the worker informs the robot station by means of a push-button switch. Upon receiving such a signal from a downstream worker, the robot transfers the processed workpieces to the buffer instead of delivering them to the problem flow line. When the buffer is full, the station controller will, in turn, signal the up-stream workers not to release that specific workpiece to the flow line. In addition, the types of workpieces in the buffer may need to be remembered for later identification, depending on post-processing handling requirements.

Providing interface with the line supervisor to assign work to the robot station: A convenient mechanism is established to enable the line supervisor to assign work to the robotic station just as he assigns work to human workers in the flow line. A job list is used to this end. Each item in the list designates a job the robot will perform on a workpiece. For single product assembly, there is only one item in the list. The supervisor can assign the robot to either perform some assembly tasks on the workpiece or just let the workpiece passing through to the downstream workers. For mix product assembly, the list contains more than one item. Before a workpiece arrives at the robotic station, the vision system will identify the type of the workpiece. Based on the types and instructions in the list, different task is to be performed: to dispatch the workpiece to specific flow line downstream; to perform certain assembly tasks; to allow the workpiece passing through. The line supervisor may modify the production by changing the list. If the robotic station is networked to a higher level controller in which job scheduling is conducted, that controller may also relate production commands to the station controller through changing the job list.

To perform the assembly and oversee the component supply within the station: The robotic station can be assign to perform some limited assembly functions if the number of product mix is small. The station controller continuously monitors the supply of components for all the assembly operations in the station and signal for attention as the supply runs short. There is also a dependency link between the availability of components and the corresponding items in the identification list. Thus, an item can be temporarily removed from the list if the supply of related component is out.

A Case Study

A toy company manufactures different motorized toy cars for export. The types and quantities of toy car to be built are affected by market requirements. This results to high product varieties and small-batches. The types of toy car manufactured are fire engine, mixer truck, crane truck, excavator truck, dump truck, police car, ambulance, etc. These products usually have the same basic functions with different outlooks. There were 70 types of component for all toy cars manufactured. Each toy car had an average of 64 components in 30 different types. Many screws were used to joint large components together. Some smaller plastic components were welded on the outer cover. Some wheels were joined by way of rivet. There was no doubt that they were not designed for mix assembly on the same manual production line.

Design for assembly

The integrated product design methodology introduced in [3-4] is the major step toward the goal of mix assembly. Some design guidelines used are

- Minimize the number of components
- Have a suitable base component on which to build
- Standardize components for the car family
- Assembly is being done in layers from the above if possible
- Provide geometric features wherever possible to aid correct guidance, positioning, and insertion
- Avoid expensive and time-consuming fastening operations
- Make component symmetric, otherwise make asymmetry as large as possible

This redesign process standardized parts for the motorized car family. It broke down the assembly into fine steps so that unskillful worker can master the operation quickly. It identified the common sub-assemblies that are suitable to every motorized toy car. As the result, the total number of components reduces to 38 types. Each toy car has an average of 37 components in 27 different types. This family of toy cars is composed of two types of components: standard components and special components as shown in Figure 3. Standard components are separated into global and local standards. Essential components are base frames, driving system, wheel, motor, batteries, outer cover, etc. Special components include extendible ladder for fire engine; crane for crane truck; excavator for excavator truck; dump for dump truck; mixer for mixer truck. Ambulance, police car and car for the fire department have the same shape of outer cover but different color and printed letters.

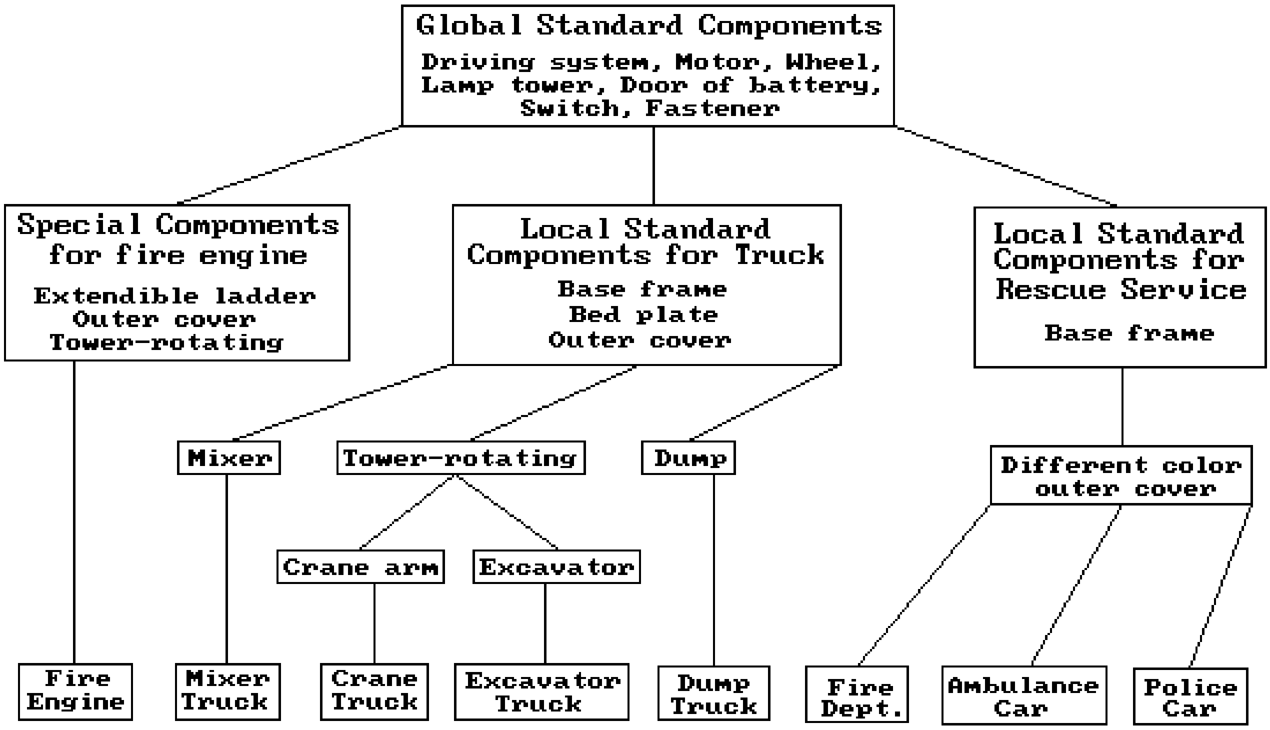

Figure 3 A family of motorized toy cars

Assembly sequence

Before planning the assembly sequence, each individual part and operation are cataloged on a planning chart that highlights the geometric and dynamic requirements of each operation. The assembly sequence is generated according to the chart and assembly liaison diagrams. The assembly liaison diagram of fire engine is shown in Figure 4. Generally, many alternative assembly sequences could be generated. Each assembly sequence should be critiqued on the basis of its cycle time, number of special tools and fixtures needed, number of non-assembly operations, and overall feasibility. The best one or two should be retained for further study of part feeding (if robot assembly is required), assembly line layout, technology selection, and economic analysis.

At the same time, useful subassemblies are also identified. Any group of parts that is physically stable and can be transported or oriented without falling apart is a candidate for subassembly. Usefulness of the subassemblies can be global and local. Three global subassemblies are identified as driving-part subassembly, gear-set subassembly, and lamp-part subassembly.

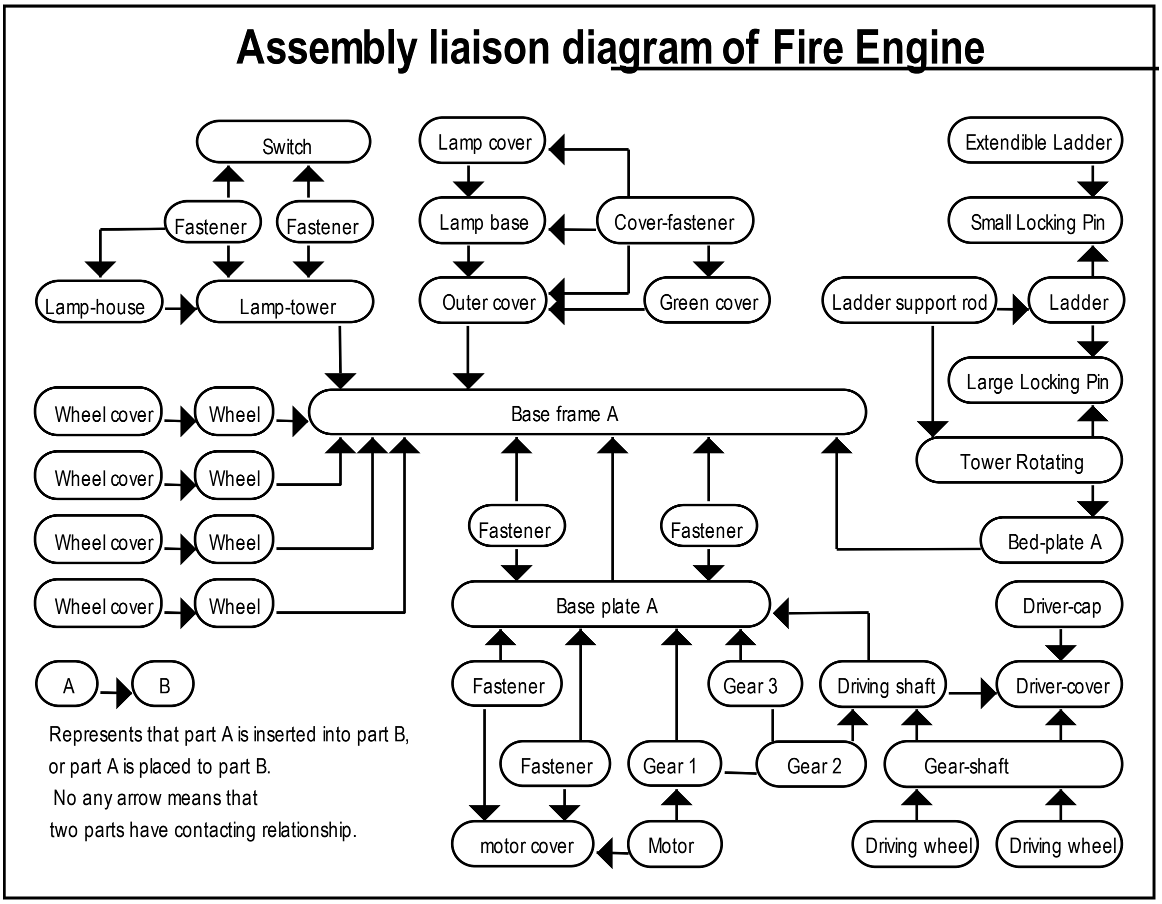

Figure 4 Assembly liaison diagram of fire engine

Assembly lines

Before the suggested hybrid assembly strategy, a large number of dedicated manual assembly lines, one for each model are setup for the simultaneous production as shown in Figure 5. This approach works well when the production volume is large and stable for each model.

Following the proposed hybrid assembly strategy, a single system for the simultanous assembly of all models ca be setup. In this system, manual workers are assigned to workstations in which the operation sequence does not vary with product models, and a robotic station is used where there are variations. The setup of the mix model assembly is shown in figure 6. All assembly operations up to the assembling of green cover are assigned to manual workers. All assembly operations after the robotic station are also assigned to manual workers if the robot is used to dispatch models to their appropriate assembly line downstream. Although two types of base-frames (those for the truck model and for the van models) share the same assembly line upstream, the sequence of operations each worker is to carry out remains the same.

In Figures 5 and 6, each name item in the flow line may actually represent more than one workstation. Items with an underline represent components with color varieties. Items in italic represent components with both structural and color varieties.

Fire-engine
Base-frame Wheel Wheel-cover Subassemblies Green-cover Outer-cover, Lamp-base, Lamp-cover, Cover-fastener Tower-rotating, Ladder, Ladder-support-rod, Extendible-ladder

Ambulance
Base-frame Wheel Wheel-cover Subassemblies Green-cover Outer-cover Lamp-base Lamp-cover Cover-fastener

Police-car
Base-frame Wheel Wheel-cover Subassemblies Green-cover Outer-cover Lamp-base Lamp-cover Cover-fastener

Fire-dept.
Base-frame Wheel Wheel-cover Subassemblies Green-cover Outer-cover Lamp-base Lamp-cover Cover-fastener

Crane-truck
Base-frame Wheel Wheel-cover Subassemblies Green-cover Bed-plate Outer-cover, Lamp-base, Lamp-cover, Cover-fastener Tower-rotating, Crane-arm, Crane-support-rod, Extendible-crane-arm

Excavator-truck
Base-frame Wheel Wheel-cover Subassemblies Green-cover Bed-plate Outer-cover, Lamp-base, Lamp-cover, Cover-fastener Tower-rotating, Excavator-arm, Excavator-support-rod, Extendible-excavator-arm

Mixer-truck
Base-frame Wheel Wheel-cover Subassemblies Green-cover Bed-plate Outer-cover Lamp-base, Lamp-cover, Cover-fastener Mixer

Dump-truck
Base-frame Wheel Wheel-cover Subassemblies Green-cover Bed-plate Outer-cover Lamp-base, Lamp-cover, Cover-fastener Dump

Subassemblies: Driving-part subassembly, Gear-part subassembly, and Lamp-part subassembly

Figure 5 Dedicated manual assembly for all models

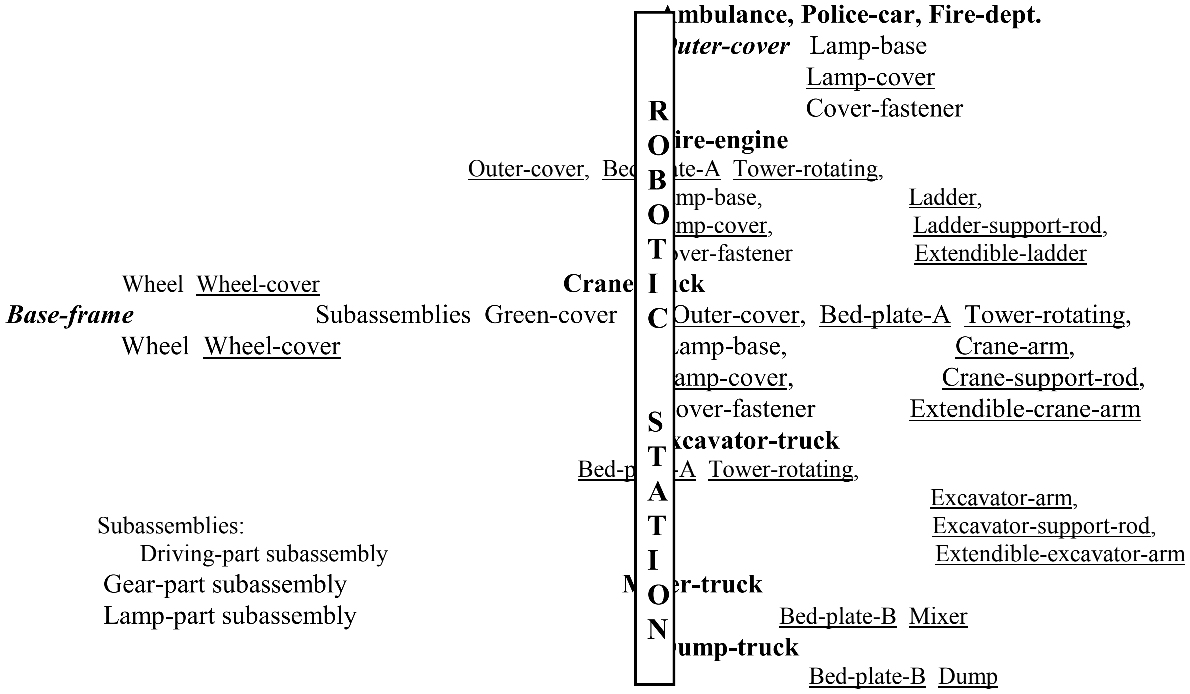

Figure 6 Mix model assembly

In addition of dispatching workpieces to the corresponding assembly lines downstream, The robotic station can be responsible for the assembly of outer-covers, lamp-base, lamp-cover and cover-fastener based on the assembly plan. Vibratory bowl feeders are used for these components. The gripper design is designed to grasp rectangular components only as shown in Figure 7. The open range of the gripper is from 11 mm to 70 mm. Subsequently, the workpiece is passed to the downstream flow lines that are destined to a specific car type such as crane-truck, ambulance, police car, etc.

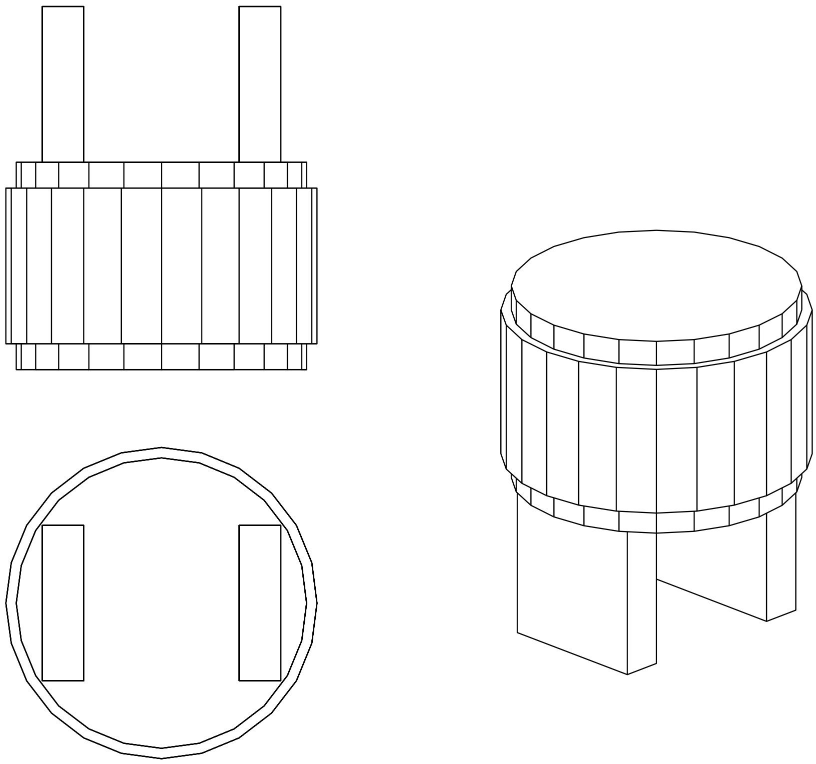

Figure 7 The configuration of gripper

Assembly Operation

Manual assembly instructions are plain and simple. Graphical illustrations are used wherever possible. Examples of a subassembly and fire engine assembly are shown below:

1. Common to all Cars

<u>*Driving System Subassembly*</u>: get and inspect a gear-shaft → holding the gear-shaft → get and inspect a driving wheel → insert one end of the gear-shaft to the driving wheel → get and inspect another driving wheel → insert the other end of the gear-shaft to second driving wheel → put down the gear-shaft with driving wheels → get and inspect a driver-cover → place the driver-cover on the fixture → repeat the above two steps until the fixture is full → get and inspect a driving shaft → insert the driving shaft to the driver-cover → repeat the above two steps until the fixture is full → place the gear-shaft with wheels on the driver-cover → get and inspect a driver-cap → fasten the driver-cap to the driver-cover → repeat the above three steps until the fixture is full → turn over the fixture to drop down the driving-part subassembly.

2. Assembly Operations of Fire Engine:

   a) Assembly operations of base part subassembly: get and inspect a base frame → get and inspect a wheel → insert the wheel to one axis of the base frame → get and inspect a wheel cover → fasten the wheel and base frame by inserting the wheel cover to that axis → repeat the step 2 to 5 for other three wheels → put the base part subassembly onto the conveyor.

   b) Assembly operations of car-base subassembly (fixture is required): place driving part subassembly to the base part subassembly → place gear set subassembly to the base part subassembly, driver-shaft should mesh with gear 3 → fasten them by two fasteners → fasten the lamp part subassembly with the gear set subassembly by snap-fit → get and inspect a green cover → snap-fit the green cover → put the car-base subassembly onto the conveyor.

   c) The robot station function: to perform assembly tasks, or to dispatch car-base subassembly to the appropriate flow line downstream, or to let the subassembly to pass through.

   d) Assembly operations of cover part subassembly: get and inspect a lamp base and a outer cover → place lamp base on the top of outer cover → get and inspect a lamp cover → place lamp cover on the top of lamp base → use cover-fastener to join the outer cover, the lamp base and the lamp cover → put the cover part subassembly onto the conveyor.

   e) Assembly operations of fire engine product: fasten the cover part subassembly with the car-base subassembly by snap-fit → get and inspect a tower rotating → join the tower rotating with the outer cover by snap-fit locker → get and inspect a ladder → join the ladder with the tower rotating by large locking pin → get and inspect a ladder support rod → join the ladder support rod with the ladder by small locking pin → get and inspect a extendible ladder → join the extendible ladder with the ladder support rod by small locking pin → get and inspect a door of battery house → install the door of battery house to the base frame → return to the conveyor.

The processes in items a) to b) are common for all models. The configurations of truck and fire engine are shown in Figures 8 and 9.

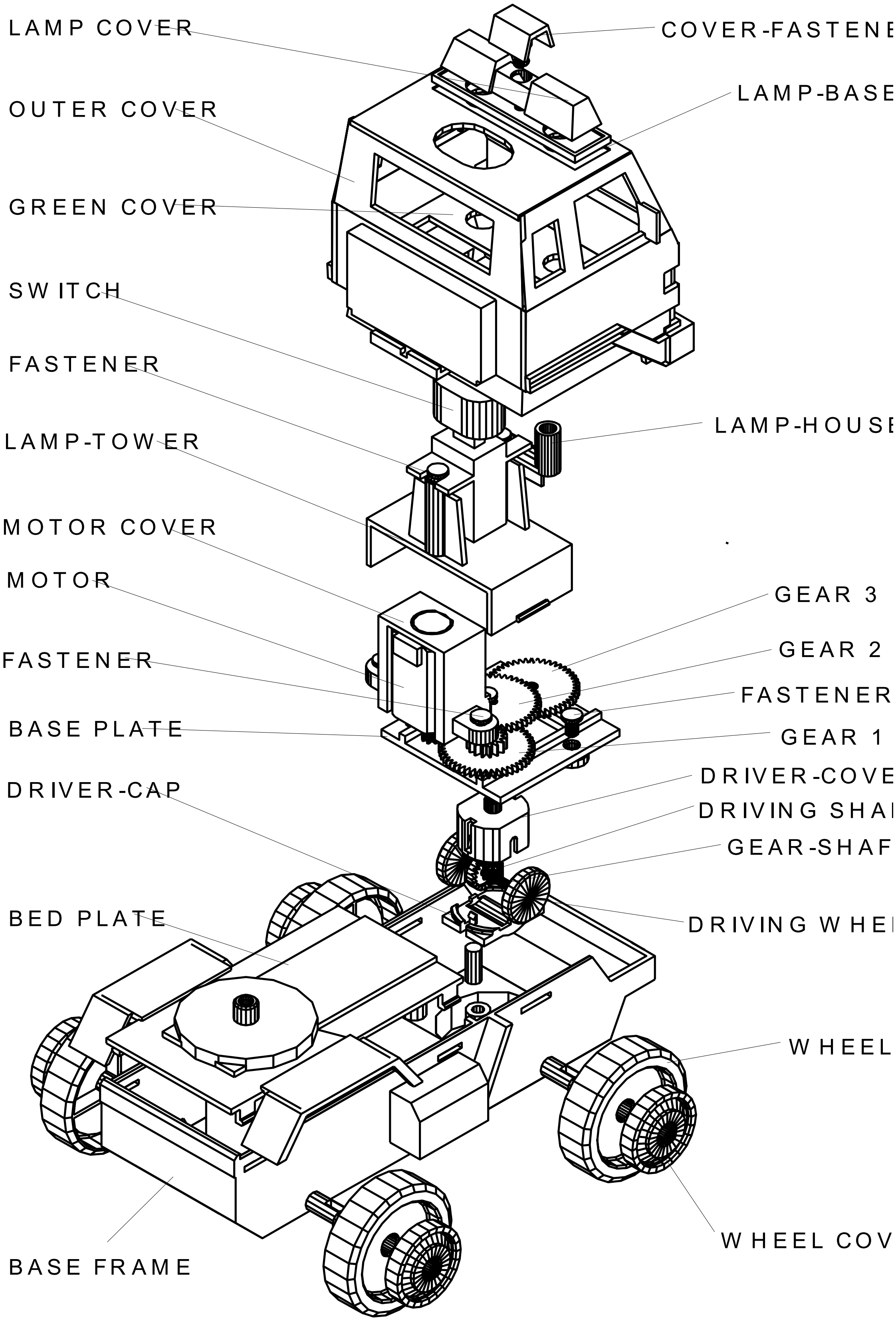

Figure 8 The configuration of trucks

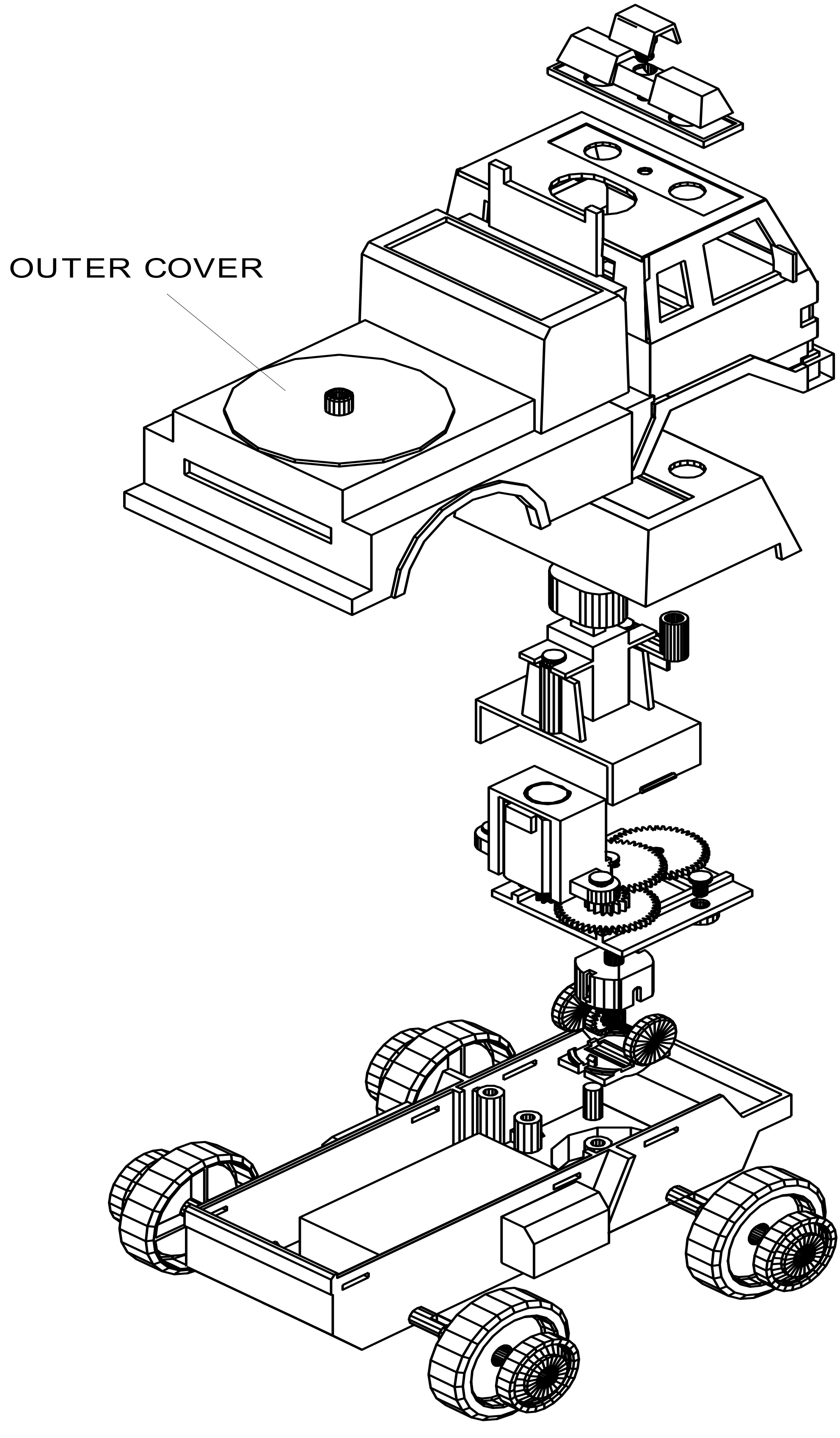

Figure 9 The configuration of fire engine

Discussion

The proposed hybrid assembly strategy is intended to allow mix-product assembly in the same assembly line by introducing robotics into manual assembly lines in small companies to. The strategy is to allow robot to be part of manual assembly line as an "intelligent worker". The success of this strategy depended on

- Robot is introduced as an enabling rather than an enhancing technology. - Small companies who are used to manual assembly are usually skeptical about robotics. The present strategy of using a small number of robots to enable mixed-product assembly would appeal to small companies as a way to introduce robotics into the shop-floor.

- Utilize strengths and avoid weaknesses of manual assembly and robotic assembly. - There are usually many pragmatic reasons behind the use of human workers in product assembly in the small companies. The present strategy intends to retain human workers for most of the processing and substitute robots for humans at those places where non-repetitive processing cycles are expected. This is a type of work that unskillful humans are relatively weak.

- Only small change to the existing assembly practice is required. - The present strategy for mix-product assembly compares favorably to an alternate strategy of using a highly automated system. The latter usually require major changes to the existing facilities and may even require the product to be redesigned to suit such an automated system. The former requires less financial resources and lower in-house technical expertises.

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