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User-Centric Workflow Ergonomics in Industrial Environments

Concept and Architecture of an Assistance System

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***Abstract*—Changes in demographic developments come along with an ageing workforce and a higher retirement age. Particularly in the industrial working environment, poor workplace ergonomics can limit the workers' quality of health and thus their ability to work until they reach their statutory retirement age. This paper presents the conceptual design of an assistance system that captures information from workers' bearings based on on-body sensors. A real-time analysis of the captured sensor data enables giving feedback to workers at the assembly site as soon as they get into an ergonomic unhealthy position during workflow execution. Workflow managers benefit from a holistic evaluation of the captured ergonomic data. By this means, critical workflow activities that are characterized by a high degree of malpositions can be identified. Based on this information, workflow managers have the possibility to optimize workflows in an ergonomic-friendly way. Furthermore, the presented approach enables a differentiated evaluation of established methods of ergonomic feedback like OWAS or EAWS.**

Keywords—ergonomic assistance system; workflow flexibility; workflow ergonomics; sensor network; workplace environment monitoring

I. Introduction

A. Motivation

Poor workplace ergonomics can limit the workers' quality of life by damaging their health [1]. The number of middle-aged and elderly employees in physically demanding jobs is sinking rapidly [2]. The main driver for these developments are working processes that in most cases are not designed in an ergonomic-friendly way [3], even though they are often evaluated according to standards like EAWS (European Assembly Sheet) or OWAS (Ovako Working posture Analysis System). Poor workplace ergonomics come along with a decline of the employer's economic results, which has an affect on the economy as a whole [1]. Current calls for research proposals as well as the latest developments in legislation like Occupational Safety and Health act of 1970, 89/391/EEC, EU Machinery directive or 2006/42/EC emphasize the increasing importance of workplace ergonomics [1], which is additionally enforced by an ageing population.

In this paper, we propose the conceptual design of an ergonomic assistance system that analyzes data from on-body sensors, which are placed at working clothes. The system analyzes the captured sensor data regarding an ergonomic risk potential within each workflow activity. Based on this information, the workforce at the assembly site receives real-time feedback through haptic sensors as soon as they adopt an ergonomic unhealthy position. Additionally, the assembly site is equipped with a mobile device. Data from the sensors is constantly sent to the mobile device, which allows to graphically represent each workflow activity including the captured ergonomic data and potentially affected body parts. The system learns with an increasing use the ergonomic health profile of the workforce and adapts recommendations for ergonomic-friendly positions and workflow executions to each individual's profile. However, not only the workforce at the assembly site receives feedback, but also workflow managers. The assistance system offers a connection to workflow management systems (WFMS) in order to support a company-wide evaluation of ergonomic data in terms of controlling and adapting workflow activities. Thus, the system supports workflow flexibility by allowing a variation of process steps. In doing so, workflow managers and persons in charge for workplace health promotion receive an overall evaluation regarding the workers' positions, movements as well as the frequency and weight of objects when carrying out workflow activities. The captured and analyzed data forms the basis for evaluating risk assessments with the goal of a health-promoting optimization of working processes. In doing so, workflow managers get an overview of critical steps in the workflow including the information, why specific workflow activities should be carried out in a modified order or by workforce with a specific ergonomic health profile. The application domain are workflows in the automotive industry. The first research results have been elaborated in cooperation with a major company in the automotive domain.

The outline of this paper is as follows: The next section introduces the applied research method followed by an introduction of important term definitions. Then, an overview of related work in the field of sensor-based workflow optimization and feedback in working environments is given. Section III introduces the architecture of the assistance system

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and the domain ontology containing the semantic representation of information related to the ergonomic analysis of workflow activities. Section IV introduces the first implemented use case scenario focusing on the workflow activities for assembling automotive parts. The paper closes with a summary of the main results and an outlook on future research.

B. *Design Science Research Method*

The presented research follows a design science oriented approach, which focuses on the creation of a design artifact within a prototypical approach [4], [5]. The goal is to meet collected requirements fitting to a specific problem description. In doing so, theories, constructs, models and instantiations are created. This paper presents the architecture (construct) of an ergonomic assistance system, which supports an ergonomic evaluation of workflow activities. In order to provide workers feedback based on their ergonomic data from the working cloths and in order to generate a global feedback regarding the ergonomic design of workflows, we developed a domain ontology, covering all relevant semantic relationships (model) that are required for the ergonomic analysis and evaluation of workflow activities. The developed system architecture and the domain ontology form the conceptual basis for the implementation of the assistance system (instantiation).

II. TERM DEFINITIONS AND RELATED WORK

A. *Term Definitions*

The *European Assembly Worksheet (EAWS)* is a standard that supports measuring risk factors for the human body. It is particularly used in industrial working environments by determining action forces, handling with objects and postures and repetitive loads affecting the upper limbs [1] [6] [6]. For each of these activities, stress points are given that are aggregated and evaluated in form of a traffic-light scheme according to EN 614-1. The measurement of EAWS in most cases is still carried out manually.

A *workflow* is a defined order of activities with the goal to transform input resources into output. A workflow defines the required roles, tasks, conditions, times, coherences and environments [7]. In many cases, the terms "workflow" and "business process" are used interchangeably [8]. Workflow management systems, such as YAWL, Apache ODE, SAP or jBPM (WFMS) are software packages that support a holistic management of business processes [8]. Workflow flexibility describes the ability of adapting workflows at run-time according to run-time information [9]–[14].

An *assistance system* supports users to carry out specific activities in several situations. Therefore, the current situation has to be analyzed in order to forecast future situations. The interactions of an assistance system should be adapted to the humans' natural activities [15]. At the same time, users should not be overstrained by unnecessary information. A *mobile assistance system* ensures mobility by integrating mobile devices to the functionalities of the assistance system [15].

B. *Related Work on Sensor-based Workflow Adaptation*

In literature, there already exists preliminary work in the field of ergonomic data monitoring and the analysis of physical strains. The project COGNITO (Cognitive Workflow Capturing and Rendering with On-Body Sensor Networks) focused on the preventive control of risky industrial processes [16], [17]. COGNITO provides an architecture supporting adaptability of workflows in industrial processes. The architecture supports an automatic recognition and analysis of critical process steps by analyzing ergonomic data from on-body sensors. Based on this information, industrial workflows can be preventively adapted. However, capturing information from the working environment, requires workers to wear a head mounted display (HMD). The ADEPT System focuses on case handling in industrial workflows [12]. The main driver for case handling represents data, which, however, is not captured automatically from the working environment. Thus, no control and adaptation of processes can be carried out on the basis of automatically gathered data. AdaptFlow [18] supports a protocol-based medical treatment by using adaptive WFMS for the controlling and consulting of clinical therapeutic processes. Therefore, it applies the AdaptFlow and ADEPTflex architecture. Adaptability is ensured in a preventive and reactive form but also by manual interventions. However, only individual data from patients can be considered during workflow adaptation, which has to be entered manually by medical staff. An automatic enrichment of environmental information is not supported by the system. Sardis et al. [19] combine sensor networks and multi-agents in industrial workflows systems. The proposed system supports adaptability based on an automatic recognition of malpositions and unhealthy bearings. Camera sensors capture activities carried out by workers as well as objects that are influenced by an activity. However, only workflow administrators get insight about carried out workflows. Workers do not receive feedback and recommendations regarding an ergonomically correct bearing. The project SCORE developed pro-active recommendations for the execution of workflow steps [20], [21], however, the focus is on desktop applications. Thus, the system does not process sensor-based information.

The related work analysis has shown that although there exists preliminary work in the field of ergonomic data monitoring, there still exist some shortcomings. Approaches that take into consideration ergonomic information from workflow activities require workers to wear devices that limit movements or devices that are expensive and thus rarely used. Furthermore, existing approaches do not support an automated evaluation according to standards like EAWS or OWAS.

C. *Requirements Derivation*

Based on the shortcomings of the state of the art, we derived the following requirements for the ergonomic assistance system:

- *Requirement 1 (R1)*: Workers should receive real-time feedback as soon as they get into an ergonomic unhealthy position.
- Requirement (*R2)*: The system should create an implicit health profile for each worker, in order to

improve recommendations regarding an ergonomic correct bearing.

- *Requirement 3 (R3)*: Workflow managers should have the possibility to globally analyzing the captured and analyzed ergonomic data. *R3.1*: Workflow managers should receive overviews of shortcomings in each workflow activity that often lead to unhealthy ergonomic positions. *R3.2*: Workflow managers should have the possibility to easily adapting workflows based on the analyzed information through an integrated functionality in the GUI of the WFMS.
- *Requirement 4 (R4)*: For each workflow activity, an evaluation according to EAWS should be carried out.

In order to ensure a practical applicability of the derived requirements, we carried out a workshop with the department of storage logistics of a major company in the automotive sector. The goal of this workshop was to identify activities that are characterized by a high degree of ergonomic risk behavior. The information for the evaluation of workflow activities has been gathered by applying the Key Indicator Method (KIM), which is a standard for the evaluation of physical strains during activities like lifting, carrying, holding or pushing heavy material. The results of this analysis have been consolidated into a catalogue of ergonomic endangerments and physical burdens, which are addressed by the ergonomic assistance system.

III. Concept of Sensor-based Workflow Adaptation

A. Core Components of the System Architecture

The following figure depicts the architecture of the assistance system and shows how the information from on-body sensors is processed and analyzed.

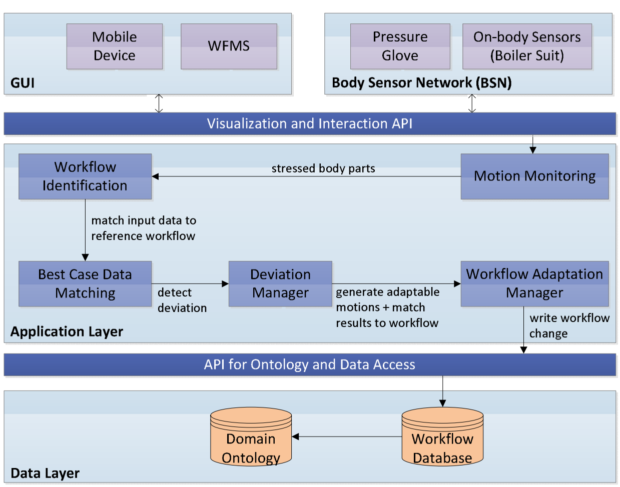

Figure 1. Architecture of the Assistance System

The **GUI** distinguishes between a view for workflow managers and a view for workers at the assembly site. The assistance system gives *workflow managers* an overview of global and anonymous ergonomic information from workers at the assembly site. They get an overview of the total number of critical workflow activities, in which many workers have malpositions (see Figure 5). Workflow managers have the possibility to evaluate the workflow analysis results according to additional criteria like physical characteristics of workers (initial health issues indicated by workers), time of the day (e.g. detecting differences in shifts), time frames (e.g. last 4 weeks, 2 hours, etc.).

Workers at the assembly site are equipped with on-body gyro sensors and a pressure glove as part of the *Body Sensor Network (BSN)*, which captures and monitors the workers' ergonomic data. Furthermore, each assembly site is equipped with a mobile device. The pressure glove enriches the mapping to ergonomic relevant criteria by enabling to determine the point in time, the duration and the weight of the workflow object. The on-body sensors are placed at the boiler suit at arms, elbows, spine and shoulders reflecting the human skeleton. The positions of the sensors within the skeletal system can be determined by semantically evaluating the distances between spine, arms and the positions to the shoulder. We distinguish between an ergonomic data monitoring and *Motion Monitoring,* which monitors the movements of workers. The raw data from the sensors is evaluated regarding the worker's body positions and the previously elevated EAWS values of the assembly site. By this means, the system recognizes whether the assembly site meets the criteria according to the EAWS standard. Furthermore, the current step in the workflow can be identified.

The company from the automotive sector determined for each type of workflow (e.g. take box out of shelve with pallet transporter; pull goods onto cross carriers; charging and discharging truck; etc.) reference processes including a documentation. We captured the best case ergonomic data by an "expert", who carried out the process in an ergonomically correct way. This data serves as a reference for capturing motion data. The reference processes are stored in the *Workflow Database* on the **data layer**. In the *Best Case Data Matching Component*, the data gathered by the *BSN* is mapped to the expert values of the respective reference process. It consists of an integrated context evaluation component that evaluates data from the interactions captured by the *BSN* and derives knowledge from this data. Each interaction is stored in the domain ontology on the data layer. The domain ontology adapts according to the concepts of ontology evolution [22]–[24]. It stores all user interactions and enriches over time. The next Section provides a detailed overview of the semantic relationships in the domain ontology.

The *Deviation Manager* identifies deviations from reference processes (e.g. many workers switch orders of certain workflow activities or carry out a workflow activity, which is not conform to the documentation). The *Workflow Adaptation Manager* contains rules and methods for workflow adaptation. It applies a filtering functionality that carries out a semantic evaluation of the captured sensor data according to EAWS. Based on the degree of deviation, the *Deviation Manager* provides an overview of deviations from the reference process, critical workflow sequences where many workers have malpositions or workflow activities that are characterized by bottlenecks. Due to compliance restrictions, only workflow managers get this information. Furthermore, global data from all workflows is indicated anonymously. The information is processed in a way that supports workflow managers to carry out decisions regarding workflow adaptation. Workflow adaptations carried out by workflow managers are transferred into the workflow database.

B. Semantic Relationships on the Data Layer

The following figure shows the domain ontology, which depicts the semantic relationships on the data layer. It contains all relevant information about sensors, interactions, workflow activities and user information. It is modeled as an OWL ontology [25] which is in line with previous approaches for the semantic representation of sensor-based information [26] [27].

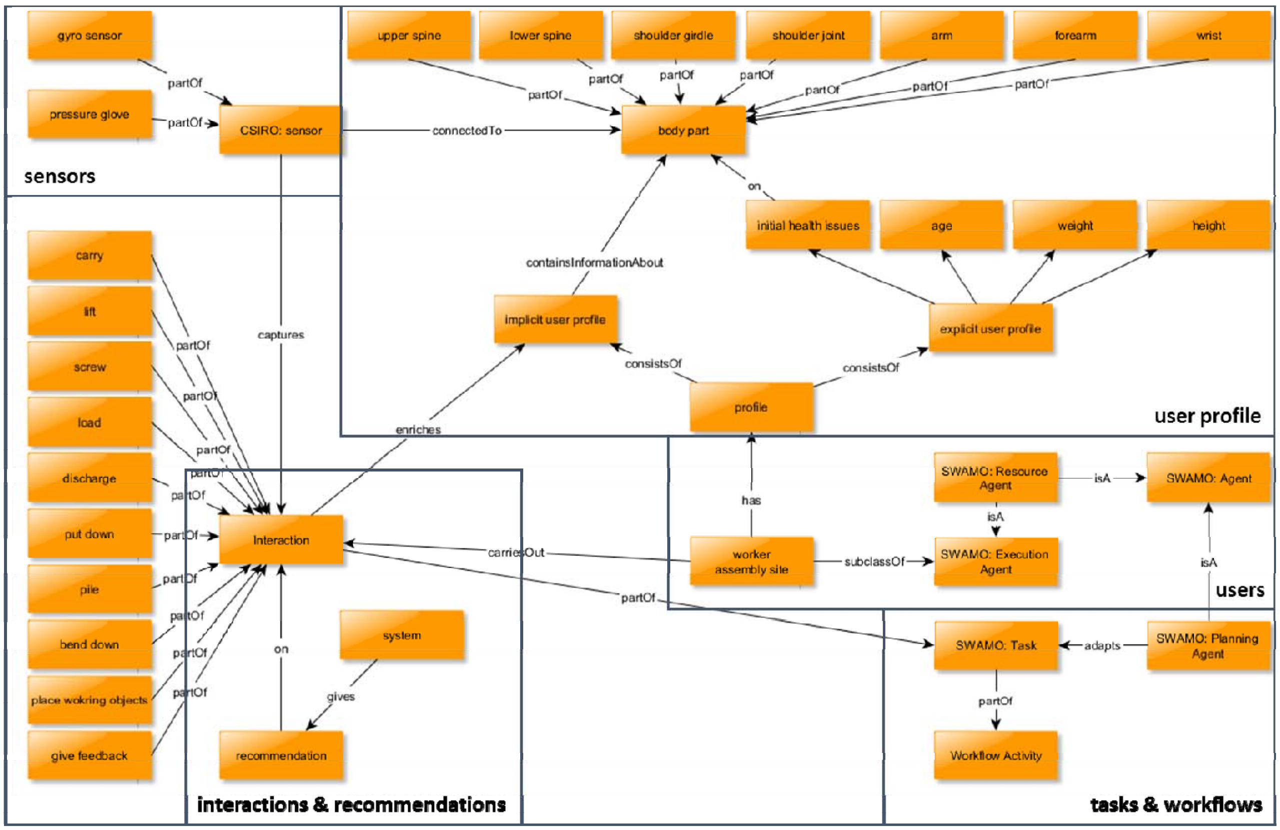

Figure 2. Domain Ontology of the Assistance System

Workers wearing the sensor suit can create their explicit user profile by indicating physical information like height, weight, age and initial health issues that are previously checked by a medical specialist. In addition to the explicit profile, the system creates an implicit user profile, which is formed by the generated sensor data in the intelligent clothing. With an increasing usage of the intelligent clothing, the user profile enriches and provides optimized recommendations that are mapped to the health profile of the involved worker.

The enrichment of the implicit user profile is based on interactions, which depend on the current use case in the industrial environment. In general, the system distinguishes between the interactions carry, lift, screw, load, discharge, put down, pile, bend down, place working objects and give feedback. The next Section gives an exemplarily overview about how interactions are carried out within the use case scenario “Assembling Automotive Parts”.

We analyzed existing ontologies for the semantic specification of sensors, in order to reuse relevant concepts in our ontology. By this means, we did not have to develop concepts for the representation of sensor information and workflows from scratch. For the semantic representation of sensor information we use the concept “sensor” from the CSIRO ontology, which – in combination with the OntoSensor ontology – represents the current standard of the expressive capability of sensors [28]. The CSIRO ontology has been used as an initial version of the Semantic Sensor Network Ontology [29]. Sensors are classified into on-body gyro sensors and the pressure glove. They are part of the intelligent clothing and thus, connected to body parts, which are limited to the upper limbs like upper spine, lower spine, shoulder girdle, shoulder joint, arm, forearm and wrist.

Concepts for the representation of the workforce and their tasks have been applied from the SWAMO Ontology, which is part of the OntoSensor ontology [26]. We integrated the concepts SWAMO: Resource Agent, which is classified into SWAMO: Agent and SWAMO: Execution Agent. Workers at the assembly site are a subclass of the SWAMO: Execution Agent.

IV. Use Case: Assembling Automotive Parts

The implementation of the use case scenario has been derived in cooperation with a large automobile manufacturer. We focus in our use case on assembling a part of a car door within the overall process of *Assembling Automotive Parts*. The following figure depicts an excerpt of relevant workflow activities that are carried out by workers involved in this process.

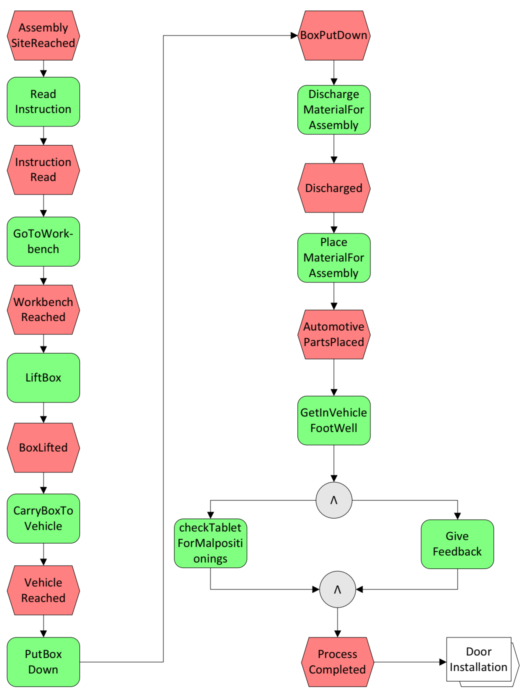

Figure 3. Workflow for Assembling Automotive Parts

The following activities are carried out in the workflow: 1) Read instruction, 2) Going to the workbench, 3) Lift box with required tools for the assembly of the car door, 4) Carry the box to the vehicle, 5) Put box down, 6) Discharge material for assembly, 7) Place material for assembly in right order and 8) Get in the footwell area of the vehicle to begin with the assembly process.

Each activity is part of the concept "interactions" as shown in the domain ontology (see Figure 2). During the execution of the workflow, workers wear a boiler suit with integrated on-body sensors. As already described in Chapter III, the system evaluates the distance of the gyro sensors to each other. As soon as critical thresholds are reached, workers receive real-time haptic feedback at the critical part of their body. If the current working situation allows so, users can already check during the execution of the workflow at their mobile device, why they position for which they received the haptic feedback was ergonomically unhealthy. After having completed the workflow, workers have the possibility to check their positions within each workflow activity at the mobile device. In doing so, they get recommendations for the improvement of their bearing as shown in Figure 4. On the left screenshot the user gets the information about the affected body parts (in this case shoulder joint, shoulder girdle and lower spine). The right screenshot shows how recommendations for an ergonomically improved bearing are displayed to the user at the assembly site. In this example the user gets the advice to pull back his shoulders and avoid a hollow back when carrying out the respective workflow activity. Furthermore, users have the possibility to indicate after completion of the workflow the perceived stress factor for each activity. The overall idea of this functionality is to carry out a mapping between the subjective stress factor and the actual burden within a certain activity of the workflow.

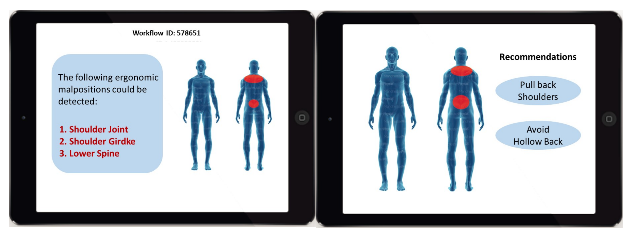

Figure 4. GUI for Workers at the Assembly Site

In addition to workers at the assembly site, our approach also supports workflow managers and health supervisors. An analysis of the gathered sensor data helps workflow managers to detect critical workflow activities that are carried out by many workers in an ergonomically unhealthy way. Figure 5 shows how ergonomic information of critical workflow activities is displayed to workflow managers.

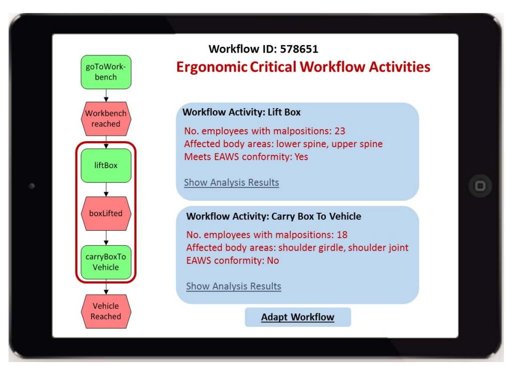

Figure 5. Display of Ergonomic Unhealthy Positions in the Workflow Manager View

Sensor data from each workflow activity is analyzed regarding its ergonomic conformity. Workflow managers determine for each workflow activity a threshold for the maximum number of workers with malpositions. As soon as these thresholds are achieved, workflow managers receive the information that specific workflow activities should be revised towards an ergonomic friendly way. Furthermore, the system enables an analysis of EAWS conformity for each assembly site as already explained in the previous Chapter. This functionality should help workflow managers in several departments to estimate the health development of the workforce and thus proactively design workflows in a preventive way.

V. Conclusions and Outlook

This paper presented the conceptual design of an ergonomic assistance system, which carries out an ergonomic evaluation of the workers' health profile by applying on-body sensors and a pressure glove in terms of intelligent clothing. The assistance system also supports workflow managers to ergonomically evaluate current workflows and adapt them, based on the captured sensor data from the intelligent clothing. Following a design science oriented approach, the usability of the artifact's design is going to be evaluated in form of a qualitative study with workers and workflow managers involved in the workflow of "Assembling Automotive Parts". In a next step, the developed concept will be applied to an additional use case, which will be also carried out in cooperation with the large automotive company. This use case focuses on the application domain of "Packing", in which workers have to remove heavy baskets out of a shelve in the storage and stacking them inside each other. As additional functionality, we plan for the future a mapping of workers to assembly sites and workflow activities that match best to their ergonomic health profile.

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