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Cloud-Based Networked Visual Servo Control

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Abstract : The performance of vision-based control systems, in particular, of highly dynamic vision-based motion control systems, is often limited by the low sampling rate of the visual feedback caused by the long image processing time. In order to overcome this problem, the networked visual servo control (NVSC), which integrates networked computational resources for cloud image processing, is considered in this paper. The main contributions of this paper are the following: 1) a real-time transport protocol for transmitting large-volume image data on a cloud-computing platform, which enables high-sampling-rate visual feedback; 2) a stabilizing control law for the NVSC system with time-varying feedback time delay; and 3) a sending rate scheduling strategy aiming at reducing the communication network load. The performance of the NVSC system with sending rate scheduling is validated in an object-tracking scenario on a 14-DOF dual-arm robot. Experimental results show the superior performance of our approach. In particular, the communication network load is substantially reduced by means of the scheduling strategy without performance degradation.

Keywords: NVSC, SURFs, DOF, PBVS

I. INTRODUCTION

THE visual sensor is one of the most essential components for a robot control system. The visual information is expected to be fast, accurate, and reliable in providing real-time information of dynamical surroundings, including the operating environments, objects, obstacles, and human activities. From “look-and-move” approaches in open-loop fashion to “vi- sual servoing” in closed-loop fashion, the performance of vision-based control systems benefits from the developments. of the sensing technology (e.g., networked cameras , camera arrays , and dense skins of cameras), image processing techniques (e.g., applying image moments , Laplacian of Gaussian , and wavelets for feature extraction), and different control schemes (e.g., position-based visual servoing (PBVS) and image-based visual servoing (IBVS) and 2-1/2 D visual servoing). Despite many advantages, vision- based control encounters a number of problems, e.g., the choice between using image-based and position-based architectures, online computation of the image Jacobian for IBVS, path- planning combined with image space feature, the stability problem in vision-based motion control, and the low sampling rate of the visual feedback ,. The sampling rate of the visual feedback is limited due to the latency induced by the image capturing with a camera, the image transmission from the camera to the processing node, and the image processing itself. In order to achieve a good control performance, a high sampling rate of the visual feedback is required. In the literature, there are techniques available, which accelerate image processing, e.g., implement- ing simplified algorithms and using advanced hardware. In , an integral image is used to speed up feature detection. Vision chips, field-programmable gate arrays, and graphics cards with parallel computation capability are favored to implement image processing algorithms However, the image process- ing delay still largely exceeds the cycle time of a robot joint position control loop. For example, it takes about 20 ms to extract Speed-Up Robust Features (SURFs) from an image (640 × 480 pixels) on graphic card NVIDIA-GeForce 8800, while the sampling interval of the joint position control loop is typically in the range of 1 ms. For the tracking of fast-moving objects, the long image processing delay increases the risk of losing the objects in the field of view and thus causes control failures. With the recent advances in computation and commu- nication technologies, parallel computation based on networked computational resources (cloud computing) has gained more and more interests for high-performance computing With the introduction of networked computation into traditional control systems, the resulting system exhibits several advan- tages. It features flexible reconfiguration capabilities, e.g., new components can easily be added. Moreover, it enables simple maintenance and diagnosis with low wiring effort and digital diagnosis protocols. Standardized components and computa- tional power can be shared among different applications, and there are no such strong constraints on the components in terms of low power and low weight as typical for mobile robotic applications. It allows also for shared sensing concepts, e.g., multiple robots/applications can share sensing resources.

In this paper, the novel concept of a networked visual servo control (NVSC) system is proposed in order to achieve high-sampling-rate visual feedback by distributed networked com- putation for highly dynamic vision-based motion control tasks. In NVSC systems, the compo- nents, including image capturing, data processing, control algo- rithms, and actuators are implemented on spatially distributed processing nodes which are connected by a shared (wireless or wired) communication network. By sending sensor data to the computational resources available over the communication network, parallel data processing is carried out to speed up sensor feedback and thus improve control performance.

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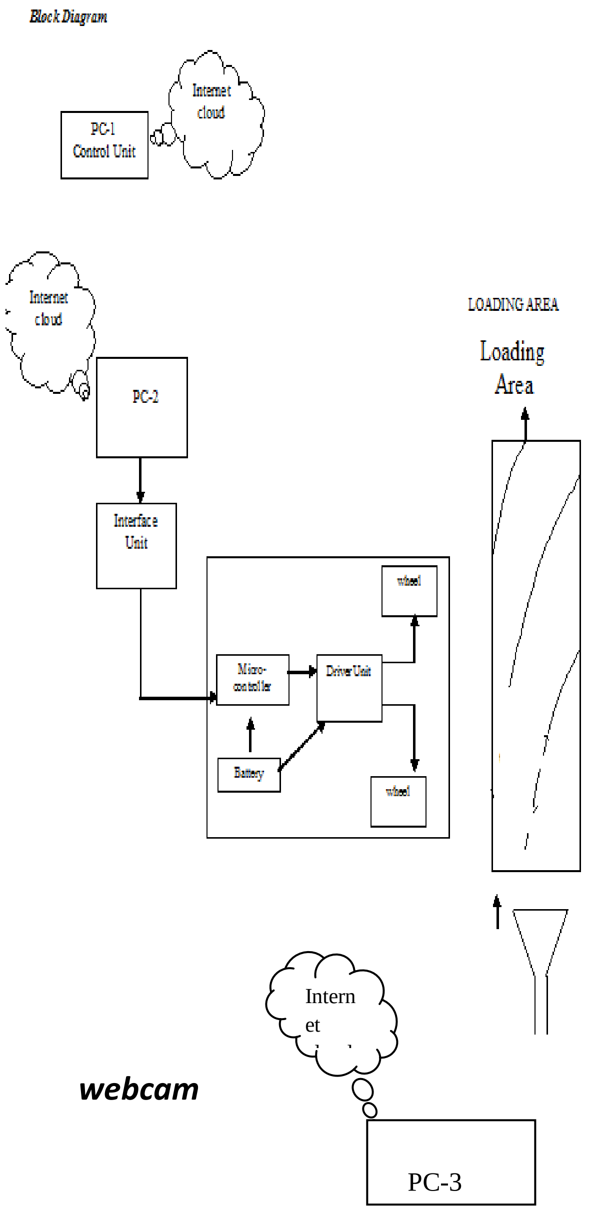

II. SUMMARY

The performance of vision-based control systems, in particular, of highly dynamic vision-based motion control systems, is often limited by the low sampling rate of the visual feedback caused by the long image processing time. In order to overcome this problem, the networked visual servo control (NVSC), which integrates networked computational resources for cloud image processing, is considered in this paper. The performance of the NVSC system with sending rate scheduling is validated in an object-tracking scenario on robot. Experimental results show the superior performance of our approach. In particular, the communication network load is substantially reduced by means of the scheduling strategy without performance degradation.

The visual sensor is one of the most essential components for a robot control system. The visual information is expected to be fast, accurate, and reliable in providing real-time information of dynamical surroundings, including the operating environments. Here In this paper, the novel concept of a networked visual servo control (NVSC) system is proposed . In this project the user can use the PC-1 which is used as the control unit and which is in the cloud as shown in the block diagram above . The user can access the PC-2 using the cloud from the PC-1 and can then control the robot movements. The robot can be made to move in all the directions and the robot is wired to the PC-2 and the micro controller is programmed using the embedded C , which will get the commands from the PC-2. Now when the user whishes to take the robot to the loading area or for unloading, the PC-3 has the camera which will read the robot movement and as the robot gets closer to the edge the PC-3 will send the data to the PC-1 and then the user can stop the robot.

This way this new technology can be very cost effective and time efficient in its operation.

Camouflage is a the act, means, or result of obscuring things to deceive an enemy, as by painting or screening objects so that they are lost to view in the background, or by making up objects that from a distance have the appearance of fortifications, roads etc. Robots have replaced humans in the assistance of performing those repetitive and dangerous tasks which humans prefer not to do, or are unable to do due to size limitations, or even those such as in outer space or at the bottom of the sea where humans could not survive the extreme environments. There are concerns about the increasing use of robots and their role in society. Here is a Robot that keeps itself concealed of otherwise visible objects by a image processing method that allows it to remain unnoticed. It may be used by animals, soldiers, military vehicles and other objects to blend with their environment, or to make them resemble something else.

This Robot is being controlled by a remote machine, which is acting as a Server (PC-1) along with the PC-2 . PC-3 includes a web camera that is connected to server machine for taking the images and also to communicate with the server and it will also send that image to the cloud server. PC-1 will retrieve image from cloud and apply Camouflage algorithm to find the color of image and then it will send the data to the PC-2 and based on that color data, Robot will change the color using the LED's which are mounted on the camera. Depending on the color of the loading area , the robot will change the color using all the 3 PC's.

III. RELATED WORK

The exchange of data between spatially distributed system components is an essential task in NVSC systems. Aiming at real-time capability, a number of specialized network protocols have been developed in the past such as CAN for industrial 556 IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 60, NO. 2, FEBRUARY 2013 automation and FieldBus for process control, which, however, require specialized hardware. More recently, Ethernet (IEEE 802.3) is also used in the field of industrial automation, which we will also adopt in this paper. Several Ethernet-based public domain communication protocols have been developed in order to alleviate the nondeterministic behavior of the standard Ethernet to meet the real-time requirements of feedback control systems, e.g., switched Ethernet, EtherCAT, and PROFInet. However, these transport protocols are not suitable for transmitting image data due to either dedicated hardware requirements or limited packet size, e.g., UDP cannot transmit data larger than 64 kB and TCP has a larger absolute value and also larger variance of the transmission time delay due to windowing behavior and retransmissions. Therefore, currently, no RTP is available for massive image data transmission over a communication network suitable for visual servo control. Transmitting images over the communication network results in a large communication network load. To cope with the trade- off between the control performance and the communication network load due to image transmission, many efforts have been made. Scheduling the real-time communication network traffic has been discussed in , e.g., in , the node with greatest absolute error wins the right to transmit data. In order to reduce the communication network traffic, the dead- band control approach is proposed in and , which only sends packets when the current value exceeds a given threshold. The benefits of such an event-triggered sampling scheme over a periodic sampling scheme are analytically shown for the first time in . The optimal combination of control and event- triggered sensor transmission is investigated in . In this paper, we will adopt an event-triggered law for image data transmission. In our specific setting, we study the vision-based object- tracking problem. The vision system sends images over the communication network considering the tracking error. Assume that the tracking error is random. The sending interval, which switches based on the random tracking error, becomes also random. The control signal can only be updated at instants the controller receives information from the vision system, which indicates an event-triggered control scheme. In addition, transmitting data over the communication network introduces transmission time delays into the system. In Ethernet, trans- mission time delays are generally random. Moreover, there are computation time delays due to image processing. Here, the computation delay is modeled randomly due to data-dependent conditional branches/loops during image processing . For stability analysis and control design, the NVSC system is mod- eled as a sampled-data system with time-varying delays. For systems with random delays, various control approaches have been proposed in the literature. Approximating a random delay by its upper bound results in a robust but conservative control design . Less conservative control design approaches are based on stochastic analysis (see also for a general overview). A Markov process is used to model the random delays as stochastic process in . The resulting closed-loop system is a Markovian jump system. However, a constant sampling interval is assumed in most of the existing . Distributed computation platform with ncRTP for parallel image processing in NVSC systems with one visual sensor. PCs: Image streaming server. PCc: Controller. PC1,...,PCG: Processing nodes. results, which cannot be applied to the NVSC systems with time-varying sampling intervals.

IV. CONCLUSION

This paper has presented a novel analysis and design ap- proach for NVSC systems with cloud computing and sending rate scheduling. Based on an RTP ncRTP for image data trans- mission, a GPGPU cluster is built for cloud image processing which enables high-sampling-rate visual feedback. A switch- ing control law is applied considering the varying feedback time delay caused by image processing and data transmission. Moreover, a sending rate scheduling at the streaming server in NVSC systems is designed based on the tracking error to reduce the communication network load caused by large- volume image data transmission. The proposed approach is validated by experiments on a 14-DOF dual-arm. The results demonstrate comparable control performance of the proposed approach with lower communication network cost than the nonscheduling counterpart. The future work is concerned with optimizing the sending rate scheduling by considering not only tracking error but also network congestion, packet loss, and motion dynamics of the object.

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