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The ultralight electro monorail system (uEMS) as the solution for transfer of light-weighing loads in large industrial areas

Das ultraleichte Elektrohängebahnsystem (uEHB) als Lösung zur Übertragung von leichten Lasten in großen Industriebereichen

Marina Belsky[1]
Manuel Wißuwa[2]
Bernd Künne[2]
Emre Koç[1]
Dennis Belsky[1]
Bernd Noche[1]

[1]Transport Systems and Logistics
Professorship Logistics Engineering
University Duisburg-Essen

[2]Department of Machine Elements
Faculty of Mechanical Engineering
TU Dortmund University

These article researches different aspects of the overhead ultralight electro monorail system (uEMS) as a solution to transfer up to 20 kg objects in large industrial areas with the aphesis on high degree of flexibility and long-term use suitability. The purpose of the uEMS to bridge over long transport routes in enterprise with help of the efficiently transporting small objects over long distances.

[Keywords: electro monorail system (EMS), intralogistics, trolley, cable system, rail]

In diesem Artikel werden verschiedene Aspekte des ultraleichten Elektrohängebahnsystems (uEHB) als Lösung zum Transport von bis zu 20 kg schweren Objekten in großen Industriegebieten mit dem Augenmerk auf hohe Flexibilität und langfristige Einsatzfähigkeit untersucht. Der Zweck der uEHB ist es, im Unternehmen mit Hilfe des effizienten Transports kleinerer Objekte über lange Transportwege zu überbrücken.

[Schlüsselwörter: Elektrohängebahn (EHB), Intralogistik, Laufkatze, Seilsystem, Schiene]

1 INTRODUCTION´

The term ultralight monorail system is referred to an overhead monorail system whose own weight (without payload) is considerably lower than the weight of conventional monorail overhead conveyors. Technically equipped and modern industrial areas must satisfy the need in constant efficiency improvement and continual decreasing costs with the goal to stay competitive amount the other existing in the market space enterprise.

1.1 Problem definition

Various electronic monorail systems (EMS) are frequently used in industry to transport objects in large areas in order to save time and effort of the company's personnel. However, such systems are usually designed for heavy loads generally based on rail-guided systems. As a result, subsequent system modification and adaptation can be performed only with great technological, financial and time-consuming efforts. Under frequently changing organization structures the adjustment of a system causes difficulties, loss of time and expenses. This problem can be solved by the ultralight electro monorail system (uEMS) for light load transfer. The uEMS system must have a very high degree of flexibility and to be intended for long term use. [AN14]

1.2 Project´s objectives

The project's scope is to develop and test a highly flexible ultralight electric monorail system (uEMS). The aim is to develop a system for the transport of light loads, which can be used flexibly and can be easily assembled and

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changed at any time, depending on the area of application. The subsequent installation in existing hangars or production facilities is unproblematic here in comparison to conventional systems. In order to meet the terminology of the ultra-light electric monorail system, the focus is placed on correspondingly low transport masses of a maximum of 20 kg. This value is not the last upper limit to define an ultra-light monorail and only used as an orientation. Higher loads (up to, e.g. 50 kg) are also generally conceivable for uEMSs. However, the mass of 20 kg is estimated as a good manageable weight to prove the principle feasibility of the uEMS and therefore formulated as a goal of requirement. During the testing and investigation phase of the planned demonstrator, the possibility is kept open to test it also with larger masses than 20 kg. The “cart” should not exceed the weight of 20 kg too.

The purpose of the uEMS is to bridge long transport distances within a company, whether by efficiently transporting small objects over long distances or by placing sensors in areas that are difficult to access. As part of the research project, all mechanical as well as all control components are developed and the logistical aspects regarding the use of the system is analysed. The system should consist of a battery-powered transport unit and the most cost-effective track or track system. The transport unit should contain the complete logistic and mechanical control. The track system should consist of a highly flexible and easily adaptable guide system made of ropes and profiles, all necessary branching options (points, conjunction, etc.) and a loading station for the transport unit. As part of the project, the system is developed and examined for its feasibility in terms of flexibility, adaptability, cost-effectiveness and safety.

1.3 Expected benefits and impact

A new approach provided by the ultralight monorail overhead system, where a "cart" with a roller undercarriage moves on easily replaceable steel wire ropes and profiles, which are used instead of massive rails of conventional systems. Since no practical systems are available, their field of application has so far been limited to a few applications.

The system developed within the framework of the research project differs from conventional EMS systems in that a highly flexible guide system (made of ropes or e.g. thin pipes) is used instead of a comparatively rigid rail system. This results in the following advantages over EMS with solid rails firmly anchored to the building substance. The structure of the system can be changed, adjusted or extended at any time with little effort, depending on the situation, or even temporarily set up for a certain period of use. This allows the guidemanagement system can to be changed, e.g. to adapt it to the required functionalities through order changes. The dismantling of the guide system and the re-installation require considerably less effort than with massive rail systems. This is especially true for intersections. In the developed system, these components should be designed passively and as a modular system. An externally installed actuator is not required and all necessary actuators are installed on the “cart” (the charging station is an exception). When a route is changed, the corresponding components are used elsewhere, which means that time-consuming electrical and mechanical installation is no longer necessary. All control operations should be made both mechanically and logistically autonomous by the transport unit. Since their sensor technology and control technology retained even when the route is rebuilt, it is possible to react to a changed route progression or logistical process by means of simple software-related adaptations.

Another advantage of the uEMS is a significant cost saving compared to conventional systems. In addition to the operating costs, these are above all the investment costs: Although the costs of the carts are higher than with conventional systems due to the necessary adjustment mechanism for the points, this is partly compensated by the lighter construction due to the lower payload. The control engineering effort is comparable to the more conventional systems. Substantial cost advantages arise in the rail system and conversions, maintenance and repairs. In conventional EMS, a fault in the rail system is accompanied by a complex repair, so that the operational processes can be permanently disturbed, which can lead to delays and production losses. In contrast, the lifetime of the passive guide elements of the uEMS (ropes, profiles,) is relatively high. If the guide elements need to be repaired, they can be replaced with little effort, so that the operation can be continued immediately. A storage of the guide elements in stock or as spare parts requires comparatively little space. Branches, switches and crossings can also be replaced at short notice due to the modular system and due to the lack of electrical or control technology integration. Overall, extremely low downtimes are to be expected.

2 STATE OF THE ART

According to the state of the art, neither the uEMS are used in logistics nor in industrial companies, since practically no corresponding systems are currently available. However, especially in the field of light industry and transport, there is an increased need for the application of the concept solution, so that the result of the planned research project as a technical innovation is very promising. For defined applications, the uEMS can be individually aligned. E.g., for large height differences to be overcome, a different uEMS may be more useful than for applications that are largely on a single plane.

2.1 Overview of existing technologies

Electric monorail systems (EMS) have been used in industry for a long time to facilitate and accelerate the transport of goods and products. Classic electric monorail

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systems (EMS systems) are rail-bound, overhead conveyors with individually driven vehicles that can also map complex material flow structures [FSS14]. The associated rail systems are solid, and rigid tuned to the desired flow and the required flow rate. The vehicles are driven individually on the rails. The motors are powered via busbars integrated into the rails [Lou19]. The subsequent adaptation or modification of these systems is rather difficult due to the relatively high weight of the system parts. As a result, these rail systems can usually only be used for the re-planning of halls or other suitable production facilities, since retrofitting would entail great difficulties and costs [Paw08].

2.2 Components and tools trends

Electric monorail models predominate related to basic system designs. Typical application areas of these models are medium and large industrial production areas, e.g. in the production area of automotive manufacturing [Böt86]. Those are usually used in the form of individually controllable vehicles, which ensure the transport between warehouse and production region [Bro87], to connect production sites in a spatial distance [Pfe87], to act as a feeder for the assembly [Kap90] or serve as a mobile assembly workstation [Lüc78].

2.3 Ongoing and closed related projects

The following projects deal with similar systems:

- *RoboGuard* - scout robot produced by Magal Security Systems Ltd., runs along secured fences, ensures the integrity of the perimeter and is able to respond immediately to intrusion alerts. It consists of an autonomous unit, traveling on a monorail and carrying several sensors. RoboGuard does not have junctions and can execute only closed loop motions. The system is battery powered and water resistant. According to the RoboGurard white paper [Mag14] the system's speed is 5-10 km/h in patrol mode and up to 20 km/h while alerted to intrusion location. Motor: 48VDC 960W 4.55 Nm Electric motor, 4WD Battery: 48V 20Ah, Battery capacity: at least 50 minutes of constant travel. Operating temperature: -20°C to 55°C (-4°F to 130°F). Optional: -40°C to 65°C (-40°F to 150°F), Weight of the system including battery: 37 kg.
- *MultiCar* [Qui15] is an automated, rail-guided conveyor system, enable both spontaneous and planned transport. MultiCar conveyor systems can be integrated into existing, complex production structures. MultiCar links workstations, assembly areas, warehouses, and even entire building units. The modular rail and switch system allows to create an internal logistical network that links all production areas and building levels. Decentralized PLC control system. All active components as well as containers and switches receive control commands via the network.
- *Electronic Monorail System (EMS)* – developed by Shin Heung Machine Company (SMC) [SMC16] is an overhead type rail guided vehicle, which therefore saves space and provides high performance in a beeline. Each carrier can be designed into cage, conveyor, or chuck type according to customer's requirement, and deliver products safely by accurate position control. Transportation and distribution of a variety of items/products can be executed simultaneously. SMC's EMS ensures stable loading/unloading as wire goes up and down and transfers to the designated destination, which can be applied to any circumstances.

3 Development concept

3.1 Control system concepts

The development of the control concept for the ultralight electric monorail systems (uEMS) includes the following key features: robustness, simplicity, autonomy and build in error detection and correction mechanisms.

- *Robustness*: the control system includes a recovery mechanism in case of after power shutdown, connection loss, blocked pathway or minor technical failures.
- *Simplicity*: the user interface is user friendly. The operations are functioning in an intuitive way even for an operator with minimal technical skill. The uEMS control system is similar to the elevator control manner. By pushing the "Call" button the system delivers any available empty cart. After loading the payload, the operator can select a target station and the control system automatically delivers the payload unattended.
- *Autonomy*: as system management is quite a complex task, all the internal activities are hidden from the operator. The battery is charged automatically. The control system decides for itself when and which cart will be sent to the charging station. In case of a partial route blockage, the control system tries to reach the destination by itself in an alternative way and only if all alternative routes are blocked it will inform operator to solve the problem. The passing of the conjunctions is fully automatic.

- *Build-in error detection and correction mechanism*: all statistical information is part of the control system. After each operation the system automatically collects all important information related to the target and destination stations, start and end times as well as errors occurred on the route. In the future, this data may be used for analytics and statistical reporting or any other type of documentation. The system should be able to recover itself form power and data connection failures and other minor technical problems. The Self-diagnosis module should be able to detect technical and operational problems and solve minor errors according to the recovery rules, e.g. the breakdown of one cart should not lead to the complete stop of the logistical system. The system should adapt to the new circumstances and rearrange the routes of the remaining carts.

3.2 Concepts for the electronic components and sensors of the carts

On the first stage of research the main control platforms, e.g. PLC controllers, Arduino C based controllers and one-board microcomputers Raspberry Pi are compared. The sensor networks and concepts are studied [HRBB06]. Each of the controllers and microcomputers listed above have been tested and analysed according to the requirements of the uEMS project, taking into account costs and limitations. It is concluded that PLC controllers are very robust and have a simple programming logic but have too large dimensions and costs compared to other alternatives in addition to a very limited functionality. For example, to add WiFi connectivity, additional hardware with power consumption is required, resulting in low efficiency. In comparison the low-cost Arduino controller is robust and has a straight forward logic that is not well suited for complex tasks. According to the project requirements, each cart must have an autonomous routing ability, including a loss of connection to the central server. In the case of the Arduino, such a logic execution requires much more programming time than object-oriented programming languages. The Raspberry Pi was chosen as the optimal controller for prototyping with the following advantages: integrated WiFi connectivity [LSS07], a web-server to run the user interface and low price. The Raspberry Pi enables the use of numerous open source projects and reduces the integration time for all additional sensors and external hardware.

Sensors allow real-time monitoring of the system and increase safety, accuracy, positioning and contribute to an improved programming logic. Each cart is equipped with the following sensors:

- *Ultrasound sensor:* used to avoid collisions with obstacles and between carts. The sensor is based on an implemented programming logic and is only enabled during the movement in a certain direction. The main function of the ultrasound sensor is safety.
- *Limit switch:* prevents physical collisions by opening the electric circuit of the motor when an obstacle touches the sensor and is the second physical safety element in case the ultrasound sensor fails.
- *RFID reader:* the prototype uses an ultra-high frequency (UHF) RFID reader with an USB interface. This type of reader works from a distance of up to 30 cm from the RFID transponder, which provides a reliable reading even when the cart is moving at a maximal speed of1,5 m/sec. This type of sensor is used for positioning with an accuracy of 30 cm.
- *Reed sensor:* used for precise positioning in the railway switch, the loading stations and the battery charger stations, when an accuracy of a few centimetres is needed. This sensor detects the magnetic field of magnets mounted on the rails and sends the signal to a controller. The more accurate the required accuracy, the lower the speed of the cart must be. Normally, the reed sensor is used when the cart has read the RFID transponder and is waiting for a precise stop position.
- *Weight sensor* (optional feature): controls the weight of the payload for the ultralight electric monorail system intended to transport up to 20 kg. The weight sensor prevents overloading.
- *Battery power sensor* (optional feature): monitors the state of charge of the battery and sends an alarm signal to the control system if the state of charge is too low and the cart must go to a charging station. In some cases, this sensor can be replaced by monitoring the motor currents and predicting the state of charge.
- *Motor sensor* (optional feature): enables to read the rotational speed of the motor. This can be used for safety reasons, e.g. if a motor is mechanically blocked, the sensor can prevent physical damage. This feedback is also useful to measure the distance covered since the last position precisely.

3.3 Mechanical carts component concepts

After building two trial versions of the cart, the uEMS requirement complied prototype is built. The prototype includes one large rubber-covered wheel and two small spring-loaded wheels to stabilize the cart while driving on a metal rail. The cart can also travel over metal wire rope. A combined route made out of metal rail and rope has been

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successfully tested. The transition between the wire rope and metal rail is smooth and stable. By using a wear-resistant rubber coating on the wheel, traveling on the metal wire rope can be prolonged.

In the last prototype version, the main frame of the cart is made of aluminium with stiffeners and can hold the payload and its own weight without deformation. The battery pack is located on the bottom of the cart, stabilizing it while moving, because of the low centre of gravity. Two additional lateral spring-loaded wheels eliminate longitudinal swinging at the beginning of the movement and stopping.

The integrated battery module is developed to work optimally with future automatic battery changing stations. When arriving at the charging station, the fixation of the battery slot releases the battery pack, which is pushed out by the replacement battery. The fixation of the battery pack is done with locking clamps, which provide reliable and safe positioning of the battery in the moving cart at a substantial height.

3.4 Conjunction concepts

The main feature of the concept for the conjunctions is the use of passive switches without actuators or power supply. In contrast, all existing monorail transport systems use motorized switches, which are similar to railway switches, so each junction is equipped with its own motor and power supply. Part of the uEMS project is testing a unique purely mechanical model of a switch without any motor. The passive junction is powered by the cart itself. For this purpose each cart is equipped with an additional motor and junction driver. The junction driver consists of a manoeuvrable lever to push the corresponding switch tongue open. At the entrance of the passive switch, the lever is turned to the left or right. The current concept includes only double junctions. If some specific route needs a triple junction, two consecutive double junctions can be used instead.

3.5 Monorail road concepts

The rails of the monorail system are made out of two section types, rectangular and flat steel profiles. Metal wire rope is used for long straight parts of the route. The rectangular metal profile is used for straight track sections. Flat sections are used for curves. Additionally, some parts of the route may have upward and downward slopes. The demonstrator is composed of all components listed above. The route sections are supported by stands or are directly attached to the walls. A great challenge is the reduction of the cable tension. A unique cable to railway adapter is developed, which works even with significant metal wire rope sagging.

3.6 Routing behaviour concepts

Development of the control system includes several assumptions: the cart can lose wireless connectivity while traveling to a target station and the carts may have no central controller. The first assumption implies several behaviour patterns for the autonomic driving. If part of the route has no wireless signal, the central controller may not be able to include this section to predict all possible routing problems, e.g. blocking a part of the route, and needs to search for alternative routes. This means that the cart should smoothly switch between the online and the offline mode. The cart detects blocked parts of the route and tries to find an alternative route several times before throwing the „blocking route" exception.

The cart is positioned with help of RFID transponders, which are distributed along the route especially in locations where the carts must change speed e.g. at curves, slopes, loading and battery stations as well as junctions. While moving along the route, the cart reads the RFID transponders and updates the actual location in the control system. After the restart of the cart controller, the cart begins with the execution of an initialization procedure. The cart moves slowly until it reaches the first RFID transponder. After that the cart updates the location and continues to move in normal mode.

The integrated diagnostic module can detect reoccurring errors, e.g. when several times the same transponder is not read. Afterwards the control system sends notification according to the error policy.

4 SOLUTION APPROACH

The last prototype version of the control system has advanced programming logic. Extended functionality and stability by adding state machine pattern. This allows for developers much more easy insert routing changes into the system. Second advantages – using generated user interface on Raspberry Pi side. This makes it possible to reduce complexity with a smaller dimensioned system with one or two carts. Such small setups do not need a central server which running and managing business logic. One cart working like a "main system" and second cart set up with "slave" settings. Generated by "main system" graphical user interface serves the second "slave" module. Web based user interface can be reached from any internet device include mobile phones, computers or tablets. This universality give flexibility to the system and reduce the need to order specific control panels.

5 CONCLUSIONS

The uEMS project achieved all the objectives set out in the project scope. Even though the steel cables are easily replaceable, it is still not an optimal solution due to the tensile forces that have to be considered.

5.1 Project achievements analysis

- *Confirmed multi rail functionality* – cart can work simultaneously on different route types: rectangular profile, flat profile, steel wire rope. A cart can move from one type of road to another smoothly.
- *Confirmed functionality of adapter* – allows a cart to go from a rail profile to a steel wire rope and back, even if the wire rope is not tightened. An unique adapter form allows a cart to move from the sagging rope to the rail.
- *Confirmed battery powered functionality* – allows the cart with the planned 20 kg payload to operate many hours or even few days of work without recharging the battery.
- *Confirmed routing concept* – allows the RFID transponder based cart localization. Ultrahigh frequency (UHF) RFID reader are precise enough even when the transponders are fixed on metal rails.
- *Confirmed functionality of user interface* –allows the operator without good technical knowledge to use the ultralight monorail.

5.2 Further developments proposal

Following future developments may be implemented in the future:

- An automatic charging stations to change the battery pack.
- A control system upgrade with a dynamic user interface with a built in studio which allows the operator to add/remove stations, change routes with the help of a graphic interface.
- The voice recognition feature will allow an operator to interact with the system with voice commands.
- A cart manipulator, which allows complex robotic tasks including the handling and transportation of an object, collecting of a payload in automatic mode and transportation to the destination station.
- Loading and unloading of payload:
    - *Integration of the video recognition technologies* by adding motorized high definition (HD) cameras to the cart in order to monitor warehouses or production lines. The system can also be used for security purposes or to detect unwanted objects.
    - *Adding movement in vertical direction* by using an internal motor and vertical junctions, since the current ultralight electric monorail systems has limitations with rail slopes. If such a system is used with multilevel environments the vertical movement abilities can be very important.
    - *Descend and move on an arbitrary horizontal surface* as additional functionality that allows the cart not only to move on a rail, but also to descend on any horizontal surface, move freely there and change back again on rails. Such hybrid functionality can create a new product with unique areas of application.

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Marina Belsky, M.Sc., PhD student and works as research assistant at Transport Systems and Logistics at University Duisburg-Essen since 2017. Marina Belsky was born in 1978 in Lensk, Russia, studied from 2000 to 2005 Software Engineering and Management in Tel- Aviv and worked as software engineer. From 2012 to 2017 she studied Computer Engineering at Duisburg.

Dipl.-Ing. Manuel Wißuwa, PhD student and works as research assistant at Department of Machine Elements since 2012. Manuel Wißuwa was born in 1983 in Zschopau, Germany and studied from 2005 to 2012 Mechanical Engineering in Dortmund.

Emre Koç, M.Sc., PhD student and works as research assistant at Department of Transport Systems and Logistics since 2010. Emre Koç was born in 1982 in Nazilli, Turkey and studied from 2007 to 2010 Logistics Engineering in Duisburg.

Prof. Dr.-Ing. habil. Bernd Künne, head of department of Machine Elements since 1993. Bernd Künne was born in 1956 in St. Andreasberg

Prof. Dr.-Ing. Bernd Noche, head of department of Transport Systems and Logistics since 2000. Bernd Noche was born in 1956 in Cedro Pampa, Peru.

Dennis Belsky, M.Sc., PhD student and works as research assistant at Transport Systems and Logistics at University Duisburg-Essen since 2018. Dennis Belsky was born in 1977 in Kharkov, Ukraine, studied from 2000 to 2005 Software Engineering and Management in Tel- Aviv and worked as software engineer. From 2013 to 2018 he studied Computer Engineering at Duisburg.