An implementation of resource negotiating agents and telemanufacturing

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Abstract: The paper reports on the original concept of introducing resource negotiating agents into telemanufacturing. Human users submit a design-file that they want manufactured. The machine that will be selected to manufacture the design-file has to fall within the user's constraints. An agent visits several processing facilities called distributed manufacturing resources (DMRs) and negotiates with an agent at each location for the most suitable machine. The agents use a plan to find resources and negotiation skills to acquire the most suitable manufacturing resource. The entire process is done in a secure environment as the design-files could contain valuable information such as early prototypes of products. Experience gained from the negotiations should be stored to allow future agents to benefit from previous negotiations. The components that are needed to implement the above and the results of the implementation are discussed in this paper.

Keywords: Telemanufacturing; resource negotiating agents; secure resource negotiations; layered manufacturing; rapid prototyping, mobile agents.

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1 INTRODUCTION

The purpose of this paper is to report on an implementation where secure resource negotiating agents are introduced into telemanufacturing. Telemanufacturing provides an internet based infrastructure, which gives the general public access to layered-manufacturing/rapid-prototyping machinery. (Bailey, M.J., 1995) Through telemanufacturing end users are provided a service that allows them to send a design-file, with a required objects design, directly to a layered-manufacturing/rapid-prototyping machine. The targeted machine will then produce the object in the design-file. Through telemanufacturing end users can customise and "just in time" produce objects from design-files. The object that is represented in the design-file can be generated by the user, using a CAD application, or purchased from a design repository as was discussed in a previous paper by the authors. (Marais, E., 2004)

Telemanufacturing presents an opportunity for an end to end manufacturing chain that can be remotely administered over the Internet. (Tan S., 1998) The users of telemanufacturing specify the design, initiate the manufacturing process, monitor the process, and take delivery of the final product. A typical on-line manufacturing system of the type presented by telemanufacturing involves a number of manual processes that require extensive human interaction. (Jiang, P., 2002) Since telemanufacturing has many e-commerce based aspects many opportunities for automation arise (Marais, E., 2000).

By introducing the agent paradigm into telemanufacturing an attempt is made to stream line and automate some of the e-commerce processes involved. Agents are capable of performing intelligently, within certain bounds, some e-commerce tasks required within telemanufacturing. (Glushko, j., 1999) Most notably are negotiating agents, which attempt to minimise the price paid by the buyer and visa versa. (Maes, P., 1999; Rahwan, I., 2001) Concerns in e-markets such as keeping all negotiations in a secure environment also need to be addressed. In a competitive environment, such as telemanufacturing, market forces will determine the final price paid for the service. The novel contribution of the work presented here is the introduction of negotiating agents into telemanufacturing. Negotiating agents take the place of humans in this competitive environment and are thus required to contend with market forces in achieving their goals.

The remainder of the paper is organised as follows. Firstly, the paper starts with a look at related work to the work presented here. Secondly, the properties an intelligent agent should exhibit for telemanufacturing will be discussed. Thereafter all the components required for the intelligent agent will be discussed. The components are comprised of the types of agents needed that will function in the environment or on the platform and also what architecture is used. Thereafter a prototype is developed to demonstrate the viability of having resource negotiating agents in telemanufacturing. The paper describes how resource negotiating agents have successfully been integrated into a test bed telemanufacturing environment. The paper concludes with a discussion of the approach taken, how it can be improved, and related work.

2. BACKGROUND

Telemanufacturing is an activity where by the operations and processes required for real time design and production of items are done using the Internet for communication. (Abdel-Malek, L.L., 1998; Abdel-Malek, L.L., 1999) In telemanufacturing specific focus is placed on the use of rapid-prototyping and layered-manufacturing machinery for the purpose of object production. (Marais, E., 2004) With an increased move towards e-commerce much effort, in the form of research and practice, in the telemanufacturing community has gone into improving and automating the process. (Lan, H., 2003)

Lan H. et al. (2003) proposed a mechanism where by the service issues between customers and manufacturers are dealt with using teleservices. Their work outlines an architecture for such a teleservice implemented in telemanufacturing. Their architecture includes support for facilitating registration, quote and production life cycle monitoring, negotiations via video conferencing, and establishment of a contractual agreements. (Lan H. 2005) The above approach tries to automate the manufacturing chain in telemanufacturing. However human interaction is still required in many respects including negotiation. In order to overcome the dependence on humans the need for agents arise.

Different approaches and motivations have been presented for introducing agents into telemanufacturing. (Marais, E., 2000; Ni, I., 2003; Verma, M., 2000; Tan, S., 1998) Tan S. et al. (1998) presents a framework, called TRADEWIND, that introduces design and manufacturing agents into telemanufacturing. The e-commerce environment presented by TRADEWIND allows for presence and accreditation of participants, presents a bidding protocol, and facilitates transaction closure. Jiang P. et al. (2002) present an entirely web based e-service manufacturing platform. In the work done by Jiang P. et al. (2002) agents go so far as to move requests, constraints, and prices back and forth between humans. The agents consolidate prices from a number of manufacturers and present these to a human to make decisions. Although agents have been introduced into telemanufacturing previously as in (Ni, I., 2003; Verma, M., 2000; Tan, S., 1998) the approach taken here is novel in the fact that resource negotiating agents are introduced to perform e-commerce functions. Further the agents actually perform the negotiations and management of the entire process on behalf of humans to arrive at a fair value with little to no human intervention.

A Distributed Manufacturing Resource (DMR) is a layered manufacturing machine made available for accepting remote jobs through telemanufacturing as seen in Figure 1. Jobs are encapsulated by design-files submitted to the DMR to be manufactured (Marais, E., 2002).

A shortcoming of the current DMR model addressed in this article is the human intervention needed in the telemanufacturing process. This is where a human user interacts with a DMR. Before this can be done the design has to be processed by a processing server and then passed on to the DMR. With the model suggested in this paper automated negotiations are possible.

Another shortcoming is that a centralised processing server is employed. A centralised processing server has the disadvantage of a single point of failure. It is better to have this functionality distributed and better still that each DMR owner can suggest a processing server to be used. The processing server can be locally located close to the DMR that is going to be used. The advantage in doing this is that the processing server is trusted by the DMR. Trust is important as the processing server creates the file used for the actual movement of the DMR's machines manufacturing method. The situation could arise where a DMR produces a process file and the product comes out incorrect. The DMR could place the blame on the processing server that in turn could blame the DMR. This unnecessary complexity can be minimized by using the DMR's own processing capabilities or the selected DMR's recommended processing server. This simplifies the grievance process if a design was not manufactured correctly as it will be between the DMR and the user. Having a third party (processing server) complicates the whole matter.

In terms of security it is also beneficial if a processing server that is trusted by a DMR is used, as this will avoid a sensitive design being sent to many locations.

3. METHODOLOGY AND METHOD

The research methodology underpinning the research is a constructivist approach. An artefact was built to test the idea that agent based systems can be used to facilitate the e-commerce, negotiation, and market force aspects, so as to reduce human interaction in Telemanufacturing. The research method can be outlined as follows.

Firstly a model for an agent oriented approach to telemanufacturing was developed. The model was then converted into a working implementation. The implementation was deployed on the Internet to ensure that it would indeed be suited to Telemanufacturing. Further the implementation served as feasibility study for the model and also showed the e-commerce aspects of increased automation could indeed be addressed using an agent oriented approach.

The solution was qualitatively evaluated against various criteria including robustness to network failure, scalability, and interoperability. Further a qualitative assessment of the match between agent oriented approach and the e-commerce aspects of Telemanufacturing was done.

4. AN AGENT ORIENTED APPROACH TO TELEMANUFACTURING

The paper proposes two groups of agents be introduced into telemanufacturing. These are: Resource negotiating agents and auxiliary agents.

The resource negotiating agents are directly involved in the secure resource negotiation process. Auxiliary agents assist the resource negotiating agents in their e-commerce endeavours. Auxiliary agents are the agents that provide supporting services and information that facilitate the negotiation process of the resource negotiating agents. Any other agents that interact with humans or layered manufacturing machines on behalf of the resource negotiating agents are also classified as auxiliary agents.

The resource negotiating agents are composed of buying and selling agents that take part in the on-line e-commerce process (bidding, bargaining, etc.). Resource negotiating agents are classified as one of the following two types listed below:

- (Distributed Manufacturing Resource) DMR agents.
- (Resource Negotiating) RN agents.

The DMR agent represents the interest of the enterprise in the e-commerce process. The DMR agent represents a DMR and provides a single unified interface for the buyer agents to interact and negotiate with. The DMR agent needs to be robust by employing any number of negotiating strategies as to prevent the agent from being undermined.

The RN agent represents the human buyer that wishes to procure the rapid prototyping service through telemanufacturing.

As an example of a procurement transaction an interaction scenario between resource negotiating agents and auxiliary agents are given below. This scenario is also graphically depicted in Figure 2. The example shows how the agents would interact to arrive at the successful procurement of a rapid prototyping resource as proposed by the model presented in this paper:

- Step 1: A human user with the need to have a design manufactured by using a layered manufacturing machine decides to query a number of DMRs for the most competitive price or any other criteria. The human submits his design-file to the GUI agent using an upload tool and specifies in the criteria that he/she is looking for the lowest possible price and the delivery time is of secondary importance.
- Step 2: The GUI agent returns a summarized result of the three RN agents that met the users constrains. Thereafter the RN agents deploy themselves to the various telemanufacturing platforms using agent mobility.
- Step 3: Once the RN agent arrives at the platform it registers with the agent management system and

requests a list of DMR agents from the directory facilitator (DF).

- Step 4: Before the RN agent can continue it first verifies the DMR agents with the authentication agent to establish trustworthiness. This is done before it enters into negotiations.
- Step 5: The RN agents then initiate its negotiations with the authenticated DMR agents. The same process is then reversed where the DMR agents use the authentication agents to check the trustworthiness of the RN agent that requested to communicate with it. If both sides are satisfied negotiations can begin.
- Step 6: The RN agent passes the design on to the DMR agents, which in turn passes it on to a processing agent. If the processing agent deems the design to be plausible it will give a time estimate for the design to be manufactured. This allows the DMR agent to compile a quote for the RN agent as to the cost and time it will take to manufacture the design. Thereafter the RN agent consolidates all quotes and selects the quote that satisfies the initial user criteria that is in this example for the lowest cost. The lowest cost is sent to the GUI agent that then collects all other quotes from the other RN agents on other platforms.
- Step 7: The GUI agent then selects the cheapest offering or allows the human user to interact with the process.
- Step 8: The corresponding RN agent with the accepted quote is then notified and the negotiation is wrapped up. Wrapping up a negotiation may include the payment for the manufacturing cost as well as the delivery cost and delivery information etc. After successful negotiations, the RN agent continues to execute on the platform and switches to a monitoring mode that allows it to pass information on to the GUI agent about the progress of production. The GUI agent can then again be used by the user to get up to date information on the progress.
- Step 9: All the RN agents eventually return home to the GUI agent where the data gathered is consolidated to be entered into the agent's knowledge base to improve the negotiating process of subsequent negotiations.

The following section explores some of the security and privacy issues that are raised as a result of introducing agents into a telemanufacturing environment.

5. SECURITY AND PRIVACY IN TELEMANUFACTURING

When an agent is entrusted with a bargaining task, it is representing a human that is accountable for the result of the bargaining process and therefore security and privacy is of utmost importance. (Ogor, P) The following has to be addressed in whatever approach is taken:

- Security of the transmitted file.
- Privacy:
    - of the knowledge base.
    - of the transaction.

Firstly the security of the transmitted file is critical as it could contain an early prototype of a product not yet patented or fully realized. If a competitor were to acquire such a file, it could translate into a serious financial loss for the owner. The reason for this is that the owner could have spent considerable amounts of money on research and development of the product represented by the file. These investments could be lost if a competitor obtains a copy of the file. Such a file is especially vulnerable as it contains an exact replica of the product. If it is possible for someone to eavesdrop on the communication, an unfair advantage can be obtained that is anti-competitive and could result in loss of income.

The second important issue to address is that of privacy. Privacy is extremely important as a leakage of information could cause the knowledge base to be compromised. Here again if the knowledge base is compromised the opposition could get an unfair advantage. The same goes for the privacy of a transaction. If the details of a negotiation are leaked the competition could get an unfair advantage.

Next the implementation of the introduction of agents into a telemanufacturing environment described here is presented.

6. IMPLEMENTING AUTO-INTELLIMANUFACTURING AGENTS INTO TELEMANUFACTURING

In order to introduce agent negotiations into telemanufacturing the use of RN agents that belong to the person requesting the service and the DMR agent that belongs to the manufacturing facility are required. These two agents will meet on an agent platform to start the negotiations. To control and present the result of negotiations a GUI agent is also required that is the link to the human user. The GUI agent allows the user to observe events, make decisions and intervene if required.

6.1. Implementation in JADE

The JADE environment provides the following interfaces:

- I/O interface.
- Human agent communication interface.
- Agent to agent communication interface.

This allows us to concentrate on the implementation of the agents that will partake in the negotiation process. The following classes need to be coded for the implementation of an agent capable of negotiating:

- Main agent class.
- Agent engine class.
- Agent planner class.
- Agent knowledge base.

The main class contains code that will be executed when the agent is initialized and also events that will trigger when the agent moves from one platform to another. Part of the initialization is the register method that allows the agent to register with a directory facilitator (DF) once it arrives at a platform.

The engine specifies the behaviour of an agent that is triggered by an event. Also part of the engine is the message filter and the link to the I/O interface that allows the agent to communicate with other agents on the platform. The agent planner is the "brain" of the agent. By using the messages received, knowledge and a plan, a course of action is decided upon. The agent planner could also compile an itinerary where the plan is to move from one platform to another. The plan is implemented as a basic expert system. These rules are hard coded in the agent.

Lastly the knowledge base contains the memory of the agent. Any information that the agent requires is stored in the knowledge base together with past experience that could be used to benefit the current negotiations. To be able to share the knowledge obtained from negotiations the agent will store the information gathered centrally once it returns to its home location. This allows other agents to have access to recently acquired knowledge at the beginning of their negotiations. Therefore the knowledge base is stored locally by the agent and once it returns it is processed and loaded into the knowledge base. All this knowledge also needs to be encrypted. This secures the knowledge in the agent.

6.2. The JADE platform

The JADE agent platform provides a fully integrated agent platform that allows the implementation of the agents as discussed previously. It is shown in Figure 3. It provides the following services:

- Agent management.
- Directory facilitator.
- Agent message passing infrastructure.

The agent management service allows an agent to register with the platform when it first moves to the platform. Once registered, an agent is given an unique identifier that is used to communicate with other agents etc. The directory service is analogous to a yellow-pages directory, as agents can look up other agents to communicate with. If it was not for the directory service agents would not be able to locate agents to negotiate with. As the agents that a RN agent locates represent DMRs this provides a way of finding appropriate DMRs for the current request. The RN agent therefore queries the directory facilitator to get a list of DMR agents. If new DMR agents join the RN agent can also be notified. This is the same as the locating agent that is previously proposed to locate appropriate DMRs. (Marais, E., 2002)

Each agent is in its own container that is linked to a GUI agent. The telemanufacturing environment is connected together by the main container. Once the agent moves from its container to the main container negotiations can commence. This is illustrated in Figure 3.

6.3. The user interface

The user interface allows human interaction with the agents as discussed previously. On the interface of the GUI agent the design-file that the user wants to be manufactured is specified as well as the constraints. From Figure 4 these options can be seen. Each user interface is supported by a auxiliary agent. By creating the disconnect between the GUI and the actual agents that perform negotiation, negotiation can continue even if the GUI is disconnected or goes down.

6.4. Agent trust

To provide the mutual authentication of agents to establish agent trust a security agent is also present on the platform. If a RN agent wants to communicate with a DMR agent it first has to query the security agent. During this request certificates are exchanged that is checked by the security agent. If the check is successful the communicating parties are introduced and negotiations can start. The security agents are also present in the main container of the agent platform. This can be seen in Figure 5.

6.5. Processing agent

The processing agent provides a processing service to the RN and DMR agents and therefore it also needs to enter the telemanufacturing environment. The processing is to take the submitted design-file and process it into a file format that can be sent directly to the target layered manufacturing machine. The steps that the processing agent performs are shown in Figure 6 and thereafter a processing agent that has registered itself with the platform is shown in Figure 7.

6.6. The DMR agents

Once the elements discussed above are in place the DMR agents need to be dispatched to the agent platform so that the RN agents can negotiate with them. Each DMR agent has constraints that are set and thereafter the agents are dispatched to the platform.

The interface to dispatched agents that have registered with the platform are given in Figure 8. The process they follow to be registered with the platform was given previously.

The DMR agent's life-cycle is shown in Figure 9. Once the DMR agents have been dispatched negotiations can commence.

6.7. The RN agents

Once the elements discussed above are in place the last part is that the RN agent has its constraints set by the user and it is dispatched to the telemanufacturing environment. The GUI agent that sets the agents constraints is shown in Figure 10 and the registered agent on the platform is shown in Figure 11. The life-cycle of an RN agent is illustrated in Figure 12.

7. EVALUATION OF NEGOTIATION OF THE DMR AND RN AGENTS

Once all the steps described in the previous sections are complete, a secure resource negotiating environment is available. The negotiation process is entered into once the RN agents locate appropriate DMR agents. Before negotiations start the security agent is queried to make sure that the agent that is going to be negotiated with is a trustworthy agent. This is naturally done by both parties, namely the RN and DMR agents. The RN agent submits its design-file to a processing agent that processes the design-file for it and returns the result to the RN and DMR agents.

The negotiation then starts when the RN agents submit its processed design-file to the DMR agents and requests a quote. Once the quotes are received the DMR agent with the highest precision is selected as this was specified with the GUI agent that was shown in Figure 10. After negotiations closes off the go ahead message is waited for by the human user. The GUI agent then gives the user the option of going with the best results returned by the agent or any other results. This whole process is illustrated in Figure 13.

For the purpose of discussion a test case is introduced, in which nine separate containers representing nine different machines. Three DMR agents representing pseudo DMRs are introduced as seen in figure 11. A number of RN agents are also introduced. The RN agents seek out the DMR agents. After a RN agent locates a DMR agent to negotiate with the two agents enter into negotiations. The RN and DMR agents then use the security agent to check the security of the other agents as indicated above in section 6.4. The RN agent then submits the CAD file to the processing agent. The processing agent verifies the CAD file design and returns the results to the DMR and RN agents. At this point the DMR agent and RN agent are ready to start negotiation using the negotiation protocol they agree on. The negotiations start with the RN agent making a request to the DMR agents for quotes. Figure 14 shows the RN agent sending a quote request to two different DMR agents. Upon receiving the requests the DMR agents will respond with a quote. Figure 15 shows the RN agent's output after receiving a set of quotes from various DMR agents. Once the RN agent has all the quotes from the DMR agents it then selects the cheapest quote from all the quotes received. Figure 16 shows the RN agent selecting the cheapest quote. After selecting the cheapest quote the RN agent will close off negotiations with all the DMR agents that will not be involved in the telemanufacturing process. The RN agent closes off negotiations with all the DMR agents. After closing negotiations the RN agent and DMR agent that reach a settlement will then confirm the negotiation. At this point the telemanufacturing process continues.

In multiple runs (>30) the systems was always able to arrive at a fair value during negotiations. This showed the correctness of the systems. Whilst the system was running across the internet, network cables between various nodes where unplugged with no effect on the system. However if the main JADE container is disconnected the system is unable to continue functioning. This is a limitation of JADE and not agent oriented systems. As each DMR system hosted its own processing systems the ability of the system to scale with up to nine DMRs was presented, however this may not be a true indicator of scalability as thousands of consumers would be expected to connect to such a system. The use of Ontologies and Agent Communication Languages facilitated interoperability. This was evident in the fact that although various agents had different implementations and encapsulated various negotiating strategies they where still able to interact using a shared ontology without the need for a set of custom protocols.

In terms of implement the match between an agent oriented approach and the e-commerce aspects of telemanufacturing was found to be a natural one. Real world entities where easily assigned to agents that fulfilled or coordinated those roles. This natural assignment lead to a cleaner and more precise solution where much focus was around the negotiation process and less around the ICT plumbing facilitating it.

8. DISCUSSION

The integration of negotiating agents into the pseudo telemanufacturing environment presented few complications for the proof of concept project. Negotiations took place over the internet with agents moving back and forth between locations. The agents were able to successfully negotiate in a competitive market using bidding and bargaining strategies and arrive at a fair value.

The implementation showed a significant benefit over continuously connected centralised brokering services. These benefits come as a result of a number of criteria inherent in distributed systems built using an agent oriented paradigm for software development. (Wood, M., 200; Wooldridge, M., 2000) Typical benefits of such distributed agent oriented software systems include increased robustness, increased scalability, and increased interoperability. These benefits are explored further below.

8.1. Increased robustness

The increased robustness comes as a result of the autonomous and distributed nature of the agents. There is a significant advantage to moving away from a single point of failure. Single points of failure are inherent in centralised stove pipe implementations. To demonstrate the increased robustness, RN agents within the implementation were still able to carry out negotiations despite the network connections between the various machines being disconnected. The ability to operate in the event of temporary network failure is an inherent property of such agent oriented implementations and did not require any specialised code other than what was already supplied by the JADE platform.

8.2. Increased scalability

Scalability is another benefit of the use of agent oriented approaches to software development. The distributed and conversational nature of agent oriented approaches indicates that the addition of new agents to the system can immediately be taken advantage of. Should more DMR agents be required to represent a DMR, due to heavy load, these additional agents can be added to the system without any system modifications.

An additional advantage over centralised brokering systems shown in the mobile and distributed nature of the implementation was that no matter how many RN agents or DMRs with their respective DMR agents are added to the telemanufacturing environment negotiation and processing takes place at the DMR agents hardware platform and so a natural load distribution occurs. The scaling property is also inherent in agent oriented systems and requires no additional code from the developers side other than adhering to the agent oriented philosophy and using a already developed platform in the form of JADE.

8.3. Increased interoperability

The increase in interoperability comes as a result of the use of standards based agent communication languages and ontologies in the implementation. Agents communicating using agent communication languages, such as FIPA-ACL, are not required to implement code relating to syntactical binding between components. Use of an agent communication language allows agents to communicate using messages that are encapsulated by a performative and common ontology. RN and DMR agents developed by various organisations need only adhere to the common ontology and implement the FIPA-ACL standards in order to engage in negotiations.

8.4. Limitations

However integrating negotiating agents into a full blown telemanufacturing environment that exists on an open system such as the Internet could pose additional challenges:

- The way data is transported in a real telemanufacturing environment may include email or other protocols.
- Various incompatible agent platforms may exist. The existence of incompatible agent platforms may hamper agents written on one system when they try to function on another platform.
- The system is unlikely to acquire a global optimum as a result of the large number of interacting agents. However this problem is acceptable in open systems where large amounts of agents are continuously joining and leaving the platform and as such a search for a global optimum would never end.
- Requiring each person involved in telemanufacturing to install an agent platform on his/her machine is a serious limitation. Instead a solution that leverages the already rolled out browser infrastructure on these machines should be considered.
- The Ontology based knowledge approach results in a large increase in interoperability. However research into Ontology and reasoning is still on going research and until the challenge has been sufficiently solved it will remain a limitation of the agent approach.

If a DMR uses multiple incompatible agent platforms and one sends agents to each of the platforms it becomes increasingly difficult to coordinate between agents running on each of the platforms. The interaction with different platforms might be required in order to establish an optimal solution.

9. FUTURE WORK WITH TELEMANUFACTURING AGENTS

Although the implementation presented in this paper worked well there are improvements that can be recommended, these include:

- Standards.
- Incompatible agent platforms.
- Multiple incompatible platforms.

The first point describes the way current submissions are made to layered manufacturing hardware. The submissions could be a proprietary web interface to e-mail submissions. So, if standards are not agreed upon agent negotiations will be difficult to roll-out to a large audience.

Secondly is the matter of agent platforms. If each DMR uses its own agent platform it makes it increasingly difficult to implement what was achieved in this paper.

Lastly multiple incompatible platforms will cause additional complications if agent mobility is required. This is due to the fact that an agent will have to support different agent platforms or the worst case scenario where agents will have to be swapped out according to the platforms they encounter. This will require an agent to return to its home location and hand its task to another agent that will work on the target platform. This will hamper the efficiency of the agents.

10. CONCLUSION

The aim of the research was to introduction secure resource negotiating agents into telemanufacturing. This was accomplished by using the JADE platform to implement negotiating agents in the telemanufacturing environment. The services that need to be available from the agents and negotiating platforms were identified. One hurdle was to identify a platform that provides all these services and that is also general enough to support change. The different kinds of agents that make resource negotiations possible were identified and how a negotiation works was given in a stepwise fashion. Lastly all the ideas were implemented. An implementation was embarked upon to ascertain the viability of all these components working together. After the successful implementation of the prototype potential problems with a real implementation was identified for further research.

The ease with which it is possible to design a secure resource negotiating environment using an agent based software engineering paradigm points to a natural fit between the problem and the potential solution. The large amount of effort going into the standardisation of agent based communications and platform standards such as IEEE-FIPA point to future continued advancements in the field. JADE as a agent platform and the number of large enterprises and open source developers working on the project shows that there is a definite need for the agent based systems and supporting technology.

The field of telemanufacturing presents one possible future in which the gap between the consumer and the producer of manufactured goods is almost completely blurred. As consumers become more accustomed to just in time manufacturing and customised products the need for supporting technologies that can enable the telemanufacturing environment will grow. The more aspects of the telemanufacturing environment that can be automated the shorter product turn around times and the greater the throughput. The work presented here points to one possible mechanism of enhancing that automation and ultimately a possible step in the right direction. For telemanufacturing to ultimately reach its goal of being completely automated many more manual aspects of the process will need to be tackled.

LIST OF ABBREVIATIONS

- AMS Agent Management System.
- DF Directory Facilitator.
- DMR Distributed Manufacturing Resources.
- FIPA Foundation for Intelligent Physical Agents.
- GUI Graphical User Interface
- JADE Java agent development environment.
- RN Resource Negotiating.

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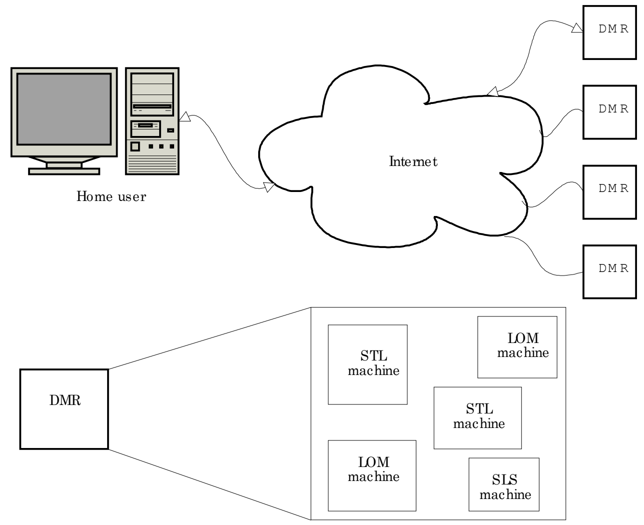

Figure 1: User interacting through the Internet (Marais, E., 2000)

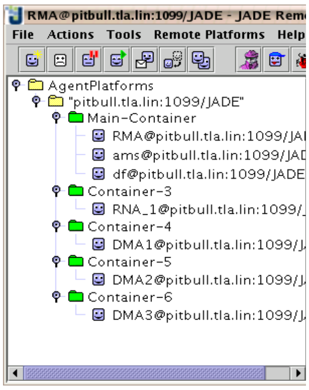

Figure 3: Telemanufacturing environment with attached containers. In this screen shot there are four additional containers attached to the main container at this time step. Three of the attached containers have DMR Agents whilst one has a RN agent.

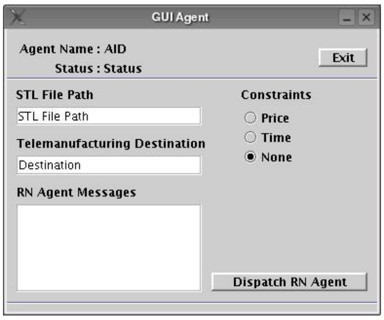

Figure 4: The GUI agent interface described here provides a pop up screen presented by the agent to it's human controller. The purpose being that the agent wishes to obtain additional information relating to the rapid prototyping process and what CAD file to be produced.

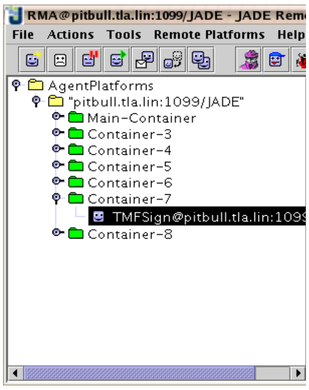

Figure 5: The security agent enters into the telemanufacturing environment in its own container.

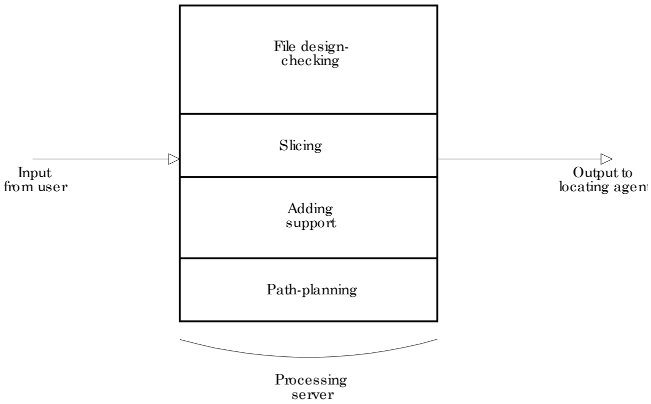

Figure 6: Steps performed by processing agent (Marais, E., 2000)

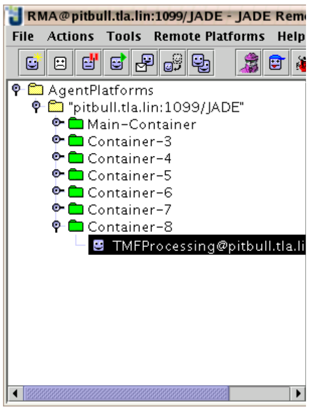

Figure 7: Processing agent entering the telemanufacturing environment, The processing agent enters through its own container. The container is representative of an execution context for the agent. From here the agent is able to move around from container to container and thus from machine to machine. However in this case when a processing job is handed to the processing agent it will use the local resources of its container to perform this possibly computationally intensive task.

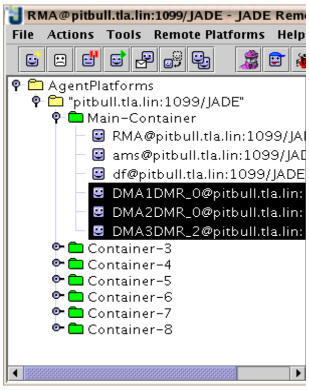

Figure 8: DMR dispatched to agent platform. Here you see a number of DMR agents that have migrated from there various DMR sites to the main agent platform to engage in negotiations.

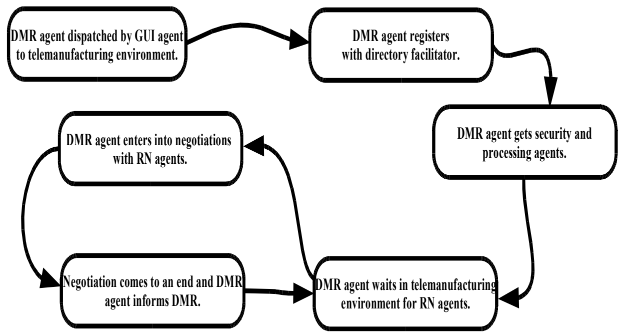

Figure 9: DMR agent life-cycle

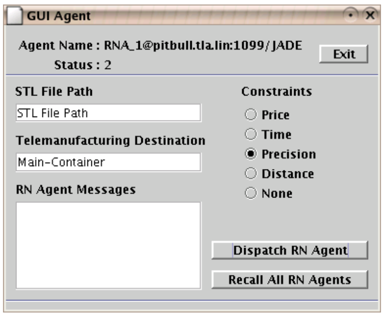

Figure 10: GUI agent sets the RN agents constraints. The RN agent is now with the above information as captured by the human user able to negotiate with the DMR agents a best fit scenario.

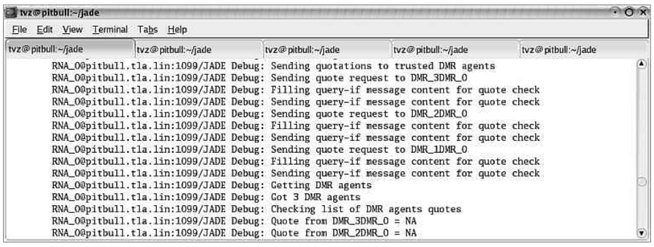

Figure 14: RN agent requests quotes from DMR agents. You can see here a text print out of some of the actions as they are being performed by the agent being logged to the screen.

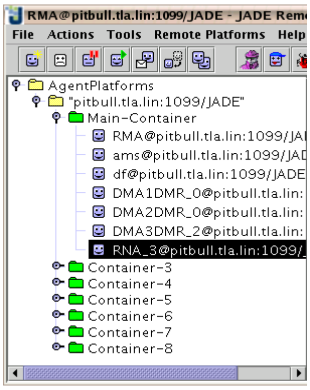

Figure 11: Dispatched RN agents are registered on the platform. The RN agent in this image will; now engage in negotiations with the current DMR agents.

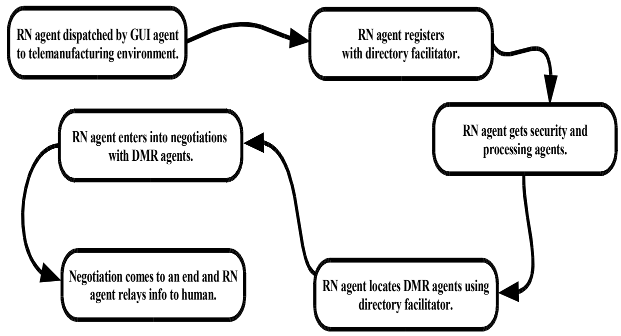

Figure 12: RN agent life-cycle

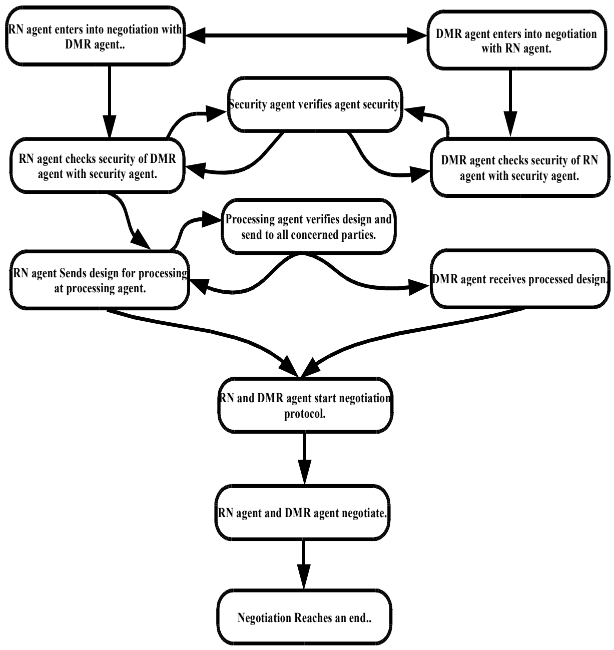

Figure 13: The negotiation process as entered into by the RN and DMR agents.

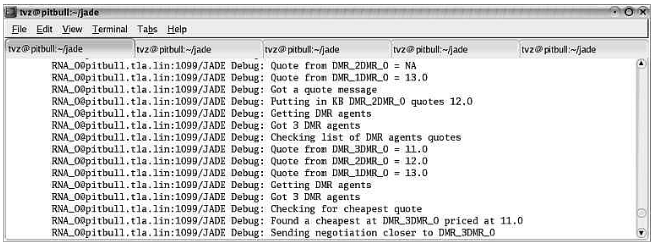

Figure 15: RN agent receives quotes from DMR agents. You can see here a text print out of some of the actions as they are being performed by the agent being logged to the screen.

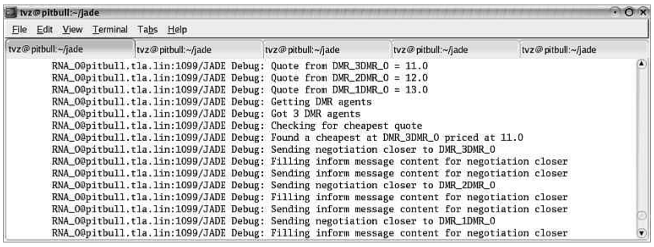

Figure 16: RN agent selects the cheapest quote from DMR agents. You can see here a text print out of some of the actions as they are being performed by the agent being logged to the screen.

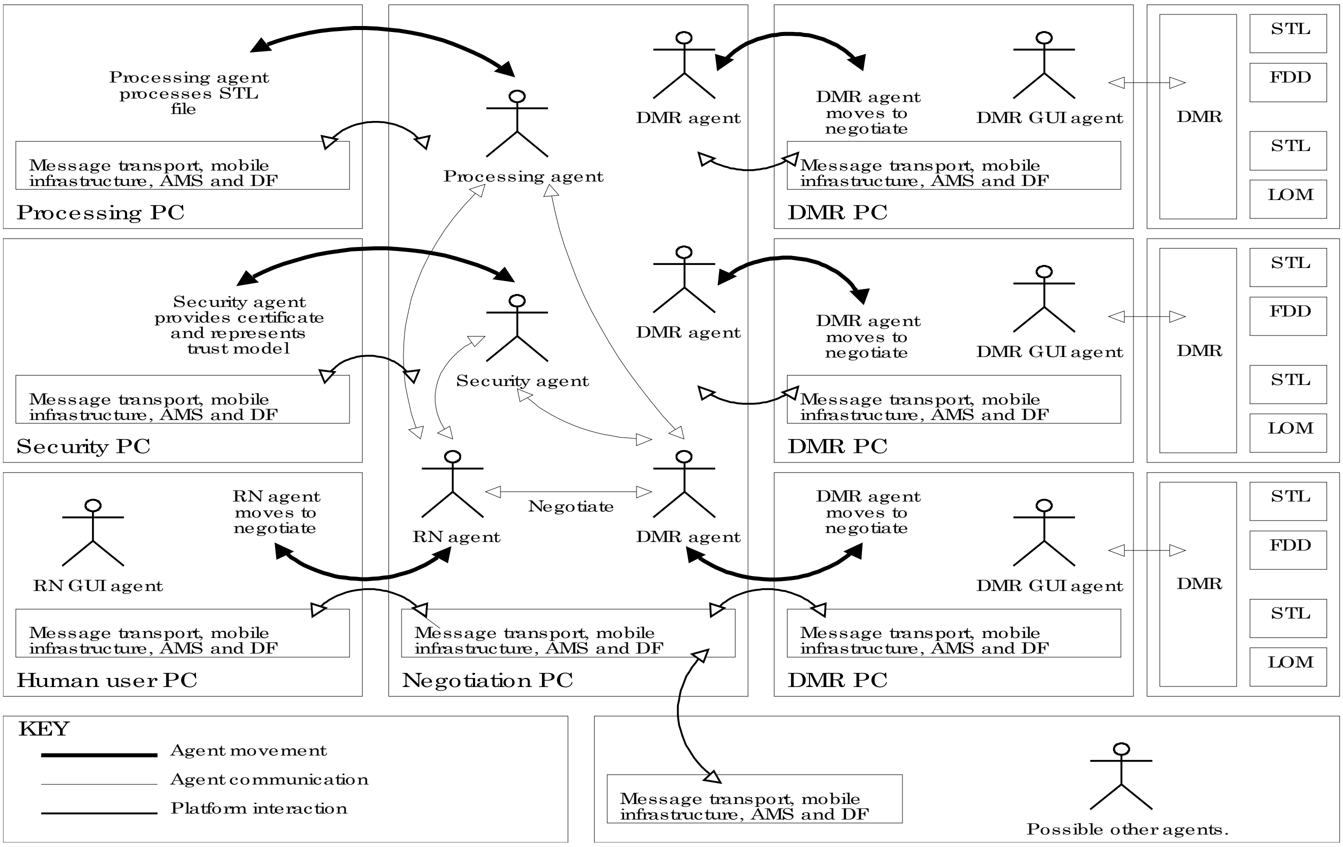

Figure 2: RN and telemanufacturing integration. This image presents a static slice in time as may play out in a typical agent based telemanufacturing environment.