DEVELOPMENT OF A REMOTELY-CONTROLLED ROAD HEADER ROBOT

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submitted by **RAMIN ENTEZARI** in partial fulfillment of the requirements for the degree of **Master of Science in Mining Engineering Department, Middle East Technical University** by,

Prof. Dr. Canan Özgen ______________________
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. Ali İhsan Arol ______________________
Head of Department, **Mining Engineering**

Assoc. Prof. Dr. Nuray Demirel ______________________
Supervisor, **Mining Engineering Dept., METU**

Examining Committee Members:

Prof. Dr. Bahtiyar Ünver ______________________
Mining Engineering Dept., Hacettepe University

Prof. Dr. Naci Bölükbaşı ______________________
Mining Engineering Dept., METU

Prof. Dr. Ümit Atalay ______________________
Mining Engineering Dept., METU

Assoc. Prof. Dr. Hakan Başarır ______________________
Mining Engineering Dept., METU

Assoc. Prof. Dr. Nuray Demirel ______________________
Supervisor, **Mining Engineering Dept., METU**

Date: 04.09.2014

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name: Ramin Entezari

Signature:

ABSTRACT

DEVELOPMENT OF A REMOTELY-CONTROLLED ROAD HEADER ROBOT

Entezari, Ramin

M.Sc., Department of Mining Engineering

Supervisor: Assoc. Prof. Dr. Nuray Demirel

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A road header is a mechanized excavating equipment utilized widely in tunnel construction and underground mining. It is composed of a boom-mounted rotating cutting head, a loading device, a conveyor, and a crawler travelling track to move the entire machine forward and backward. The productivity and performance of the road header is directly affected by the operator efficiency. Besides that road headers are usually operated in deep excavations and hazardous underground mine environments. Therefore, development of a robot of this machine both eliminates any deficiency related to the operator and prevents loss of life in case of mine accidents.

This study presents the design and development of a remotely-controlled road header robot. The research methodology involves 4 main stages: (i) development of 3-D solid model of the road header using photogrammetric techniques and CAD design programs, (ii) designing the 1/10-scaled physical prototype of the road header, (iii) integrating control mechanism into the developed physical prototypes, (iv) running the developed

road header to validate the model. As a result of the study, 1/10scaled remotely controlled KSP-32 model road header robot of 1.31 m length and 25 cm height, and 45 kg weight was developed together with its control systems. The robot can be controlled in a circle area of 50 m diameter. This study is original towards achieving fully automated robotics of mining machines.

Key words: Underground mining, road header, robotics, automation, mechanization.

ÖZ

UZAKTAN KUMANDALI GALERİ AÇMA MAKİNASI ROBOTUNUN GELİŞTİRİLMESİ

Entezari, Ramin
Yuksek Lisans, Maden Mühendisliği Bölümü
Tez Yöneticisi: Doç. Dr. Nuray Demirel

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Galeri açma makinası (road header), tünel inşaatlarında ve yeraltı madenciliğinde yaygın olarak kullanılan bir mekanik kazı makinasıdır. Bum üzerine yerleştirilmiş kesme başlığı, yükleme aparatı, bantlı taşıyıcı ve makinanın ileri geri hareketini sağlayan bir paletten oluşmaktadır. Operatör faktörünün etkili olduğu bu makinanın üretkenliği ve performansı üretim projelerinin başarısı açısından çok önemlidir. Aynı zamanda, galeri açma makinası, iş güvenliği açısından yüksek risk teşkil eden tehlikeli ve zor koşullarda çalışmaktadır. Bu makinanın uzaktan kontrol edilebilen robotunun yapılması, hem operatör ile ilgili arızalanma ve yanlış kullanıma mani olacak hem de olası iş kazalarında insan kayıplarının önüne geçecektir.

Bu çalışma, bir galeri açma makinasının küçük ölçekli bir modeli için uzaktan kumanda edilebilen robotunun geliştirilmesini amaçlamaktadır. Araştırma metodolojisi başlıca şu aşamalardan oluşmaktadır: (i) Galeri açma makinasının 3-B katı modelinin, CAD tasarım programları ve fotogrametrik tekniklerle oluşturulması, (ii) 1/10 ölçeğindeki bir galeri açma makinasının fiziksel prototipinin geliştirilmesi, (iii) geliştirilen bu modele kontrol sistemlerinin entegre edilmesi, (iv) robotun çalışıp çalışmadığının test edilmesi. Bu çalışma sonucunda, 1.31 m uzunluğunda, 25 cm yüksekliğinde ve 45 kg ağırlığında KSP-32 model bir galeri açma makinasının (1/10 ölçeğinde) 50 metre çaplı dairesel alan içerisinde uzaktan kumanda edilebilen bir robotu geliştirilmiştir. Bu çalışma, maden makinalarında robot tasarımı veya tam otomasyona yönelik özgün bir çalışmadır.

Anahtar kelimeler: Yeraltı maden işletmeciliği, galeri açma makinası, robot, otomasyon, mekanizasyon

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TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

CHAPTER 1

INTRODUCTION

1.1 General Remarks

Automation and robotics in mine mechanization have been increasingly utilized in recent decades to enhance health and safety, to improve economic profitability, and to ensure sustainable surface and underground mining operations (Torlach, 1998). These technologies provide more energy-efficient methods, which obviously is essential for a successful mining project. Moreover, intensive mining operations require less number of higher-skilled labor forces in tough situations. Therefore, risk of mine accidents could be reduced significantly by reduced exposure of miners to potential hazards. Although it is thought bminers that automation and robotics could be a threat to the continued employment, considering the aging and retirement of experienced mining practitioners and lack of mentorship for younger miners, automation and robotics will be the unique opportunity to get training and experience.

Regardless of their sizes and types, due to technical and economical reasons, mines should be equipped with smart mining systems such as, robots and automated machines, satellite communications, and smart sensors for accomplishing sustainable mining objectives. The use of advanced technologies provides more competitive working environments in a safe and environmentally sound manner through efficient and reliable operations (Bandopadhyay *et al.*, 2002).

Among the earliest developments in mine mechanization was the introduction of locomotives to replace manual or pony haulage. In present-day mining, operations such as, loading the mine cars, placing them in the cage at the hoist shaft, discharging the cars at the surface are all performed automatically. As technology advances in many industries around the world, machines and/or robots have started to take place of labor force. For the last two decades, automation and robotics have been on the agenda of the mining industry. Especially in the North America and Australia made many investments in mining automation. Although automation has entirely and successfully been achieved in other industries, the mining industry does still not fully benefit of a complete automation. Therefore, advancements of mine automation and robotics are emerging issues especially for underground mining operations where increased efficiency and productivity and reduced risk of accidents are of paramount concern for sustainability.

One of the main excavation machine used in underground mining is a road header. It consists of a boom-mounted cutting head, a loading device usually involving a conveyor, and a crawler travelling track to move the entire machine forward into the rock face. Road headers are used both in underground excavations and tunneling for cutting coal or rock face for a range of cross-sections, diameters, and directions flexibly (Rostami *et al.*, 1996). The advantage of a road header is that it is more flexible and versatile in soft to medium rock excavation because it has the capacity to excavate and clear muck from the tunnel simultaneously.

The first road header appeared in the early 1950s primarily for mechanical excavation of coal. By the 1960s, road headers were being widely used in tunneling and gradually gained worldwide acceptance by the end of the 1970s. A number of improvements made over the last 50 years have expanded their initial use in coal mining. The machines have steadily increased in weight, size, and cutter head power. Developments have also been made in the design of the boom and muck pick-up and loading systems. Today's modern road headers also come equipped with electrically-or hydraulically-controlled systems that are connected to microprocessor-based guidance and profile control systems. However, remotely-controlled fully automated road header has not been developed up to date.

In this research study, remotely-controlled 1/10 scaled robot of a road header was developed to provide an insight into the benefits of automation for future studies.

1.2 Problem Statement

One of the biggest challenges in the labor-intensive mining industry is the mine accidents resulting in injuries or fatalities happened in mine sites especially in underground mines. These problems occurred especially in labor-intensive traditional and classical methods of mining processes during exploration, excavation, and haulage. The risk of mine fatalities could be prevented and/or reduced by involving high technology and advanced techniques such as, automation and robotics.

Training of inexperienced miners on complex machinery is another important issue to be addressed in mining industry considering the fact that the number of experienced miners are decreasing due to retirement in recent years. Thus small scale robots of such complex machines like road header is essential for training operators before they need to go to underground for reducing the risk of accidents and increasing productivity. Remotely-controlled robots can be utilized efficiently to improve productivities and to reduce high risk of accidents.

1.3 Objectives and Scope of the Study

The main objective of this study is to design, develop, and implement a remotely controlled road header robot to provide an aid in increasing the operation efficiency and decreasing risk of operator induced failures.

Main objective of the study entails: (i) data collection on the selected road header, (ii) modeling of a road header using computer-aided drawings, (iii) development of the physical model of the robot, and (iv) integrating control systems on the developed physical prototype.

1.4 Research Methodology

The research methodology consists of five main stages. The first stage includes the selection of a road header type and data collection. Data includes the technical machine specifications including sizes of all components. In the second stage, computer modeling of the 1/10 scale of the KSP-32 model road header was completed. After developing the computer model, physical model was developed. At this stage, individual components of the robot was developed and assembled. In the last part, the developed model was equipped with the motors and control systems to complete the robot of the selected road header.

The research methodology essentially entails:

- selecting the specific model which is being used in underground coal mining
- designing 3D solid model of the road header using photogrammetric techniques and CAD design programs
- developing the 1/10-scaled physical prototype of the road header
- integrating control mechanism into the developed physical prototypes
- running the developed road header to validate the model

Robotics and automation technologies have recently started to be used in mining industry and the use of these technologies have been increasing gradually. In this sense, this research study advances the current research frontiers in mining industry.

1.5 Outline of the Thesis

The first chapter of this dissertation introduces the subject matter of the thesis, objectives and scope of the thesis, research methodology, and outline of the thesis. Following the first chapter, the second chapter presents literature survey about the smart mines equipped with robots and their effects on the mining safety and efficiency. It also includes previous works in this field. In the third chapter, robot designing is explained comprehensively. In addition, development of the mini mining robot of KSP-32 road header is presented. The fourth chapter presents the main conclusion and recommendations derived from this research study.

CHAPTER 2

LITERATURE SURVEY

2.1 Introduction

This chapter presents a review on functionality of road headers, basic concepts of automation with advantages and disadvantages, applicability of automation in mining sector with recent studies, and importance of small-scale prototyping in education. In this basis, Chapter 2.2 introduces utilization, classification, and types of road headers used in underground mines. Brief explanation of automation issue and how automation effects production negatively or positively are discussed under Chapter 2.3. Developments in mining automation in recent decades, its utilization area, and leading studies on improvement of mining production by automation are the issues addressed in Chapter 2.4. Finally, which advantages small-scale prototypes bring in training of operators and in prior stages of automation is covered in Chapter 2.5.

2.2 Overview on Road Headers

Mechanized tunneling in underground mines or transportation openings can be achieved by full-face boring machines such as, tunnel boring machine (TBM) or partial-face heading machines such as, road header, multi-tool miner, boom-mounted impact hammers, and backhoe excavators (Tatiya, 2005a). Among these excavators, road headers are extensively utilized in tunneling of sedimentary formations with soft-to-medium hardness, using axially-mounted single cutting head or transversely-mounted double head on tip of boom (Ramamurthy, 2010). Front-end components of the road header with single and double cutting heads are illustrated in Figure 2.1.

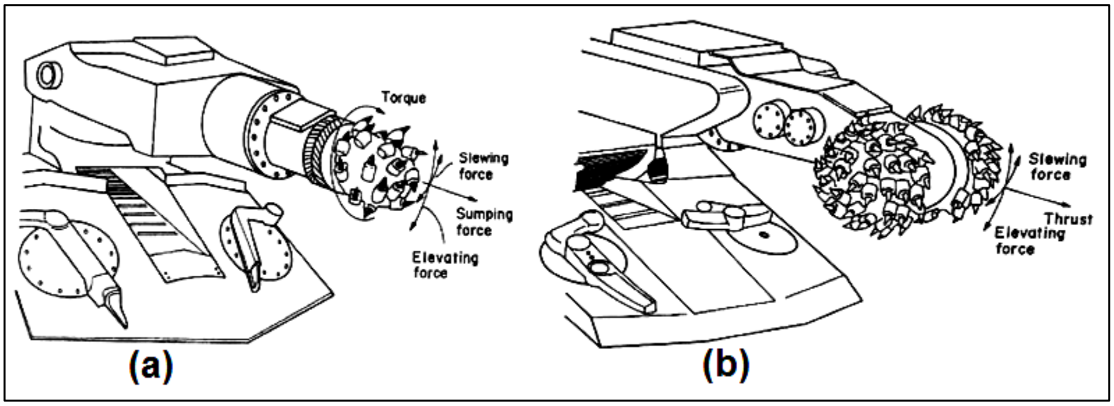

Figure 2.1Road Headers Types: a) Milling b) Ripping (Fowell, 1993)

Milling road headers cut formation with axial rotation of single cutting head where ripping type road headers penetrate rock using cutters perpendicular to boom, not axial (Sinha, 1989). Both version of the machine penetrate formation consistently and remove loose material accumulated at operation face using conveyor belts lying along centerline of machine. This mucking material is then transferred to rear of road header and dropped into another haulage unit.

Factors affecting cuttability and performance of a road header are listed as follows: i) Mechanical factors such as, machine weight, dimensions, and type, bit type, cutting head type, and boom force capacity; ii) geological-geotechnical factors such as, rock mass properties, physical and mechanical specifications of intact rock, and iii) operational factors such as, tunnel shape, inclination, support type, kind of much haulage unit, ground water, and labor availability and quality (Bilgin *et al*., 2014). Geological property of excavation side dominantly affects road header performance and causes wearing problem in the cutting bits (Ramamurthy, 2010). In order to overcome tough rock conditions, various road headers with different gross weight and head power were manufactured (Table 2.1). Whereas the most powerful road headers can penetrate a formation up to 150 MPa, optimum rock strength for cuttability of these machines is about 30 MPa (Hemphill, 2013).

Table 2.1 Classification of Road Headers (Tatiya, 2005a)

Road header	**Weight range: t**	**Cutter head power: kW**	**Road header with standard cutting range**		**Road header with extended cutting range**	
			Max. Section: m2	Max. UCS MPa	Max. Section: m2	Max. UCS MPa
Light	8-40	50-170	25	60-80	40	20-40
Medium	40-70	160-230	30	80-100	60	40-60
Heavy	70-110	250-300	40	100-120	70	50-70
Extra heavy	>100	350-400	45	120-140	80	80-110

Road headers hold high level of versatility and mobility in underground operations and they can cut excavation face continuously in various cross-sections without any drilling and blasting requirement (Tatiya, 2005b; Hemphill, 2013). Moreover, utilization of road header eliminates negative effects of drilling and blasting operation arising due to handling, storage, transportation, and use of explosives. On the other hand, road header operations can cause various risks appearing due to moving parts of machinery, combined operation with other face equipments such as, dust collectors and fans, high voltage exposure due to the cables and transformers, firing of machine itself, and related maintenance operations (Dyczko *et al.*, 2011). One can also expect that additional exposures such as, heat and vibration can arise as well as dust and noise in road header operations may arise. Therefore, elimination of health and safety risks raised due to road header utilization using automation tools has a vital role in enhancing the performance of this earthmover. Availability and performance of road header can also be improved owing to automation. In this regard, the following section introduces automation concept with positive and negative sides. Requirement of automation for more competitive mining will be later discussed with recent automation studies carried out for various mining systems.

2.3 Automation Concept

Production industries attempt various investments to raise their production capacities and product qualities with decreasing safety risks and personnel requirement. Natural extension of this desire has initiated development of self-proceeding operations with improving technology. In this sense, successive researches have carried out to create system with ability of (i) determining and monitoring when performance of system is under desired levels, (ii) raising effectiveness of operation to keep outputs above limits, (iii) arranging ongoing operations to improve system productivity in term of capacity, dimensional accuracy, and output quality, and (iv) performing previously assigned functions without any human interaction (Nof, 2009). Requirements of these semi-intelligent production techniques induced rise of automation concept. This chapter briefly presents automation concept, positive and negative effects on working area due to automation, and automation levels considering human-machine interaction.

2.3.1 Definition of Automation

Automation can be basically described as the pre-organized order of operations with little or no labor requirement, utilizing specialized machines and devices with the ability of managing and monitoring the production process (Nof, 2009). Concept of automation initially rose in mid-1940s in the United States automotive sector to achieve automatic handling of automobile parts between the manufacturing machines and the concept was evaluated in recent decades with improvements in computational technology (Gupta and Arora, 2007). Nowadays, automation is integrated with production cycle in many sectors such as, aerospace, air conditioning, television, computer, mining, and communication. Autonomous machines can be utilized as machine tools to process parts, assembly machines, industrial robots, material handling machines, storage and retrieval systems, inspection systems, feedback control systems, and computer systems for planning and decision making (Gupta and Arora, 2007). Decision of how automation will be adopted to the production cycle should be evaluated carefully considering the following factors:

i) Type of product, ii) quantity and rate of production, iii) particular phase of automation, iv) skill level of available personnel, v) reliability and maintenance, vi) economics aspects, and vii) intensity of human-machine interaction, i.e. automation level.

2.3.2 Motivation for Automation

Utilization and development of automation in industries is motivated due to following issues (Nof, 2009): i) Feasibility: Implementation of some micro-scale operation requires high speed and accuracy which humans cannot handle, ii) Productivity: Automatic devices can continuously operate with high speed and large capacity, rising overall efficiency and productivity, iii) Safety: Automated machines can work in environments that are not safe for humans, iv) Quality and Economy: Automation allows the organized operations to be handled with high quality and it reduces economic losses due to labor salaries and insurance, safety and maintenance expenses. Besides the advantages, automation holds some limitations such as, high initial investment, labor resistance, and requirement of skilled labor (Rajput, 2008). Suitability of automated devices for operations and payback period of the expenses for automation should be analyzed carefully. Technology without suitable integration with production can result in loss of money and time. In addition, although utilization of skilled machines raises productivity, presence of these machines in a work environment can cause more competitive jobs and leads to decrease in labor intensity. It can induce unemployment inside the sector. Therefore, all factors with negative and positive sides should be analyzed both socially and economically before adapting automation to production cycle.

Productivity is one of the most motivating items for automation in a cyclic production system. Companies in every sector are under pressure to achieve high quantity of production at low-level cost to raise productivity and profitability (Humbert, 2007). This pressure generally eventuates in increasing number of workplaces with new improved technology. Profitability is critical since economical implementation of sectors depends on production that can be traded above limit profits where total cash outflow for capital and operation expenses as well as environmental and social cost is lower than cash inflow. Therefore, companies must monitor their expenses to ensure their long-term profitability. In this sense, personnel expenses such as, salary, insurance, transportation, and food, one of the largest variable cost items, can be reduced owing to automation. Automation allows controlling of machines by less number of operators. In addition, unmanned machines controlled away from operation area allow rapid implementation of risky and small-size operation with high accuracy in hard working environments. Besides, manually controlled machines work with lower availability compared with autonomous ones since responsible personnel for manual systems cause system downtimes due to rest breaks or other human needs. Automated systems can operate continuously without any break except for compulsory maintenance breakdowns due to failures.

Another motivation for automation is clean working environment with less health and safety problems. Introducing remotely managed systems provides direct benefits in regard to occupational health and safety since automation allow same task management of process physically away from potentially dangerous working place (Dozolme, 2010). In addition to health and safety benefits, compensations paid to labors due to accidents and workforce loss are also eliminated with minimizing human factor in production area with unmanned autonomous systems.

Reduction in human errors and growth in production quality is another item in automation motivation. Task complexity and stress on personnel for increased performance may cause human errors in production. Sensors and diagnostic tools with programmable monitoring services mounted on automated systems support production with high accuracy as well as minimized maintenance cost and downtime periods.

2.3.3 Automation Levels

Integration of automation to systems and human machine interaction level during operation vary due to complexity of system, operation type, and sensitivity of automation design. Some researches on human-machine interaction in automation have showed that full automation does not always follow requirements of design and it may cause undesired functionality effects in working environment (Billing, 1996). Therefore, level of human-machine interaction should be arranged considering nature of operation and some qualified personnel can be adapted to automatous system in changeable proportions. Differently from manual systems, automation changes role of human in these production cycles by shifting human role from physical into cognitive one (Paige, 2000). In this sense, task allocation approach by Schneiderman (1992) as stated in Table 2.2 can be beneficial to specify tasks by autonomous systems and relevant personnel.

Table 2.2 Task Allocations in an Automated System (Schneiderman, 1992)

Tasks Better Performed by Humans	**Tasks Better Performed by Automation**
Remember Principles and Strategies	Recall Quantities of Detailed Information
Retrieve Pertinent Details without a Prior Connection	Process Quantitative Data in Pre-specified Ways
Adaptability	Accuracy
Reason Inductively — Generalize from Observations	Reason Deductively — Infer from a General Principle
Sense Unusual and Unexpected Events	Monitor Pre-specified Events
Act in Unanticipated Emergencies and Novel Situations	Perform Repetitive Preprogrammed Actions Reliably
Draw on Experience and Adapt Decisions to Situation	Perform Several Activities Simultaneously
Detect Stimuli in Noisy Background	Calculate Accurately and Quickly

Task allocation in an automated system changes automation level applied in working environment. Sheridan and Verplank (1978) classified automation levels into ten classes. The highest level refers that computational system decides everything and system is fully automated with ignoring human decisions while the lowest level implies that there is no computer decisions on machine decisions and system is manually controlled. A detailed classification for automation level by Amber and Amber (1964) can be viewed in Table 2.3. According to the table, the highest level automation system is interactive companions with humor ability while non-automated tools such as, knife and scissor are at the lowest level in automation level. Autonomous mining machineries can be grouped in level A_8 with ability of guided mobility.

Table 2.3 Automation Levels (Amber and Amber, 1964)

Level	**Automation**	**Automated Human Attribute**	**Examples**
A_0	Hand-tool; manual machine	None	Knife; scissors
A_1	Powered machine tools	Energy. Muscles	Electric hand drill; electric food processor
A_2	Single-cycle automatics and hand-feeding machines	Dexterity	Pipe threading machine; machine tools
A_3	Automatics; repeated cycles	Diligence	Engine production line; automatic copying lathe
A_4	Self-measuring and adjusting; feedback	Judgment	Feedback about product: dynamic balancing; weight feedback
A_5	Computer control; automatic cognition	Evaluation	Rate of feed cutting; maintaining pH
A_6	Limited self-programming	Learning	Sophisticated elevator dispatching; artificial neural network models
A_7	Relating cause from effects	Reasoning	Sales prediction; weather forecasting
A_8	Unmanned mobile machines	Guided mobility	Autonomous vehicles and planes
A_9	Collaborative networks	Collaboration	Collaborative supply networks; collaborative sensor networks
A_{10}	Originality	Creativity	Computer systems to compose music; design fabric patterns
A_{11}	Human-needs and animal needs support	Compassion	Bio inspired robotic seals to help emotionally challenged individuals
A_{12}	Interactive companions	Humor	Humorous gadgets; interactive comedian robot

2.4 Automation in Mining

Leading mining companies on the world have realized that automation is one of the essential steps to survive and provide an advantage in competitive industry. In this sense, automation in mines has prominently evaluated and improved from remotely managed control devices to automated mobile machineries, due to economic, safety, and productivity necessities. Automation presents an efficient way of raising profit margin by reducing operation and labor cost and also provides a safe working environment. Ongoing researches about this issue aim to create automated mining environments where mobile and stationary devices will be entirely integrated to meet the overall requirements of mining operations. This chapter will state about applicability of automation in mining covering the issues that encourages mining sector for automation and recent automation studies and application on mining systems.

2.4.1 Applicability of Automation in Mining Sector

Economical mining of an ore reserve depends on profitability of material where the income is much higher than the costs due to mining and processing operations, waste material removal, salaries, environmental, and social responsibilities. Rating of annual income is highly based on the market demand and supply amount of the extracted mineral, out of the company's ability to control. In this basis, company may maintain profitability only by controlling inter-corporate operating costs. Companies can choose automation in some suitable portion of mining operations to enhance output and decrease labor intensity. Moreover, removal of workers in excavation area by adapting automated systems decreases direct costs by eliminating environmental maintenance for humans such as, ventilation and small rock falls. Since a substantial effort in mining schedule is given to sustain mining environment suitable for human safety, less labor in the area means less infrastructure expenses, higher profitability. In addition to economic effects, automation also eliminates health issues of workers due to the exposure of dust, vibration, toxic gases, noise, heat, and humidity. It reduces injuries and fatalities by removing labors from the dangerous operation areas. Moreover, automation also offers benefits to protect machine health and safety by monitoring various functions with the help of sensors. Therefore, potential machinery failures can be predicted by observing critical vibration, heat or force limits and then, overall maintenance and production losses can be reduced.

Automation studies in mining sector have given opportunity for improvements of drilling machines, haulage trucks, load-haul-dump systems, monitoring devices for atmosphere, temperature, water and acid rock drainage, and ventilation systems (Parreira, 2008). Efficient automation of these mining systems can be achieved by successful integration of three main concepts as sense, decision, and control as given in Figure 2.2 (Jonathon *et al*., 2014). These concepts can be described as situational awareness, i.e. sensing, of system to define the job, decision making mechanism to arrange the organization of operation, and management mechanism of system to control and execute the job, respectively. Proper identification of each step in automation provides safety and productivity in the working area and sustainable implementation of the work schedule.

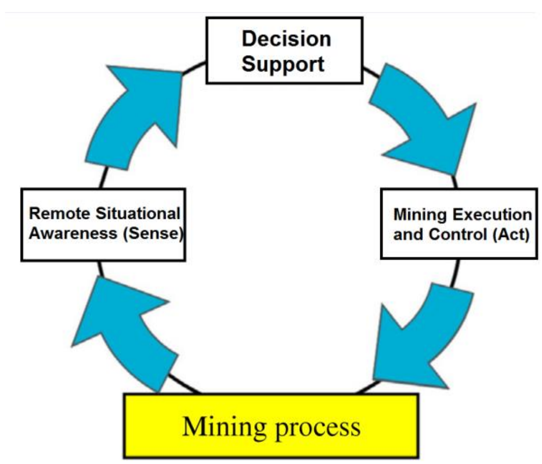

Figure 2.2 Items of Effective Mining Automation (Jonathon *et al*., 2014)

Control of target systems to be automated can be achieved in various ways such as, local manual, remote manual, tele-operation, tele-supervision, and full automation (Jonathon *et al.*, 2014). In local manual control, the system can be managed by staff in line-of-sight, using direct monitoring interface in connection with system through hard wires. Remote manual control is similar to local manual control except that controlling of the system is carried out using portable wireless console. Tele-operation is achieved by staff in line-of-sight with utilizing sensors to create situational awareness in the system. On the other hand, tele-supervision is the controlling of system by staff not in line-of-sight but monitoring the operation using additional automation facilities. Lastly, full-automation means automated system perform functionality autonomously without direct control of any staff.

2.4.2 Recent Studies in Mining Automation

Automation was started in mining sector in 1960s to increase the abilities of mining equipment (Bellamy and Pravica, 2011). Konyukh (2002) classifies the improvement stages of automation in mining into three groups. In late 1960s, first automation trials were on unmanned rail haulage in an underground mine in Germany. Later on, automation concept was extended to automated drilling operations in Europe and in the United States by safe operation of drilling with programmed drilling pattern. After early ages of automation in mining, the concept was enlarged using remote-controlled excavation machineries in mid-1970s. In this period, coal extraction machines were automated using cameras in mines where excavation area was form of low-stability sedimentary formations. However, adaptation between real time computer application and operator skill was hard to control properly. This situation induced new automation researched. Third and the last stage of automation started in mid-1990s introduced improved technologies in automation sector and adapted these new innovations to various mining equipment. Rail haulage, load-haul-dump (LHD) machines, underground and surface trucks, straddle carriers, underground face drills, longwall mechanisms, dragline swing mechanisms, drilling and rock recognition devices are prominent mining systems which are capable of autonomous operation ability.

Automation of longwall mining is extensively applied in many underground coal mines. In this sense, Australia is one of the leading countries in automation which adapts this technology in many parts of underground mines. One of the automation project conducted by Australian Coal Association Research Program (ACARP) is the development of automatized longwall mining system. One project by Kelly et al. (2005) held a budget of 4.31 million Australian $ to contribute the improvement and developments of new sensor for close loop control of machine, interconnected communication system, data flow and management devices, real-time monitoring and failure detection systems. In addition, qualifications of the operators to be employed in automatized longwall system were also specified. Another ACARP project (Hainsworth *et al.*, 2008) aimed to extend the scope of prior longwall automation research (Kelly *et al.*, 2005) by implementing a prototype controlling system called as longwall automation steering committee (LASC) in order to visualize longwall production environment in three dimensional perspective. LASC system was adapted to the half of longwall mine in Australia in 2008 and this utility is expected to be benefitted in 85 % of mine in future. In addition, new software and hardware technologies were developed to maintain the monitoring of shearer position. By this way, the project purposed to improve productivity in 5 % and raise interoperability level of shearer as well as the health and safety issues. Related with longwall automation, Mundry and Weßelmann (2009) introduced an automation technology developed by Bucyrus, which is capable of powerful logging, analyzing, and monitoring utilities with high-speed network communication. In addition, Kumar *et al.* (2011) discusses optimization of fiber optic connection for pressure and performance monitoring of automatized longwall shield supports. They also developed a prototype to validate the performance of monitoring by comparing configuration and detection findings. It was dclaimed that system errors were in acceptance limits which proved scalability and reliability of the system. Another research study by Hargrave*et al.* (2007) aimed to improve implementation of wireless communication systems in automation of longwall mining. The researchers attempted several configuration and bandwidth arrangements to find out how wireless technology could be adapted to automation effectively.

Load-haul-dump (LHD) machines are another automated systems extensively utilized in technologically developed mines. These machines are controlled by various combinations of navigation and tele-operation systems with integration of multi-functional sensors. Various research studies have been carried out to improve the performances of auxiliary devices in LHD automation. Dasys *et al.* (1994) introduced a controlling system for LHD to monitor the loading cycle of the machine. In accordance with the project, 60 sensors were mounted to inform the control panel about axial movements of machinery by using amplitude and frequency of oscillations in the operations. Baiden (1993) discussed the abilities of a tele-operation system using high speed and capacity production network and holding three dimensional monitoring with video facility. The system was applied in an underground copper mine and it was defensed that a remarkable productivity was achieved as well as improved safety conditions due to controlling of the machine in remote control station away from operation area. Knights *et al.* (1994) mentioned about a fault detection and diagnosis system utilized to raise availability of automated LHDs by early identification of faults in the system. The authors investigated abilities of other expert systems for failure diagnoses and offered a hybrid expert system with examining decision support system with reliability centered maintenance. Nowadays, automation allows LHDs to operate with cm accuracy (Nebot, 2007). Therefore, many prominent mining companies prefer automated LHDs for reliability, availability, and profitability reasons. One remarkable application of LHD automation is performed in El Teniente copper mine in Chile (Nordic Steel and Mining Review, 2007). The company replaced 16 LHD operators with 4 automation control operators. This strategy was eventuated in productivity increase up to 25%. Although automated operations raised the number of maintenance staff, many positive improvements were provided such as, decrease of safety risk, staff cost and improvement of machine's lifetime and utilization. Figure 2.3 illustrates an automated LHD equipped with various navigation tools.

Figure2.3AutomatedLoad-Haul-Dump (LHD) Machine (Nebot, 2007)

Shovel is another target system in mining machinery automation. An ACARP project conducted in 2004 was aimed to automate operation of rope shovels (Dunbabin and Corke, 2006). Researchers in the study attempted to improve a system to control crowd, hoist, and swing drives, three dimensional mapping of terrain utilizing laser scanner, bucket capacity detection system using motor signals, and cross-sectional profile change of bucket with the help of laser scanner. Performance and validity of the improved systems were proved using $1/7^{th}$ scale electrical rope shovel. This project was progressed with another ACARP project in 2006 with automating loading and swinging cycles of shovel for complete truck loading (Dunbabin and Usher, 2006; Wade, 2007). Multiple passes in complete loading cycle was achieved by improving a system with ability of face excavation, swing and deciding optimal loading and dumping plans. It was defensed that the developed technology in this study allowed damage control of shovel such as, collision prevention and decreased digging downtime and productivity improvements such as, optimized loading and positioning and online volume calculation. Figure 2.4 shows the automated rope shovel in $1/7^{th}$ scale and terrain monitoring using laser scanner.

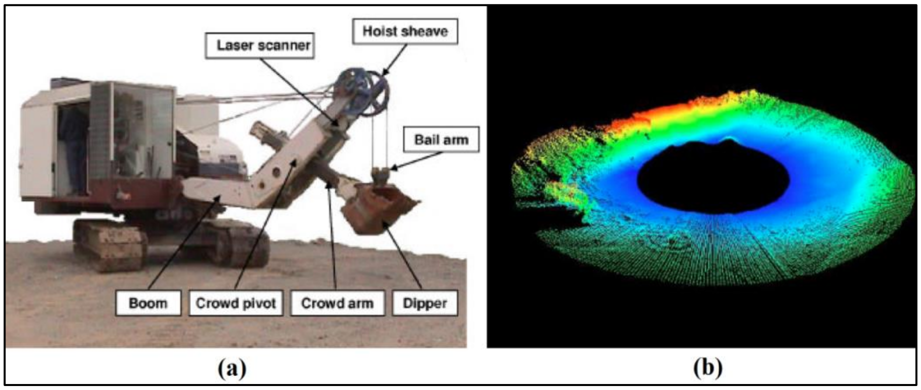

Figure 2.4 Automation of 1/7th Scale Rope Shovel and Its Terrain Scanning Ability (Dunbabin and Corke, 2006)

Haulage trucks are other target systems in mining automation. Utilization of material haulage via automation is economically significant since it is in charge of 40-50 % of total surface mining operating cost (Nebot, 2007). Moreover, truck automation takes benefits for reducing green-house gases and maintenance expenses, elimination of safety problems, and increasing productivity (Parreira, 2008). Initial project on these systems were carried out in 1985 with automating truck with 70 tons (Baiden, 1992). The automated driverless trucks utilized electrical power to induce pumps in hydrostatic wheel control and employed angular transducers in order to estimate position of truck compared with track. Intended speed and steering angle of truck were calculated using a computer system and communication system installed on the truck. In addition, video cameras were mounted on the body to provide machine vision. A case study in Mt. Keith nickel mine in Australia revealed that truck automation is effective on total operator wages, fuel utilization, truck availability, truck tire-lifetimes, and pit design (Bellamy and Pravica, 2011). According to the research, each truck operator costs about 152,000 Australian dollars and automation allowed control of eight trucks by only one operator in monitoring room away from operation area. One prominent finding in the research was that automation provided design of pit more economically since GPS systems on trucks with cm accuracy allowed closer operation of trucks and saving millions of dollars due to less pit operation. A sample automated truck can be viewed in Figure 2.5.

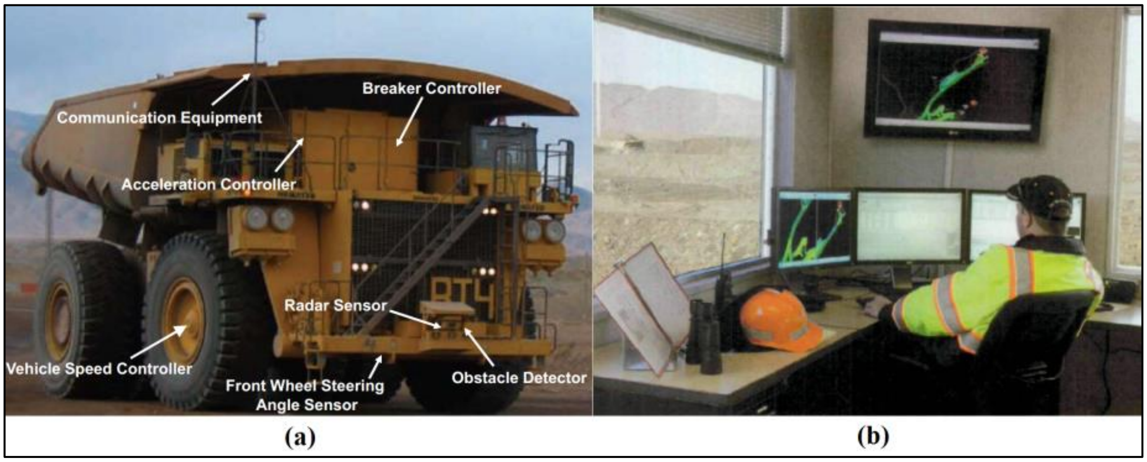

Figure2.5Automated Haulage Truck and Controlling Room (Brown, 2012)

Automation is also applicable in mine drilling operations to satisfy repetitive performance of drilling machineries more consistently. In this basis, Fiscor (2010) introduced a new technology for blasthole drilling system called as Ardvarc which provide a management tool using data for production, machine health, and GPS position of machinery. This system was employed in various metal mines in Chile, Arizona, and Indonesia and 20-30 % productivity increase were achieved owing to operation ability close to toe or edges without any safety risk. The machine held full-autonomous interaction and semi-autonomous mode. Full-automation allowed utilization of drilling machine without any machine-human interaction in ordering or drilling of blastholes while semi-automation gave control of machinery to operator when positioning the machine. In addition to blasthole drilling, Karliński *et al.* (2008) introduced a new generation drilling machine utilized to drill shot or anchor holes on tunnel or underground mine faces. Monitoring and control system in the machine allowed operator to take real-time parameter values of operation area such as space intervals of drill holes, hardness of rock and three dimensional profile of drilling face. This computational system aimed to ensure optimality of blast profile with the lowest cost as well as healthy of drilling tools and machine itself. Figure 2.6 illustrates a sample autonomous blast hole drilling and face drilling machines, respectively.

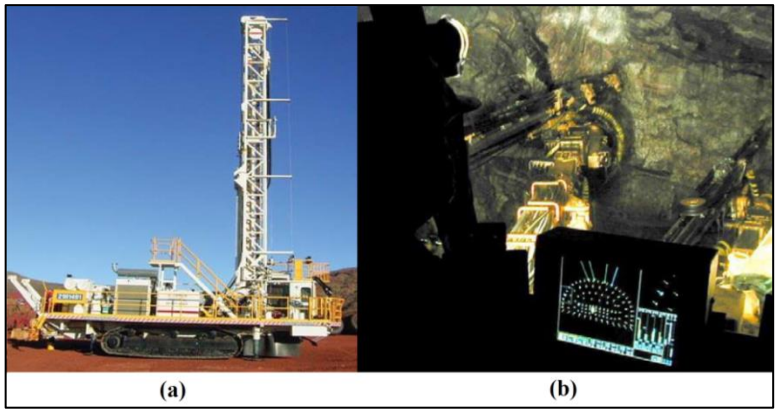

Figure2.6 Autonomous Drilling Machines for Surface (a) and Underground (b) Activities (Calderone, 2013 ; Karliński *et al.*, 2008)

Dragline automation is another advancing issue in development of mining machineries. Draglines are single operating earthmovers with boom length over 100 meters and weight up to 5000 tons; and any automation which improves the productivity of dragline up to 4 % can lead to an economic saving with 3 million dollar annually (Winstanley *et al.*, 1997). In this sense, Winstanley*et al*. (1997) made research on the automation of dragline swing movement since time period for each swing constituted the largest portion of cycle, 80 % of total time per cycle. The automation was basically achieved using interconnection between infra-red camera mounted under the sheave at boom tip, control computer, and operator interface. It was stated that usage of infra-red camera eliminated the restrictions of machine vision due to undesired light conditions. In addition, communication between camera and control computer was provided using radio local network and overall automation system allowed interchangeable management of dragline with either manual or automatic control, minimal disruption of related electrical systems, and nonexistence of any system safety failure. Another dragline automation study was carried out by Ridley and Corke (2001) on automation of drag axis of the machinery. It was built a prototype on 1:20 scale dragline bucket to comprehend the open-loop dynamics of the body and relationships between carry angle and dragging motor input voltage, in order to automate the control of dragline bucket carry angle with corresponding drag axis. The study was based on the control of drag axis by evaluating carry angle of the model bucket with the help of signal frequencies variously induced in payloads of drag rope. Experimental apparatus for dragline automation can be viewed in Figure 2.7.

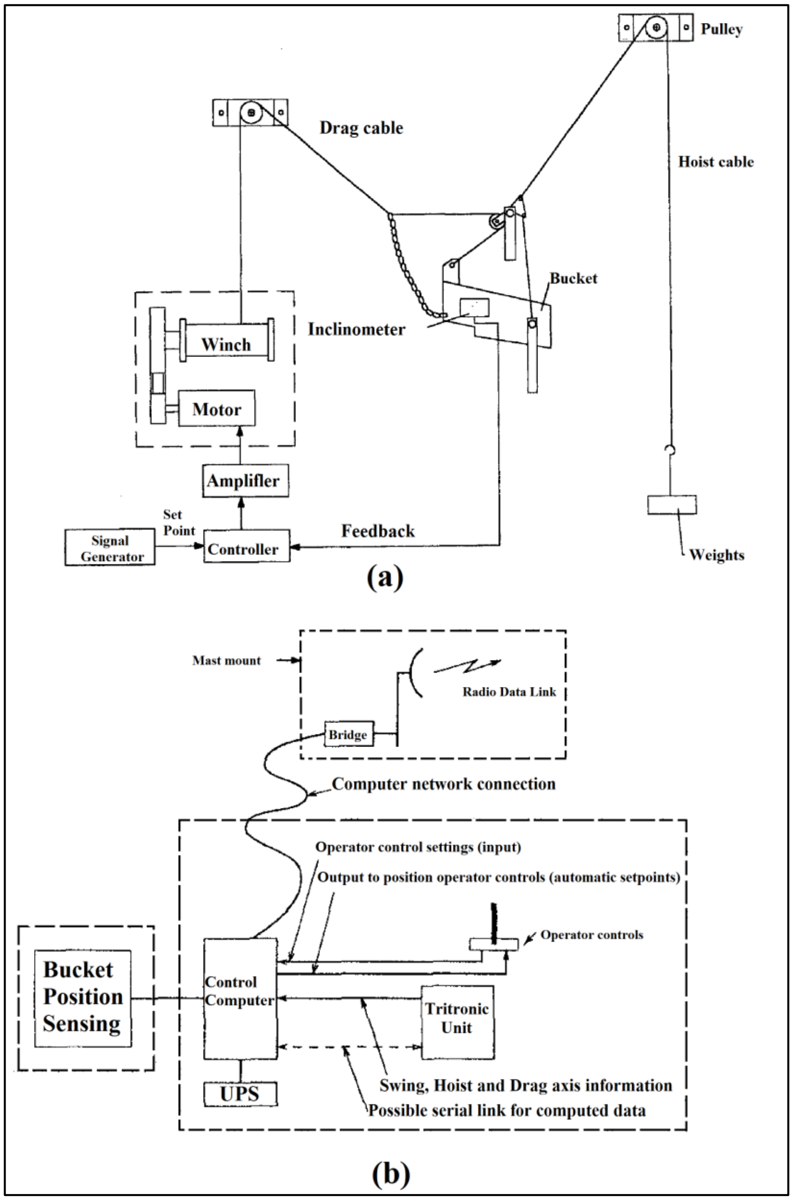

Figure2.7 Swing Automation (a) by Wintanley *et al.* (1997) and Drag Axis Automation (b) by Corke (2001)

2.5 Small-Scale Machines in Automation and Education

Automation is a challenging issue in mining sector. Leading companies of this sector allocate fund in million dollars to improve productivity and safety of operations via automation. Rio Tinto Group alone spends 518 million $ on researches for unmanned trucks and plans to automate 40 percent of overall truck fleet by the end of 2016 (Kara, 2013). It is clear that development and improvement of automation in giant mining machineries is highly expensive. It is critical to test a new automation technology in small-scale model as in shovel automation research of Dunbabin and Corke (2006) instead of original ones. A small-scale prototype allows testing of all control and operational factors together more economically. In this sense, automation of road header in small-scale is important for full automation of road header in the future.

Building of small-scale models is also important for educational purposes. Mining is a machine intensive sector where various equipments are utilized for different operations depending on mine production method. For instance, large capacity haulage trucks, shovels, and draglines can be employed in a surface mine where face drilling machines, LHDs, and longwall mechanisms are systems utilized in underground mine production. Understanding functionality and working philosophy of these machineries are important to comprehend operations in a mine production cycle. In an engineering education, effectuality of teaching needs a combination of both theoretical information and practical activities (Rosa, 2003). In this sense, development of a small-scale automated road header can be utilized as an auxiliary tool to introduce working principles of machinery in mining engineering education. A model road header holding various subsystems for mechanical, pneumatic, electrical, and controlling purposes will allow interested people to comprehend the harmony between these systems and fully understand of how road header perform rock penetration and material haulage activities in an operation area.

CHAPTER 3

REMOTELY -CONTROLLED ROAD HEADER ROBOT DEVELOPMENT

3.1 Introduction

As a result of rapid rise in mining sector and demand for raw materials today, there has been an increasing demand on different types of products, Therefore, in manufacturing systems there have been extraordinary developments. Accordingly as a consequence of this expanding of the automation-based manufacturing system that was occurred in the middle of the last century, optimization age was passed through and the mechanization especially automation allows increasing productivity by decreasing investment costs, increasing quality level with production rate and providing more humanitarian working conditions has begun. Moreover, in this context mining automation has begun growing quickly just recently, but unfortunately it takes just 2% of industrial automation applications

A machine, a robot of which was developed in this study, was selected to be KSP-32 road header before beginning to design stage after doing a comprehensive research on various machines (Figure 3.1). The selected model has to be challenging to achieve the best results. Moreover, the performance of the selected model in the field of human safety and performance has the greatest impact on the efficiency of mine in total (Healey*et al.*, 1995). On the area of the efficiency the excavating machines as the main production machinery which is utilized in mines has the biggest impact of this area. Until now, the excavating machinery in the mines is selected and the other issue has to be considered is human safety which is the first priority in underground mines. Because of these two considerations human safety and efficiency the selected machine has to be excavating machine used in underground mine. As a result, the model which is selected is underground excavation machineries. The machine which is suitable to these demands is a road header.

The design phase of a product is perhaps the most challenging part of the entire process (Golonski, 2000). Once, the idea was finalized the designing process could be started. Furthermore, good designers are willing to be flexible when making tough decisions and willing to make trade-offs and omissions to make the design practical and possible. In addition, along developing a robot design follow an engineering design process is crucial.

Figure 3.1KSP-32 Model in Solid Works Design Program

The first step is to start sketching to get the ideas on paper. For this reason, it is important to have accurate and complete sketches in order to translate the idea into hand or designing soft wares like sketch up or CAD drawings and models. This phase also allows for virtual prototyping or testing of the product in the computer. In other words, potential and sometimes costly flaws in a design could be founded before the real world mock-up is constructed. Therefore, mock-ups are representations of the product to test and evaluate. This process is still valuable even though computers can accomplish the same results. It means the only thing these models cannot accomplish is provide a real product to evaluate. After the mock-up is evaluated, the project continues to the prototyping stage.

3.2 Road Header KSP-32 Specification

The KSP-32 road header is a completely up-to-date medium duty machine for cutting hard strata to reduce a share of blasting and drilling operations. The machine is designed to mechanize breaking and loading of the mined rock while driving mine workings in mixed faces with single-axis compressive strength of up to 100 MPa and abrasives not more than 15 mg with an inclined gradients ±12° and cutting profile from 10 m^2 in the finished section and up to 29 m^2 in the rock section in mines having hazardous gas (methane) and coal dust. A powerful boom assembly with high arcing and lifting forces enables the machine to cut harder strata. Features of the machine listed as below:

- Robust cutting boom powered by a 110 kW air cooled electric motor,
- Heavy duty cutting head with efficient pick face flushing facility,
- Telescopic action to allow cutting head to be sumped in with the machine stationary and therefore independent of floor conditions,
- Center scraper chain conveyer built for abrasive applications with an enlarged throat,
- Large crawler tracks which are independently operated to give maximum machine maneuverability for working on steep gradients and poor floor conditions,
- Real floor spragjack to increase machine stability in adverse cutting conditions,
- Loading apron performs as a front support, and
- Scraper conveyor and stage loader enable to use the machine with various type of excavated material handling.

3.3 Real Machine Inspection

As long as researches and sketches continued in that stage the most commonly utilized rotary-headed tunnel boring equipment called road header KSP-32 was chosen (Figure 3.2). In that part of the process, the real dimensions of the machine was needed to get the idea of designing and manufacturing the mini robot of the real machine. For that reason, the real dimensions was gotten from the internet and set the appointment to see the real machine. For this matter after 12 days of trying and getting so many agreements, field study was conducted to see the equipment in the field, which was located 340 km away from capital of Iran in the heart of the alboorz damn. The machine was inspected in site and its damnations were taken to start to design the small wooden duplicate model of it.

Figure 3.2 Virtual View of KSP-32 Road Header Modelled in the Study

3.4 Accurate Blue Prints Redesigning Process

In this section the mini pneumatic robot designing process explained. In other words, after wooden model manufacturing project completed the mini robot model manufacturing could be started (Chapanis, 1988), Thus, in this part the process of blue print redesign will be defined. In addition, the major components of the model of the mining machinery which were the main chasse, front plate, rotation gear, and boom will be discussed.

In the process of designing any objects, the real scaled blue prints played very vital role. For this reason, redesigning the blue prints based on the old designing and not clear blue prints were done and the results were 12 sheets of the fine scaled blue prints. In this section, designing the all separate parts in the sketch up designing program based on the new blue prints was defined by all details (Figure 3.3).

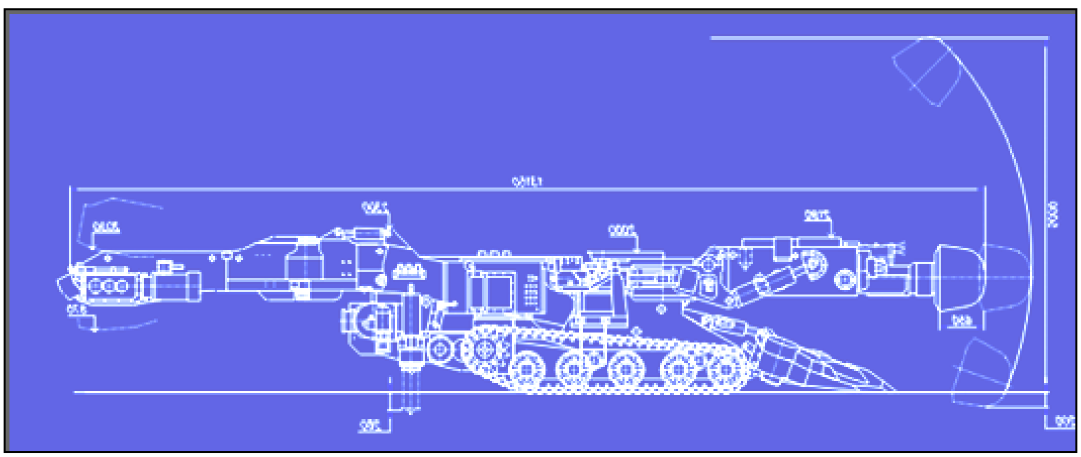

Figure 3.3 KSP-32 Blue Prints

3.5 Design Stages of the Mini Robot

The first step of information gathering is to have the clear idea to what should be gathered and the idea for what is the practical function of the design (Teniswood *et al.*, 1993). Moreover, the main function of the mini robot which should be considered is to have the all basic movements of the main machine because after the designing of the mini robot, it should be compared with the real machine. Therefore, all the advantages and disadvantages of these types of robot will be important factors for comparison. Besides, to achieve this goal all practical functions of the robot, it should be classified and defined clearly. In this part the practical functions of this robot will be explained as below:

i. **On the Ground Movement System Design:** The main subject in this section is understanding of how the robot moves within its environment and how it deals with rough and different environment. As result, for this section the crawler system would be the best selection which is used in real machines because of the functionality and performance. Hence, these features help to overcome the hardship of climate and geography encountered in mining hard working conditions. The crawler system provides full component for the undercarriage of mining size excavators and including crawler shoes, sprockets, idlers, load rollers, and return rollers. For this model special motorcycle chain is used with two rows of chain with attached shoe part as a crawler shoes rings and load, which is specially designed and ordered to the manufacturer.

ii. **Movement System Design:** Pneumatic system is preferred for the total movement system rather than hydraulic system which was consists of mini portable flat tires compressor with the pressure supply of 18 bar air compressing power because of the limitations about weight and power supply systems including miniature cylinder, compressor, compressor tank, solenoid valves, tubes, and controller brain.

iii. **Energy System Design:** The energy system design is the most challenging part of the project because of the pinch of the space and the special design of the robot which is just allowed to use the empty boxes two sides of the crawler system. It is powered with two batteries located in these spaces.

iv. **Remote Controller System:** The remote control system is designed and developed as a 16 channel sender and receiver and to modify it the new remote control system is replaced with old one to improve the performance and to synchronize with the area of the operation.

v. **Remote Sensing System:** The remote sensing part is designed and planned to equip the robot to artificial intelligence which was the next part of the project. In that section the robot will be equipped with computer brain which could be programmed to do all functions automatically.

vi. **Materials Selection which is Suitable for the Design:** The properties of a material determine its suitability for a design. For this designing work, the iron plates and special plexiglas plates were chosen to work with. However, there are many different types of materials that can be used in the construction of robots like steel, titanium and special hard polymers. For material selection these factors should be considered strength, hardness, toughness, density, durability, and the aesthetic qualities determined by color, surface texture, and pattern. The materials cost and availability is also important factors which are crucial to be considered along the design and manufacturing the project.

3.6 Computer Added Drawings

In this part the process of researching and designing of the robot will be discussed. Moreover, after model selection to progress in design process gathering information started which help us to produce a successful design. However, if an initial design and prototype does not fully solve the problem or specifications, identify the design parameter or remained at an acceptable cost, a designer may return to the design and redesign it. The engineering design process has a complicated process which is contained multiple loops to go back to the design and refine or redesign. As an initial step of the design process, it is needed to decide which information is required. This will be different from project to another and it will also depend on the amount of information and knowledge is available already. Accordingly, the successive steps will be stated as:

i. Data collection,
ii. Identifying particular details of the design which must be content,
iii. Identifying possible and alternative design solutions, and
iv. Designing and planning an appropriate structural design include drawings.

In this part four items were considered which have to be cleared to specify the roadmap of robot designing is explained.

3.6.1 Main Chassis Design

The general idea for design all objects is to start from the main body which is the biggest and massive part of the robot because of the scaling of the attached body parts measurements to align with it. In this case, the biggest part was main chasse of the machine. This part was the fundamental part of the robot’s body. Therefore, this part was designed with the thicker profiles to support the other parts. For designing this part 2 cm x 1 cm profiles were used which have rectangular section and because of the difference, width and length in the longitudinal direction have a high bending strength.

As a result, the main body designed as a hollow frame with 2 cm x 1 cm profiles and which was welded completely to get the strong body frame. Moreover, the whole body covered with the 1mm thickness steel plates which were shaped and cut based on the design templates (Figure 3.4).

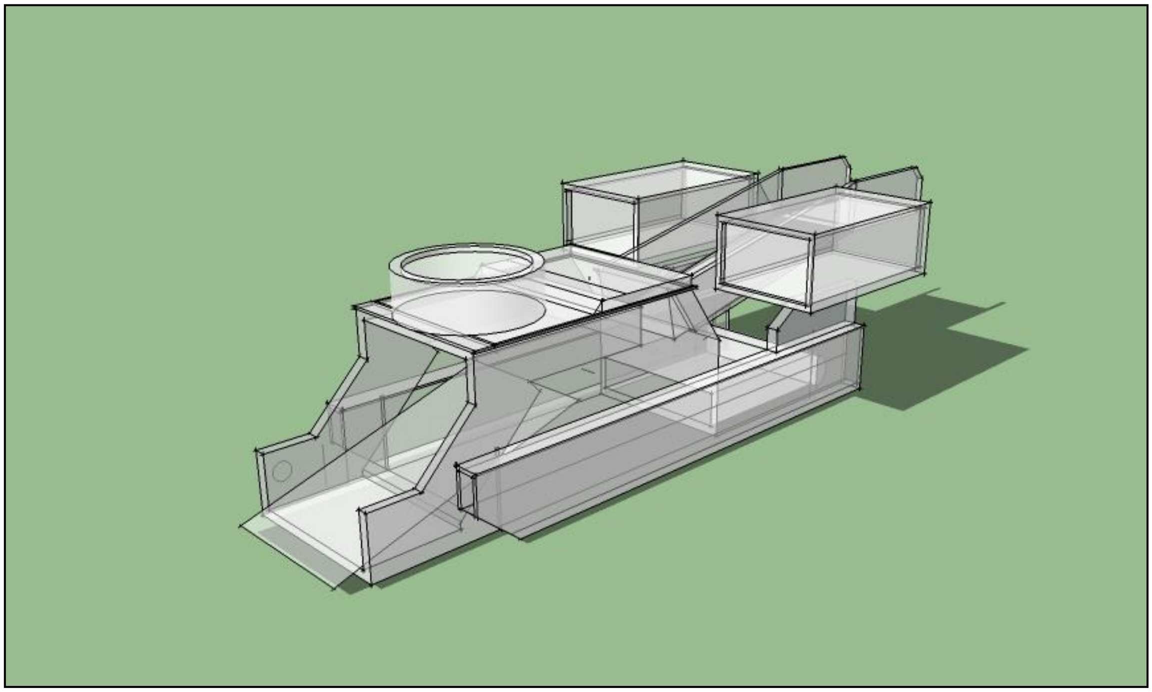

Figure 3.4 KSP-32 Chassis

3.6.2 Crawler System Design

The crawler system or continuous track system is a system of vehicle propulsion in which a continuous band of treads is driven by two or more wheels. This band is typically made of modular steel plates with steel wires for the purpose of the lighter transportation systems (Figure 3.5). For designing this part inspired from the tank crawler system which is commonly used in this type of vehicles. The purpose of the utilization of this technology for these kinds of heavy industrial equipments is to expand the area of the applied forces from the machine. This crawler system was chosen to move and carry the whole machine.

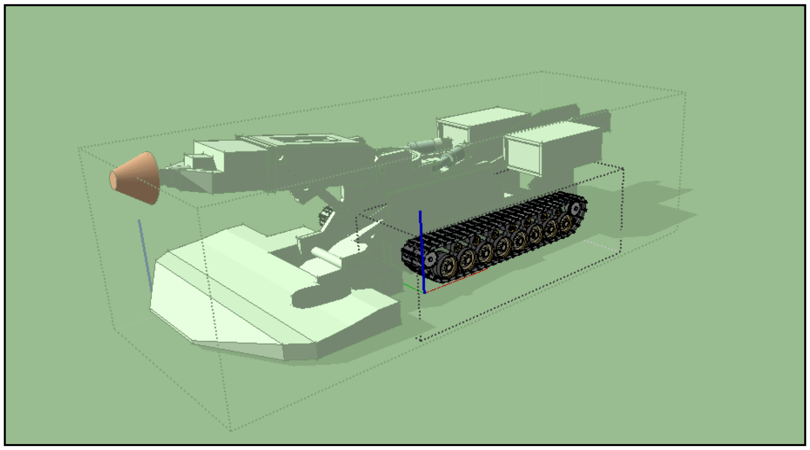

Figure 3.5 KSP-32 Crawlers

3.6.3 Front Plate Design

Front plate was a free part equipped with two crap arms to collect the excavated rocks and feed them to the main conveyer located in the heart of the body (Figure 3.6). This plate is made from the separate parts which are: body of the plate, axels to attach the plate to the body, rotating plate established the rotation of the crap arms, crap arms which are collect the excavated rocks and fed them into the conveyer located in the middle of the main body, and rotating motor which is coupled with the rotating plates.

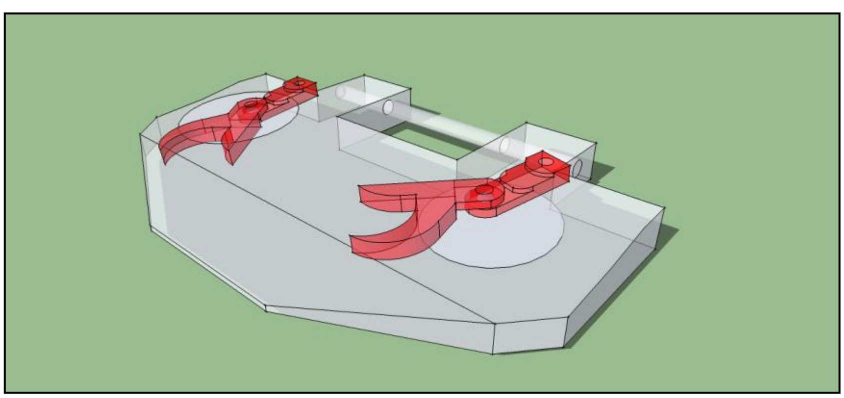

Figure 3.6 KSP-32 Front Plate

3.6.4 Boom System Design

The extending boom consist of two sliding internal parts: body of the boom and the extension part which was equipped to the rotating head, engine which is mounted on the extension part to achieve the high degree of freedom for extend and its shaft. Although the external part equipped to the railing system to move forward and backward (Figure 3.7).

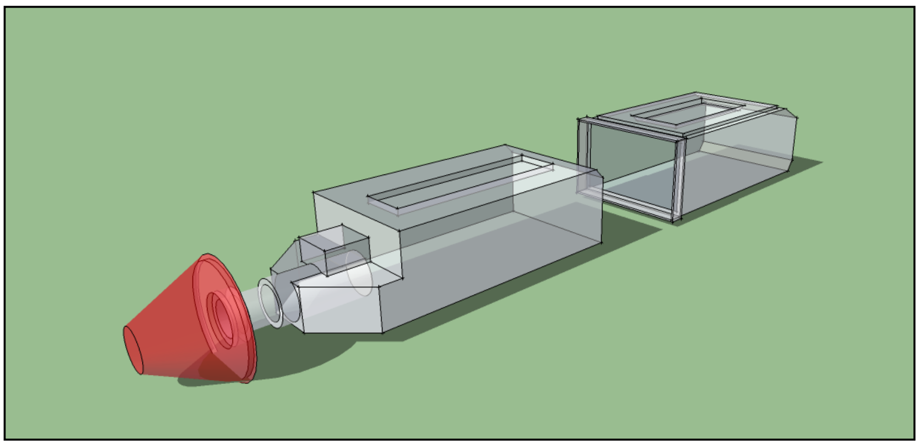

Figure 3.7 KSP-32 Boom

3.6.5 Rotation System Design

Rotating system was the main part of the moving system which was the complex part because of the limitation of motions could be caused by the dimension of the other attached parts. As a result, to solve this problem the cardboard duplicated model of this part with the real dimensions was made and the whole motion limitations were resolved. After getting the almost range of the dimensions by using the utility of the sketch up program to rotate the designed parts and resolve all limitations by moving the rotating parts on the roll axis to get the free ±45 degree of freedom for right-left motion and +45, -25 degree of freedom for up-down motion of the boom (Figure 3.8).

Besides, these motions powered by two pneumatic jacks work parallel for up-down motion and two pneumatic jacks work vice versa from each other for right-left on the two sides of the main rotating gear.

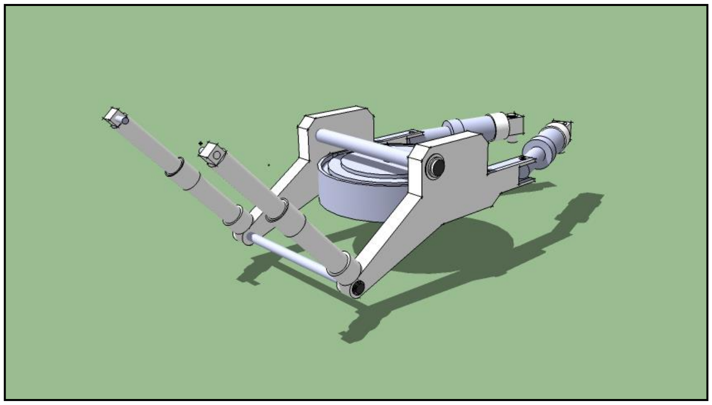

Figure 3.8 KSP-32 Rotation

3.6.6 Final Design

The last stage of the 3D modeling and designing of the prototype is to assemble all of the designed parts as shown in Figure 3.9 which presents the final design for the KSP-32 excavation mining machinary in sketch up designing program.

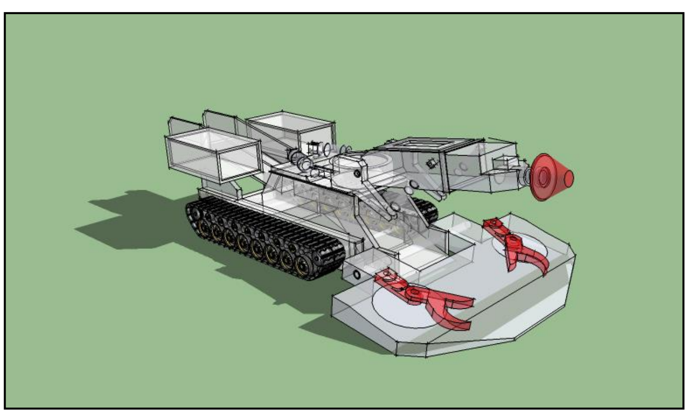

Figure 3.9 KSP-32 Robot Final Design

3.7 3D Solid Computer Modeling

In this section the designing session is finalized and the overall shape of the machine reveals. In this section to work on the detailes to complete and modify the designing parts, the project is exported to the Solid Works designing program which is the most appropriate software to design. Solid Works is a 3D mechanical CAD (computer-aided design) program that runs on Microsoft Windows and is being developed by Dassault Systems Solid Works Corp., which is currently used by over 2 million engineers to design and validate their objects. This program is used for designing all objects mostly for moving objects especially for mechanical motion involved objects. The final solid word output could be used in CNC machines and production lines. Figure 3.10 visualizes different views of solid modeling of the road header.

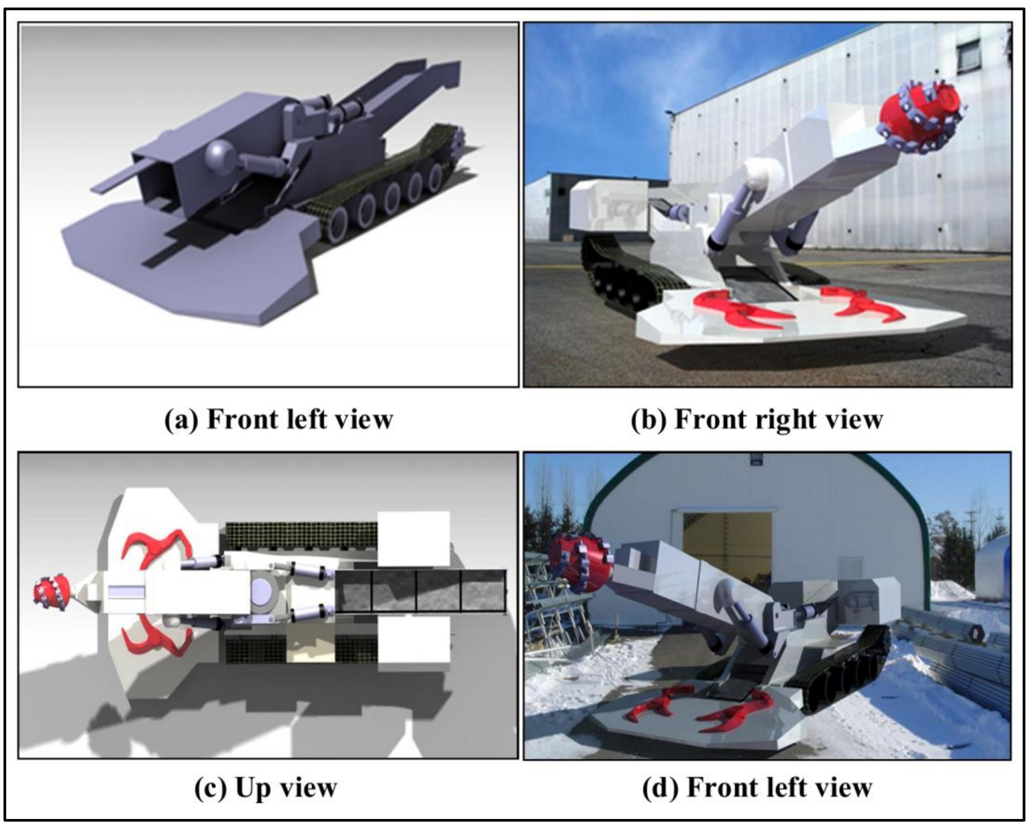

Figure 3.10 KSP-32 Robot Final Solid Works Designs

3.8 Physical Prototyping

In this chapter the process of manufacturing the 1/10 scaled physical prototype will be described. The process of manufacturing consists of building all parts one by one upon the design script and manufacturing process which is described as below.

3.8.1 Robot's Chases Manufacturing

For manufacturing the chassis part 2 cm x 1 cm profiles used. Moreover, in this part steel profiles according to the blue prints which are designed and modify in the designing part cut, bended, and welded to each other to create a hallow chasse. Since, manufacturing of the frame accomplished the 2 mm sheets of steel mounted and welded on the frame to create the final body. Furthermore, empty side boxes manufactured from the steel sheets bended based on the scheme and to create a vast space to placement of the electronic control units. Figure 3.11 shows the chassis of the robot.

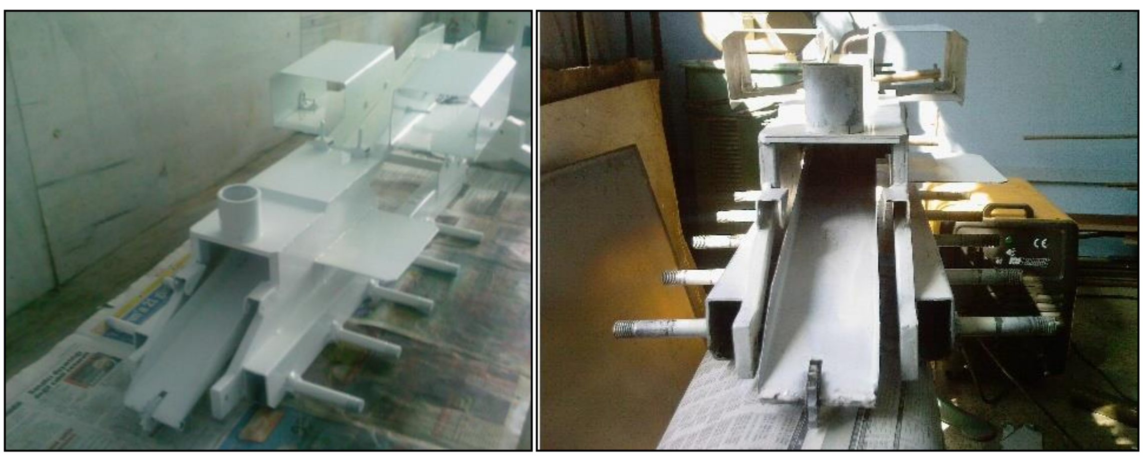

Figure 3.11 KSP-32 Robot's Chassis

3.8.2 Robot’s Crawler System Manufacturing

The crawler system consists of two lines of motor cycle chains especially developed with double shoe plates according to design’s pattern (Figure 3.12). Because of the width of the crawler two lines of custom made chain riveted to each other parallel and manufactured double width chain.

Figure 3.12 KSP-32 Robot’s Crawler Chains

3.8.3 Robot’s Front Plat Manufacturing

To rotate the crap arms of the robot two high density poly ethylene disks were manufactured and turned (Figure 3.13) to supply the arms rotations. These disks equipped with two bearing mounted in the middle of the disks and attached to the axels which are welded vertically to the covering underneath base plate.

Figure 3.13 KSP-32 Robot's Front Plate

3.8.4 Robot's Boom Manufacturing

According to the design sketches 2 mm steel sheets used to develop this part. Thus, after take down templates on the sheets, cut and bended to designed pattern (Figure 3.14). In this part the external platform manufactured to cover the internal part and also manufactured the empty boxes to mount the rail system.

Figure 3.14 KSP-32 Robot's Boom

3.8.5 Robot's Rotating System Manufacturing

To manufacturing this part, truck boll bring used and designed skeleton which would carry the boom welded on the two side of it (Figure 3.15). Besides, reinforcement for this part was performed by heavy welding process, accordingly makes it heavier and stronger.

Figure 3.15 KSP-32 Robot's Rotating System

3.8.6 KSP-32 Unfeasible Final Robot

In this section of the project, after assembling all the mechanical parts the whole machine was ready to perform as a integrated robot. Therefore, the process of the final alignments and fixation progressed to check all the functions and motions of the robot. For example, the length of the chain needs some fixation to work properly because of the length which was the main factor and besides, the height of the rotation gear was not calculated accurately it cause the crawlers chain get out of the axial and defect all the crawling operation. Therefore, redesign this part was the axial of main rotating gear located on the surface plate of the other rolling axial of the crawler system. Besides, the middle conveyer for carrying out the excavated rocks needs another axial with the rotating gear under the conveyer to prevent the whole belt to suspend which was resolved with the explained redesigning. Figure 3.16 illustrates colorless form of the manufactured road header.

Figure 3.16 KSP-32 Final Colorless Robot

3.9 Control System

It is ready to mount the electrical units which is consist of 18 channel sender and receiver mounted on the two empty boxes two sides of the machine. To relay the transmission of the signals from the sender to receiver, the telescopic antenna used which is located in the middle of the right boxes roof. In addition, the pneumatic system inclusive of the miniature jacks and solenoid valves mounted on the skeleton of the robot which is the source of the motions. It consists of 11 miniature pneumatic jacks, connected to solenoid valves, and air compressor, and also compressor tank. Compressor supply the compressed air up to 18 bars which is needed at least 8 bars compressed air to setup the movements. To supply the electrical power needed from the system, which is 12 volt, 800 mA for the electrical control boards and 12 volts, 40 ampere two different source of power supply were used. Two sets of nine volt batteries for control units mail board power and one set of car batteries with 12 volts, 50 ampere current for two sets of car wiper motors were equipped to gear box system which belongs to Chevrolet caprice classic.

These gear box shafts welded to rotating gear of the crawler system main axial to mobilize the robot forward and backward. To supply the needed thrust for rotating the cutting head a mini electromotor with gear box to convert 3000 rpm to 30 rpm is used. Also a similar electromotor was used for crap arms movements. This electromotor located on the right corner of the front plate upside down to rotate the crap arms joints mounted on the Plexiglas disks. Also another electromotor with gear box system is used to mobilize the conveyer system which is located in the heart of the robot. This motor also powered by 12 volt, 50 ampere battery which is connected parallel to other electrical systems.

3.10 Assemble the KSP-32 Final Robot

As a result, the final appearance of the robot is revealed as can be seen in Figure 3.17. In this section of the project, painting process was accomplished. For painting, the whole robot disassembled to the basic parts and painted with the air compressed sprayer and repainted by the disposable spray for elimination of defects. After the painting process passed by the machine , it is ready to mount the electrical units which consists of 18 channel sender and receiver mounted on the two empty boxes two sides of the machine.

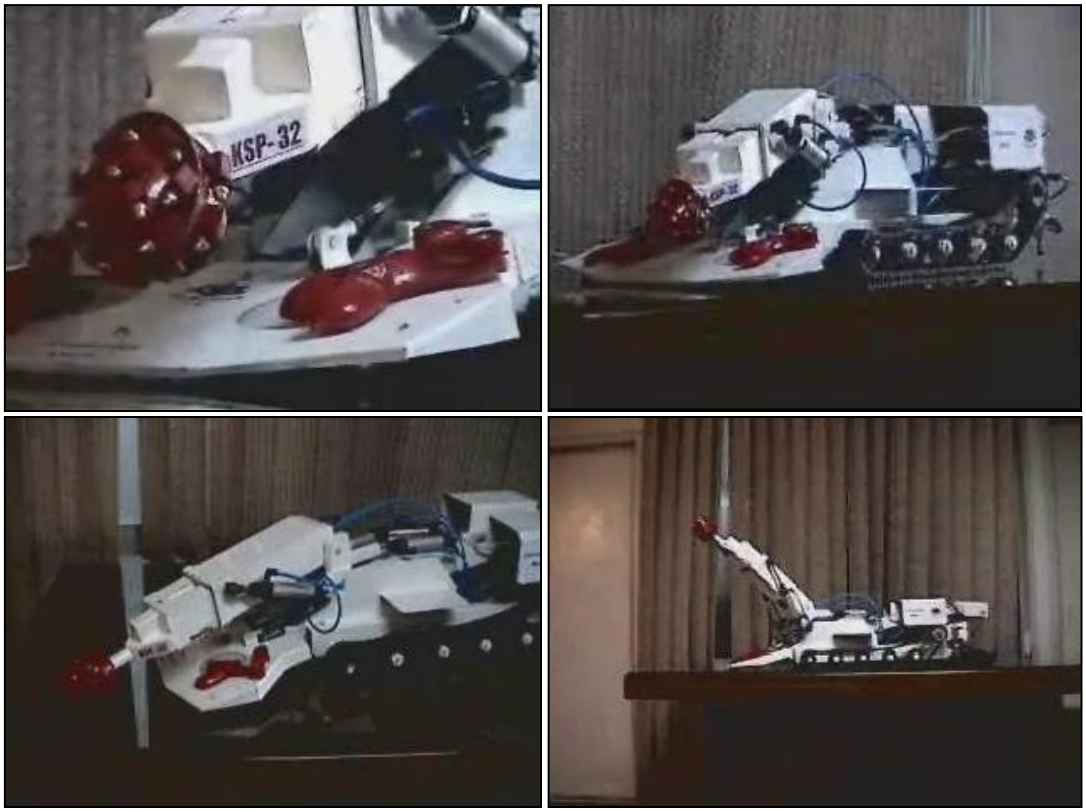

Figure 3.17 KSP-32 Final Robots

3.11 Summary

In this chapter the process of robot designing by the special point of view on the KSP-32 road header tunnel excavation machinery was explained and the engineering process which should be followed from author's point of view was stated. As a result, author tracked the process and manufactured the mini robot of the road header which is the small type of the real size machine. This model does all of the functions of the real machine in small size like all the movements which is powered by pneumatic system by the 9 pneumatic miniature jacks. Also, it is controlled by 18 channel remote control system which is commanded by two joysticks. This model is in scale of 1/10 of the real machine which has 131 cm length and 45 kg weight (Figure 3.18). Its body is colored pearl white and drill head is colored red. Its pneumatic compressor has the power of 2

HP and its control solenoid valves worked by 7 up to 9 bar pressure which is supplied by the compressor.

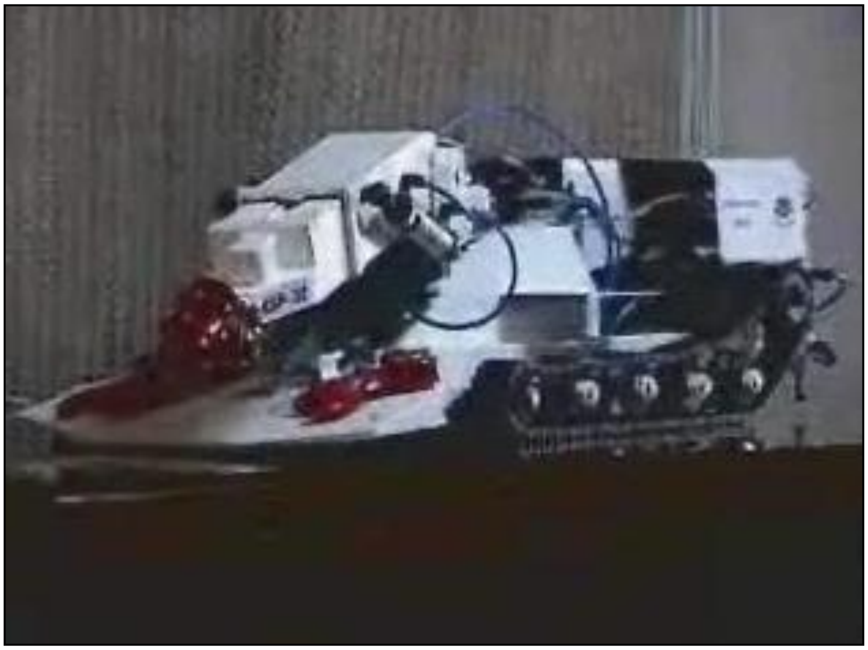

Figure 3.18 KSP-32 Mini Robot

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The main conclusions derived from this study are:

1. The conventional methods which are utilized in mining procedure for improvement of the efficiency and safety factors in mines are mechanization and in the next level automation. Mechanization in the first steps improves these factors but for achievement of the higher level of productivity and secure the human life's automation as a next level of improvement utilized in mines. In this study, it was focused on the human errors and the advantages of the automation to prevent those problems which are done by operators.

2. Wide range of issues influences the mine efficiency. Efficiency of mine depends on the productivity and safety. Although, the safety factor is crucial, the focus of this thesis is on the topic of productivity. However, the safety factor will be increased by utilization to the automated machines. Productivity in crescent would depend on the reduction of human errors which are divided to six parameters: Failing to perform or omitting a task, performing the task incorrectly, performing an extra or non-required task, performing tasks out of sequence, and failing to perform the task within the time limit associated with it and Failing to respond adequately to a contingency. In this study, human errors and disadvantages of it discussed and advantages of replacement of operators by automation systems were emphasized.

3. The mining robots are the mining machineries equipped with the remotely-controlled systems which controlled by the human or computers. The result of this study is obtaining the knowledge about the source of human errors and factors have negative effects on the efficiency and reduce the productivity and emphasize the advantages of automation in mining. Besides, explained manufacturing process of the mini robot of the KSP-32 rotary excavation road header to study the process of the mining robot designing, manufacturing and modifying and this process stated this fact that the mini scale robots designing and manufacturing could be progressed by focusing on the productivity aspects.

4. Redesigning and manufacturing the mini robot of the mining excavation machinery which works underground as a high risk and hazardous places expresses this fact that, by utilizing the mines with this technology and remotely controlled all the mining applications affected safety and productivity of mines in the positive direction which is the future mining perspective.

4.2 Recommendations

The main recommendations for this study are:

1. In this study, advantages of the automation applications in mining processes, utilizing mining robots and mini mine excavation robot's manufacturing processes were explained. Because of the lack of the reliable information and mine site's report for efficiency of the application of this kind of technologies, usage of a real data from the application of these kind of robots in the mine sites and analyze the results is vital task.

2. Sketch Up program were utilized for designing this robot. However, this designing program has limitations and restriction in accuracy of joint designing and overall complex objects. Thus, application of the more advanced design programs like RHINO 4 which is utilized for high tech CNC machineries is recommended.

3. For attainment of better results, availability of a large range of data is crucial.

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