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Evaluation of the teleoperation system based on force-free control and visual servo control by using different human operator perception: evidence verified by experiments and statistical analysis

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Abstract: This research considers the teleoperation of an articulated robot arm by means of force-free control and visual servo control over communication channels using Internet technology. The main investigation is carried out to find how effectively improves the accuracy and the effectiveness of the teleoperation after provision of a visual feed back channel to the system. The system accuracy, effectiveness, repeatability, and handleability based on the human operator's skills and operator's cognitive aspects are evaluated by using statistical data analysis and experimental results. Effectiveness of the statistical analysis is assured by increasing number of experiment data and assuming environmental factors and implicit variables maintain to be unchanged.

Keywords: Force-free Control, Teleoperation, Visual Servo Control, Template Matching, Accurate Motion, Rough Motion, Human Operator perception, Correlations, Human cognitive aspects.

1 INTRODUCTION

In many years, telerobotics has been a major concern among researchers. It becomes more focused and justified for space and undersea operations, fire-fighting and rescue operations in battlefronts and disasters, and also for training and entertainment activities. Teleoperation is of utmost importance, when the working site is hazardous, such as nuclear plant activities, land-mine extraction, toxic chemical plant activities and so forth. In recent two decades, Internet has been much popular infrastructure for the communication activities and therefore, researchers use Internet for telerobotic applications as consistent communication platform. The TCP sockets have also been consistently used in many areas in telecommunication so that it gives past track records to be guaranteed as reliable communication with flow control, sequencing and re-transmitting of lost data [1]. The first Internet based telerobotics started as *Goldberg* [2] connecting a SCARA and ASEA IRb-6 type robots to the Internet in 1994. Since then, more researchers found their interest to use Internet for the development of advanced robot teleoperation applications, and remarkable early stage developments are published in [3], [4] and [5].

However, the major concern in Internet technology based teleoperation is that an uncertain transmission delay between human operator in the master side and the teleoperated robot in the slave side. Major contributions to overcome such transmission issues are given in [6]. The *Sheridan's* supervisory control [7] was proposed and it was appreciated in view of stable teleoperation. Supervisory control approach implements an autonomous local feed back loop at the slave manipulator. Remote human operator needs only to send key parameters or few required data to initiate and the slave manipulator, of what just slave manipulator required for planing the trajectories and controlling the manipulator. In this research is also based on a human supervisory control approach.

Figure 1 shows the schematic model representation of an Internet-based supervisory controlled teleoperation system. It also illustrates the main components and the terminologies in the context of a teleoperation systems. In our research, we adopted the same base architecture for experimental teleoperation setup. Moreover, the applicability and effectiveness of the supervisory control in teleoperation is highly depended and affected by the capability of the supervisory control in the master side as well as the local controller of the slave side. The investigation is based on the evaluation of the human operator's skills and cognitive factors on a supervisory control. And how those factors can correlate with an effectiveness of the investigated teleoperation system.

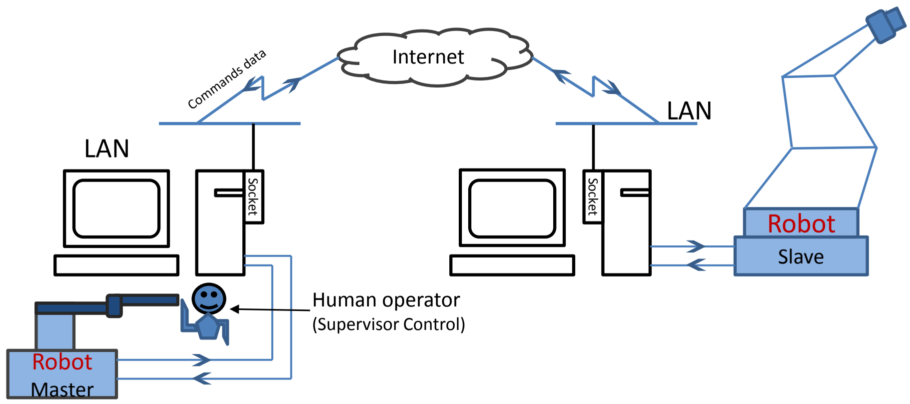

Fig. 1: Schematic diagram of general supervisory controlled semi-autonomous teleoperation system.

The teleoperation system of this research comprises of two different techniques which are attached in to different modules. First one is the force-free control (FFC) which is used to realize the passive motion of robot arm for given external force by human operator. The details of the FFC are described in [8] and references therein. The second one is the image processing module in which template matching (TM) techniques are used to carry out the accurate motion control by means of visual servo control [9]. Experiments were carried out by selecting operators appropriately corresponding to the following three kinds of experiments:

1. Providing camera view feedback to the operator.
2. Giving a guided map including desired path of the target.
3. Both map and visual feedback provided.
4. No additional aid provide (by seeing remote location robot from operational point).

2 TELEOPERATION BY FORCE-FREE CONROL AND VISUAL SERVO CONTROL

Our teleoperation system consists of two different motion control mechanisms. First is to accomplish remote control action by means of human operator assistance, in which FFC method is used. The details of the mechanisms and functions are described in author's work [10]. Figure 2 shows the detailed schematic presentation of the teleoperation system in this paper. The position control can be achieved by two kinds of motions for the reference position of the robot arm, i.e., the rough motion and the accurate motion. For the rough motion, the reference position is generated manually by using the FFC. Second is to accomplish the accurate motion where the reference position is generated automatically by using the vision system based visual servo control (VSC). In order to generate the reference position of the robot arm for the accurate motion, the image obtained from the USB camera is analyzed and processed. The vision system attached to the camera side is responsible for detecting the target position. The reference position data for the robot arm are sent through the network.

After receiving reference position data from the master control, slave robot in the working side moves accordingly as "rough motion." The human operator moves the master robot arm manually until the camera mounted on the working side robot captures the image of the target object. Then system switches to the second control scheme for "accurate motion."

2.1 Force-free control (FFC)

The FFC realizes the passive motion of the robot arm due to external force so that the robot arm can move freely according to the external force. In this teleoperation system FFC control plays an important role by generating reference positions when human operator executes the desired movement on the operational side robot. The generated reference position data is sent to the working side robot via network by using the socket communication TCP/IP [11]. The FFC for passive motion of the robot arm is applied without changes to the robot manufacturer's hardware configurations [12].

2.2 Visual servo control (VSC)

In our teleoperation system, VCS [9] plays an important role by helping working side robot arm to reach the target, after switching from the "rough motion." A general USB camera can be used in the VSC. At each sampling time, image is sent to the image processing in the camera side computer.

The image analysis is done by using template matching (TM) techniques [13, 14], in which, it calculates the position

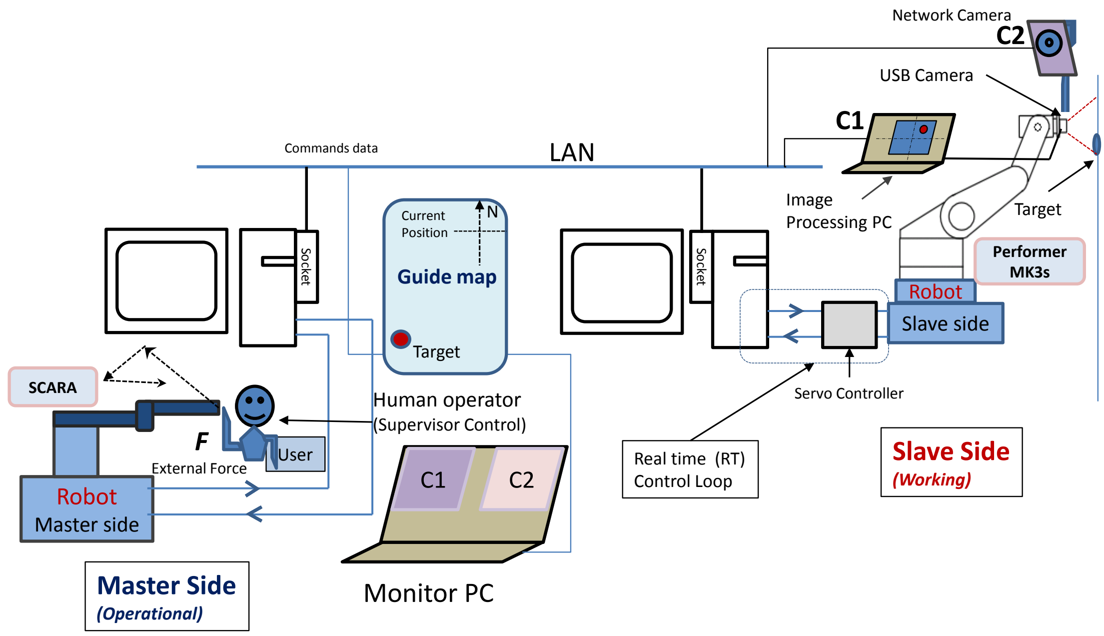

Fig. 2: Schematic overview of the investigated teleoperation system with visual feed back

of the target inside the image. Then, system calculates the corresponding reference position and send it to the working side robot. To apply the template matching algorithm, camera image must be processed at a each sampling so that, robot can reach to the target position. The center of the camera view and the target object at a particular instance of the VSC are calculated in each sampling. And continuously, image is processed and applied the template matching until target would coincides with the center of the camera view.

3 HUMAN OPERATOR'S PERCEPTION

The main objective of this research to investigate the applicability of the system by using different users and scenarios. Therefore, this research is focused on some aspects of the system especially for accuracy, effectiveness, repeatability, handleability and so forth.

In a practical situation no one can guarantee that high skill exclusive operator would be available in all time. Therefore, teleoperation system design is focused to make it as simple to operate even by the average user who does not have prior experience or special skills of operating the system. And also it can be operated with the minimum guidance as shown in Fig. 2. the system would provide the operational assistance by means of online camera views (C1 and C2 in Fig. 2) and the guide map of the target location.

The human operator's responsibility is to manipulate the robot arm in the operational side as to give "rough motion" to the working side robot that would catch the target within its camera view. To investigate the ability of applying the supervisory action by the general user, a larger number of experiments were carried out by providing different means of aid to human user and also sample of users were selected with irrespective of experience, age, field of studies and anthropometry of the body [15].

In general, each human has different levels of cognitive power, persistence, reactive or response time, level of skill for particular area, level of experience, prior knowledge of a particular subject etc. Therefore, any system with human involvement subjects to above mentioned aspects [16]. Due to above mentioned reasons, system is designed in such way that it should be identified the tolerances of those aspects if the system is intended to be applied in real practice.

4 EXPERIMENTAL RESULTS

Figure 2 is illustrated the experimental setup, the robot arm named Performer MK3s with attached USB camera in working side was controlled by the reference position generated in the operational side using SCARA robot. The SCARA is manually operated by a human operator until the target was included in the view of the camera. Then, Performer MK3s is controlled autonomously by the reference position generated in the camera side. As in the Fig. 2, target object is located in the slave side. A Network camera is used to capture the view of the target area and it will give the video feed back to the monitor PC as a camera view $C2$. The SCARA and the MK3s robots are connected to the computers in the master side and the slave side respectively. Image processing is done in the image processing pc $C1$ in the slave side of the system. The arrow marks are given to show the movements of the SCARA robot which are performed by a

Table 1: Experiment data and results for teleoperation using different users

Exp. No.	User No. (Operator)	Skill / Experience. Level	Results (Success or Failed) Direct View	Guide Map	Camera View	Guide & Camera View	Remarks Age-Field of Study (Related or Not)
1	User No.1	High	Success	Success	Success	Success	23 - Related
2	User No.2	High	Success	Success	Success	Success	23 - Related
3	User No.3	High	Success	Success	Success	Success	34 - Related
4	User No.4	Low	Success	Failed	Success	Success	21 - Related
5	User No.5	Low	Success	Failed	Failed	Success	22 - Related
6	User No.6	New	Failed	Failed	Failed	Failed	20 - Non Related
7	User No.7	New	Success	Success	Success	Success	20 - Related
8	User No.8	New	Success	Failed	Success	Success	21 - Non Related
9	User No.9	New	Success	Failed	Failed	Success	21 - Non Related
10	User No.10	New	Success	Success	Success	Success	21 - Non Related
11	User No.11	New	Success	Success	Success	Success	23 - Non Related
12	User No.12	New	Failed	Success	Success	Success	23 - Non Related
13	User No.13	New	Success	Failed	Success	Success	20 - Related
14	User No.14	New	Failed	Failed	Failed	Failed	20 - Related
15	User No.15	New	Failed	Failed	Success	Success	21 - Non Related
16	User No.16	New	Success	Success	Success	Success	21 - Related
17	User No.17	New	Success	Failed	Failed	Success	20 - Non Related
18	User No.18	New	Success	Failed	Success	Success	20 - Non Related
19	User No.19	New	Success	Failed	Success	Success	20 - Related
20	User No.20	New	Success	Failed	Success	Success	21 - Non Related
21	User No.21	New	Success	Success	Success	Success	21 - Non Related
22	User No.1-R	High	Success	Success	Success	Success	23 - Related
23	User No.4-R	Low	Success	Success	Failed	Success	21 - Related
24	User No.9-R	New	Success	Failed	Success	Success	21 - Non Related
25	User No.19-R	New	Failed	Failed	Success	Failed	20 - Related
26	User No.20-R	New	Success	Failed	Failed	Success	21 - Non Related

NB:User No.X-R means Repeat by same user

human operator.

In this experiment, each of the experiments was done by volunteer users as listed in the table 1. The experiments were arranged to get four readings from each user. Users skill level is defined based on the past experience of using the system and ranked them as "High", "Low" and "New" as in the table 1. Four reading were taken form different scenarios of the experiments as listed in the table 1 as follows:

1. "Direct View" is given for an operator manipulate the robot arm by looking at the master side robot directly and no any other aid is given.

2. "Guide Map" is given for an operator manipulates the robot arm by only looking at the site map of the target position as shown in the Fig. 2.

3. "Camera View" is given for an operator manipulates the robot arm by looking at the computer monitor which has camera view of the target location of the working side as shown in the Fig. 2.

4. "Guide and Camera View" is given when operator has both aids of guide map and camera view feed back.

However, communication delays contracted in the system are assumed to be constant for all the scenarios and effects of them are not taken into the account.

The results showed that visual feed back improved the effectiveness of the total teleoperation cycle in regardless of the age and level of experience. However, communication delay on video stream can degrades the decision taking time for performing desired movements by applying external force. Statistical data analysis using the "probability and correlation coefficients" are carried out to verify the results based on how effectively target is reached on different experiment scenarios by different human operators as shown in tables 2 and 3. The "success level" gives the probability of success in each category.

To identify a feasibility of the use of the teleoperation system by different users with different perceptions, thorough investigation are carried out by using unbiased sample of human users. In this investigation, we used 26 different trials of experiments as given in table 1 which denotes the abstract and final information about the total investigation. User age and user's field of studies whether it related to the teleoperation or not are also given under remarks. From the research, We draw main objective that how effectively new user having different perspectives can operate the teleoperation system by using different visual aids such as a video feed back or/and a guide map of the target location.

In addition, a new user was given an introduction prior to begin his trials of experiment. It was found that certain either new or experience users shown energetic and confident interest, and also they wanted to perform more and more trials, however, few of them were found an uncomfort feeling and were lethargic during their turns. Hence, the effectiveness of the supervisory action also depends upon operators instantaneous condition and cognitive aspects of their mind or/and their perspectives regardless of their experience or skills at the time of an experiment [17].

Table 2: Correlation variations with skill level

	Category	Correlation with skill level	Remarks
1	Direct View	-0.2218	Negative
2	Guide map Only	0.1379	Positive
3	Cameras Only	-0.1011	Negative
4	Cameras & Guide	-0.1136	Negative

Table 3: Probability of success variation with category

	Category	Success level %	Remarks (Skilled user)
1	Direct View	80.77	all success
2	Guide map Only	42.31	2 failed
3	Cameras Only	73.1	2 failed
4	Cameras & Guide	88.46	all success

5 DISCUSSION

According to the table 2 guide only scenario is shown positive correlation with skill level. However, all other scenarios, correlation with skill level and success rate have negative correlation. Also it is observed that negative correlation decrease with introduction of camera view, this indicate giving online visual feed back with instruction to the users give better performance. And also introduction of a camera view, it increases the correlation coefficient value between skill level and success rate. Table 3 shows the success probability variation for an each category. Results show that positive increment on a system effectiveness by introducing online camera feed back regardless of a user being an experienced or not. However, experienced users of the system show characteristics that they can handle the system successfully even without an online visual feed back. Moreover, certain amount of users who found difficult to use and manipulate the teleoperation system and results show that success percentage varies when category changes. It is also observed that some users could not be able to manipulate the system in a way that the working robot on desired rough motion towards the target. However, in their second attempt, same users could get succeeded. Therefore, we conclude that system operational functions can easily be understandable for a general user who did not have either any previous interactions or experience on using the system. Since, the sample of users is used for the investigation does not include female users, correlation results might have a high possibility of variation if sample includes female users.

6 CONCLUSION

In this contribution, an investigation is carried out for the teleoperation system to find out how human factors with cognitive aspects affect the system effectiveness and performance when it applies in practice. It is essential that we must test the system with large number of real scenarios to validate the applicability, if the teleoperation system claims to be used in real application. Moreover, especially if a system has human user involvement and which is a critical factor for a fulfillment of final objectives then a sample of users should be selected with a high degree of variation and a sample amount must also be higher. The relevance of the real world application of the teleoperation system, particularly in case of human supervisory involvement, is highlighted from this paper. Finally, by providing a visual feed back for the human user effectively increases an applicability and an effectiveness of the teleoperation system regardless of users' skills, age and relevance to their major field of study. By considering the results, if the user sample number increases nearly up to 100 then, regression analysis can be carried out by using a fitted model for the experimental results.

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