Ecological-Inspired System Design for Safety Manipulation Strategy in Home-care Robot

Mohamad Yani[1,3]

[1]Department of Computer Engineering, Faculty of Electrical Engineering, Institut Teknologi Telkom Surabaya, Indonesia
mai@ittelkom-sby.ac.id,
mohamad-yani@ed.tmu.ac.jp

Adnan Rachmat Anom Besari [2,3]

[2]Departement of Information and Computer Engineering, Politeknik Elektronika Negeri Surabaya
Surabaya, Indonesia
anom@pens.ac.id
1904mext@tmu.ac.jp

Nao Yamada[3], Naoyuki Kubota[3]

[3]Department of Mechanical, Faculty of System Design, Tokyo Metropolitan University, Japan
yamada-nao1@ed.tmu.ac.jp
kubota@tmu.ac.jp

***Abstract*— Manipulation tasks such as grasping, placing, and hand-over ability is crucial for the robot home application. In order to help the elderly at home, robots should have awareness and react carefully to prevent injury or accidents. The idea of safety strategy in robotics mainly used for industrial environment with less uncertainty. However, the home-care robot deals with many uncertainties condition and it is difficult to predict the human behavior than predict the industrial moving object. Thus, it is important to formulate a systematic approach to improving safety awareness on home-care robots. The following paper describes an approach of safety strategy for robot home manipulation task. This system uses an ecological approach based on the interconnection between perceptual system and action system according to spatial-temporal context of the updated information from environment. Some recommendation and preliminary experiments are conducted to show the possibility of further development for future research.**

***Keywords*— home-care robots, safety strategy, manipulation task, ecological approach**

I. Introduction

A large number of the elderly population and low birthrate problem has grown a serious social issue in several countries. To gain a better living, it is necessary to support the independence of physiques with disabilities and the elderly as well as give household assistance to these societies and the broad population. Thus, developing a robot which works to help this kind of society is considered as a potential solution. In recent years, many researchers have developed the robot service with manipulation tasks such as grasping, placing, hand over, and verbal communication ability [1], [2]. Various sensors are installed in these robots, such as IMU, RGB-D Camera, laser range sensor, and stereo camera for ease of use as research. Additionally, the Robot Operating System (ROS) is built as a software system architecture.

Effective human-robot collaboration should have the ability to estimate and learn the spatial and environmental context in which operations take place [3]. Many researchers and developers are interested in developing the learning model and task planning to help older people in the home environment. It is necessary to consider the safety strategy on home-care robots to perform manipulation task in the elderly environment to prevent accidents and decrease the anxiety of older users to home-care robot behavior. The idea of safety strategy in robotics, which is mainly used for industrial applications, is included in the standards which prescribe that safety is ensured by defining an operation where the robot terminates when human intervention is detected. However, the home-care robot deals with several uncertainties situation,

Fig. 1. One of the Home-care robot from Toyota Motor Corporation

and it is more difficult to predict the older user behavior (human) than predict the industrial moving object. Moreover, existing manipulation strategies for the robotic hand are focusing on affordance detection or effective grasping area detection, where the perception sensor of the robot is pinned on the fixed frame and only localize the effective grasping point for fixed base hand manipulator robot [4], [5]. However, if the robot using a moving camera at mobile manipulator such as home-care robots, the perceived affordance can change corresponding to the change of behavior. Therefore, it is essential to formulate a systematic approach to improve safety awareness or accident prevention in manipulation tasks for home-care robots.

Recently, robotics researchers have been studied in various fields such as cognitive science, psychology, brain science, and animal behavior to build the behavior-based robotics [6]–[9]. However, it is hard for a robot to perform complicated tasks such as human or animal behavior. For instance, the walking behavior on humans can unconsciously prevent the approaching dangerous object, and then, they return to the main intention. In this case, the intention priority shifted temporarily according to the logical inference. If the human gets an accident due to hitting by the car, they will not reach the main intention. To realize this kind of awareness and cognition in robot, ecological inspired model has been proposed by many researchers. In [9] has used combination of a hierarchical method such as multiple neural network

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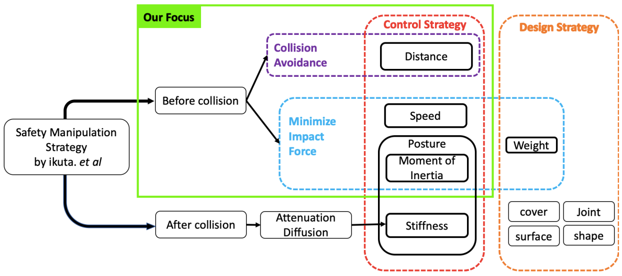

Fig. 2. Safety strategy for pick and place adopted from Ikuta. *et al*

based on perceptual and action cycle. In this method, they consider the error in learning process can affect the behaviors change. However, they did not deal with complicated environment such as human intervention and various shape of object detection. Saputra *et al*. [7], [10] using a perception and action inspired system for locomotion animal-like robot. In this work, the authors deal with ladder climbing (grasping) and obstacle avoidance behavior. To optimize the effective motion and behavior with less energy consumption, the optimization approach is applied in this research by using a multi-objectives genetic algorithm. The robot was smoothly passing the obstacle 18 times and succeeding climb the ladder. While the perception information in deactivated mode, the robot always hit the obstacles.

The following paper presents an approach of safety manipulation strategy for robot home applications. This approach uses ecological-inspired system based on the interconnection between perception and action system according to spatial temporal context of the updated information of environment. Some preliminary experiments are conducted to show the possibility of further development in system design.

II. Safety Manipulation Strategy

Performing home-care robots safer for humans and environment is a field that is getting increasing attention. Ikuta et al. [11] define three categorization of robot safety evaluations, specifically collision avoidance, impact minimization, and post-impact suppression methods. Specifically, in our manipulation strategy, we will focus on designing the safety strategy on grasping (picking) and relocating the object (placing) such as Fig. 2. For example, when the home-care robot detects the potentially dangerous situation in the home environment such as a bottle of water located near the laptop or another electronics stuff on the table, the robot will decide that this situation has a dangerous possibility to the other object, then, safety grasping behavior will be generated based on that information. After that, the robot will localize the safety area and safety position to perform safety post-grasp action and relocated action. Using the information from the perception sensor, we defined dangerous situation based on home accident phenomena, object to object relation and object to human relation to generate the safety awareness and to localize the safety area for home-care robots manipulation tasks such as grasping (picking) or relocating the object (placing).

III. Ecological-inspired System for Robot Manipulation

Before discussing the detailed and specific ecological-inspired system for robotic, we need to know what is the definition of ecological knowledge. Ecological knowledge is the ability to understanding the interaction between humans, objects, and the surrounding environment [12]. In ecology, human expresses a complex of physiological, behavioral, social, and environmental changes that occur at the individual level as well as at the broader community level. An ecological system is suitable for expressing this complex combination, such as various objects, behavior, and environment [13]. These elements can be adaptive, complex, and can have uncertainty consequences, changing, and evolving.

To improve the quality of life for elderly living independently at home, we proposed an ecological framework for home-care robot manipulation tasks as a way to develop an awareness of the safe or dangerous situation from the complicated relationship between people, objects, and activities. In the home environment, home-care robots act as agents that should have the ability to perceive all information from the environment. Such information is like the relationship between objects around the robot, human activities, and other variables. This representation is the first step in developing the safety affordances concept [14] that requires robots to understand the possibility of a safety manipulation tasks from the human and inter-object relationship. This method also becomes the foundation for robots in managing behavior or giving the best service according to the elderly situation at that time. Before discussing more our proposed approach in the ecological-inspired system, we need to know more about the relationship about safety awareness and risk perception in the next section.

A. *Risk Perception*

The dominant source of safety knowledge is mainly from risk perception. In order to generate safety manipulation task on robots, labeling objects to object relationships and object human interaction emphasize potential dangers and consequences in the view of robot perception [15]. Practically, the initial labeling is based on semantic reasoning. For instance, when the robot sees the cup of water located on the edge of the table, this such of situation will be labeled based on object to object relation and types.

Then, the robot intuitively localized the safety affordance area and relocated the cup of water in the intended location. However, the detected affordances do not always represent the accurate information for the considered behavior. From the initial state of robot, the cup of water on the edge of table looks dangerous but it may not fall due to very close to the wall. In order to avoid this mismatch, the visual information should be updated every time and correspond to the robot motion. Based on neuroscience evidence [14], perception and behavior are tightly connected and give mutual representations. In the ecological psychology field, it is named as the perception-action cycle. In the following, we discuss the perception-action cycle as our inspired system for safety manipulation strategy.

B. *Perception-Action Cycle*

The ability of cognitive robots to do manipulation tasks critically depends on the selection of relevant actions for its physical state and visible environment. A significant problem combining these decision-making mechanisms arises from predicting the appropriate behavior of the robot itself as well as that of its desired goal. Therefore, action and perception are suggested to couple simultaneously. There is strong evidence

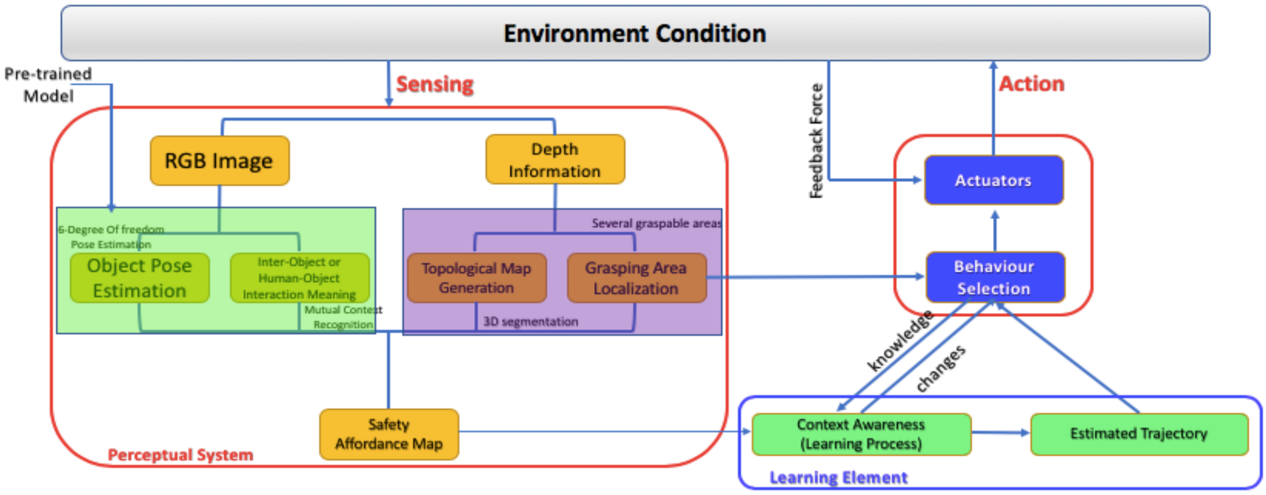

Fig. 3. Proposed System Design of Safety Manipulation Strategy for Home-Care robots

that perceptually-guided action intrinsically depends on active observer and understanding of the relationship between behavior and sensory response [16], [17]. We note that the visual input of an autonomous robot cannot be improved without feedback from its behavior response, and the action cannot be enhanced without feedback from its visual sensor. In order to solve this problem, perception-action with learning systems are the main elements in an ecological-inspired system.

In general, there are two key points in the system design, the core system, and the external environment. Sensors and actuators connect the system and the environment. Sensors take in perceptions of the environment and communicate the signals to the behavior selection part, which is responsible for selecting actions based on visual input and evaluation part. The evaluation part uses reference knowledge as input. Practically, the reference knowledge can be represented as a pre-trained model. Then, the evaluation part gives out feedbacks to the learning process part, which makes a significant difference between an ecological-inspired system and the other method. The learning part is responsible for making improvements using feedback from the evaluation component on how the system is doing to solve manipulation problems and learns how the behavior should be modified to do better performance in the future. In the following section, we will discuss the detail of our proposed system design based on perception-action cycle for home-care robot manipulation with safety strategy.

IV. Proposed System Design and Evaluation

In this section, we will explain and discuss each part of the proposed system design that will be used in the safety manipulation strategy for home-care robots. Fig. 3 illustrates the whole proposed system design for the safety manipulation strategy. The learning-based perception-action cycle concept is used in this approach in order to combine perceived affordance and safety behavior response, such as accident prevention behavior. This section will discuss one by one part of the system design in more detail as well as some recommendations for future research of the robotics safety manipulation field.

A. *Perceptual Systems*

Generally, many home-care robots such as HSR, Pepper, and PR2 are equipped with an RGB-D camera, laser scan, stereo camera, and 2D camera as parts of sensory input of the manipulation system. In this system design, we define the information of the perceptual system consists of RGB image and depth information from the RGB-D camera of the home-care robot. The RGB image information is extracted into two sub-systems. The first sub-system is estimating the object position and orientation based on 6 degrees of freedom (DOF) object pose estimation approach. The second sub-system of the RGB image is used to construct the relationship knowledge between inter-object correlation and human-object relationship.

On the other hand, the depth information has an essential role in constructing the grasping area localization and building the topological map. The topological map based on point cloud has an important role in localizing the safety zone and in performing manipulation tasks on the object that has risk possibility in the environment. Then, the safety affordance map is built from each result of the sub-systems in RGB image and depth information to generate the context of awareness of home-care robots. After that, the robot will locate the intended object with risk possibilities and generate the estimated trajectory as a motion reference. In order to decide the appropriate behavior, the behavior selection part will determine the manipulation tasks, such as picking the risk object to prevent accidents and placing that object to the safety area. The grasping task's feedback signal is used to maintain the force of the robot hand to avoid the object deformation. In the following section, we will discuss each element of the perceptual system, learning system, and behavior selection system in detail.

B. *6-DOF Object Pose Estimation*

Recently, the 6-DOF object pose estimation is gained much interest in robot manipulation research [18], [19]. Using the YCB dataset, Tremblay et al. [18] have proposed the 6-DOF object pose estimation with a domain randomization approach to alleviating the problem of the reality gap on synthetic data. The result of this research was imposing due to only using the RGB image to get the estimated 6-DOF pose of the object. Moreover, it has good robustness on extreme lightning conditions and occlusion. To analyze the real-time performance, we test this approach in our computer. In the first test, we use one object to measure the frame rate speed. However, average frames rate speed only reached by 2.4 frame per second (fps) in this test. In the

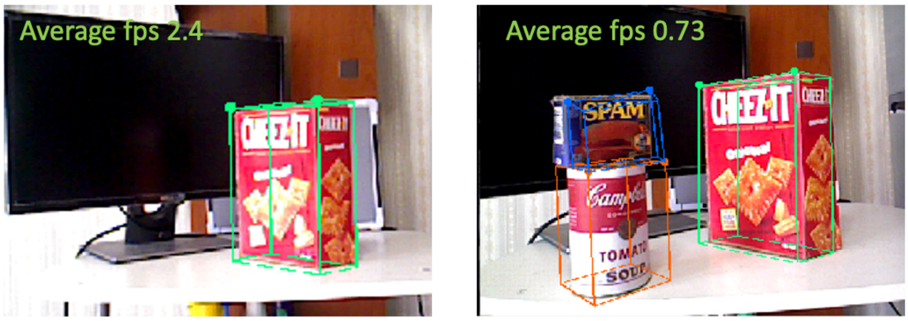

Fig. 4. Experiment test of Deep Object Pose Estimation with YCB dataset

(Tested on Intel i7-8750H 2.20GHz, GeForce RTX 2070 Max-Q Mobile Version 16GB of RAM)
(a) Tested using an object with 2.4 fps (b) Tested using 3 objects reduced to 0.73 fps

second test, we evaluate this method using 3 objects, and the average frame rate speed reduces to 0.73 fps, such as Fig. 4. From the result of the evaluation test, we conclude that this method is high computation cost as well as challenging to implement in real-time performance. Moreover, the 6-DOF object pose estimation only estimated the object translation and orientation. The grasping area detection was not included in this research. Therefore, we recommend to improve this method for real-time performance and combined with grasping point localization in object detection by using point cloud data for future research.

C. *Inter-Object Relationship and Human-Object Interaction Approach*

Understanding interactiveness knowledge between humans and inter-objects relationships is one of the main problems in scene understanding and building the context of awareness in a risk situation. This method is the most critical step on applying the concept of ecology that robot requires to understand how each object or human relates to one another. Previous works showed a significant contribution to human and object relationship meaning [20], [21]. We suggest using human-object detection with the interactiveness approach as the primary information of the robot to determine the potential safety or dangerous situation. When the robot localized the intended situation, the home-care robot intuitively picks up the object, which has a potential risk to one another. For example, when the robot sees a cup of water near the electronics, such as PC, monitor, mouse, and keyboard described in Fig. 5. The robot intuitively picks up a cup of water carefully and change the location of the object into a safe spot. The cup of water has a dangerous possibility if this object fall, and the water can damage the surrounding electronics stuff.

However, there are a lot of significant challenges when designing a detection solution. It is due to many complex and diverse interaction scenarios in home environment conditions. Therefore, we suggest developing the human-object interaction based on risk potential in-home environment for future work research in safety manipulation strategy. According to [22], [23], there are some categories for home accidents such as “cut”, “burn”, “fall”, “drowning” and etc. The accident prevention behavior can be generated correctly when the robot has pre-knowledge about the risk potential based on frequently home accidents.

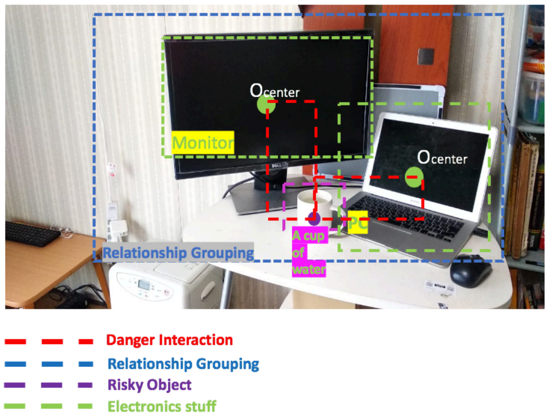

Fig. 5. Illustration of potential dangerous between one object to another

D. *Grasping Area Localization*

Many approaches can detect the graspable area under cluttered and occlusion scenarios in various environmental conditions. Some strategies also dealt with unknown object detection [4], [24], [25]. In 6-DOF object pose estimation, the object can be recognized well in cluttered scene and the center position of the object can be estimated in 3D translation and 3D orientation. However, grasp affordance is not included in this method. Therefore, it is required to localize the correct grasp affordance. In [25], the authors used YOLO v3 framework to detect the object and used the growing neural gas approach to localize the grasp area. However, all possible grasp affordances are generated in this method instead generate the most efficient one only. Meanwhile, in [4], [26] has developed a method of accurately and quickly localizing the most efficient types of graspable areas. We evaluate this method [4] to know the effectiveness of grasp affordance detection in moving camera scenario such as Fig. 6. Several previous works have only implemented the grasp affordance detection in fixed camera or pinned hole-camera [4], [26], [27]. If we intend to implement this method on mobile manipulator robot with moving camera, the grasp position should be updated and changed correspond to the robot position.

The first evaluation test of this method has shown in Fig.6 (a). The camera can detect the grasping area at the handle of the yellow bottle and rubber toilet pump that indicated with labeled numbers. However, when we changed the camera position from the first experiment state, the location of grasp affordance is not changing in real-time such as in Fig 6 (b).

We need to restart manually to recalculate the graspable area in our ROS system to get an updated grasping area position. Therefore, the grasping area localization for mobile robot manipulator is suggested to develop in future research for real-world application. The perception-action cycle approach in our home-care robot manipulation system design is supposed to develop a new graspable affordance detection based on moving cameras to get the most effective graspable area during the change of the robot poses.

(a) Initial visualization of camera to detect grasp affordance

(b) The camera position is changed and the grasp affordance is not updated

Fig. 6. The evaluation test of grasp affordance in [4]

E. *Topological Map Generation*

Topological maps based on semantic segmentation of 3D point cloud have been proposed in recent years[7], [28], [29]. The objective of generating the topological map using point cloud is to extract the environmental knowledge related to an affordance of robot motion and a dangerous spot such as rubble with the high-risk possibility of a collapse in order to behave quickly and safely in the disaster zone. This method is highly recommended in home-care robot manipulation to localize the danger spot and safe spot. The danger spots can be defined based on human and inter-object interaction space. On the other hand, the robot requires to find a safe spot to manipulate the object by considering the risk relationships between objects and objects or humans and objects. After that, the 3D point cloud segmentation can be implemented based on the risk perception of the robot.

F. *Safety Affordance Map and Context of awareness*

In [30], the safety affordance map for robot object manipulation has been proposed. This method introduces a new concept of accident prevention in the home environment by the home-care robot. However, in this research, the authors only explained the technical concept on how the risk possibility measures in brief. We extend more detail about the idea of a safety affordance map in this paper. From our safety manipulation strategy, the safety affordance map is built by the extraction information of RGB images and depth information to generate the context-awareness of the environment.

The context of awareness contains the risk possibility of an object to another, the estimated pose and orientation of the object, and the safety spot to manipulate the object in order to prevent the accident that explained in the previous section. From this context, the robot can select the correct behavior that corresponds to the updated visual input extraction. The visual input extraction is updated corresponding to the robot action, such as the perception-action cycle in those mentioned above. In future development, all the perception systems should be integrated into one system in order to measure the computation cost and the effectiveness of the system design. Next section, we will discuss how the robot learns the visual input extraction to determine the correct action to prevent collision or accident during robot motion.

G. *Optimal Behavior for Safety Manipulation*

In this system design, we proposed the learning element part in order to generate safety and optimal behaviors. The robots generally operate on the trial and error concept: they try to evaluate the result and then choose which better behavior. However, trial and error exploration concept might try dangerous action that causes the accident in real-world robot application. Therefore, we recommend using transfer learning in simulation and distributional shift problem to optimize the home-care robot manipulation. Simulation could open new robotic learning strategies by producing an almost limitless amount of training data, primarily for free. In [6], the authors used deep reinforcement learning to solve the problem of end-to-end learning of the grasping task on daily objects in the simulation. The robotic simulator is capable of training the grasping task using physical model reality. After the simulation part, the optimal behavior parameter is collected and then transferred to the real-world application experiment. This result was showing promising performance for future robot manipulation, especially in the home-care

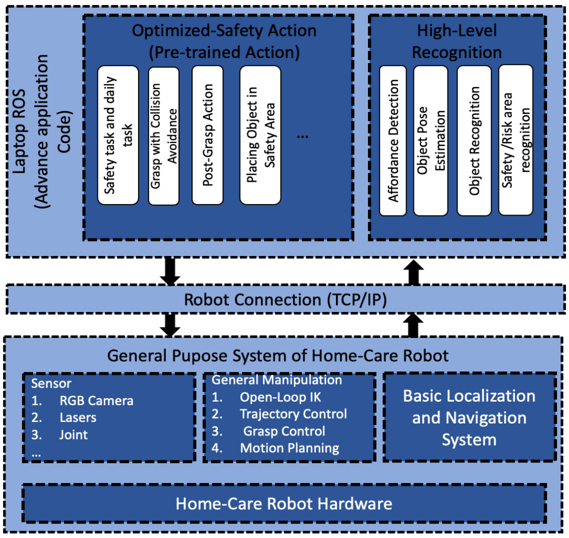

Fig. 7. The overall proposed experimental system using ROS

robots manipulation task. Mostly, home-care robot system using Robot Operating System (ROS) to integrate the advance application system and general application system. We will explain more detail in the next section.

H. Proposed Experimental System Architecture

The proposed experimental system architecture is built based on the proposed system design of safety manipulation such as in Fig. 3. We will integrate the hardware, learning and perceptual system software using ROS system. We identify three important of element classes, namely:

i) General Purpose System – contain the general code for general task manipulation and navigation. it can be reused by other application
ii) Advance Application System – provides the integration of perception and other sensor data processing and high-level behavior optimization that are specific for advance safety manipulation task
iii) Robot connection – TCP/IP will connect the Laptop ROS to home-care robot hardware. The advance application system will be processed in the laptop ROS. Normally, the home-care robot hardware system equipped with low cost GPU (Graphics Processing Unit) and low-cost CPU. The result of high-level system will be sent to the robot hardware through the TCP/IP connection and vice versa. Fig.7 represents an overview proposed experimental system architecture.

V. Conclusion

In this paper, we have designed a safety manipulation strategy based on the ecological inspired model for home-care robot applications. The ecological inspired model has been proposed based on the perception-action cycle concept to realize the safety and risk of awareness in robots. In this concept, the robot can take many behaviors; at the same time, the extracted visual information is updated concerning the robot action. Then, the robot generates the updated response based on the newest information in the environment. We explain each element of our proposed system design and evaluate some of them in order to conduct future development and research. Each element of the proposed system design should be integrated into one system for future works to evaluate the effectiveness of this method and computation cost.

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