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# SENSOR FUSION CONTROL SYSTEM FOR COMPUTER INTEGRATED MANUFACTURING

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**ABSTRACT**

A new competitive environment for industrial products and services is emerging and is forcing a change in the way in which manufacturing enterprises are designed and managed. Competitive advantages in the new global economy belongs to manufacturing enterprises that are capable of responding rapidly to the demand for customized, high-quality products.The manufacturing system used for this new approach must be rapidly designed, able to quickly integrate all the systems in order to produce a large variety of products in unpredictable quantities. Computer Integrated Manufacturing (CIM) systems plays an important role towards integrating such flexible systems.

This paper presents a methodology of increasing flexibility and reusability of a generic CIM cell-control system using simulation and modelling of mechatronic sensory system (MSS) concepts. Models and guidelines developed in the research are intended to support system developers when implementing generic control software for CIM cells. The utilisation of sensors within the CIM cell is high lighted specifically for data acquisition, analysis and multi-sensor data fusion. Thus, the designed reference control systems architecture provides the comprehensive insight for the functions and methodologies of a generic Shop-floor Control System (SFCS), which consequently enables the rapid deployment of a flexible system.

**Keywords**: Mechatronic Sensory System, Computer

## I. INTRODUCTION

There is an increasing demand, due to globalisation, for manufacturing systems to be able to be re-configured quickly to accommodate new varied products, utilising new machines or processes. Nowadays businesses are pressured to deal with increased complexities and challenges of customers demanding high quality, low cost products, higher product variety, small batches and shorter throughput times. Various strategies have been employed in order to enhance the competitiveness of businesses, this include, but not limited to; agile manufacturing, computer integrated manufacturing, reconfigurable manufacturing, automation and mechatronics.

Mechatronics, as an engineering discipline, strives to optimally integrate mechanical, electronic and computer systems in order to create high precision products and manufacturing processes. As an interdisciplinary subject it has now evolved to incorporate optical, communication, and information technologies. In particular, optical sensing and data processing technologies are being integrated, at an accelerated rate, into mechatronic systems because these optical based technologies provide components for high precision, rapid information processing, and smart functions.

Sensor fusion is a method of integrating signals from multiple sources. It allows extracting information from several different sources to integrate them into single signal or information. In many cases sources of information are sensors or other devices that allow for perception or measurement of changing environment. Information received from multiple-sensors is processed using "sensor fusion" or "data fusion" algorithms. These algorithms can be classified into three different groups. First, fusion based on probabilistic models, second, fusion based on least-squares techniques and third, intelligent fusion. The probabilistic model methods are Bayesian reasoning, evidence theory, robust statistics, recursive operators. The least-squares techniques are Kalman filtering, optimal theory, regularization and uncertainty ellipsoids. The intelligent fusion methods are fuzzy logic, neural networks and genetic algorithms.

This paper will present the development of a mechatronic sensory system (MSS) and the application of predefined algorithms/heuristics for the solution of decision-making activities within the CIM cell utilising the mechatronics design methodology. Data capture methodology is highlighted to present the pallet navigation based on sensor/data fusion method for signals received from single sensor scanner mechanism and bar code system as well as modular conveyor sensors. The fusion process allows for more efficient navigation and depiction of the pallet within the CIM cell.

## II. EXPERIMENTAL SET UP

The experimental setup at the University of KwaZulu Natal CIM cell in the Mechatronics and Robotics Research Group ($MR^2G$) laboratory is shown in Figure 1. It comprises;

- A single aisle automated storage and retrieval system (AS/RS in which raw materials, work in progress (WIP) and finished goods are stored. The storage and retrieval (S/R) machine delivers pallets/goods from the conveyor belt into storage or retrieving pallets/goods from storage and delivering them to the conveyor belt.
- A modular roller conveyor belt is used to transport parts among the different workstations within the CIM cell.
- A PC based PUMA robot and indexing devices are used to load and unload components on the conveyor belt.
- An automated guided vehicle (AGV) is used for parts delivery operating in an omni-directional manner. This system allows the AGV to be integrated with a conveyor system such that there will be a physical mating between the AGV and part conveyor. A path made of a black metallic strip lined on the ground enables the AGV to follow a certain path as it connects other components of the CIM cell.
- A MAHO MH 400C Milling machine with a CNC Heidenhain controller is utilised for processing components.
- A Co-ordinate Measuring Machine (CMM) station adds flexible quality control to the cell by reducing the need for fixturing and special gauges during inspection. As the CMM is computer controlled, inspection data can be stored and inspection programs can be executed automatically.
- An Automated Visual Inspection System (AVIS) monitors the quality of a manufactured part visually throughout its manufacturing cycle.
- CIM cell components comprise PC based controllers which are linked to a host computer which can be activated by an operator remotely via the internet.

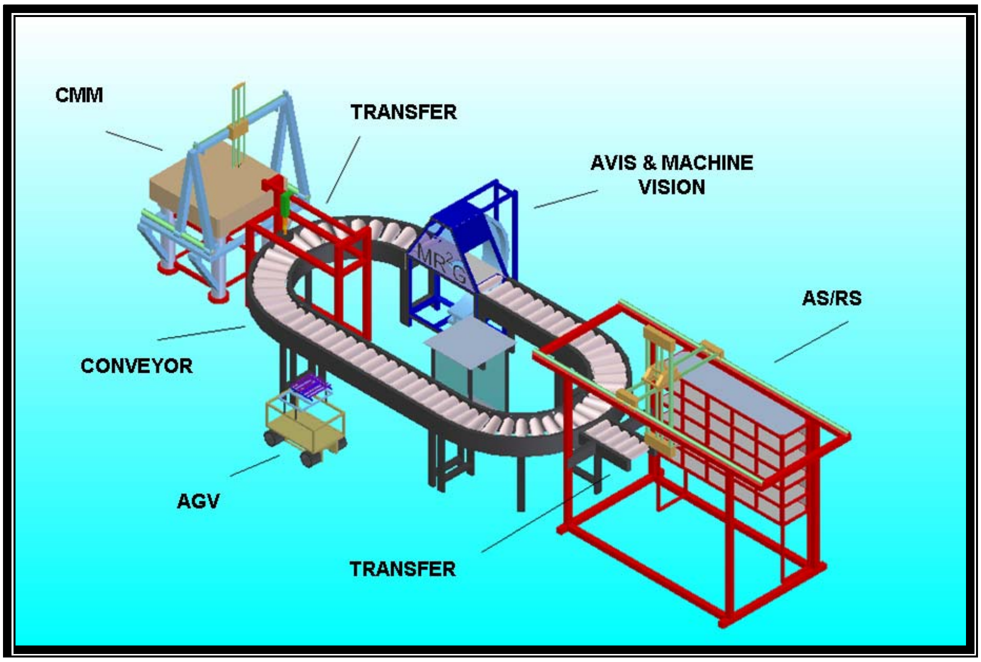


**Figure 1 -** UKZN CIM Cell Layout

## III. MECHATRONIC FUNDAMENTALS

The term "mechatronics" has been attributed to the Yaskawa Electric Co. in Japan in the 1970s to describe the philosophy in design of electro mechanical products to achieve optimum systems performance. Although there are definitions of mechatronics there is still considerable debate on what it means. There are numerous definitions by many researchers, practitioners and educators in the field of mechatronics, however none of them can always be complete in describing mechatronics, since the field is continually evolving. In the late 1980s and early 1990s, a number of attempts were made to provide a definition of mechatronics which read: "*Mechatronics is the synergetic combination of precision mechanical engineering, electronic control and systems thinking in the design of products and processes*." An alternative definition took the form: "*Mechatronics represents an approach to the design of engineering systems which involves the integration of mechanical engineering, electrical and electronic engineering with software engineering and computer technology at all levels of the design process*" see Figure 2 [Craig].

Today, cost-effective electronics, microcomputers, and digital signal processors have brought space technology to appliances and consumer products. Systems with hearts of precision sensors and actuators have increased performance by orders of magnitude over what was once not possible. There are many designs where electronics and controls are combined with mechanical components, but with little synergy and poor integration, they become just a marginally useful, error-prone, expensive conglomeration. Synergism and integration in design set a *mechatronic system* apart from a traditional, multidisciplinary system.

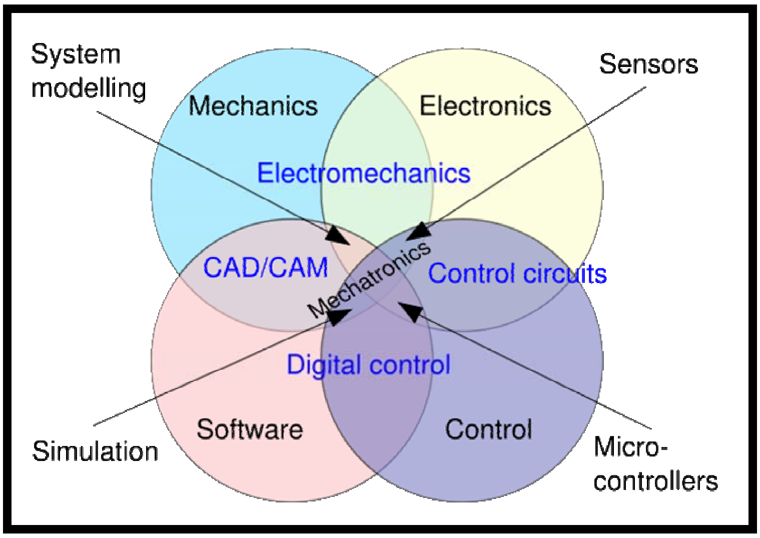


**Figure 2 -** Mechatronics: Synergism and Integration through Design

## IV. MECHATRONIC SENSORY SYSTEM

To enable conveyor segment operation, tracking and exact positioning of the pallet on the conveyor belt, a series of infra-red (IR) emitter and receiver sensors are installed in strategic positions on the conveyor. Light sensors used are the paired emitter and receiver type, which use modulated IR beam.

Twenty four (24) pairs of the light sensor circuits are used and interfaced with the PC30GA series board developed by Eagle Technology I/O board for data acquisition and procession along the conveyor segments shown in Figure 3. The programmable digital input/output card includes the driver software callable form to Visual Basic 6 (VB 6) software allowing for easy access to the ports. The I/O card interfaces with peripheral devices via an interconnecting harness that allows fast cable assembly and termination. The I/O card carries signals to and from the port's power supplies..

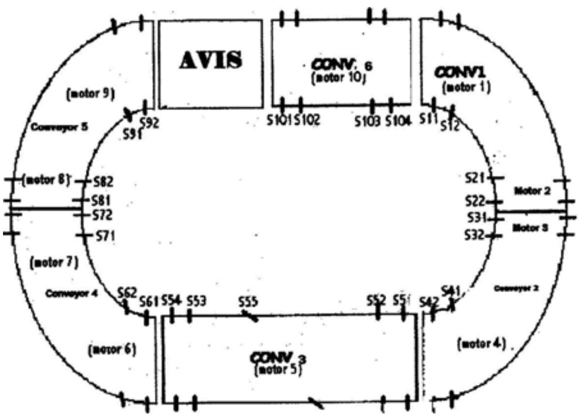


**Figure 3 -** Sensor Numbering within the Conveyor

## 5 THE CONVEYOR CONTROL SYSTEM

The Visual Basic (VB) 6 software program which is consistent with the standard windows operating environment was used in the experiment to provide an interface between the hierarchical controller and the modular conveyor system as well as sensors. The manual control allows for individual conveyor motor drives to be turned on or off and their direction of rotation changed in real-time. On start up, the operator is presented with the Conveyor Operating Form (COF), this is the main control window of the program that contains all menus and short cuts for the user to navigate around various options (Figure 5).

The COF comprises of the information and the simulation screen. The information screen provides information such as the board type, the value of the base address, the number of digital inputs and output ports available and the ability for configuration of a port for input or output.

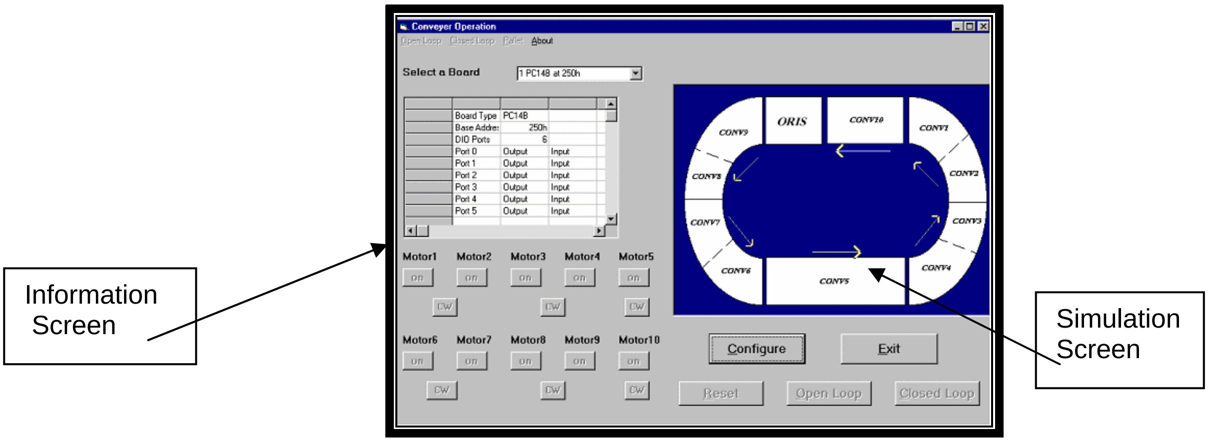


**Figure 4 -** Conveyor Operating Form

The simulation screen provides a graphical view of the conveyor initially in a neutral position and can be executed to provide analysis in pallet mobility (Figure 7). The simulation screen shows modular conveyer segments in its neutral state without the arrows depicting the direction that a pallet would follow if a motor where to be switched on. The simulation provides an easy check for the user to keep track of all events. It offers a real time update of the state of the motors (on or off), their directions of motion (CW or CCW) and the position of the pallet as it makes its journey around the conveyer segment that is being powered by the motor. The direction of pallet movement is indicated by means of an arrow as the motor is being activated. By choosing the ''Pallet recognition ON'' command on the pallet menu or using the short cut Shift + Ins, the simulation will show the pallet movement along the conveyer. An orange solid pallet is used to show fixed positions (when both sensors in a pair both see the pallet) and a transparent rectangle is seen when the pallet is between sensors on a conveyer segment. Thus the fixed position simulations are of a closed loop nature while the indeterminate state of the pallet between the sensors is open loop. The Pallet Recognition command can be inactivated by clicking on the ''Pallet recognition OFF'' command on the pallet menu. The pallet position and movement throughout the conveyor segments can be determined and depicted in frames as shown in Figure 5.

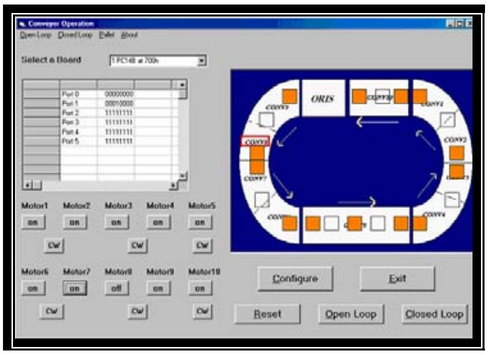


**Figure 5 -** Pallet Depiction and Recognition

## VI. MULTI SENSOR DATA FUSION

Multisensor data fusion is the process of combining data and knowledge from different sensor sources with the aim of maximising the useful information content. It improves reliability or discriminate capability while offering the opportunity to minimise the data retained. Figure 5 shows an overview of considerations which characterise data fusion applications, dividing the domain into three overlapping regions:

- Pre processing: data reduction
- Data alignment and correlation: Interpolation and spatial or temporal correlation
- Post processing: combination of mathematical data and knowledge, decision making

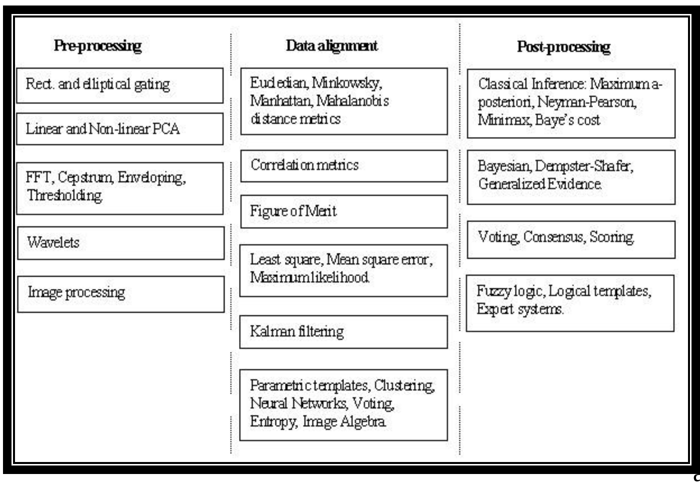


**Figure 5** Data Fusion Applications

In this research, information pertaining to the class state of the pallet was derived form led pair sensors, bar code and scanner sensors, and from a digital camera. The position estimator is based on an extended Kalman Filter (EKF) that requires a system model of the pallet motion to be defined. Formulation of models to closely represent actual vehicle behaviour is the first step to achieve accurate and consistent state estimates.
A measurement model which describes the characteristics of the sensor measurements and their relationship with the plant states is needed in the state update. Two major sources of sensory measurements are considered: the temporary absolute position measurements from a landmark-based local reference system are fused with the periodically sampled odometry measurements from the emitter receiver sensor pairs. The characteristics of the measurements must be accurately modelled so that the filter can exploit the different strengths of the measurements in the fusion process. The design also stresses robustness and flexibility in handling measurements. Odometry measurements are pre-filtered to remove corrupted observations, and redundant odometry measurements are used to suppress noise and improve estimation accuracy. In addition, a method is proposed to constantly calibrate the LED's resolution to allow odometry measurements to adapt to the varying load and friction conditions of the pallet.

The system and measurement models must be defined on real time at the start of each estimation cycle, depending on the manoeuvres and the type of measurements available. Once the model is selected, the extended Kalman filter provides a set of recursive equations to minimise the sum of squares of the error in the state estimation.

## VII.SUMMARY

This paper describes the procedures needed to achieve flexibility of a CIM cell utilising sensors have been presented. A system control design model for the conveyor belt segments operation and the definition of data from a bar code utilizing a scanner is also described. The data from the bar code denote work-piece path, manufacturing process flow, and resource behaviour. This paper has outlined the theoretical development of an adaptive estimator using an extended Kalman filter to estimate the position, orientation and velocity of a work piece pallet with substantial load variations. It has demonstrated the fusion of odometry measurements with absolute position measurements from a landmark-based local reference system to obtain an optimal estimate of the pallet states.

The framework has been created that defines a formalisation of shop-floor control using sensors previously missing in manufacturing research. The contribution is in the ease and the elegance that the concept provides finite state/ automata activities as well as the production engineering elements such as planning, scheduling and process plan representation within a CIM cell.

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